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# MORPHOGENIC STUDY ON THE EARLINESS OF GROWTH STAGES AND YIELD IN SPRING BARLEY (*Hordeum vulgare* L.)

BY

© ELIZABETH A. HAMID

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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The undersigned certify that they have read, and recommend to the Faulty of Graduate Studies and Research, for acceptance, a thesis entitled MORPHOGENIC STUDY ON THE EARLINESS OF GROWTH STAGES AND YIELD IN SPRING BARLEY (Hordeum vulgare L.) submitted by Elizabeth A. Hamid in partial fulfilment of the requirements for the degree of Master of Science in Plant Breeding and Agronomy.

Supervisor

J. A. Robertson

Date October 19, 1979

## ABSTRACT

The earliness of maturity and growth habit of 144 lines of six-row barley (Hordeum vulgare L.) was studied over a period of three years. In the winter of 1971/72 the material was raised in a growth chamber at a constant temperature of 21°C and an 18 hour photoperiod. In the summer of 1973 each line was planted by hand 30 seeds per row in 1.2 meter rows, 23 cm apart, for 1 to 3 replicates as seed permitted. In the following summer, 1974, the material was planted in 4-row plots, 5 meters long and 23 cm apart, in a randomized block design with 2 replicates.

Recordings were made on time taken from seeding to emergence, internode elongation, heading, and maturity. Also recorded were yield, height and head length for all three years. In addition, the two field years included 1000 kernel weight; test weight; number of plants, heads and secondary tillers per 1.2 m sample; leaf and tiller spread at internode elongation, and lodging.

The length of four major growth periods (seeding to emergence, emergence to internode elongation, internode elongation to heading, heading to ripe) was calculated, along with combinations of these periods. It was found that the growth period C (internode elongation to heading) contained the greatest variability, a high heritability, high correlations with total time to maturity, high and consistent correlations between the three environments, and fairly low correlations with yield. For this reason it was chosen as the most likely candidate for manipulation to produce earliness. Of the longer growth periods, period (B + C) (emergence to heading) was selected, but it did not show as great a variability as the single period C.

Of the morphological characters studied, consistent positive correlations with yield were provided by height, head length and number of plants per 1.2 meter sample. The regression equations showed that in the growthroom height was the most important contributor to grain yield, while in 1973 it was the number of heads per 1.2 meter sample, followed by height and head length.

Comparison of the three years' material showed that, with the exception of growth periods B and C and their combinations, relations between the field environment and the growth chamber were low, while associations between the two field years were much higher.

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# INTRODUCTION

The growing season of northern and central Alberta is frequently characterized by long cool springs and early fall frosts. Therefore, if a cereal crop is to be cultivated in this environment it is essential for it to display a relatively short growing season characterized by early maturity. One of the most frequently grown and successful cereal crops in northern and central Alberta is spring barley (Hordeum vulgare L.). There are several varieties of spring barley that are well adapted to local conditions but, in many cases, their characteristic earliness has sacrificed the high yield so desired by local farmers.

In studying the physiology of yield and maturity in cereal crops, researchers have been successful in dividing the lifespan into morphological stages. Various scales have been developed in order to measure a crop's growth and development. These have enabled the researcher to isolate certain physiological occurrences in the plant's growth. The development of such a scale has been employed in this experiment in order to study in detail the morphological characters of a large and diverse number of varieties of spring barley (Hordeum vulgare L. 6-row) selected from the World Barley Collection in Aberdeen, Idaho. This material was selected to display a wide diversity in the length of time taken to reach each of four major growth stages. It was hoped that analysis of such a diverse genetic base would provide the information necessary in order to manipulate the lifespan of a crop without the attendant sacrifice of yield. Thorne et al., 1968, stated that such a manipulation is possible under certain environmental conditions.

The purpose of this study then, was to examine in detail the physiology and behavior of four major growth periods and their attendant combinations in order to discover the period, if any, that would be the most receptive to manipulation. Recordings were taken for every sample as it developed to each of the four major growth stages: emergence; internode elongation; heading; and maturity. By analysing the behavior of all these growth periods, it was hoped to discover the relative contribution of each period to the plant's overall growth and development in an Alberta environment.

Also studied were several important morphological characters that would give a better indication of the behavior expected from such a diverse collection of material during certain phases of the crop's development. This would give a more comprehensive idea of the overall contribution to earliness and yield of the various growth stages. A variety of environments was provided in order to attain a better idea of the behavior of such diverse material.

# LITERATURE REVIEW

## I. GROWTH STAGES, THEIR HISTORY AND USAGES

### i. The History of Quantitative Measurements in Cereals

In order to study the physiology of growth and yield in cereals, it was necessary for early workers to divide the lifespan of the crop into a series of growth stages. Pope, in 1932, pioneered this approach by developing a "growth curve" for barley and by attempting to describe events in the curve by examining specific stages in the development of the plant. Bonnet, in 1935 (revised in 1966) conducted an exhaustive study into the development of the cereal spike, and described the formation of the barley spike in relation to the development of the plant. He stated that the morphological development of a head-bearing barley stem can be divided into two phases. These phases can be approximately determined by examining the stem and shoot apex. The first complete scale for studying the growth stages of cereals was devised by Feekes in 1941 and modified and illustrated by Large in 1954. Here, the main morphological stages of cereals were numbered from 1 to 11 in ontogenetic order from seedling emergence until grain ripening. For many years, this was one of the best known and widely used scales. Other scales were frequently devised however, in order to meet specific requirements of certain crops. The requirements of a suitable growth scale were given by Hanway in 1963, when he stated that any useful system of sampling plants should satisfy the following criteria:

(a) It should permit sampling at different times throughout the growing season;

(b) It should permit sampling at any important transitional period in the physiological or morphological development of the plant; and (c) It should permit sampling at stages of plant development which can be readily assessed in the field.

Examples of these alternate systems were developed by Hanway, who described a system specific for corn (Zea mays L.) on a scale of 1 to 10; and by Vanderlip and Reeves (1971) who described the lifespan of sorghum (Sorghum bicolor (L) Moench) with a scale of 0 to 9. Haun, in 1973, devised a scale to closely follow the growth curve of wheat using decimals that described continuous development for physiological studies. However he stated that his system would not apply to barley because it has a differently shaped growth curve.

It was not until 1974 that Zadok et al. presented the ten requirements that a successful growth scale must fulfil and proceeded to develop a specific one for cereals. They used a system of principal growth stages described on a scale of 0 to 9, with secondary growth stages using a second digit, also on a scale of 0 to 9, with position 5 reserved for the median value.

For the purposes of the present study, however, a less detailed scale has been employed, showing the major stages of growth and dividing the lifespan into four different periods. It is similar to scales commonly employed by other researchers to show major events in the plants' life (Thorn et al., 1968, and Faris et al., 1969). Comparisons of this system with those of Feekes and Zadoks et al. are shown in Appendix C.

ii. Definition of the Stage Internode Elongation (IE)

There has been considerable discussion concerning the importance of the stage described as Internode Elongation. Since Bonnett (1935) described the concurrent appearance of double ridges on the shoot with the beginning of internode elongation, there has been confusion as to whether floral initiation has been completed

by the time the culm elongates. In 1963, Nicholls and May found that the initiation of double ridges occurred when the apex was a particular length (0.45 mm), and that the initiation of stamen initials on the most advanced spikelet and the cessation of primordia formation all occurred concurrently. Biswambhar (1964) showed that culm elongation constituted a part of the reproductive growth phase, and that internode elongation prevails after ear initiation. Aspinall (1966) found that IE varied among different varieties, commencing at a much earlier stage of floral organogenesis in some varieties than in others, and that these differences were genetically controlled. This was supported by Fairey et al. (1975), who stated that the cessation of spikelet initial formation and the beginning of internode elongation did not occur simultaneously. The latter began just before or at double ridge formation. These effects were summarized by Faris et al. (1969), who stated that almost invariably the appearance of the stage Node at Ground Level (beginning of internode elongation) can be used to indicate that floral initiation has occurred in a barley plant, but cannot be used to indicate the stage of floral organogenesis under all conditions, as there may be variation among the genotypes.

iii. Applications of Growth Scales

There have been numerous approaches to the application of growth scales, both in the varied forms of analysis used, and in the purposes to which these results have been put. Relationships among the stages have been employed in studies of earliness, of physiological and pathological processes, and of yield in a plant.

For example, Aksel and Johnson in 1961 performed a genetic analysis on two major growth periods in barley (seeding to heading and heading to ripe) in order to find their relationships in length, and their correlations with yield. Chang et al.

(1969) performed a component analysis on the vegetative phase and the photoperiod sensitive phase of rice in order to discover their genetic relationships. Robinson (1971) used Growing Degree Day summations to certain stages in sunflower (Helianthus annus L.) in order to discover the physiological requirements of these stages. Williams (1971) compared the dates of phenological stages in wheat over a large geographical area in order to discover the differences in relationships of these stages between environments.

Other researchers have studied the effects of the length of the growth period on yield by dividing yield into three components, namely X (number of heads per plant), Y (number of kernels per head), and Z (kernel weight), each of which is influenced differently by an individual growth phase (Rao and Prasada, 1972; Nickell and Grafius, 1969; Faris and Guitard, 1969; Thomas et al., 1971).

## II. INHERITANCE OF HEADING TIME AND MATURITY IN CEREALS

In past years there have been conflicting reports in the literature concerning the inheritance of heading time in cereals. Early reports showed that heading time was under the control of only one or two genes, while others showed that it was quantitatively inherited by a number of polygenes. Frey (1954), working with barley, reported that heading date was controlled by one, two or three gene pairs. Environmental effects on heading date were seen as additive. Also supporting this view of additivity were Johnson and Paul (1958). Using means and variances of $F_2$ and $F_3$ generations of barley, they concluded that the parents differed by additive, increaser alleles at two loci in each cross. Eunus (1964), reanalyzed the data and concluded that earliness was controlled by polymeric genes. Two to five effective factors, which were

possibly groups of polygenes acting together, were estimated to be affecting earliness. Crumpacker and Allard (1962), using a diallel analysis on barley, found that most of the genetic variability could be attributed to additive and dominance effects of genes, with a major part of this variability associated with three major genes (effective factors). Two of these major genes exhibited partial dominance in the direction of earliness, and one of them exhibited dominance in the direction of lateness. Evidence was also produced of a smaller system of minor genes displaying little or no dominance. Riggs and Hayter (1972), working on the estimation of genetic components of spring barley, confirmed that additive genetic variance was high, and that partial dominance was operating in the expression of the character in the direction of earliness. A slightly different approach was adopted by Aksel and Johnson (1961), again with barley, when they divided the growing time into two periods: one being the sowing to heading period; and the other being the heading to ripening period. They found that a short sowing to heading period was dominant over long, and a long heading to ripening period was dominant over short. In a given parent, a long first period was associated with a short second period, and vice versa. These relations were broken rarely in the progenies, suggesting close linkage.

Paroda and Hayes (1971) studied the association between genotype x environment interaction and the expression of earliness in barley. Rate of ear emergence was governed by partial dominance, and interaction between the additive components and the environment was found to be greater than that of the dominance component in different environments.

Takahashi and Yasuda (1972) employed a different approach when they pointed out that there were at least three internal physiological factors responsible for

the time of heading in barley. They were:

1. Vernalization Response, or the degree of spring and winter growth habit.
2. Photoperiodic Response (sensitivity to shortened photoperiod).
3. Earliness in the Narrow Sense (sensitivity to long photoperiod).

The last two factors are always concealed or masked by winter habit, and are clearly manifested only in the highly spring genotype. They therefore concluded that a large number of genes were involved in different early varieties.

In studies of vernalization response, Takahashi and Yasuda concluded that at least three pairs of genes were responsible for growth habit in barley, with one recessive and two dominant genes for spring habit, and alleles for winter habit. Pugsley (1971), working with winter wheat, stated that the range of intensity of the winter character may be due to the operation of multiple recessive alleles. Klaimi and Qualset (1974) employed crosses between spring and winter wheats to determine the vernalization response. They concluded that in some spring x winter crosses most variation in heading time could be attributed to the effects of major genes. In other crosses, genes with smaller effects are also involved in the control of heading response under spring or summer environments.

Other approaches to earliness have been made by studying the photoperiodic responses of a cereal. These responses can usually be determined once the vernalization requirement is accounted for. Takahashi and Yasuda (1972) stated that earliness under a short photoperiod was due to a single recessive gene in barley. It was generally agreed among later authors that early heading in short days was associated with photoperiodic insensitivity. Keim et al. (1973) indicated a two gene system

discovered that radiation and temperature requirements were variety specific up to time of heading, and that the varieties differed as to their requirements at specific growth stages. Varieties did not differ in their light and temperature requirements after heading.

i. Photoperiod Sensitivity

An important characteristic affecting the growth and development of a cereal is its photoperiodic sensitivity. It was found that generally the early maturing varieties were those with low day length sensitivity, with the earliest varieties being completely day neutral (Syme, 1973 and Martinic, 1975 in wheat). However, Martinic (1973) has found exceptions to this rule and states that it is possible to produce varieties with little or no relationship between photoperiod and life-cycle durations. Rawson (1971) has quantified this relationship in wheat by presenting the different responses shown by early and late varieties. The early wheats maintained high rates of spikelet production up to the terminal spikelet appearance under all daylengths, and varietal differences occurred only in the duration of spikelet production. The medium-late and late varieties were characterized by the maintenance of high rates of spikelet production under long photoperiod, but with shortening photoperiod the rates became progressively lower and were further reduced as the terminal spikelet differentiation was approached.

The effects of photoperiod seem to be generally consistent in cereal crops with differences produced being due to the degree of sensitivity. Long days decreased the time to heading in wheat (Halse and Wier, 1970; Wall and Cartwright, 1972) and in barley (Aspinall, 1966; Paleg and Aspinall, 1966). However, there were fewer

spikelets produced in this shorter time. Short days resulted in an increase in the time to heading, resulting in an increase in primordia number which compensated for a decreased rate of production (Fairey et al., 1975). Photoperiodic response can occur in either or both of the two stages of development (before initiation and post-initiation to heading) in wheat (Rawson, 1971); and can also occur in both stages in barley (Aspinall, 1966; Paleg and Aspinall, 1966). However, it has been generally agreed that there is a close association between the length of the preheading phase and the number of spikelets produced, thus affecting the yield of the plant (Rawson, 1970; Wall and Cartwright, 1974).

Differing responses to changes in photoperiod may occur, depending on when during the life cycle this change is applied. Guitard (1960), working with barley, showed that increases in photoperiod during stage I (seeding to internode elongation) resulted in a reduction of the number of days to internode elongation and to heading; and an increase in the number of days from heading to maturity. An increase in photoperiod during stage II (internode elongation to heading) reduced the number of days in this period. Faris and Guitard (1969) found that longer daylengths always reduced the time to maturity in barley, but decreased final yield only when applied during stage I (seeding to IE).

It has been found that not only the amount of light (daylength) received affects the photoperiod sensitivity of the cereal, but also the type and quality of light. Responses to night interruption have been recorded in barley (Paleg and Aspinall, 1966) and in oats (Sampson and Burrows, 1972). The latter suggested that the photoperiodic control of heading date in oats is exercised by the length of the dark period. Aspinall

(1966) and Tingle et al. (1970) found that both the intensity of light and the amount of far-red energy present affected the rate of primordium development in barley. In some cases, where intensity was low and there was a low amount of far-red energy, some varieties failed to head.

ii. Vernalization Response

A second important influence on the length of a cereal's lifespan is its vernalization response. Defined as the amount of spring or winter growth habit present in a cultivar, the presence or absence of vernalization response has been found to affect the earliness or lateness of barley even when it is obviously of spring habit (Takahashi and Yasuda, 1972). Aitken (1966) showed that early varieties of cereals (wheat, barley, oats and rye) were almost insensitive to temperature and photoperiod and that the length of the growing period to floral initiation was controlled by its vernalization response. Supporting this was Rawson (1970) working with wheat, who found with varieties that showed a marked response to vernalization the period up to inflorescence initiation was the most important, as potential spikelet sites were being established. Once floral initiation occurred, inflorescence development proceeded rapidly. In those varieties with only a slight response to cold, both the period to floral initiation and the period of development were important. Syme (1973) found that vernalization sensitivity and photoperiodic sensitivity in the period from sowing to ear emergence combined accounted for 77 to 94% of cultivar variation in spring wheat. Halloran (1975) working with varying vernalization responses of wheat, showed that prior vernalization did not significantly alter the rate of photoperiodic response, indicating the physiological independence of vernalization and photoperiodic responses.

iii. Temperature Response

A third factor influencing the time to maturity is the plant's response to temperature. Halloran (1975, 1976) produced evidence that this response is independent of vernalization and photoperiodic sensitivities. Shigolev (1957) and Mayr (1969) have shown that the length of the growing period of wheat is dependent on the summation of temperature to which it was exposed, as well as light. This was confirmed by Marcel-Jos and Single (1971) who showed that the durations of pre-initiation and post-initiation phases in wheat were highly correlated with photoperiod and temperature.

Faris (1967) has found varietal differences in barley response to temperature in the time taken to germinate. He stated that varieties tended to maintain their ranking over a wide range of temperatures.

High temperatures have been found to reduce the number of days to germination to initiation and anthesis but did not affect spikelet number except through vernalization (Halse and Weir, 1970, in wheat; Coligado and Brown, 1975, in corn). Reduction of yield in barley by high temperatures has been shown to be due to a reduced production of tillers (Cannell, 1969). On the other hand, Wall and Cartwright (1974) found that temperature altered the developmental pattern of wheat by decreasing both leaf and spikelet numbers, while Tingle et al. (1970) showed that alternating day/night temperatures increased the spikelet number in barley.

Temperature changes have been shown to affect the photoperiodic response of a variety (Caddel and Weibel, 1971, in sorghum) for the sensitivity to photoperiod is reduced at higher temperatures (Coligado and Brown, 1975, in corn).

Aitken (1966) found that in the post-initiation stages of barley, temperature produced a greater environmental effect than photoperiod. Within the early group of varieties there was a ranking of sensitivity to temperature both before and after floral

initiation which allowed the ranking of varieties from very early to late, with the earliest varieties being insensitive to temperature. In the later varieties of wheat, exposure to high temperatures after floral initiation resulted in a delay in the rate of growth.

## IV. GENETICS OF YIELD IN CEREALS

Close association between yield and its components has been found in numerous cases of study of the inheritance of yield in cereals. Fonseca et al. (1968) and Singh et al. (1970), both working with wheat, found that grain yield was highly and positively correlated with the components tillers per plant, grains per ear and grain weight. This was supported by Walton (1971) who used factor analysis and a stepwise multiple regression to show that a large portion of the variation in yield was supplied by these three components. Nickell and Grafius (1969), working with barley, stated that an optimum combination existed in a given gene pool for yield components and their interrelationship, in order that maximum yields may be reached for a given environment. A close association between plant height and yield in wheat has also been shown by Bhatt (1972, 1973), but Khadr and Morsy (1973) found a negative relationship between height and kernel weight.

Anwar and Chowdry (1969) showed that yield and plant height in wheat were quantitatively inherited and that substantial heterosis occurred for higher grain yield. Aksel and Johnson (1961) stated that those varieties which were dominant for the length of the sowing to heading period tended to be dominant also for the number of kernels per spike, for kernel weight and for yield. Walton (1969), Bhatt (1972), and Khadr and Morsy (1973) found that most of the genetic variance for plant height,

kernel weight and spike length in wheat were due to additive gene action. Partial dominance was also important for variance in number of spikelets per spike and for heavy kernel weight. Bhatt found a tetragenic control of kernel weight in wheat.

Halloran (1975) indicated that additive genetic variance in wheat was present for the characters kernel weight, spikelet number, tiller number and total grain yield; but he also detected evidence of genic interaction in tiller number and grain yield. He associated high expression of grain weight, tiller number and yield with dominance, while high expression of spikelet number was associated with recessiveness.

A different approach has been adopted by Grafius and his associates in a series of papers. Working with a number of cereals (barley, rice, wheat, and oats), ey have studied the sequential appearance of yield components. Thomas et al. (1971) transformed the yield component data to rule out correlations with previous components. Their analysis revealed that the genetic variance of the untransformed components was mainly additive in control. However, when the correlations between components were removed, deviations from additivity which increased in magnitude as the developmental traits progressed were observed. The relative variance of the transformed variable compared to the untransformed variable approached zero in the last component, kernel weight. Therefore the heritability of a component, after confounding correlations are removed, can differ considerably from the apparent (untransformed) situation. In an associated paper, Grafius and Thomas (1971) showed that the plant followed an oscillatory pattern in the sequential development of its components. They showed that direct genetic control of kernel weight ($X_3$) was very weak, and that it

depended largely on the control of prior events: number of heads ($X_1$) and number of seeds per head ($X_2$). If the same $X_1$ values were present at the start, success (high yield) of a variety depended mainly on the election of high or low $X_2$, which was mainly under genetic control.

Heritabilities for the same variable will not remain constant between populations as the relative values of the components of heritability depend on the gene and gene frequencies, types of gene action, the level of environmental variation and the experimental design. However, comparison can be made of the relative magnitudes of heritabilities of the same character in different populations, or of different characters in the same population, thus providing a guide to the relative responses expected (Mather and Jinks, 1974). Examples of such differences are shown in a number of experiments with wheat. Anwar and Chowdhry (1969) gave a broad sense estimate of 61 and 70% for grain hield heritabilities in spring wheat, while Fonseca and Patterson (1968) showed a lower estimate of yield heritabilities (narrow sense) of 17 and 49% in winter wheat. Heritabilities for kernel weight varied from 15 and 55% (Fonseca and Patterson, 1968) to a high of 89% (Bhatt in spring wheat, 1972). Borthaker and Poehlman (1970, in winter barley) showed that the heritability of kernel weight is affected by the environmental influence between seasons, as well as the method of calculation. These heritabilities ranged from 24% to 46%. The values for number of kernels per spike varied from 38.1% (Khadr and Morsy in winter wheat, 1972) to 85% (Fonseca and Patterson, 1968). In most of these cases a trend developed where heritabilities for yield were generally lower than those of the yield components, while those for plant height remained relatively high.

## V. THE PHYSIOLOGY OF YIELD IN CEREALS

As yielding ability is one of the most important characters a variety can possess, a large amount of study has been put into the physiology of yield, and into methods for increasing this yielding ability. In 1923, Engledow and Wadham conducted an exhaustive study into the possible factors that would affect the yield of a cereal. They designated five broad categories of factors which would affect yield, including (1) soil, (2) climate, (3) agricultural practice, (4) disease and damage, and (5) botanical variety of form. It was through studying the fifth character (botanical variety or form) that the authors explored the physiological contributions to yield. They divided yield into four components, which are: (1) average number of ear-bearing tillers per plant; (2) average number of grains per ear; (3) average weight of a single grain; and (4) average percentage of dry matter.

As the concept of yield components became accepted, it became necessary to study the relative importance of each of these components in order to obtain maximum yield. It rapidly became obvious that there were negative relationships present between these components, and that maximum yield was obtained by different interactions among them. Some intetesting examples of these relationships were provided by the use of path-coefficient analysis to find the direct and indirect effects of the components on yield. Fonseca et al. (1968), using winter wheat, showed that all components had large direct effects on grain yield, with number of spikes and kernels per spike having the highest direct effects. Important indirect effects resulting from negative correlations among yield components were observed, especially between number of spikes and number of kernels per spike. Malhotra and Jain (1972)

employed this method and concluded that grains per ear and 1000 seed weight are the most important of the yield components in barley. Bhatt, in 1973, concluded that kernel weight exerted the greatest direct and indirect influence on grain yield per plant in spring wheat. He then quoted Asana and Mani (1958) as showing that with adequate water supply, ear number had the greatest effect on grain yield, whereas under water stress the grain number per ear and 1000 kernel weight had the same effect as ear number.

These conflicting results can best be summed up by quoting from Smoček (1969) who, working with winter wheat stated: "In the absence of abnormal stress conditions affecting the course of photosynthetic processes, the relative proportionally decreasing number of grains per ear increases the run of photosynthates available for one grain, and thus the wieght of one grain increases".

An interesting approach to this problem was adopted with the development of the concept of sequential yield components. Researchers found that manipulation of environmental influences at different stages of development would affect different yield components. For example, manipulation of the time to spikelet initiation produced changes in all three components, but mostly in number of grains per head; manipulation of period 2 (time between floral initiation and anthesis) influenced the number of fertile florets and the number of ears; and manipulation of period 3 (anthesis - ripe) affected mainly the kernel weight (Thorne et al., 1968; Faris and Guitard, 1969). Further supporting this were Willey and Holliday (1971) who conducted shading studies on barley and wheat during the different growth phases. They found that shading in phase 1 (time to floral initiation) produced a decrease

in ear number due to suppressed tillering and also reduced spikelets per ear. Shading in phase 2 (floral initiation to heading) produced the greatest decrease in yield of all the phases, due mainly to a decrease in grains per ear. A significant decrease in yield in phase 3 was due to a decrease in grain weight.

In 1969 Nickell and Grafius represented yield in winter barley as a geometrical construct of the three components, which were developed in a sequential manner. They were heads per unit area (X), kernels per head (Y), and kernel weight (Z). The concluded that "optima" exist in a given gene pool for yield components and their interrelationships in order that maximum yield can be reached for a given environment. In a subsequent paper, Thomas et al. (1971) attempted to discover the sources of variation in these components by transforming them (Y and Z) to delete effects of previous characters (X), and concluded that stress was the force tending to disguise the true nature of the source of control over the expression of the second and subsequent characters in a developmental sequence. That is, environmental effects that control the expression of the first character (X), are reflected in the expression of the second character (Y); and both the effects that control X and Y are reflected in the third character (Z). Tai (1975) supported this relationship with the use of path analysis to determine the direct and indirect effects of control over a given character.

i. Number of Tillers

The first of the yield components to occur in the sequence was described by Willey and Holliday (1971) as number of tillers, either per plant or per unit area. In 1960, Guitard, working with barley, found that the tillering pattern of the

varieties Olli and Vantage reacted differently to an increase in photoperiod during the period of growth up to internode elongation. Increasing the photoperiod during the second growth period increased the number of fertile tillers produced, but a reduction of fertile tillers was experienced if there was increase during the third growth period. However in 1968 Puckridge, working with barley in different light regimes, found that plants exhibiting very different flowering responses produced identical tillering patterns. This suggested that in the early stages tillering was not directly controlled by the flowering apex, and that the growth of tiller buds depends on the assimilates from other parts of the plant. In 1971 Leakey, working with plant density variations of barley, found that tiller number was the most plastic character, with tiller production being earlier in those plants which emerged into low plant density, and being delayed or inhibited with higher or increasing densities.

In two sequential papers Cannell (1969) studied the complete tillering patterns of two barley varieties, Spratt Archer and Deba Abed, and also the effects of temperature, light intensity, and daylength on these tillering patterns. In the first paper he showed that after the main stem (M) the most frequently occurring tiller was the tiller appearing in the axil of the first true leaf ($T_2$), followed by the coleoptic node tiller ($T_1$) and the tiller in the axil of the second true leaf ($T_3$). M contributed the largest percentage of the grain yield, followed by $T_2$, $T_1$, and $T_3$, with varietal differences in yield mainly being accounted for by differences in the number of $T_1$ tillers. He concluded that varietal differences in yield were partially due to the number and position of axillary buds which developed, and the extent of variation of

development (in apical dominance). Differences were also due to the number and weight of grains formed on the various shoots.

The second paper enlarged on these conclusions, and showed that with environmental variation, the major varietal differences in yield (grain weight/$m^2$) were contained in $T_1$, $T_2$, and $T_3$. Variation in total tiller number was a reflection of variation in the $T_1$ tiller number, with the reduction in total tiller number by higher temperature (at sowing period), shorter photoperiod, or reduced light intensity being explained by change in the supply of assimilates. A low tiller number is a reflection of the failure of tillers to emerge and must reflect the pre-emergence growth. Under adverse conditions such as high temperature, fewer $T_1$ tiller buds developed, and consequently the mean length of the tiller was restricted from the early stages of growth. It was shown that a rise in temperature during the sowing period was the over-riding factor in determining the number of $T_1$ tillers produced.

ii. Number of Kernels Per Head

The second of the sequential yield components, the number of kernels per head, has been regarded in many cases as the most important of the three components. Thorne et al. (1968) working with wheat, followed by Willey and Holliday (1971) with barley, found that environmental differences in periods 1 and 2 (pre-heading phase) affected yield by altering the capacity of the ear to accumulate carbohydrates, determined by the number of grains per ear, rather than by altering the supply of carbohydrates. High correlations of spikelet number and yield were also found by Faris [illegible] (1969) in barley, and Rawson (1970) in wheat.

In most cases the spikelet number of a cereal was closely related to the length of the pre-heading phase. Rawson (1970) divided this period into two phases when working with wheat. He found that with those cultivars sensitive to vernalization the period up to inflorescence initiation (double ridge) is more important for controlling spikelet number. In this period, potential spikelet sites were established, and in a variety sensitive to vernalization, once floral initiation had occurred development of inflorescences proceeded rapidly and few additional spikelet primordia were differentiated. In those cultivars where daylength is important (with no vernalization response) it is the duration of the period from initiation to terminal spikelet formation during which all of the spikelet initial are formed, which appeared critical in determining spikelet number. The spikelet number of cultivars with a slight response to cold was associated with the length of both these periods (time to initiation and initiation to anthesis). Rawson enlarged upon this in 1971, again with wheat. He found that differences in final spikelet number arose from differences in double ridge number at floral initiation, in the rate of production of spikelet primordia and in the duration of production. However, he stated that the final spikelet primordium number was not determined solely by the duration of production, for under shorter photoperiods the initial rates of spikelet appearance were lower for later cultivars, and in all but the earliest varieties rates of appearance fell as the terminal spikelet was approached. Thus the early varieties maintained a high rate of spikelet production up to the appearance of the terminal spikelet and differences occurred only in the duration of spikelet production.

Willey and Holliday (1971) found similarities between the development of barley and wheat, while Paleg and Aspinall (1966) stressed that in barley the further

development of spikelet initials and differentiation of floral organs was influenced by the photoperiod regime. They correlated changes in primordium production and the cessation of apical meristematic activity with the progress of the differentiating ear, while cessation of primordium production occurred at the stage of stamen initiation in the central spikelets. Further evidence of the photoperiodic sensitivity of barley in controlling spikelet number was shown by Tingle et al. in 1970.

On many occasions it has been discovered that in barley and wheat there was often a reduction in the number of fertile spikelets from the number of primordia initiated. Rawson (1971) linked fertility toward the tip of the ear with the establishment of many spikelet primordia before the appearance of glume initials and with the concurrent development of spikelets. Paleg and Aspinall (1966) and Kirby (1974) linked the failure of these florets to develop with the competition for assimilates, ultimately controlled by the available supply of carbohydrates.

In summation, the potential for grain yield, as expressed by the number of grains per ear, is affected by the light environment of the shoot at any stage before ear emergence and is therefore a function of the latitude of the planting site, the date of planting, and the photoperiodic sensitivity of the variety sown (Puckridge, 1968, with wheat; and Paleg and Aspinall, 1966, with barley).

iii. Kernel Weight.

The third and final component of yield, weight of the grain, in many cases has a high correlation with yield, and, in others, a low relationship. It is during this final period, anthesis to maturity, that the accumulation of carbohydrates occurs to produce the final grain weight. Nass and Reiser (1975) found that the rate

of filling in spring wheat appeared to be a more important factor to grain weight, while the length of the filling period was not. However, Kirby (1974) concluded that varietal differences in the accumulation of ear dry matter in spring wheat were mainly in the duration of the filling period, and not in the initial size or rate of filling. He suggested that duration of the period of ovary formation could determine the potential size of the grain. Also important in the development of the grain after anthesis is the production of photosynthates as influenced by temperature and duration of light, since most of the carbohydrates available for grain filling are formed after heading (Nass and Reiser, 1975; Ford and Tharne, 1975).

Kirby (1974) found that the distribution of weight of individual grains within the ear was determined during this period, and was probably due to a limited supply of nutrients to support potential growth of all the florets. In addition, Paleg and Aspinall (1966) demonstrated that there was photoperiodic sensitivity present in barley in the later stages of development, including the grain-filling period.

Wardlaw (1970) made a more detailed study of the development of the grain by examining the effects of temperature and light during two periods after anthesis in wheat. He found that high temperatures during the first ten days immediately after anthesis affected yield by causing a reduction in seed set, which was partially compensated for by increased grain size. However, high temperatures during the stage of starch deposition (15-25 days after anthesis) had a greater effect and reduced the weight of individual grains.

Walpole and Morgan (1971) discovered that the grain weight of barley increased almost linearly for 4 to 5 weeks after anthesis, after which there was a loss

shortly before the ear reached maturity. He found that this filling period consisted of three distinct phases characterized by:

1. The accumulation of more dry matter per grain in the central region of the ear;
2. The lower region of the ear putting on more weight than the others;
3. The loss of dry weight.

In the first phase barley and wheat showed similar development, but in the second phase the wheat grains in midear retained the advantage they showed in phase 1, while in barley they lost it to the basal grains. It was shown that different barley varieties can have identical yielding ability and yet behave differently in each of these three phases. Walpole and Morgan (1971) concluded that the characters most important to a high yielding variety were a long period from anthesis to senescence, a high initial rate of grain growth, low grain respiratory requirements, and a coincidence of grain maturity and its decrease in respiratory demands with the cessation of assimilate availability.

Debate now centers on whether the yield of a cereal is limited by its source (carbohydrate supply) or its sink (capacity of the ear to accumulate carbohydrates). Willey and Dent (1969) suggested that grain yield should be regarded as being determined neither by carbohydrate supply nor by ear capacity but by the resultant of the two. According to Ford and Thorne (1975), grain yield is usually controlled by both source and sink, but one or the other can predominate in a particular situation. When temperature and sunshine affect yield before anthesis they

act on the number of grains (sink) rather than on the photosynthetic system. Crops after anthesis are more susceptible to environment (daylight and temperature) which acts mainly on the production of carbohydrate for grain filling rather than on the sink capacity of the grain. Therefore, to increase yield it should be possible to genetically change the number of grains in the head by lengthening the period before anthesis, but this must be done without shortening the period of carbohydrate accumulation after anthesis (Thorne et al., 1968).

## VI. LODGING

As lodging in cereals can play a significant part in affecting the yield, thus lowering productivity as well as creating mechanical problems in harvesting, there has been fairly continuous research into the causes and effects of this phenomenon. Laude and Pauli (1956) showed that lodging in winter wheat affected the yield in different ways before and after heading. The major effect on yield by lodging that occurred up to and including heading time was created by a decrease in the number of kernels per head. If lodging occurred one week or more after heading, it was the size of the kernel that was dominantly affected. It was also found that the greatest effect on kernel size occurred 11 to 15 days after heading. Any further lodging after this had a lesser effect on yield. These results were partially supported by Day (1957) who found that lodging after heading time created losses in test weight and seed weight of barley.

Since it became evident that early lodging (before heading) had such an important effect on yield, investigations began to uncover the probable reasons for this behavior. Gardener and Rathjen (1975) showed that juvenile lodging in barley,

which occurred before stem elongation, affected the number of ears per plot and the number of seeds per ear. However, they found that a lower seed number created at this stage did not always affect the final yield as it was often compensated for by a higher grain weight. Cooper (1971) also found this effect on the yield of soybean when he showed that early lodging stimulated terminal growth and exessive branching at the expense of seed set.

There is a general consensus in the literature that the greatest yield losses from lodging (apart from mechanical losses from shattering and difficulty in harvesting) are due to changes in the canopy. Even with juvenile lodging in varieties that later recovered, light relationships in the canopy, along with ventilation, evaporation, and temperature were drastically (and often permanently) changed (Gardener and Rathjen, 1975). Increased shading led to a decreased light distribution over total leaf area, thus restricting the capacity of lodged plants to absorb nutrients or to synthesize materials and store them in the grain (Laude and Pauli, 1956; and Cooper, 1971). Also important is the fact that lodging may stimulate increased vegetative growth at the expense of seed set (Luellen, 1970). With lodging that occurred after heading, yield reductions were probably the effect of a decrease in translocation from the leaves to the head, particularly if stalk break occurred (Larson and Maranville, 1977).

Three different approaches towards quantifying lodging will give an idea of the complex interactions involved in lodging resistance. In 1934 Brady showed by physicat observation that lodging resistance in oats could be due to shorter, lower internodes, thicker internodes, and thicker culm walls. Neenan and Spencer-Smith (1975) tackled the character as an engineering problem and derived a formula

to describe lodging resistance. They showed that structural failure (lodging) resulted from stem buckling rather than a loss of anchorage, for root failure is extremely unlikely unless soil conditions are such that the plant cannot be supported. Therefore the resistance to bending of the straw is determined by two factors: 1) Young's modulus, which is a co-efficient of rigidity that can be directly affected by the wetness of the straw, the maturity of the straw, and by the variety; 2) the outer diameter of the straw. Also found to be of importance was the amount of taper in the straw.

Another approach towards quantifying lodging resistance is chemical. Debate exists on whether the amount of potassium present in the stalk is important in determining resistance (Esechie et al., 1977). Also under investigation is the total amount of non-structural carbohydrates and protein concentrations in the stem. However, the authors showed that lodging resistant varieties were generally more resistant to post-freeze senescence and therefore later maturing.

# MATERIALS AND METHODS

Thirty-two lines of six-row barley (Hordeum vulgare L.) were selected from the World Barley Collection at Aberdeen, Idaho, for their variability in growth pattern in time taken to mature. For the purpose of this study these lines were subsequently grown during a period of three years. The first year's material was grown in the growth chamber at Agriculture Canada Experimental Station, Beaverlodge, Alberta, by D. G. Faris, in the winter of 1971-72. In the summers of 1973 and 1974 the material was grown in replicated field trials at the Edmonton Research Station, University of Alberta.

The lines in the 1971-72 test were grown in vermiculite with a modified Hoagland's solution (half strength). Five seeds of each line were planted, two lines to a box. The material was seeded November 25, 1971, and grown at a constant temperature of 21°C. Eighteen hours of light were provided daily to reduce sterility, and the boxes were regularly rotated on the benches to minimize positional effects in the growthroom. The seed obtained from this material was harvested separately from each plant, thus establishing thirty-two families with up to five lines within each family. In 1973, each line was planted by hand with 30 seeds per row in rows 1.2 meters in length and 23 cm apart for as many replicates (ranging from 1 to 3 as available seed permitted.

In 1974 the lines were grown in 4-row plots 5 meters long with rows 23 cm apart. The center two rows of each plot were harvested. This design was a randomized block with two replicates. In the field trials of 1973 and 1974 extra control varieties, listed in Appendix II, were added to the test. Date of seeding in 1973

was May 14, and in 1974, May 18. Notes were taken on the dates of emergence, internode elongation, heading, and maturity (as described in Appendix III), as well as height, head length and yield for all three years. Growth periods were calculated from these notes to produce, along with additional observations taken in the field, the variables listed in Table I. For simplicity, these growth periods were designated under alphabetical names as indicated in Table I. Also, in 1974, daily observations on meteorological conditions were taken.

Because of limitations on the amount of seed produced in 1973, bushel weights were measured using the A. S. B. C. * approved method, whereby the volume of 110 grams of seed was measured and transformed to bushel weight using the appropriate scale. About one-third of the samples produced a yield of under 110 grams, thereby preventing the use of this method of estimate. The following experiment was performed to find a method suitable for estimating bushel weight for these small samples: Samples of 25, 50, 75 and 110 grams were taken from each of 14 licensed cultivars of known bushel weight. The volume of each one of these samples was measured in ml. These volumes were then plotted against the bushel weight of each variety for each sample weight, producing a curve for each sample weight. Since the volume from the small samples of low yielding lines was recorded, it was possible to make an extrapolation on these curves and to provide a reasonable estimate of bushel weight. Bushel weights for both years were then transformed into metric test weights.

*American Society of Brewing Chemists

TABLE I. Variables Studied in Each Year

| | Variables | Year Studied | | |
|---|---|---|---|---|
| | | 1972 | 1973 | 1974 |
| 1. | Days from Seeding to Emergence (A) | * | * | * |
| 2. | Days from Emergence to Internode Elongation (B) | * | * | * |
| 3. | Days from Internode Elongation to Heading (C) | * | * | * |
| 4. | Days from Heading to Ripe (D) | * | * | * |
| 5. | Days from Seeding to Internode Elongation (A + B) | * | * | * |
| 6. | Days from Emergence to Heading (B + C) | * | * | * |
| 7. | Days from Internode Elongation to Ripe (C + D) | * | * | * |
| 8. | Days from Seeding to Heading (A + B + C) | * | * | * |
| 9. | Days from Emergence to Ripe (B + C + D) | * | * | * |
| 10. | Days from Seeding to Ripe (A + B + C + D) | * | * | * |
| 11. | Combination of Periods (A + C) | * | * | * |
| 12. | Combination of Periods (A + D) | * | * | * |
| 13. | Combination of Periods (B + D) | * | * | * |
| 14. | Combination of Periods (A + B + D) | * | * | * |
| 15. | Combination of Periods (A + C + D) | * | * | * |
| 16. | Yield (grams) | /plant | /1.2 m row | /4 row 5 m plot |
| 17. | Height (cm) | * | * | * |
| 18. | Head length (cm) | * | * | * |
| 19. | No. plants/1.2 meter row | | * | * |
| 20. | No. heads/1.2 meter row | | * | * |
| 21. | No. secondary tillers/1.2 meter row | | * | * |
| 22. | 1000 Kernel weight (gm) | | * | * |
| 23. | Test weight (converted to kg/hl) | | * | * |
| 24. | Plant habit at IE on a scale of 1 (erect) to 5 (prone) | | * | * |
| 25. | Lodging date 1 on a scale of 1 (no lodging) to 9 (total lodging) | | * | * |
| 26. | Lodging date 2 " " " " | | * | * |
| 27. | Lodging date 3 " " " " | | * | * |
| 28. | Lodging date 4 " " " " | | * | * |
| 29. | Lodging date 5 " " " " | | * | * |
| 30. | Lodging date 6 " " " " | | | * |
| 31. | Lodging date 7 " " " " | | | * |
| 32. | Lodging date 8 " " " " | | | * |

N. B. Lodging notes were taken on a series of sequential dates.

Statistical Analysis

Preliminary analysis of results for each year indicate differences between results shown by lines of the same family, thus showing that seed thought to be identical within a family showed variation that could only be attributable to genetic differences. The origin of these genetic differences can probably be attributed to lack of homozygosity or purity in the lines originally obtained from the World Collection. This suspicion was confirmed by the application of a Duncan's Multiple Range Test on line means of the 1974 data. Here the lines causing discrepancies were identified as significantly different from their family mean.

Because of these differences, analysis was then performed on the means of the lines, rather than grouping them into families. Each line was then treated as an independent sample, thus bringing the total number of lines to 144, in addition to the checks. As there was a variable number of replicates in 1973, analyses were performed only on means of the replicates for each line in 1973 and 1974, respectively.

Analyses in all three years included simple correlations for all variables, a factor analysis on these correlations, and various stepwise multiple regressions. These analyses were conducted to determine the relationships among the variables, and to give an indication of what associations and dependencies might exist. Also included in 1974 was an analysis of variance, performed upon the two replicates with 169 samples. From this, broad sense heritabilities and a Duncan's Multiple Range Test on the means of the two replicates were calculated.

i. Simple correlations: The simple correlation coefficient was calculated between n variables for the sample means of each of the three sets of data, giving a $n \times n$

matrix of correlations for each year. Correlations for each variable were also calculated among the three sets of data.

ii. Factor analysis: The three matrices of intercorrelated n variables of N lines [made of all possible $1/2n(n-1)$ pairings of variables] were then tested by the use of factor analysis. Here, each correlation matrix was transformed into an n x k factor matrix, forming a principal component matrix described as:

$$Z_j = a_{j1}F_1 + a_{j2}F_2 + \ldots a_{jn}F_n$$

where $Z_j$ = variable j in standardized form

$F_1$ = hypothetical factors ($F_1, F_2, \ldots F_n$)

$a_{j1}$ = standardized multiple-regression coefficient of variable j on factor i (factor loading)

Here, each of the n observed variables was described linearly in terms of n new uncorrelated components $F_1, F_2, \ldots F_n$; each of these is in turn defined as a linear combination of the n original variables.

The principal component model can be described as transforming a given set of variables into a new set of composite variables that are orthogonal to each other. It forms the best linear combinations of variables in the sense that the particular combination of variables would account for more of the variance in the data as a whole than any other combination of variables.

The total variance of a variable accounted for by the combination of all common factors, designated $h_j^2$, gave the communality of the variables.

The principal factor matrix was then subjected to a varimax rotation which simplified the columns of a factor matrix in order to maximize the variance of the squared loadings in each column (SPSS, 1976; Cattell, 1965).

iii. Multiple Regressions: Data for each year were tested by various stepwise multiple regressions in order to find the amount of dependency yield had on the other variables. Variable Y (yield) was regressed on variables $X_1$, $X_2$, $X_3$, . . . $X_n$, with various combinations of these being taken to obtain a minimum of unexplained residual variance in terms of the smallest number of independent variables. This was done by dropping any potential independent variables that did not remove a significant independent portion of the variation (Sokal and Rolf, 1969). $R^2$ values giving an indication of the amount of variation accounted for by the equation were also calculated.

iv. Analysis of variance: For the 1974 test a complete randomized block design with 2 replicates and 169 treatments was used in the Analysis of Variance for each variable, as described below:

| Source of Variation | df. | Mean Square is an Estimate of: |
|---|---|---|
| Blocks | $(r - 1)$ | $\sigma_E^2 + t\sigma_B^2$ |
| Genotypes | $(t - 1)$ | $\sigma_E^2 + r\sigma_G^2$ |
| Error | $(r - 1)(t - 1)$ | $\sigma_E^2$ |
| Total | $(rt - 1)$ | |

t = number of genotypes (treatments)

r = number of replicates (blocks)

Here the treatment x replicate interaction was used as the error term, thus accounting for genotype x environment interactions. From these results it was possible to arrive at an estimate of Broad Sense Heritabilities for each variable, using the method described by Steel and Torrie (1960) for the partitioning of mean squares. Here, mean squares were partitioned to give an estimate of $\sigma_G^2$ or the variance attributed to genetic differences within a population; $\sigma_E^2$ which was the variance attributed to environmental differences within a population, and $\sigma_B^2$ which was the variance due to replicate differences within a population. Broad Sense Heriabilities were then calculated using the formula:

$$H = \frac{\sigma_G^2}{\sigma_G^2 + \sigma_E^2}$$

As a final test, means of the two replicates were compared for each variable as mentioned above, in a Duncan's Multiple Range Test, using the method described in Steel and Torrie, 1960.

# RESULTS

## I. COMPARISON OF MEANS OF LINES AS A TEST OF WITHIN FAMILY HOMOGENEITY

A Duncan's Multiple Range Test was performed on the means of 17 of the characters in the 1974 material to check for possible lack of homogeneity within each of the thirty-two families. Results (Table II) indicated that there were significant difference within twenty of the families for one or more characters, thus showing a lack of homogeneity in these families.

Where growth stages were involved, in most cases it was the same line (Table III) that repeatedly showed differences within a family. These lines showed differences at different stages of growth. In some of the later stages the effect appeared to be additive. That is, the differences were not significant in an individual growth phase, but with two or more phases combined the differences became significant.

There is a marked difference between those families showing heterogeneity in growth stages, and those showing heterogeneity in morphological characters (Table III). Also, in the latter cases, there are few lines in common. One exception is family 13 which shows significant differences in both head length and yield.

An interesting exception to the above is family 39, which is heterogeneous in the largest number of characters. Differences are shown in most of the growth stages with line 39-4 having longer growth periods after internode elongation (C and D) than 39-3; as well as in 1000 kernel weight, where 39-3 shows a significantly greater mean of 10 grams.

TABLE II. Families Showing Significant Differences at the Five Percent Level in Duncan's Multiple Range Test (1974 Data)

| Family Number | No. of Non-homogeneous Characters |
|---|---|
| 4 | 4 |
| 7 | 1 |
| 8 | 1 |
| 9 | 3 |
| 13 | 3 |
| 14 | 3 |
| 19 | 1 |
| 26 | 1 |
| 27 | 1 |
| 29 | 1 |
| 31 | 1 |
| 32 | 3 |
| 34 | 1 |
| 39 | 8 |
| 41 | 1 |
| 44 | 3 |
| 46 | 1 |
| 49 | 1 |
| 52 | 3 |
| 54 | 1 |

Families 1, 3, 5, 6, 10, 15, 18, 30, 38, 47 and 53 showed homogeneity for all characters tested, out of a total of 32 families.

TABLE III. Table of Lines that show Non-homogeneity for each Character (1974 Data)

| | Character | Line Number |
|---|---|---|
| 1. | Days from Seeding to Emergence | - |
| 2. | Days from Emergence to I. E. | 07-4, 52-5 |
| 3. | Days from I. E. to Heading | 08-5, 09-3, 14-1, 39 (3/4), 44-1 |
| 4. | Days from Heading to Ripe | 04-3, 04-4, 39 (3/4) |
| 5. | Days from Seeding to I. E. | - |
| 6. | Days from Seeding to Heading | 09-3, 14-1, 32-4, 39 (3/4), 44-1, 44-4, 52-3 |
| 7. | Days from Seeding to Ripe | 04-3, 04-4, 39 (3/4) |
| 8. | Days from Emergence to Heading | 09-3, 14-1, 32-4, 39 (3/4), 44-1, 52-3 |
| 9. | Days from Emergence to Ripe | 04-3, 04-4, 32-3, 39 (3/4) |
| 10. | Days from I. E. to Ripe | 04-3, 04-4, 39 (3/4) |
| 11. | Yield | 13-1, 13-4, 19-1, 41-3 |
| 12. | 1000 Kernel Weight | 34-3, 39 (3/4), 49-3 |
| 13. | Test Weight | - |
| 14. | Head Length | 13-1, 31-2 |
| 15. | Height | 07-4, 26-3, 46-3, 54-5 |
| 16. | Lodging, Date 3 | 13-3, 27-5, 29-4 |
| 17. | Lodging, Date 8 | - |

## II. VARIABILITY OF CHARACTERS

### i. Range, Means, and Variance

Tables IV, V, and VI give the ranges shown by the characters and their means and variances over the three years. There are large differences between the ranges in the growthroom material (Table IV) and those of the field years 1973 (Table V) and 1974 (Table VI). Period A shows a similar range of 6 and 5.4 days in the growthroom and 1973 material, but dropped to 2 days in 1974. Means for days to emerge were similar for the three years and, in all cases, the variances for this period were extremely low.

The range covered by period B dropped from 25 days in the growthroom to 19.5 and 6.0 days, respectively, in the two years of field material. Mean number of days covered by period B were similar in the growthroom and 1974 material, but increased to 31.3 in 1973. The highest variance for period B was 25 for the growthroom material, followed by the lower values of 10.2 in 1973 and 1.8 in 1974. The range of days covered by period C showed a similar pattern of 29 days in the growthroom, 19 days in 1973, and 22.5 days in 1974. Means for this period were 27.7, 12.5 and 24.4 days respectively, and variances were 60.1, 24.4 and 26.4.

Period D showed the greatest differences in range with 42 days in the growthroom and 12.7 and 18.0 days respectively in 1973 and 1974. Means for this period were 48.9, 46.4 and 44.8 days. The growthroom data again shows the largest variance of 116.1 followed by a dramatic drop in the field material with variances of 9.8 in 1973 and 13.5 in 1974. Of interest is the similar large range taken by the total time from seeding to maturity in the growthroom, decreasing

TABLE IV. Range, Means and Variance of Growth Periods, Height and Head Length in 1971/72

| Variable | Minimum | Maximum | Mean | Variance |
|---|---|---|---|---|
| Days from Seeding to Emergence (A) | 7.0 | 13.0 | 8.5 | 0.8 |
| Days from Seeding to Internode Elongation (A + B) | 21.0 | 47.0 | 29.3 | 25.6 |
| Days from Seeding to Heading (A + B + C) | 44.0 | 84.0 | 56.9 | 115.4 |
| Days from Seeding to Ripe (A + B + C + D) | 80.0 | 141.0 | 105.9 | 186.2 |
| Days from Emergence to IE (B) | 13.0 | 38.0 | 20.0 | 25.0 |
| Days from Emergence to Heading (B + C) | 35.0 | 73.0 | 48.4 | 115.9 |
| Days from Emergence to Ripe (B + C + D) | 71.0 | 139.0 | 97.3 | 182.1 |
| Days from IE to Heading (C) | 18.0 | 47.0 | 27.7 | 50.1 |
| Days from IE to Ripe (C + D) | 54.0 | 97.0 | 76.6 | 119.0 |
| Days from Heading to Ripe (D) | 32.0 | 74.0 | 48.9 | 116.1 |
| Height (cm) | 78.0 | 150.0 | 109.0 | 290.0 |
| Head Length (cm) | 4.0 | 9.0 | 6.5 | 1.9 |
| Yield (grams per plant) | 0.6 | 19.4 | 4.3 | 7.2 |

TABLE V. Range, Means, and Variance of Growth Periods, Yield Components and Lodging in 1973 (Calculated on means of Replicates)

| Variable | Minimum | Maximum | Mean | Variance |
|---|---|---|---|---|
| Days from Seeding to Emergence (A) | 5.3 | 10.7 | 7.4 | 0.7 |
| Days from Seeding to Internode Elongation (A + B) | 35.3 | 54.7 | 38.6 | 19.6 |
| Days from Seeding to Heading (A + B + C) | 41.7 | 72.3 | 51.1 | 53.9 |
| Days from Seeding to Ripe (A + B + C + D) | 86.0 | 119.3 | 97.5 | 51.9 |
| Days from Emergence to IE (B) | 27.5 | 47.0 | 31.3 | 10.2 |
| Days from Emergence to Heading (B + C) | 34.0 | 64.7 | 43.8 | 55.9 |
| Days from Emergence to Ripe (B + C + D) | 55.2 | 79.3 | 90.1 | 55.2 |
| Days from IE to Heading (C) | 6.0 | 25.0 | 12.5 | 24.4 |
| Days from IE to Ripe (C + D) | 49.3 | 73.0 | 58.9 | 26.6 |
| Days from Heading to Ripe (D) | 41.0 | 53.7 | 46.4 | 9.8 |
| Height (cm) | 55.0 | 118.3 | 92.3 | 179.4 |
| Head Length (cm) | 4.0 | 11.0 | 6.8 | 2.1 |
| 1000 Kernel Weight (g) | 21.7 | 45.0 | 35.4 | 25.4 |
| Test Weight (kg/hl) | 38.7 | 78.6 | 60.9 | 4 |
| No. of Plants per 1.2 m sample | 16.3 | 28.0 | 23.8 | 5.5 |
| No. of Heads per 1.2 m sample | 40.7 | 176.0 | 108.0 | 518.7 |
| No. of Secondary Tillers per 1.2 m sample | 0.0 | 116.7 | 43.1 | 428.8 |
| Habit at Internode Elongation* | 1.0 | 4.0 | 2.7 | 0.5 |
| Lodging, date 1 | 1.0 | 6.5 | 1.7 | 1.1 |
| Lodging, date 2 | 1.0 | 5.0 | 1.3 | 0.4 |
| Lodging, date 3 | 1.0 | 6.0 | 1.9 | 1.3 |
| Lodging, date 4 | 1.0 | 9.0 | 4.2 | 2.5 |
| Lodging, date 5 | 1.0 | 8.0 | 4.6 | 3.2 |
| Yield (grams per 1.2 m sample) | 52.8 | 287.7 | 161.2 | 2539.4 |

* Defined as leaf and tiller spread at Internode Elongation.

TABLE VI. Range, Means and Variance of Growth Periods, Yield Components and Lodging in 1974 (Calculated on means of Replicates)

| Variable | Minimum | Maximum | Mean | Variance |
|---|---|---|---|---|
| Days from Seeding to Emergence (A) | 5.0 | 7.0 | 6.2 | 0.4 |
| Days from Seeding to Internode Elongation (A + B) | 23.0 | 28.5 | 25.3 | 1.6 |
| Days from Seeding to Heading (A + B + C) | 39.5 | 62.0 | 49.7 | 31.1 |
| Days from Seeding to Ripe (A + B + C + D) | 82.0 | 110.0 | 94.5 | 48.7 |
| Days from Emergence to IE (B) | 16.0 | 22.0 | 19.1 | 1.8 |
| Days from Emergence to Heading (B + C) | 34.0 | 56.5 | 43.5 | 31.8 |
| Days from Emergence to Ripe (B + C + D) | 76.0 | 104.0 | 88.3 | 47.9 |
| Days from IE to Heading (C) | 15.5 | 38.0 | 24.4 | 26.4 |
| Days from IE to Ripe (C + D) | 56.0 | 84.5 | 69.2 | 43.4 |
| Days from Heading to Ripe (D) | 37.0 | 55.0 | 44.8 | 13.5 |
| Height (cm) | 55.0 | 117.5 | 85.6 | 104.4 |
| Head Length (cm) | 3.0 | 9.0 | 6.0 | 1.0 |
| 1000 Kernel Weight (g) | 30.5 | 51.5 | 38.1 | 19.3 |
| Test Weight (kg/hl) | 48.6 | 73.0 | 57.7 | 41.3 |
| No. of Plants per 1.2 m sample | 21.5 | 67.0 | 39.6 | 70.3 |
| No. of Heads per 1.2 m sample | 66.0 | 230.0 | 116.2 | 556.2 |
| No. Secondary Tillers per 1.2 m sample | 0.0 | 97.5 | 19.0 | 300.1 |
| Habit at Internode Elongation | 1.0 | 5.0 | 2.8 | 0.6 |
| Lodging, date 1 | 1.0 | 8.5 | 2.0 | 4.9 |
| Lodging, date 2 | 1.0 | 9.0 | 2.0 | 3.1 |
| Lodging, date 3 | 1.0 | 7.0 | 1.6 | 1.3 |
| Lodging, date 4 | 1.0 | 9.0 | 3.7 | 4.8 |
| Lodging, date 5 | 1.0 | 7.5 | 2.2 | 2.2 |
| Lodging, date 6 | 1.0 | 7.5 | 3.4 | 2.9 |
| Lodging, date 7 | 1.0 | 7.0 | 3.0 | 2.3 |
| Lodging, date 8 | 1.0 | 9.0 | 6.1 | 2.8 |
| Yield (grams/plot) | 157.0 | 1374.0 | 775.0 | 77445.9 |

to 12.7 days in 1973 and 18.0 days in 1974. Means over the three years were similar with variances dropping from 186.2 to 51.9 and 48.7.

Height and head length showed fairly consistent ranges over all three years with values of 72, 63.3 and 62.5 for height and 5.0, 7.0 and 6.0 cm for head length. Means for these characters were 109.0, 92.3 and 85.6 for height and 6.5, 6.8 and 6.0 for head length. Variances for height remained high for the three years at 290.0, 179.4, and 104.4 $cm^2$. Variances for head length in all cases were low with values of 1.9, 2.1 and 1.0 $cm^2$, respectively.

Of the morphological characters studied only in the two field years, the greatest range was shown by the number of heads per sample with values of 135.3 in 1973 and 164.0 in 1974. Means were 96.0 and 116.2 heads per sample respectively, while the variances were extremely high for both years at 518.7 and 556.2. The next highest range was shown by the number of secondary tillers, with values of 116.7 and 97.5. Means of secondary tillers were much lower, especially in 1974 with 43.1 tillers in 1973 and 19.0 tillers in 1974. Variances in this case were still extremely high at 428.8 and 300.1. Number of plants per sample showed a fairly low range of 12.7 in 1973 but increased to 45.5 in 1974. Means were 96.0 and 116.2 plants and variances were 5.5 and 70.3 respectively. The range for the test weight was higher in 1973 at 39.9 $kg/h^2$ but dropped to 24.4 in 1974. Means were similar at 60.9 and 57.7 $kg/h^2$ respectively, while the variance increased from 14.4 in 1973 to 41.3 in 1974. Ranges, means and variances for 1000 kernel weight were all fairly similar between the two years. Kernel weight showed ranges of 23.3 grams in 1973 and 21.0 grams in 1974, means of 35.4 and 38.1 grams, and variances of 25.4 and 19.3 respectively. Smallest variance for the morphological characters was Habit (leaf and tiller spread) with ranges of 3 in 1973 and 4 4 in 1974, means of 2.7 and 2.8 and variances of 0.5 and 0.6 respectively.

ii. Analysis of Variance (1974 Field Material)

Genotype differences were highly significant (0.001)(Table VII) for the growth periods A, B, C, (B + C), and (C + D), and for all growth stages. Period D showed no significant differences among lines. Replicate differences were significant in all cases except for days from seeding to internode elongation (A + B).

Genotype differences were highly significant (0.01)(Table VIII) for the morphological characters height, number of heads, head length, habit, number of secondary tillers, kernel weight, test weight and yield. Number of plants was significant only at the 0.05 level. Variation between replicates was not so evident here as only height, kernel weight and yield were highly significant. Of still lower significance were habit, number of secondary tillers and test weight at the 0.01 level; and head length and number of heads at the 0.05 level. The number of plants per sample was non-significant.

There were highly significant differences (0.001) in the amount of lodging among genotypes at every recording (Table IX). Significant differences between replicates were observed on every occasion with the exception of lodging dates 1 and 6.

iii. Coefficients of Variation

The coefficients of variation for the growth periods and stages (Table X) ranged from fairly low (<15%) to quite high (>25%) over the three years. The growth-room material generally showed the largest variation over the three years with the smallest amount being shown by the field year 1974. In all three years period C had the highest CV's of the growth stages with values of 25.6, 39.6 and 31.8% respectively. These values were much greater than those shown by total time to head and

TABLE VII. Analysis of Variance Giving Mean Squares and F-Values for Growth Stages and Periods for 1974 Data

| Source of Variance | df | Days from Seeding to Emergence (A) | | Days from Seeding to Internode Elongation (A + B) | | Days from Seeding to Heading (A + B + C) | | Days from Seeding to Ripe (A + B + C + D) | | Days from Emergence to Internode Elongation (B) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MS | F | MS | F | MS | F | MS | F | MS | F |
| Replicate | 1 | 11.37 | 69.15*** | 1.07 | 0.70 | 106.80 | 77.95*** | 539.43 | 28.88*** | 19.41 | 2.15*** |
| Treatment | 168 | 0.70 | 4.27*** | 3.22 | 2.17*** | 62.12 | 45.34*** | 97.49 | 2.22*** | 3.67 | 11.36*** |
| Error | 168 | 0.16 | | 1.52 | | 1.37 | | 18.68 | | 1.71 | |
| | | Days from Emergence to Heading (B + C) | | Days from Emergence to Ripe (B + C + D) | | Days from Internode Elongation to Heading (C) | | Days from Internode Elongation to Ripe (C + D) | | Days from Heading to Ripe (D) | |
| | | MS | F | MS | F | MS | F | MS | F | MS | F |
| Replicate | 1 | 48.47 | 30.67** | 307.46 | 37.35*** | 129.23 | 45.11*** | 492.50 | 25.45*** | 1126.30 | 53.78*** |
| Treatment | 168 | 63.69 | 40.30*** | 95.84 | 5.06*** | 52.77 | 18.42*** | 86.81 | 4.49*** | 26.97 | 1.29 |
| Error | 168 | 1.58 | | 18.94 | | 2.86 | | 19.35 | | 20.97 | |

* Significant at the 5 per cent level

** Significant at the 1 per cent level

*** Significant at the 0.1 per cent level

TABLE VIII. Analysis of Variance Giving Mean Squares and F-Values for Morphological Characters in 1974 Data

| Source of Variation | df | Height | | No. of Plants per 1.2 m sample | | No. of Heads per 1.2 m sample | | Head Length | | Habit at Internode Elongation | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MS | F | MS | F | MS | F | MS | F | MS | F |
| Replicate | 1 | 4,353.2 | 175.28*** | 190.98 | 0.19 | 14,151 | 16.70* | 1.70 | 4.25* | 3.62 | 9.10** |
| Treatment | 168 | 208.74 | 8.40*** | 140.53 | 0.04* | 1,132.4 | 1.34*** | 2.10 | 5.24*** | 1.12 | 2.83*** |
| Error | 168 | 24.84 | | 107.57 | | 847.26 | | 0.40 | | 0.39 | |
| | | No. of Secondary Tillers per 1.2 m sample | | 1000 Kernel Weight | | Test Weight | | Yield | | | |
| Replicate | 1 | 2,322.5 | 7.23** | 197.70 | 20.05*** | 121.44 | 10.11** | 554,970 | 15.12*** | | |
| Treatment | 168 | 600.25 | 1.87*** | 38.54 | 3.91*** | 33.11 | 2.76*** | 154.890 | 4.22*** | | |
| Error | 168 | 321.16 | | 9.86 | | 12.01 | | 36,710 | | | |

* Significant at the 5 per cent level

** Significant at the 1 per cent level

*** Significant at the 0.1 per cent level

TABLE IX. Analysis of Variance Giving Mean Squares and F-values for Sequential Lodging Notes in 1974 Data

| Source of Variation | df | Lodging Date 1 | | Lodging Date 2 | | Lodging Date 3 | | Lodging Date 4 | |
|---|---|---|---|---|---|---|---|---|---|
| | | MS | F | MS | F | MS | F | MS | F |
| Replicate | 1 | 0.14 | 0.31 | 29.00 | 29.26*** | 15.77 | 30.89*** | 203.09 | 40.14*** |
| Treatment | 168 | 6.43 | 13.61*** | 6.27 | 6.33*** | 2.53 | 4.96*** | 9.56 | 1.89*** |
| Error | 168 | 0.47 | | 0.99 | | 0.51 | | 5.06 | |
| | | Lodging Date 5 | | Lodging Date 6 | | Lodging Date 7 | | Lodging Date 8 | |
| Replicate | 1 | 16.20 | 8.38** | 10.30 | 3.18 | 28.40 | 14.48*** | 231.95 | 92.55*** |
| Treatment | 168 | 4.37 | 2.26*** | 5.77 | 2.14*** | 4.53 | 2.31*** | 5.52 | 2.20*** |
| Error | 168 | 1.93 | | 2.70 | | 1.96 | | 2.51 | |

* Significant at the 5 per cent level

** Significant at the 1 per cent level

*** Significant at the 0.1 per cent level

TABLE X. Coefficients of Variation Comparing Growth Stages, Yield Components and Lodging for the Three Years, and Broad Sense Heritabilities for 1974 Data

| Variable | 1971/72 (%) | 1973 (%) | 1974 (%) | 1974 Heritabilities |
|---|---|---|---|---|
| Days from Seeding to Emergence (A) | 10.7 | 11.4 | 9.5 | 0.620*** |
| Days from Seeding to Internode Elongation (A + B) | 17.3 | 8.0 | 5.0 | 0.358*** |
| Days from Seeding to Heading (A+B+C) | 18.9 | 14.4 | 11.2 | 0.960*** |
| Days from Seeding to Ripe (A+B+C+C) | 12.9 | 7.4 | 7.4 | 0.678*** |
| Days from Emergence to IE (B) | 24.2 | 10.2 | 7.1 | 0.635*** |
| Days from Emergence to Heading (B + C) | 22.3 | 17.1 | 13.0 | 0.952*** |
| Days from Emergence to Ripe (B + C + C) | 13.9 | 8.0 | 7.8 | 0.670*** |
| Days from IE to Heading (C) | 25.6 | 39.6 | 21.0 | 0.897*** |
| Days from IE to Ripe (C + D) | 14.2 | 8.8 | 9.5 | 0.635*** |
| Days from Heading to Ripe (D) | 21.1 | 6.8 | 8.2 | 0.126 |
| Height | 15.6 | 14.5 | 11.9 | 0.786*** |
| Head Length | 21.0 | 21.5 | 17.2 | 0.679*** |
| 1000 Kernel Weight | | 14.2 | 11.5 | 0.588*** |
| Test Weight | | 10.9 | 8.8 | 0.468*** |
| No. of Plants per 1.2 m sample | | 10.0 | 21.2 | 0.133* |
| No. of Heads per 1.2m sample | | 23.7 | 20.5 | 0.144* |
| No. of Secondary Tillers per 1.2 m sample | | 48.1 | 91.0 | 0.303*** |
| Habit at Internode Elongation | | 25.8 | 27.0 | 0.478*** |
| Lodging, date 1 | | 59.1 | 113.4 | 0.863*** |
| Lodging, date 2 | | 46.5 | 88.4 | 0.727*** |
| Lodging, date 3 | | 59.0 | 69.0 | 0.664*** |
| Lodging, date 4 | | 37.6 | 57.0 | 0.308*** |
| Lodging, date 5 | | 39.0 | 65.7 | 0.387*** |
| Lodging, date 6 | | | 49.6 | 0.364*** |
| Lodging, date 7 | | | 51.0 | 0.396*** |
| Lodging, date 8 | | | 27.3 | 0.375*** |
| Yield | 62.0 | 31.3 | 35.9 | 0.617** |

total time to ripe. Lowest of the CV values shown in the growth periods was period A in the growthroom and period D in the field years 1973 and 1974. Variation shown by period A was much the same over the three years with values of 10.7, 11.4 and 9.5% respectively. However, periods B and D showed much higher values in the growthroom than in the field. Variation for total time to ripen (from seeding) followed a similar pattern, but CV's for total time were smaller than those shown by component growth periods.

CV's for the morphological characters were generally higher and showed much greater variation. Height and head length showed similar fairly high values over the three years. Again, variation in the field was less than in the growthroom. Lowest CV in 1973 was given by number of plants followed closely by test weight; and in 1974 it was test weight. Highest CV's in both years were produced by the number of secondary tillers, followed by habit. Values for yield were again highest in the growthroom and dropped in the field, though all were extremely high with CV's of 62, 31.3 and 35.9% respectively.

CV's for lodging results were extremely high for both field years, but generally dropped as the crop matured.

iv. Broad Sense Heritabilities (1974 Field Material)

Broad sense heritabilities for the growth periods and stages in 1974 were all highly significant at the 0.001 level (Table X) with the exception of period D which had a non-significant heritability of 0.126. Highest heritabilities were shown by days from seeding to heading (A + B + C)(0.960) followed closely by days from emergence to heading (B + C) (0.952). The highest of the individual growth periods was period C with 0.897. Periods A and B were lower with values of 0.620 and 0.635.

Of the morphological characters, the highest heritability was shown by height with a value of 0.786 followed by head length (0.679). These values, together with those for kernel weight, test weight and number of secondary tillers, were all highly significant at the 0.001 level. Lowest heritabilities were given by number of plants (0.133) and number of heads (0.144) with significance at the 0.05 level. Yield had a highly significant heritability of 0.617. Lodging results at all dates were shown to be highly heritable ($P \geq 0.001$) with the results ranging from 0.863 at the first lodging to 0.308 at the fourth lodging date. The results indicated a general pattern of decline in heritability of lodging to after heading time, and then a levelling off for the remainder of the growing season.

## III. ASSOCIATION OF VARIABLES FOR THE THREE YEARS

### i. Simple Correlations

Although some associations significant to the 0.01 level did occur, the relationship between any two growth periods and stages was generally low (Table XI)*. Period A showed its strongest positive associations with period D for all three years, though a significant and negative relationship with period B did occur in the field years of 1973 and 1974. The highest positive correlations for any pair of growth periods was that between periods B and C, though in the growth chamber and the 1973 field experiment. Associations between periods B and D are low and negative with significant differences occurring only in 1973. Correlations of periods C and D are low and negative but significant in the growthroom material and 1973 field material.

*Note: A test of homogeneity was applied to the three sets of correlations in order to see if the three years' data could be considered as coming from the same population. Certain of these sets of correlations, though biologically similar, showed significant differences (i.e. ABCD vs BCD). This is due to the high degrees of freedom used, and also to the extreme skewedness experienced in the distribution of the upper end of the Z-transformation.

TABLE XI. Simple Correlation Coefficients Between Growth Periods and Stages

(Upper values: 1971/72 data, N = 144; middle values: 1973 data, N = 152; lower values: 1974 data, N = 163)

| | Days from Seeding to Emergence (A) | Days from Seeding to Internode Elongation (A + B) | Days from Seeding to Heading (A+B+C) | Days from Seeding to Ripe (A+B+C+D) | Days from Emergence to Internode Elongation (B) | Days from Emergence to Heading (B + C) | Days from Emergence to Ripe (B+C+D) | Days from Internode Elongation to Heading (C) | Days from Internode Elongation to Ripe (C + D) |
|---|---|---|---|---|---|---|---|---|---|
| Days from Seeding to Internode Elongation (A+B) | 0.157<br>0.037 ns<br>0.082 | | | | | | | | |
| Days from Seeding to Heading (A + B + C) | 0.019<br>- 0.110 ns<br>- 0.066 | 0.836**<br>0.856** s<br>0.445** | | | | | | | |
| Days from Seeding to Ripe (A + B + C + D) | 0.199*<br>0.033 ns<br>0.142 | 0.672**<br>0.781** s<br>0.393** | 0.667**<br>0.907** s<br>0.852** | | | | | | |
| Days from Emergence to Internode Elongation (B) | - 0.024<br>- 0.229** s<br>- 0.360** | 0.984**<br>0.967** s<br>0.900** | 0.843**<br>0.864** s<br>0.455** | 0.644**<br>0.752** s<br>0.305** | | | | | |
| Days from Emergence to Heading (B + C) | - 0.066<br>- 0.221** ns<br>- 0.170* | 0.821**<br>0.836** s<br>0.931** | 0.996**<br>0.994** ns<br>0.994** | 0.821**<br>0.886** ns<br>0.827** | 0.843**<br>0.873** s<br>0.477** | | | | |
| Days from Emergence to Ripe (B + C + D) | 0.134<br>- 0.083 ns<br>0.058 | 0.669**<br>0.775** s<br>0.389** | 0.673**<br>0.918** s<br>0.865** | 0.998**<br>0.993** s<br>0.996** | 0.653**<br>0.777** s<br>0.339** | 0.660**<br>0.910** s<br>0.848** | | | |
| Days from Internode Elongation to Heading (C) | - 0.083<br>- 0.186 ns<br>- 0.092 | 0.554**<br>0.643** s<br>0.236** | 0.920**<br>0.946** s<br>0.975** | 0.532**<br>0.855** s<br>0.828** | 0.576**<br>0.676** s<br>0.261** | 0.925**<br>0.949** s<br>0.972** | 0.543**<br>0.875** s<br>0.843** | | |
| Days from Internode Elongation to Ripe (C + D) | 0.177*<br>0.024 ns<br>0.135 | 0.376**<br>0.490** s<br>0.223** | 0.446**<br>0.752** s<br>0.818** | 0.939**<br>0.927** s<br>0.984** | 0.349**<br>0.471** s<br>0.150* | 0.430**<br>0.736** s<br>0.793** | 0.938**<br>0.921** s<br>0.981** | 0.408**<br>0.311** s<br>0.831** | |
| Days from Heading to Ripe (D) | 0.244**<br>0.334** ns<br>0.371** | 0.018<br>- 0.209** ns<br>0.071 | - 0.159<br>- 0.256** s<br>0.102 | 0.629**<br>0.174* s<br>0.608** | - 0.026<br>0.293** ns<br>- 0.095 | - 0.180<br>- 0.289** s<br>0.002 | 0.620**<br>0.134 s<br>0.581** | - 0.255**<br>- 0.248** s<br>0.094 | 0.779**<br>0.633** ns<br>0.630** |

Significance values:

1972: $P_{0.05} = 0.164$, $P_{0.01} = 0.213$

1973: $P_{0.05} = 0.159$, $P_{0.01} = 0.208$

1974: $P_{0.05} = 0.105$, $P_{0.01} = 0.190$

s - significant

ns - not significant

Correlations between the individual growth periods and total time from seeding to maturity showed varying results which could be affected by the relative size and variance of the individual period, as well as the presence of interactions produced when the growth period is a part of the total growing time. Relations of total time with period A were low with significance at the 0.05 level occurring only in the growth-room material. Associations between the second growth period (B) and total time were positive and highly significant with correlations of 0.64, 0.75, and 0.31. However, highest associations are found in the first two years (growthroom and 1973 field) while lower correlations occurred in the 1974 material. The third period (C) showed positive and highly significant correlations of 0.53, 0.86, and 0.83 with total time. Here, the association was lowest in the growthroom but equally high for the two field years. Relationships of period D and total time are positive but lower, with correlations of 0.63 in the growth room and 0.61 in 1974. 1973 material showed a very low association of 0.17 with only 5% significance.

A comparison of total time from seeding to maturity with its component stages (from seeding) revealed extremely low correlations with time to emergence, and progressively higher relationships with times to internode elongation and heading. Time to internode elongation showed high and positive significant correlations of 0.67, 0.78, and 0.39 with total time. The relationship is highest in the 1973 material and growthroom material, and much lower in 1974. Time to head showed positive and high significant associations of 0.67 and 0.91 with total time in the growthroom and 1973 material, but a lower but still highly significant correlation of 0.31 in 1974.

There were no extremely high correlations occurring between the length of the growth phases and the morphological characters (Table XII) but relationships significant to the 1% level did occur. Correlations of yield with the length of the growth periods C and D were consistently significant for all three years. Period B achieved a significant association with yield in the growthroom and 1974 field material, the latter producing the highest correlation.

Correlations of yield with the longer growth phases (i.e. combined periods and stages) showed some significant values, but were not consistent over the three years. The period of early growth (seeding to internode elongation), the period from seeding to heading, and also the period from emergence to internode elongation, showed positive significant results in the growthroom material and negative significant associations in 1974. The total growing time (A + B + C + D) showed a significant relationship with yield in the growthroom and 1973. The periods from emergence to ripe (B + C + D) and from internode elongation to ripe followed a similar pattern.

The correlations between height and growth periods were more variable, with the highest association being found in the growthroom material. Here, periods B and C showed the highest correlations with height while period D showed a significant negative correlation. In 1973 significance showed only with period C, while 1974 showed significant results in both periods B and C. Therefore period C seems to be the only growth period consistently showing significant differences in its relationship with the height of the plant. This pattern continued in the relationships of height and combinations of period. Highest associations were again achieved in the growthroom and 1973 material with little significance being found in 1974. The highest relationships were found in 1972 in the growth periods (A + B + C) and (B + C).

TABLE XII. Comparison of Simple Correlation Coefficients Among the Length of Individual Growth Periods and Yield, Height, Head Length, and 1000 Kernel Weight for the Years 1971/72 (Top), 1973 (Center), 1974 (Bottom), and Significance for Homogeneity of r.

| | GROWTH PERIOD OR STAGE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Days from Seeding to Emergence (A) | Days from Emergence to Internode Elongation (B) | Days from Internode Elongation to Heading (C) | Days from Heading to Ripe (D) | Days from Seeding to Internode Elongation (A + B) | Days from Seeding to Heading (A+B+C) | Days from Seeding to Ripe (A+B+C+D) | Days from Emergence to Heading (B + C) | Days from Emergence to Ripe (B+C+D) | Days from Internode Elongation to Ripe (C + D) |
| Yield | - 0.140 | 0.383** | 0.275** | 0.256** | 0.353** | 0.348 | 0.467** | 0.359** | 0.481** | 0.420** |
| | 0.012 ns | - 0.100 ns | 0.256** ns | 0.437** ns | - 0.099 s | 0.130 s | 0.322** s | 0.127 ns | 0.320** s | 0.511** s |
| | 0.397** | - 0.544** | - 0.298** | 0.305** | - 0.396** | - 0.364** | - 0.130 | - 0.401** | - 0.165* | - 0.063 |
| Height | - 0.061 | 0.633** | 0.581** | - 0.263** | 0.614 | 0.673** | 0.331** | 0.677** | 0.339** | 0.129 |
| | - 0.031 ns | 0.068 s | 0.364** s | 0.116 s | 0.059 s | 0.270** s | 0.325** ns | 0.269** s | 0.329** ns | 0.420** ns |
| | 0.048 | - 0.208** | 0.175* | 0.122 | - 0.200** | 0.116 | 0.157* | 0.109 | 0.154 | 0.204** |
| Head Length | - 0.084 | 0.153 | 0.288** | - 0.142 | - 0.166* | 0.111 | - 0.020 | 0.118 | - 0.014 | 0.052 |
| | 0.091 ns | - 0.202* ns | 0.165* s | 0.288** s | - 0.183 ns | 0.034 ns | 0.134 s | 0.023 ns | 0.123 ns | 0.297** ns |
| | 0.081 | - 0.191** | 0.197* | 0.249** | - 0.166* | 0.143 | 0.246** | 0.133 | 0.240** | 0.292** |
| 1000 Kernel Weight | - | - | - | - | - | - | - | - | - | - |
| | 0.005 ns | - 0.076 ns | 0.200* ns | 0.131 ns | - 0.076 s | 0.103 ns | 0.161* ns | 0.100 ns | 0.160* ns | 0.272** ns |
| | 0.123 | 0.207** | 0.240** | 0.042 | 0.279** | 0.285 | 0.250** | 0.268** | 0.241** | 0.211** |

Significance values:

1972: $p_{0.05} = 0.164$, $p_{0.01} = 0.213$

1973: $p_{0.05} = 0.159$, $p_{0.01} = 0.208$

1974: $p_{0.05} = 0.145$, $p_{0.01} = 0.190$

Associations with head length were generally low with significant results for all three years occurring only with period C. Significance was also found in the field years 1973 and 1974 with periods B and D, but the correlations are too low for conclusions to be made. Combinations of periods continued this low association, with no significance in any of the three years. The two field years (1973 and 1974) shared the highest correlation with head length and period (B + C).

Values for 1000 kernel weight were recorded only in 1973 and 1974, with significant correlations found in periods B and C in 1974. This pattern continued with the combinations, with significant values for both years being shared by the period (C + D).

Associations of yield and other morphological characters (Table XIII) in most cases were quite low, though there are relations significant to the 1% level present. The highest and most consistent association with yield over the three years was supplied by height. Lower but still significant is the positive relationship between yield and head length, which had a closer association in the field than in the growthroom. The yield components kernel weight and number of heads showed highly significant positive associations of 0.58 and 0.48 in the growthroom and 1973, but decreased to close to 0 in 1974. This was also true for test weight and habit. There was a significant correlation between number of plants and yield for both the field years, but these relationships were fairly low. Very little relationship was found between number of secondary tillers and yield.

Associations between the morphological characters were generally low and inconsistent. Exceptions were provided by height and head length which showed

TABLE XIII. Simple Correlation Coefficients Between Yield and Other Morphological Characters for the Three Years: Upper values: 1972 (n = 144); Center value: 1973 (n = 156); and Lower values, 1974 (n = 169)

| | Yield | Height | Head Length | 1000 Kernel Weight | Test Weight | Habit | No. of Heads | No. of Secondary Tillers |
|---|---|---|---|---|---|---|---|---|
| Height | 0.476** | | | | | | | |
| | 0.485** | | | | | | | |
| | 0.399** | | | | | | | |
| Head Length | 0.225** | 0.377** | | | | | | |
| | 0.437** | 0.605** | | | | | | |
| | 0.371** | 0.532** | | | | | | |
| 1000 Kernel Weight | - | - | - | | | | | |
| | 0.578** | 0.292** | 0.025 | | | | | |
| | - 0.046 | 0.046 | 0.005 | | | | | |
| Test Weight | - | - | - | - | | | | |
| | 0.356** | 0.137 | 0.041 | 0.342** | | | | |
| | 0.139 | 0.114 | 0.099 | 0.102 | | | | |
| Habit at Internode Elongation | - | - | - | - | - | | | |
| | 0.355** | 0.344** | 0.177* | 0.172* | 0.122 | | | |
| | 0.099 | 0.071 | 0.039 | 0.279** | - 0.139 | | | |
| No. of Heads | - | - | - | - | - | - | | |
| | 0.480** | - 0.037 | - 0.026 | 0.302** | 0.124 | - 0.018 | | |
| | - 0.063 | - 0.188 | - 0.268** | - 0.126 | - 0.051 | - 0.167 | | |
| No. of Secondary Tillers | - | - | - | - | - | - | - | |
| | 0.192* | - 0.105 | - 0.176 | 0.356** | - 0.029 | 0.214 | 0.253** | |
| | - 0.080 | - 0.277** | - 0.332** | 0.176* | - 0.111 | - 0.018 | 0.230** | |
| No. of Plants | - | - | - | - | - | - | - | - |
| | 0.389** | 0.192* | - 0.028 | 0.326** | 0.014 | 0.127 | 0.395** | 0.156 |
| | 0.229** | 0.106 | - 0.061 | - 0.127 | - 0.027 | - 0.091 | 0.489** | 0.131 |

Significance Values:

1972: $P_{0.05} = 0.164$, $P_{0.01} = 0.213$

1973: $P_{0.05} = 0.159$, $P_{0.01} = 0.208$

1974: $P_{0.05} = 0.145$, $P_{0.01} = 0.190$

fairly high significant correlations. Again, associations in the field were stronger than in the growthroom. One other exception is provided by the significant positive correlation between the number of plants and the number of heads.

Lodging effects on yield in 1973 (Table XIV) were generally low and negative and showed significance at the 5% level only in the latter part of the season. However, the effects in 1974 were much greater as shown by the negative associations significant to the 1% level. Greatest effects were experienced at lodging date 2, which occurred between internode elongation and heading, and lodging date 5, which occurred at about the time of heading for most families, though these correlations were not significantly higher than the rest. In most of these cases in 1974, the material was exposed to violent storms with high winds and heavy rain.

Time from seeding to maturity was significantly affected by lodging in 1973 and 1974 (Table XV). Correlations of time to maturity with the early lodging (Dates 1 in 1973 and 1, 2, 3 in 1974) were generally positive and then changed to negative as the crop developed. Significant correlations were found between the individual growth periods A and B and lodging. Also, early lodging had a positive and significant association with the length of period C. Correlations between lodging and period D were generally lower with less significance. Greatest effect on the length of this period was supplied by lodging date 1 in 1973, which occurred in period C. The effect was positive on period C, lengthening the time taken to head, and then negative on period D, where there was a limited time remaining for ripening. The 1974 results for the same time gave high positive correlations with period C but did not show the same dramatic effect on the length of period D. Significant results here occurred only with the lodging

TABLE XIV. Comparison of Simple Correlations Showing the Effects of Lodging at Different Times on the Yield in 1973 and 1974

| Time of Lodging | Year | |
|---|---|---|
| | 1973 | 1974 |
| Lodging date 1 | - 0.00 | - 0.380** |
| Lodging date 2 | - 0.010 | - 0.400** |
| Lodging date 3 | - 0.173* | - 0.383** |
| Lodging date 4 | - 0.177* | - 0.307** |
| Lodging date 5 | - 0.165* | - 0.405** |
| Lodging date 6 | | - 0, 315** |
| Lodging date 7 | | - 0.314** |
| Lodging date 8 | | - 0.341** |

Significance values 1973: $P_{0.05} = 0.159$, $P_{0.01} = 0.208$

1974: $P_{0.05} = 0.145$, $P_{0.01} = 0.190$

TABLE XV. Simple Correlation Coefficients Comparing Length of Growth Periods with Lodging Ratings Taken Periodically After Internode Elongation in the Field in 1973 (upper values) and 1974 (lower values).

| Time of Lodging | GROWTH PERIOD | | | | |
|---|---|---|---|---|---|
| | Seeding to Emergence (A) | Emergence to IE (B) | IE to Heading (C) | Heading to Ripe (D) | Total Time to Ripe (A+B+C+D) |
| Lodging date 1 | - 0.529** | 0.359** | 0.632** | - 0.425** | 0.345** |
| | 0.247** | 0.326** | 0.518** | - 0.065 | 0.436** |
| Lodging date 2 | 0.057 | - 0.134 | - 0.142 | - 0.089 | - 0.189* |
| | - 0.415** | 0.319** | 0.638** | - 0.152* | 0.416** |
| Lodging date 3 | 0.099 | - 0.265** | - 0.341** | - 0.188** | - 0.421** |
| | 0.451** | 0.231** | 0.434** | - 0.146* | 0.249** |
| Lodging date 4 | - 0.178 | - 0.262** | - 0.163* | - 0.291** | - 0.376** |
| | - 0.322** | 0.087 | - 0.238** | 0.232** | - 0.315** |
| Lodging date 5 | - 0.056 | - 0.379** | - 0.302** | - 0.185** | - 0.462** |
| | - 0.339** | 0.185* | - 0.109 | - 0.213** | - 0.204** |
| Lodging date 6 | - 0.249** | 0.163* | - 0.032 | - 0.152 | - 0.110 |
| Lodging date 7 | - 0.313** | 0.106 | - 0.124 | - 0.191** | - 0.203** |
| Lodging date 8 | - 0.356** | 0.273** | - 0.080 | - 0.145* | - 0.144 |

Significance Values: 1973: $p_{0.05} = 0.159$, $p_{0.01} = 0.280$
1974: $p_{0.05} = 0.145$, $p_{0.01} = 0.190$

that occurred after heading, and these were low. Later lodging, occurring during the latter half of period D, had little effect on the total lifespan of the crop.

There were highly significant relationships in the behavior of each variable for all of the growth periods and stages between any two of the three years. Of the four major growth periods, the one that showed the greatest consistency of behavior for all three years was period C. Here, correlations between the years were extremely high. Growth periods A and D displayed much lower relationships between the years with the greatest constancy between the two field years. Period B, on the other hand, showed its greatest similarities in behavior between the growthroom and 1973 field years, with 1974 values differing. This trend was duplicated in the combinations of periods and stages with days to heading (A + B + C) and days from emergence to heading (B + C) displaying extremely high and stable associations between all three years. Again, the two field years showed the greatest similarities for all combinations with the exception of days to internode elongation (A + B) which duplicated the behavior of period B.

The only morphological characters taken in common for all three years were height, head length and yield. Here, greatest similarities were again seen between the two field years, especially in height. Head length showed weaker, but fairly stable relationships among all three years. Yield, on the other hand, showed absolutely no relationship between the growthroom and either of the field years.

TABLE XVI. Correlation Coefficients Comparing the Three Years of Data (n = 144 for all years).

| | 1972 vs 1973 | 1972 vs 1974 | 1973 vs 1974 |
|---|---|---|---|
| Days from Seeding to Emergence (A) | 0.271** | 0.304** | 0.602** |
| Days from Seeding to Internode Elongation (A + B) | 0.795** | 0.460** | 0.405** |
| Days from Seeding to Heading (A + B + C) | 0.881** | 0.898** | 0.927** |
| Days from Seeding to Ripe (A+B+C+D) | 0.588** | 0.609** | 0.830** |
| Days from Emergence to Internode Elongation (B) | 0.794** | 0.449** | 0.435** |
| Days from Emergence to Heading (B + C) | 0.887** | 0.899** | 0.934** |
| Days from Emergence to Ripe (B + C + D) | 0.588** | 0.613** | 0.838** |
| Days from Internode Elongation to Heading (C) | 0.847** | 0.846** | 0.923** |
| Days from Internode Elongation to Ripe (C + D) | 0.358** | 0.468** | 0.796** |
| Days from Heading to Ripe (D) | 0.214** | 0.250** | 0.397** |
| Height | 0.356** | 0.400** | 0.838** |
| Head Length | 0.616** | 0.595** | 0.691** |
| Yield | - 0.047 | - 0.173* | 0.457** |

Significance values: $P_{0.05} = 0.164$

$P_{0.01} = 0.213$

ii. Factor Analysis

A factor analysis of the growth periods and their combinations in the growthroom material indicated that the variables were separated into four groupings of similar behavior, accounting for 96% of the total variability (Table XVII). Communalities were all extremely high with the exception of yield, showing that the major portion of variability in each character was accounted for in the four factors. The first factor which contained 54% of the variability was mainly composed of period D and all those stages and combinations which contained this period. Also included was total time from seeding to maturity. The second factor, which accounted for 27% of the variance contained the total period to heading and combinations which included period C. The Third factor which grouped period A and yield as having similar behavior, and the fourth which contained the periods up to Internode Elongation, were similar in size, accounting for 7 and 6% of the total variability respectively. With the exception of yield, the loadings given to each character were extremely high.

In the 1973 field year (Table XVIII) the groupings were not as clear-cut as those shown in the growthroom, but accounted for 98% of the total variance. Here, the greatest amount of variation (60%) was supplied by a grouping of the period of floral development and those combinations containing periods B and C. Loadings again were high with the exception of growing period (C + D) and the combination (A + C + D) which shared equal weight in the first three factors. The second grouping contained period D and its combinations, accounting for 25% of the total variance. The third factor, accounting for 8% of the variability included a portion of (C + D) and (A + C + D) along with yield as having similar behavior. The remaining factor included

TABLE XVII. A Factor Analysis of All Combinations of Growth Periods for 1971/72

| | Communalities | Factors 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Factor 1: Total Growth Plus Assimilation Period | | | | | |
| Days from Seeding to Ripe (A + B + C + D) | 0.99 | 0.80 | - 0.48 | - 0.02 | 0.35 |
| Days from Emergence to Ripe (B + C + D) | 0.99 | 0.79 | - 0.49 | - 0.07 | 0.34 |
| Days from Internode Elongation to Ripe (C + D) | 0.99 | 0.91 | - 0.40 | - 0.04 | 0.03 |
| Days from Heading to Ripe (D) | 0.99 | 0.96 | 0.24 | 0.03 | - 0.08 |
| Combination A + D | 0.99 | 0.96 | 0.24 | 0.10 | - 0.07 |
| Combination B + D | 0.99 | 0.94 | 0.03 | - 0.03 | 0.31 |
| Combination A + B + D | 0.99 | 0.95 | 0.03 | 0.04 | 0.32 |
| Combination A + C + D | 0.99 | 0.92 | - 0.40 | 0.03 | 0.04 |
| Factor 2: Growth to Anthesis | | | | | |
| Days from Seeding to Heading (A + B + C) | 0.99 | 0.09 | - 0.85 | 0.04 | 0.52 |
| Days from Emergence to Heading (B + C) | 0.99 | 0.07 | - 0.85 | - 0.12 | 0.51 |
| Days from IE to Heading (C) | 0.99 | 0.00 | - 0.98 | - 0.10 | 0.16 |
| Combination A + C) | 0.99 | 0.03 | - 0.98 | 0.01 | 0.17 |
| Factor 3: | | | | | |
| Days from Seeding to Emergence (A) | 0.84 | 0.25 | - 0.01 | 0.88 | 0.09 |
| Yield | 0.59 | 0.38 | - 0.17 | - 0.59 | 0.29 |
| Factor 4: Time to End of Floral Initiation | | | | | |
| Days from Seeding to IE (A + B) | 0.99 | 0.20 | - 0.42 | 0.05 | 0.88 |
| Days from Emergence to IE (B) | 0.99 | 0.15 | - 0.43 | - 0.11 | 0.88 |
| Percentage of Total Variance | 96 | 54 | 27 | 7 | 6 |

TABLE XVIII. A Factor Analysis of All Combination of Growth Periods for 1973

| | Communalities | Factors 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Factor 1: Periods Containing Floral Development | | | | | |
| Days from Seeding to Internode Elongation (A + B) | 0.98 | 0.95 | 0.13 | - 0.23 | 0.10 |
| Days from Seeding to Heading (A + B + C) | 0.99 | 0.97 | 0.01 | 0.23 | - 0.01 |
| Days from Seeding to Ripe (A + B + C + D) | 0.99 | 0.82 | 0.44 | 0.35 | 0.03 |
| Days from Emergence to IE (B) | 0.98 | 0.94 | 0.06 | - 0.24 | - 0.17 |
| Days from Emergence to Heading (B + C) | 0.99 | 0.97 | - 0.01 | 0.22 | - 0.12 |
| Days from Emergence to Ripe (B + C + D) | 0.99 | 0.84 | 0.42 | 0.34 | - 0.08 |
| Days from IE to Heading (C) | 0.99 | 0.87 | - 0.06 | 0.47 | - 0.08 |
| Days from IE to Ripe* (C + D) | 0.98 | 0.60 | 0.53 | 0.59 | - 0.01 |
| Combination A + C | 0.99 | 0.86 | - 0.02 | 0.48 | 0.09 |
| Combination A + C + D* | 0.98 | 0.57 | 0.44 | 0.58 | 0.14 |
| Factor 2: Period of Assimilation | | | | | |
| Days from Heading to Ripe (D) | 0.99 | - 0.27 | 0.92 | 0.27 | 0.10 |
| Days from IE to Ripe* (C + D) | 0.98 | 0.61 | 0.53 | 0.59 | - 0.01 |
| Combination A + D | 0.99 | - 0.25 | 0.88 | 0.26 | 0.30 |
| Combination B + D | 0.99 | 0.49 | 0.87 | 0.06 | - 0.05 |
| Combination A + B + D | 0.99 | 0.45 | 0.87 | 0.07 | 0.16 |
| Combination A + C + D* | 0.98 | 0.57 | 0.55 | 0.58 | 0.14 |
| Factor 3: Time from Floral Initiation to Ripe | | | | | |
| Yield | 0.80 | 0.09 | 0.35 | 0.81 | 0.07 |
| Days from IE to Ripe* (C + D) | 0.98 | 0.60 | 0.53 | 0.59 | - 0.01 |
| Combination A + C + D* | 0.98 | 0.57 | 0.55 | 0.58 | 0.14 |
| Factor 4: Period to Emergence | | | | | |
| Days from Seeding to Emergence (A) | 0.99 | - 0.06 | 0.23 | 0.06 | 0.97 |
| Percentage of Total Variance | 98 | 60 | 25 | 8 | 6 |

* Denotes characters shared by two or more factors

period A alone and accounted for 6% of the variation. Communalities in all cases were extremely high, the lowest being that of yield at 0.80.

The 1974 field material (Table XIX) was grouped into three factors accounting for 94% of the total variance. Again combination (A + C + D) was shared by more than one grouping, though the greatest weighting appeared in the first factor. This factor grouped together periods B and C and their combinations accounting for 57% of the total variance. The second factor, accounting for 26% of total variance, grouped together period A and D, as well as their respective combinations, as behaving similarly. However, only 55% of the variance for period A was contained in these three factors. The third factor, accounting for 12% of the total variance included yield and time to internode elongation, as well as period B. All communalities, with the exception of period A, were again very high.

The second set of matrices was supplied by the individual growth periods along with morphological characters recorded in each year. In 1972 (growthroom) there was only height and head length included (Table XX) but the matrix of five factors accounted for 93% of the total variance. The first factor contained growth periods B and C, and accounted fo 38% of total variance. Period D, head length, and period A made up three separate factors, each accounting for 20, 16 and 14% of the total variability, respectively. Height and yield, accounting for 7% of the variance were grouped together in the fifth factor. Communalities in all cases were high. A similar equation in 1973, containing the growth periods morphological characters and lodging, gave six factors accounting for 77% of the total variance (Table XXI). The first factor, using up 23% of the variance, includes loding dates 2 through 5. The

TABLE XIX. A Factor Analysis of All Combinations of Growth Periods for 1974

| | Communalities | Factors 1 | 2 | 3 |
|---|---|---|---|---|
| Factor 1: Periods Containing Floral Development after Initiation | | | | |
| Days from Seeding to Heading (A + B + C) | 0.99 | - 0.95 | 0.06 | - 0.29 |
| Days from Seeding to Ripe (A + B + C + D) | 0.99 | - 0.85 | 0.49 | - 0.14 |
| Days from Emergence to Heading (B + C) | 0.99 | - 0.94 | - 0.01 | - 0.33 |
| Days from Emergence to Ripe (B + C + D) | 0.99 | - 0.87 | 0.45 | - 0.18 |
| Days from Internode Elongation to Heading (C) | 0.99 | - 0.99 | 0.02 | - 0.10 |
| Days from IE to Ripe (C + D) | 0.99 | - 0.87 | 0.48 | 0.02 |
| Combination A + C | 0.99 | - 0.99 | 0.09 | - 0.05 |
| Combination A + C + D* | 0.99 | - 0.85 | 0.53 | 0.06 |
| Factor 2: Periods of Assimilation and Emergence | | | | |
| Days from Seeding to Emergence (A) | 0.55 | 0.02 | 0.61 | 0.41 |
| Days from Heading to Ripe (D) | 0.97 | - 0.21 | 0.94 | 0.19 |
| Combination A + D | 0.99 | - 0.19 | 0.95 | 0.24 |
| Combination B + D | 0.97 | - 0.29 | 0.91 | - 0.22 |
| Combination A + B + D | 0.99 | - 0.26 | 0.95 | - 0.14 |
| Combination A + C + D* | 0.99 | - 0.85 | 0.53 | 0.06 |
| Factor 3: Time to End of Floral Initiation | | | | |
| Yield | 0.81 | 0.13 | 0.37 | 0.81 |
| Days from Seeding to IE (A + B) | 0.88 | - 0.19 | 0.20 | - 0.90 |
| Days from Emergence to IE (B) | 0.98 | - 0.17 | - 0.09 | - 0.97 |
| Percentage of Total Variance | 94 | 57 | 26 | 12 |

* Denotes character shared by two or more factors

TABLE XX. A Factor Analysis of the Four Growth Periods Only Plus Height and Head Length in 1971/72

| | Communalities | Factors 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Factor 1: Period of Floral Initiation and Development | | | | | | |
| Days from Emergence to IE (B) | 0.91 | 0.72 | - 0.05 | 0.38 | 0.04 | - 0.49 |
| Days from IE to Heading (C) | 0.94 | 0.93 | - 0.10 | - 0.23 | - 0.06 | - 0.10 |
| Factor 2: Assimilative Period | | | | | | |
| Days from Heading to Maturity (D) | 0.95 | - 0.12 | 0.95 | 0.08 | 0.15 | - 0.10 |
| Factor 3: Head Length | | | | | | |
| Head Length | 0.95 | 0.09 | - 0.09 | - 0.96 | - 0.02 | - 0.16 |
| Factor 4: Period A | | | | | | |
| Days from Seeding to Emergence (A) | 0.98 | - 0.02 | 0.13 | 0.02 | 0.98 | 0.07 |
| Factor 5: Height and Yield | | | | | | |
| Height | 0.90 | 0.50 | - 0.36 | - 0.21 | 0.09 | - 0.68 |
| Yield | 0.89 | 0.12 | 0.30 | - 0.15 | - 0.16 | - 0.86 |
| Percentage of Total Variance | 93 | 38 | 20 | 16 | 14 | 7 |

TABLE XXI. A Factor Analysis of the Four Growth Periods Plus Yield Components and Lodging for 1973

| | Communalities* | Factors 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Factor 1: Lodging | | | | | | | |
| Lodging date 2 | 0.75 | - 0.75 | 0.10 | 0.08 | - 0.07 | 0.04 | 0.41 |
| Lodging date 3 | 0.83 | - 0.87 | 0.11 | 0.12 | - 0.03 | - 0.15 | - 0.03 |
| Lodging date 4 | 0.87 | - 0.87 | - 0.22 | - 0.09 | 0.01 | - 0.16 | - 0.17 |
| Lodging date 5 | 0.83 | - 0.85 | - 0.12 | - 0.02 | 0.06 | - 0.29 | - 0.13 |
| Factor 2: | | | | | | | |
| No. of Secondary Tillers* | 0.82 | - 0.04 | 0.52 | 0.57 | - 0.25 | 0.31 | - 0.26 |
| Days from Seeding to Emergence (A) | 0.74 | - 0.03 | 0.83 | 0.20 | 0.06 | - 0.01 | 0.02 |
| Days from Heading to Ripe (D) | 0.66 | 0.31 | 0.56 | - 0.05 | 0.36 | - 0.34 | 0.06 |
| Lodging date 1 | 0.80 | - 0.04 | - 0.70 | - 0.09 | 0.26 | 0.45 | - 0.18 |
| Factor 3: Yield Components | | | | | | | |
| 1000 Kernel Weight | 0.64 | - 0.08 | 0.14 | - 0.69 | 0.15 | 0.09 | 0.32 |
| No. of plants per 1.2 m row | 0.51 | - 0.02 | - 0.29 | - 0.63 | 0.01 | 0.17 | 0.02 |
| No. of heads per 1.2 m row | 0.70 | - 0.00 | - 0.24 | - 0.79 | - 0.04 | - 0.14 | - 0.04 |
| No. of Secondary Tillers* | 0.82 | - 0.04 | 0.52 | 0.57 | - 0.25 | 0.31 | - 0.26 |
| Yield** | 0.87 | 0.15 | 0.18 | - 0.64 | 0.56 | 0.03 | 0.29 |
| Factor 4: Vegetative Characters Contributing to Yield | | | | | | | |
| Height | 0.76 | 0.16 | - 0.10 | - 0.10 | 0.81 | 0.21 | 0.09 |
| Head Length | 0.86 | - 0.19 | 0.04 | 0.05 | 0.90 | 0.01 | - 0.04 |
| Yield** | 0.87 | 0.15 | 0.18 | - 0.64 | 0.56 | 0.03 | 0.29 |
| Factor 5: Period of Floral Initiation and Development | | | | | | | |
| Habit at Internode Elongation | 0.74 | 0.26 | 0.15 | - 0.09 | 0.26 | 0.75 | 0.10 |
| Days from Emergence to IE (B) | 0.81 | 0.21 | - 0.20 | 0.08 | - 0.19 | 0.83 | - 0.07 |
| Days from IE to Heading (C) | 0.85 | 0.14 | - 0.23 | - 0.19 | 0.22 | 0.83 | - 0.04 |
| Factor 6: Test Weight | | | | | | | |
| Test Weight | 0.81 | 0.04 | 0.04 | - 0.17 | 0.07 | - 0.04 | 0.88 |
| Percentage of Total Variance | 0.77 | 23 | 15 | 15 | 10 | 8 | 6 |

*, ** denote character shared by two or more factors

variables, number of secondary tillers and yield, were each weighted evenly between the two factors. The second factor groups together period A and D, lodging date 1 and the number of secondary tillers, as behaving similarly. It and factor three, which included kernel weight, number of plants, number of heads, number of secondary tillers, and yield, each accounted for 15% of the total variance. Factor four, grouping together height, head length and yield, and factor five, grouping habit and periods B and C, were responsible for 10 and 8% of the total variance respectively. The remaining factor, which contained 6% of the variance, included test weight. Communalities ranged from 0.51 for number of plants to 0.87 for yield.

The 1974 material (Table XXII) again presented the lodging data as supplying the greatest variability, with dates 4 through 8 accounting for 23% of the total. Growth periods A, B, and yield were each weighted evenly in more than one factor. The second factor grouped together periods A, B, and C, lodging dates 1 to 3, and yield, as behaving similarly, and accounted for 16% of the total variance. Factor three, which included period B and yield, along with height, head length, and number of secondary tillers, accounted for 11% of the variance. The remaining three factors accounted for similar but small amounts of variance at 8, 6 and 6%, respectively. Factor four included period A, habit, and kernel weight; factor five included period D and test weight; and factor six grouped the number of plants and the number of heads. Communalities ranged from 0.47 for period D to 0.88 for lodging date 7, with only 70% of the total variance being accounted for in the six factors.

Inclusion of morphological characters and lodging into the matrix, along with all combinations of growth periods was performed in order to detect changes in

TABLE XXII. A Factor Analysis of the Four Growth Periods Plus Yield Components and Lodging for 1974

| | Communalities | Factors 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Factor 1: Later Lodging after Time of Heading | | | | | | | |
| Lodging date 4 | 0.78 | - 0.87 | 0.04 | - 0.06 | - 0.09 | 0.04 | - 0.07 |
| Lodging date 5 | 0.76 | - 0.85 | - 0.05 | - 0.15 | - 0.10 | 0.08 | 0.06 |
| Lodging date 6 | 0.80 | - 0.89 | 0.03 | 0.03 | 0.01 | - 0.01 | 0.05 |
| Lodging date 7 | 0.88 | - 0.93 | - 0.04 | - 0.04 | - 0.07 | - 0.05 | - 0.05 |
| Lodging date 8 | 0.64 | - 0.77 | - 0.14 | - 0.01 | 0.04 | - 0.14 | - 0.04 |
| Factor 2: Early Growth to Heading with Early Lodging and Yield | | | | | | | |
| Days from Seeding to Emergence**(A) | 0.56 | 0.37 | 0.48 | 0.15 | 0.41 | 0.01 | - 0.00 |
| Days from Emergence to Internode Elongation *(B) | 0.54 | - 0.20 | - 0.49 | - 0.44 | 0.23 | 0.03 | 0.09 |
| Days from IE to Heading (C) | 0.72 | 0.14 | - 0.75 | 0.16 | 0.27 | 0.14 | 0.16 |
| Lodging date 1 | 0.72 | 0.06 | - 0.79 | 0.09 | 0.07 | - 0.23 | 0.13 |
| Lodging date 2 | 0.87 | 0.03 | - 0.92 | 0.06 | - 0.10 | - 0.06 | - 0.02 |
| Lodging date 3 | 0.73 | 0.12 | - 0.79 | 0.02 | - 0.28 | 0.07 | - 0.01 |
| Yield* | 0.76 | 0.37 | 0.52 | 0.57 | - 0.02 | 0.14 | - 0.13 |
| Factor 3: Period B and Contributions to Yield | | | | | | | |
| Days from Emergence to IE* (B) | 0.54 | - 0.20 | - 0.49 | - 0.44 | 0.23 | 0.03 | 0.09 |
| Yield* | 0.76 | 0.37 | 0.52 | 0.57 | - 0.02 | 0.14 | - 0.13 |
| Height | 0.70 | 0.01 | - 0.08 | 0.82 | 0.14 | - 0.00 | - 0.10 |
| Head Length | 0.64 | 0.08 | - 0.10 | 0.76 | 0.01 | 0.13 | 0.15 |
| No. of Secondary Tillers | 0.51 | 0.22 | 0.11 | - 0.53 | 0.19 | - 0.10 | - 0.35 |
| Factor 4: | | | | | | | |
| Days from Seeding to Emergence** (A) | 0.56 | 0.37 | 0.48 | 0.15 | 0.41 | 0.01 | - 0.00 |
| Habit at IE | 0.65 | 0.05 | 0.20 | 0.10 | 0.72 | - 0.21 | 0.19 |
| 1000 Kernel Weight | 0.65 | 0.03 | - 0.18 | - 0.12 | 0.74 | 0.23 | - 0.03 |
| Factor 5: Assimilation | | | | | | | |
| Days from Heading to Ripe (D) | 0.47 | 0.21 | 0.15 | 0.26 | 0.27 | 0.49 | 0.14 |
| Test Weight | 0.82 | - 0.04 | 0.01 | 0.07 | - 0.07 | 0.90 | 0.00 |
| Factor 6: Density | | | | | | | |
| No. plants per 1.2 m sample | 0.80 | - 0.00 | 0.11 | 0.17 | - 0.07 | - 0.09 | - 0.87 |
| No. heads per 1.2 m sample | 0.67 | 0.02 | 0.07 | - 0.26 | - 0.09 | 0.03 | - 0.76 |
| Percentage of Total Variance | | 70 | 23 | 16 | 11 | 8 | 6 | 6 |

*, ** Denote character shared by two or more factors

groupings and to discover any possible relationships between these characters and the growth stages. The growthroom material included only height and head length (Table XXIII). There were no changes in the variables present in the first factor (which accounted for 49% of the total variance) from that of Table XVII. The second factor, however, grouped time to Internode Elongation and height along with those variables describing time to heading, to account for 28% of the variance. Factor 3 was composed of head length alone and accounted for 8% of the variance. What was the third grouping in Table XVII became the fourth here, and contained the same variables, period A and yield. This accounted for 6% of variation. Communalities in many cases were slightly lowered, ranging from 0.52 for period A to 0.99. The percentage of total variance covered by the four factors dropped slightly to 92%.

The 1973 field year revealed greater changes with the inclusion of the morphological characters (Table XXIV). Here, the percent of total variance accounted for dropped to 78% and the number of factors increased to five, from four in Table XVIII. The first factor showed a similar grouping of period B and C and their combinations, and also included growth habit. However, its portion of the total variance dropped to 38%. The second factor showed periods A and D grouped together, along with the first lodging to account for 16% of total variance. Factor 3, including yield components and yield, together with factor four which included the lodging dates 2 to 5, accounted for 11 and 8% of the total variance. The fifth factor was composed of height and head length, accounting for 6% of the variance. Communalities here were much lower, ranging from 0.43 for number of plants to 0.99.

The inclusion of morphological characters in 1974 (Table XXV) reduced the percentage of total variance to 81% and increased the number of factors from three in

TABLE XXIII. A Factor Analysis for All Combinations of Growth Periods Plus Height and Head Length in 1971/72

| | Communalities | Factors 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Factor 1: Total Growth Plus Assimilation Period | | | | | |
| Days from Seeding to Ripe (A+B+C+D) | 0.99 | 0.82 | - 0.56 | - 0.04 | - 0.01 |
| Days from Emergence to Ripe (B+C+D) | 0.98 | 0.81 | - 0.57 | - 0.36 | - 0.05 |
| Days from Internode Elongation to Ripe (C + D) | 0.97 | 0.91 | - 0.33 | 0.16 | 0.05 |
| Days from Heading to Ripe (D) | 0.99 | 0.95 | 0.29 | - 0.04 | 0.03 |
| Combination A + D | 0.99 | 0.95 | 0.28 | - 0.05 | - 0.09 |
| Combination B + D | 0.99 | 0.96 | - 0.10 | - 0.24 | - 0.08 |
| Combination A + B + D | 0.99 | 0.96 | - 0.10 | - 0.24 | - 0.03 |
| Combination A + C + D | 0.98 | 0.92 | - 0.32 | 0.15 | 0.10 |
| Factor 2: Vegetative Growth and Floral Development | | | | | |
| Days from Seeding to IE (A + B) | 0.94 | 0.24 | - 0.81 | - 0.46 | - 0.[illegible] |
| Days from Seeding to Heading (A+B+C) | 0.99 | 0.13 | - 0.99 | - 0.01 | - 0.35 |
| Days from Emergence to IE (B) | 0.96 | 0.25 | - 0.81 | - 0.45 | - 0.25 |
| Days from Emergence to Heading (B + C) | 0.99 | 0.10 | - 0.98 | - 0.01 | - 0.09 |
| Days from IE to Heading (C) | 0.95 | 0.02 | - 0.92 | 0.31 | 0.04 |
| Combination A + C | 0.97 | 0.05 | - 0.93 | 0.30 | 0.12 |
| Height | 0.71 | - 0.06 | - 0.71 | 0.09 | 0.44 |
| Factor 3: Head Length | | | | | |
| Head Length | 0.78 | - 0.07 | - 0.13 | 0.84 | - 0.24 |
| Factor 4: Period A and Yield | | | | | |
| Days from Seeding to Emergence (A) | 0.52 | 0.26 | - 0.03 | - 0.08 | 0.66 |
| Yield | 0.74 | 0.40 | - 0.27 | 0.13 | - 0.70 |
| Percentage of Total Variance | | 92 | 49 | 28 | 8 | 6 |

TABLE XXIV. A Factor Analysis for All Combinations of Growth Periods Plus Yield Components and Lodging for 1973

| | Communalities | Factors 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Factor 1: Vegetative Growth and Floral Development | | | | | | |
| Days from Seeding to Internode Elongation (A + B) | 0.90 | 0.86 | - 0.03 | 0.22 | - 0.12 | 0.31 |
| Days from Seeding to Heading (A + B + C) | 0.99 | 0.97 | - 0.20 | - .01 | - 0.10 | 0.00 |
| Days from Seeding to Ripe (A + B + C + D) | 0.99 | 0.96 | 0.18 | - 0.07 | - 0.18 | - 0.10 |
| Days from Emergence to IE (B) | 0.90 | 0.85 | - 0.20 | 0.19 | - 0.15 | 0.28 |
| Days from Emergence to Heading (B + C) | 0.99 | 0.95 | - 0.27 | - 0.03 | - 0.11 | - 0.01 |
| Days from IE to Heading (B + C + D) | 0.94 | 0.90 | - 0.28 | - 0.16 | - 0.07 | - 0.19 |
| Days from IE to Ripe (C) | 0.93 | 0.82 | 0.27 | - 0.23 | - 0.17 | - 0.32 |
| Combination A + C | 0.90 | 0.90 | - 0.17 | - 0.15 | - 0.05 | - 0.18 |
| Combination B + D* | 0.84 | 0.66 | 0.57 | 0.06 | - 0.28 | 0.04 |
| Combination A + B + D* | 0.93 | 0.63 | 0.69 | 0.08 | - 0.24 | 0.06 |
| Combination A + C + D | 0.94 | 0.80 | 0.37 | - 0.21 | - 0.15 | - 0.31 |
| Habit at IE | 0.54 | 0.68 | [illegible]7 | - 0.13 | - 0.20 | - 0.13 |
| Factor 2: Emergence and Ripening Periods | | | | | | |
| Days from Seeding to Emergence (A) | 0.45 | - 0.04 | 0.65 | 0.10 | 0.10 | 0.07 |
| Days from Heading to Ripe (D) | 0.89 | - 0.07 | 0.88 | - 0.13 | - 0.18 | - 0.24 |
| Combination A + D | 0.96 | - 0.07 | 0.95 | - 0.09 | - 0.14 | - 0.19 |
| Combination B + D* | 0.84 | 0.66 | 0.57 | 0.06 | - 0.28 | 0.04 |
| Combination A + B + D* | 0.93 | 0.63 | 0.69 | 0.08 | - 0.24 | 0.06 |
| Lodging date 1 | 0.75 | 0.44 | - 0.65 | - 0.02 | 0.00 | - 0.37 |
| Factor 3: Yield Components | | | | | | |
| 1000 Kernel Weight | 0.61 | 0.09 | 0.07 | - 0.77 | - 0.06 | - 0.06 |
| No. plants per 1.2 m row | 0.43 | 0.20 | - 0.27 | - 0.56 | 0.03 | 0.06 |
| No. heads per 1.2 m row | 0.61 | - 0.07 | - 0.28 | - 0.72 | - 0.01 | 0.07 |
| Yield | 0.85 | 0.18 | 0.29 | - 0.74 | - 0.07 | - 0.42 |
| Factor 4: Lodging | | | | | | |
| Lodging date 2 | 0.59 | - 0.06 | 0.08 | - 0.01 | 0.76 | - 0.11 |
| Lodging date 3 | 0.81 | - 0.26 | - 0.00 | 0.14 | 0.85 | - 0.06 |
| Lodging date 4 | 0.81 | - 0.21 | - 0.28 | - 0.01 | 0.82 | 0.05 |
| Lodging date 5 | 0.79 | - 0.33 | - 0.15 | 0.03 | 0.80 | 0.06 |
| Factor 5: Vegetative Characters Contributing to Yield | | | | | | |
| Height | 0.68 | 0.25 | 0.02 | - 0.18 | - 0.15 | - 0.75 |
| Head Length | 0.79 | 0.08 | 0.14 | - 0.03 | 0.21 | - 0.85 |
| Percentage of Total Variance | 78 | 38 | 16 | 1 | 8 | 6 |

* Denotes character shared by two or more factors

TABLE XXV. A Factor Analysis for All Combinations of Growth Periods Plus Yield Components and Lodging for 1974

| | Communalities | Factors 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Factor 1: Development and Lodging up to Anthesis | | | | | | |
| Days from Seeding to Heading (A + B + C) | 0.96 | 0.96 | 0.04 | 0.25 | - 0.01 | - 0.29 |
| Days from Seeding to Ripe* (A + B + C + D)* | 0.99 | 0.72 | 0.14 | 0.64 | 0.08 | - 0.18 |
| Days from Emergence to Heading (B + C) | 0.97 | 0.92 | - 0.02 | 0.20 | - 0.02 | - 0.27 |
| Days from Emergence to Ripe* (B + C + D)* | 0.99 | 0.76 | 0.09 | 0.61 | 0.08 | - 0.17 |
| Days from Internode Elongation to Heading (C) | 0.94 | 0.90 | 0.11 | 0.21 | 0.15 | - 0.24 |
| Days from IE to Ripe* (C + D) | 0.98 | 0.69 | 0.20 | 0.63 | 0.21 | - 0.26 |
| Combination A + C | 0.93 | 0.86 | 0.18 | 0.27 | 0.16 | - 0.26 |
| Combination A + C + D* | 0.97 | 0.65 | 0.24 | 0.65 | 0.21 | - 0.15 |
| Lodging date 1 | 0.81 | 0.87 | - 0.10 | - 0.17 | - 0.08 | 0.02 |
| Lodging date 2 | 0.88 | 0.87 | - 0.13 | - 0.25 | - 0.05 | 0.19 |
| Lodging date 3 | 0.73 | 0.71 | - 0.25 | - 0.23 | 0.02 | 0.32 |
| Factor 2: Generally Lodging after Anthesis | | | | | | |
| Days from Seeding to Emergence**(A) | 0.71 | - 0.31 | 0.58 | 0.50 | 0.05 | - 0.16 |
| Lodging date 4 | 0.88 | - 0.15 | - 0.91 | - 0.16 | - 0.03 | 0.05 |
| Lodging date 5 | 0.86 | - 0.04 | - 0.91 | - 0.18 | - 0.07 | - 0.03 |
| Lodging date 6 | 0.92 | - 0.00 | - 0.96 | 0.00 | - 0.00 | - 0.06 |
| Lodging date 7 | 0.94 | - 0.07 | - 0.96 | - 0.10 | 0.02 | - 0.01 |
| Lodging date 8 | 0.76 | 0.05 | - 0.80 | - 0.24 | - 0.22 | 0.08 |
| Factor 3: Growth plus Assimilation Period | | | | | | |
| Days from Seeding to Emergence** (A) | 0.71 | - 0.31 | 0.58 | 0.50 | 0.05 | - 0.16 |
| Days from Seeding to Ripe* (A + B + C + D) | 0.99 | 0.72 | 0.14 | 0.64 | 0.08 | - 0.18 |
| Days from Emergence to Ripe* (B + C + D) | 0.99 | 0.76 | 0.09 | 0.61 | 0.08 | - 0.17 |
| Days from IE to Ripe (C + D) | 0.98 | 0.69 | 0.20 | 0.63 | 0.21 | - 0.14 |
| Days from Heading to Ripe (D) | 0.95 | 0.01 | 0.22 | 0.92 | 0.19 | 0.10 |
| Combination A + D* | 0.97 | - 0.04 | 0.30 | 0.92 | 0.18 | 0.06 |
| Combination B + D | 0.94 | 0.20 | 0.03 | 0.94 | - 0.08 | 0.02 |
| Combination A + B + D | 0.96 | 0.14 | 0.12 | 0.96 | 0.06 | - 0.01 |
| Combination A + C + D* | 0.97 | 0.65 | 0.24 | 0.65 | 0.21 | - 0.14 |
| Factor 4: Early Growth and Vegetative Contributions to Yield | | | | | | |
| Days from Seeding to Internode Elongation (A + B) | 0.83 | 0.37 | - 0.25 | 0.27 | - 0.69 | - 0.29 |
| Days from Emergence to IE (B) | 0.86 | 0.45 | - 0.46 | 0.02 | - 0.63 | - 0.19 |
| Height | 0.49 | 0.11 | 0.07 | - 0.07 | 0.68 | - 0.00 |
| No. of Heads per 1.2 m sample*** | 0.65 | - 0.11 | 0.07 | 0.12 | - 0.58 | 0.53 |
| Head Length | 0.68 | 0.17 | 0.11 | 0.17 | 0.78 | - 0.08 |
| No. of Secondary Tillers | 0.67 | - 0.18 | 0.30 | - 0.23 | - 0.70 | - 0. 3 |
| Yield | 0.85 | - 0.41 | 0.46 | 0.24 | 0.64 | 0.10 |
| Factor 5: Yield Components | | | | | | |
| No. of Plants per 1.2 m sample | 0.46 | - 0.21 | 0.09 | 0.17 | - 0.01 | 0.61 |
| No. of Heads per 1.2 m sample*** | 0.65 | - 0.11 | 0.07 | 0.12 | - 0.58 | 0.53 |
| Habit at IE | 0.54 | - 0.08 | 0.08 | 0.47 | 0.01 | - 0.55 |
| 1000 Kernel Weight | 0.47 | 0.19 | 0.08 | 0.02 | - 0.21 | - 0.6 |
| Percentage of Total Variance | 81 | 33 | 23 | 10 | 10 | 5 |

*, **, *** Denote character shared by two or more factors

Table XIX to five. Here, a larger number of variables were shared by one or more factors, and the groupings were not as clear-cut. Generally however, the first factor remained similar with the inclusion of those combinations containing period C, as well as the first three lodging dates which occurred before heading time. This factor made up 33% of the total variance. Period A was fairly evenly distributed between the second and third factors. In factor two it was grouped with lodging dates 4 to 8 to account for 23% of the variance. In factor three, it was again included with period D and its combinations to give a grouping similar to the second factor in Table XIX to make up 10% of the variance. Factor four included time to Internode Elongation and yield, similar to factor three in Table XIX, but also included height, number of heads, head length, and number of secondary tillers to make up 10% of the total variance. The remaining factor (five) grouped together the yield components number of plants, number of heads, kernel weight, and habit, to make up 5% of the variation. Communalities were again generally lower and ranged from 0.46 for number of plants to 0.99.

iii. Stepwise Multiple Regression

In the first set of equations yield was regressed on the individual growth periods resulting in 28, 43 and 41% of the variation being accounted for in 1972, 1973 and 1974 respectively (Table XXVI). The growth periods entered the equations in different sequences and all periods (A, B, C, D) were highly significant. The equations obtained were:

1972: $Y_1 = -0.21 + 0.09X_1 + 0.14X_2 - 0.60\ X_3 + 0.07X_4$

where $X_1$, $X_2$, $X_3$, and $X_4$ are growth periods D, B, A, and C, respectively.

TABLE XXVI. Partial Regression Coefficients of Characters from Growth Room Data (1971-72), and Field Data (1973, 1974) on Yield in the Order Introduced in the Stepwise Multiple Regression. Characters Include the Four Growth Periods

| Year | n | | Step 4 | $\bar{X}$ |
|---|---|---|---|---|
| 1971-72 | 144 | Days from Heading to Ripe (D) | 0.09** | 48.9 |
| | | Days from Emergence to Internode Elongation (B) | 0.14** | 20.0 |
| | | Days from Seeding to Emergence (A) | - 0.60** | 8.5 |
| | | Days from IE to Heading (C) | 0.07** | 27.7 |
| | | Intercept | - 0.21 | |
| | | $R^2$ | 0.28 | |
| 1973 | 152 | Days from Heading to Ripe (D) | 8.39** | 46.4 |
| | | Days from IE to Heading (C) | 6.49** | 12.5 |
| | | Days from Emergence to IE (B) | 6.48** | 31.3 |
| | | Days from Seeding to Emergence (A) | - 8.23** | 7.4 |
| | | Intercept | - 45.62 | |
| | | $R^2$ | 0.43 | |
| 1974 | 169 | Days from Emergence to IE (B) | - 86.15** | 19.1 |
| | | Days from Heading to Ripe (D) | 17.52** | 44.8 |
| | | Days from IE to Heading (C) | - 10.67** | 24.4 |
| | | Days from Seeding to Emergence (A) | 66.66** | 6.2 |
| | | Intercept | 1478.59 | |
| | | $R^2$ | 0.41 | |

** Significant at the 1 per cent level

1973: $Y_2 = +0.43 + 8.39X_1 + 6.49X_2 - 6.48X_3 - 8.23X_4$

where $X_1$, $X_2$, $X_3$, and $X_4$ represent growth periods D, C, B, and A, respectively.

1974: $Y_3 = 1478.59 - 86.15X_1 + 17.52X_2 - 10.67X_3 + 66.66X_4$

where $X_1$, $X_2$, $X_3$, and $X_4$ represent the growth periods B, D, C, and A, respectively.

It should be noted that in 1972 period A and in 1973 periods A and B had a negative influence on yield, while in 1974 the length of periods B and C had negative influences on yield.

The second set of equations regressed the grain yield on all combinations of growth periods and stages. The addition of combinations does not change the percentage of yield accounted for over the individual growth periods, though different variables were entered. In 1972 the combination (B + C + D) and period A were included in the equation to account for 28% of the variation in grain yield (Table XXVII). The amount of variation in yield accounted for in 1973 (Table XXVIII) increased to 42% with the inclusion of the periods of growth (C + D) and (A + B + C + D) into the equation. In 1974 41% of the variation in the grain yield was due to the period of growth (B + C), the combination (A + D) and the period of growth (B + C + D)(Table XXIX).

Upon entry of the morphological characters as independent variables along with the individual growth periods, the percentage of grain yield accounted for rose to 33, 83, and 64% over the three years. As the only extra variables added in 1972 were height and headlength (Table XXX) there is still a large portion of the variability in yield unaccounted for. In 1972 the characters height, period D and period A accounted for 33% of the variation in grain yield. Addition of all other variables into the equation explained an additional 11% of the yield.

TABLE XXVII. Partial Regression Coefficients of Characters from Growth Room Data (1971-72) on Yield in the Order Introduced in the Stepwise Multiple Regression. Characters Include Growth Periods and Stages, and All Combinations of Periods. (n = 144)

| | Step 2 | Step 4 | $\bar{X}$ |
|---|---|---|---|
| Days from Emergence to Ripe (B + C + D) | 0.10** | 0.07** | 97.3 |
| Days from Seeding to Emergence (A) | - 0.61** | - 0.68** | 8.5 |
| Days from Seeding to IE (A + B) | | 0.08 | 29.3 |
| Days from Heading to Ripe (D) | | 0.02 | 48.9 |
| Intercept | - 0.31 | - 0.21 | |
| $R^2$ | 0.28 | 0.29 | |

** Significant at the 1 per cent level

TABLE XXVIII. Partial Regression Coefficients of Characters from Field Data (1973) on Yield in the Order Introduced in the Stepwise Multiple Regression. Characters Include All Growth Periods and Stages, and All Combinations of Periods (n = 152)

| | Step 2 | Step 7 | $\bar{X}$ |
|---|---|---|---|
| Days from Internode Elongation to Ripe (C + D) | 14.73** | - 126.17 | 58.9 |
| Days from Seeding to Ripe (A + B + C + D) | - 7.52** | - 149.19** | 97.5 |
| Combination (B + D) | | 321.87 | 77.6 |
| Combination (A + C) | | 423.05 | 19.9 |
| Days from Seeding to Heading (A + B + C) | | - 141.33 | 51.1 |
| Days from Seeding to Emergence (A) | | - 103.48 | 7.4 |
| Combination (A + B + D) | | - 37.79 | 85.0 |
| Intercept | 27.10 | - 57.72 | |
| $R^2$ | 0.42 | 0.44 | |

** Significant at the 1 per cent level

TABLE XXIX. Partial Regression Coefficients of Characters from Field Data (1974) on Yield in the Order Introduced in the Stepwise Multiple Regression. Characters Include All Growth Periods and Stages, and All Combinations of Period (n = 169)

| | Step 3 | Step 4 | $\bar{X}$ |
|---|---|---|---|
| Days from Emergence to Internode Elongation (B) | - 79.15** | - 37.01 | 19.1 |
| Combination (A + D) | 31.47** | 28.20 | 51.0 |
| Days from Emergence to Ripe (B + C + D) | - 11.27** | - 49.14 | 88.3 |
| Days from Seeding to Heading (A + B + C + D) | | 38.47 | 94.5 |
| Intercept | 1673.34 | 1478.58 | |
| $R^2$ | 0.41 | 0.41 | |

** Significant at the 1 per cent level

TABLE XXX. Partial Regression Coefficients of Characters from Growth Room Data (1971-72) on Yield in the Order Introduced in the Stepwise Multiple Regression. Characters Include the Four Growth Periods, Height, and Head Length (n = 144).

| | Step 3 | Step 6 | $\bar{X}$ |
|---|---|---|---|
| Height | 0.09** | 0.07 | 109.0 |
| Days from Heading to Ripe (D) | 0.12** | 0.12 | 48.9 |
| Days from Seeding to Emergence (A) | - 0.64** | - 0.61 | 8.5 |
| Head Length | | 0.21 | 6.5 |
| Days from Emergence to IE (B) | | 0.05 | 20.0 |
| Days from IE to Heading (C) | | 0.00 (3) | 27.7 |
| Intercept | - 6.17 | - 6.88 | |
| $R^2$ | 0.33 | 0.44 | |

** Significant at the 1 per cent level

The inclusion of the eleven variables, number of heads, period D, kernel weight, head length, lodging date 2, height, habit, test weight, number of plants, period C, and lodging date 4, accounted for a much greater portion of the variability in yield in 1973 (Table XXXI). This was increased only an extra 2% by the introduction of the remaining variables into the equation.

The accounted variation in yield in 1974 (Table XXXII) dropped from the previous with the inclusion of the ten variables; period B, lodging date 5, period C, height, period D, lodging date 1, head length, number of plants, lodging date 8, and number of heads. Addition of the remaining variables into the equation resulted in explaining an additional 2% of the variation in yield.

The final set of equations involves grain yield being dependent on all the growth periods, stages, and their combinations, and all the morphological characters (Table XXXIII). This resulted in 40% of the variation in grain yield being accounted for by period D, height, the growing period (A + B + C) and period A. Introduction of the remaining variables into the equation succeeded in explaining an additional 2% of the variation in yield.

The entry of these extra variables into the 1973 equations (Table XXXIV) did not explain any additional variation in grain yield. 83% of the yield was accounted for by eleven variables, most of which remained unchanged from the previous 1973 equation. An exception was the replacement of period C with the growing period (C + D). Introduction of the remaining variables accounted for an additional 3% of the variation in yield.

In 1974 as well (Table XXXV), the explainable variation in grain yield remained at 65%, which was an increase of 1% with the inclusion of period combinations

TABLE XXXI. Partial Regression Coefficients of Characters from Field Data (1973) on Yield in the Order Introduced in the Stepwise Multiple Regression. Characters Include the Four Growth Periods Plus Morphological Characters and Lodging Notes (n = 152)

| | Step 11 | Step 17 | $\bar{X}$ |
|---|---|---|---|
| Number of Heads per 1.2 m sample | 0.96** | 0.93** | 96.0 |
| Days from Heading to Ripe (D) | 6.17** | 5.88** | 46.4 |
| 1000 Kernel Weight | 2.45** | 2.57** | 35.4 |
| Head Length | 7.75** | 6.65** | 6.8 |
| Lodging date 2 | 11.50** | 4.85 | 1.3 |
| Height | 0.59** | 0.59** | 92.3 |
| Habit at Internode Elongation | 8.30** | 11.54** | 2.7 |
| Test Weight | 0.98** | 0.74** | 60.9 |
| Number of Plants per 1.2 m sample | 1.74** | 2.02** | 23.3 |
| Days from IE to Heading (C) | 0.79** | 2.99** | 12.5 |
| Lodging date 4 | - 3.92** | - 3.45 | 4.2 |
| Lodging date 1 | | - 11.12** | 1.7 |
| Days from Seeding to Emergence (A) | | - 5.97** | 7.4 |
| Number of Secondary Tillers per 1.2 m sample | | - 0.19** | 43.1 |
| Days from Emergence to IE (B) | | - 1.75** | 31.3 |
| Lodging date 3 | | 4.78** | 1.9 |
| Lodging date 5 | | 0.29 | 4.6 |
| Intercept | - 532.59 | - 418.48 | |
| $R^2$ | 0.83 | 0.85 | |

** Significant at the 1 per cent level

TABLE XXXII. Partial Regression Coefficients of Characters from Field Data (1974) on Yield in the Order Introduced in the Stepwise Multiple Regression. Characters Include the Four Growth Periods Plus Morphological Characters and Lodging Notes (n = 169)

| | Step 10 | Step 20 | $\bar{X}$ |
|---|---|---|---|
| Days from Emergence to Internode Elongation (B) | - 45.33** | - 48.46** | 19.1 |
| Lodging date 5 | - 44.47** | - 20.09 | 2.2 |
| Days from IE to Heading (C) | - 12.94** | - 12.43** | 24.4 |
| Height | 6.08** | 5.49** | 85.6 |
| Days from Heading to Ripe (D) | 12.01** | 8.53** | 46.8 |
| Lodging date 1 | - 24.13** | - 16.58** | 2.0 |
| Head Length | 50.69** | 49.58** | 6.0 |
| Number of Plants per 1.2 m sample | 4.42** | 5.70** | 39.6 |
| Lodging date 8 | - 19.91** | - 3.22 | 6.1 |
| Number of Heads per 1.2 m sample | - 1.17* | - 1.24** | 116.2 |
| Number of Secondary Tillers per 1.2 m sample | | - 1.15 | 19.0 |
| Lodging date 4 | | - 14.94 | 3.7 |
| 1000 Kernel Weight | | 3.71 | 38.1 |
| Test Weight | | 3.67 | 57.7 |
| Lodging date 7 | | - 19.67 | 3.0 |
| Lodging date 2 | | - 14.90 | 2.0 |
| Habit at Internode Elongation | | - 8.53 | 2.8 |
| Lodging date 3 | | - 7.50 | 1.6 |
| Days from Seeding to Emergence (A) | | 6.96 | 6.2 |
| Intercept | 824.10 | 728.67 | |
| $R^2$ | 0.64 | 0.66 | |

* Significant at the 5 per cent level

** Significant at the 1 per cent level

TABLE XXXIII. Partial Regression Coefficients of Characters from Growth Room Data (1971/72) on Yield in the Order Introduced in the Stepwise Multiple Regression. Characters Include All Growth Periods and Stages, Combinations of Periods, Height and Head Length (n = 144)

| | Step 4 | Step 10 | $\bar{X}$ |
|---|---|---|---|
| Days from Emergence to Ripe (B + C + D) | 0.12** | - 2.71 | 97.3 |
| Height | 0.09** | 0.07** | 109.0 |
| Days from Seeding to Heading (A + B + C) | - 0.11** | - 8.25 | 56.9 |
| Days from Seeding to Emergence (A) | - 0.53** | - 3.90 | 8.5 |
| Head Length | | 0.21 | 6.5 |
| Combination (B + D) | | 9.89 | 68.9 |
| Combination (A + C) | | 9.84 | 36.2 |
| Days from Heading to Ripe (D) | | - 8.76 | 48.9 |
| Combination (A + D) | | 0.57 | 57.4 |
| Days from Seeding to Ripe (A + B + C + D) | | 1.13 | 105.9 |
| Intercept | - 6.23 | - 6.88 | |
| $R^2$ | 0.40 | 0.44 | |

** Significant at the 1 per cent level

TABLE XXXIV. Partial Regression Coefficients of Characters from Field Data (1973) on Yield in the Order Introduced in the Stepwise Multiple Regression. Characters Include All Growth Periods and Stages, Combinations of Periods, Morphological Characters, and Lodging Notes (n = 152)

| | Step 11 | Step 19 | $\bar{X}$ |
|---|---|---|---|
| Number of Heads per 1.2 m sample | 0.96** | 0.77** | 96.0 |
| Days from Heading to Maturity (D) | 5.38** | 1250.30** | 46.4 |
| 1000 Kernel Weight | 2.45** | 2.74** | 35.4 |
| Head Length | 7.75** | 8.10** | 6.8 |
| Lodging date 2 | 11.50** | 0.74 | 1.3 |
| Height | 0.59** | 0.32** | 92.3 |
| Test Weight | 0.98** | 0.95** | 60.9 |
| Habit at Internode Elongation | 8.30** | 9.43** | 2.7 |
| Lodging date 4 | - 3.32** | - 1.92 | 4.2 |
| Number of Plants per 1.2 m sample | 1.74** | 2.62** | 23.3 |
| Days from IE to Ripe (C + D) | 0.79** | - 3227.06** | 58.9 |
| Lodging date 1 | | -14.35** | 1.7 |
| Days from Seeding to Maturity (A + B + C + D) | | - 337.25** | 97.5 |
| Combination (A + C) | | 327.84** | 19.9 |
| Days from Emergence to Heading (B + C) | | 919.52** | 43.8 |
| Days from Emergence to Ripe (B + C + D) | | - 584.45** | 90.1 |
| Lodging date 3 | | 8.35** | 1.9 |
| Number of Secondary Tillers per 1.2 m sample | | - 0.13 | 43.1 |
| Lodging date 5 | | - 0.38 | 4.6 |
| Intercept | - 532.59 | - 405.54 | |
| $R^2$ | 0.83 | 0.86 | |

** Significant at the 1 per cent level

TABLE XXXV. Partial Regression Coefficients of Characters from Field Data (1974) on Yield in the Order Introduced in the Stepwise Multiple Regression. Characters Include All Growth Periods and Stages, Combinations of Periods, Morphological Characters and Lodging Notes (n = 169).

| | Step 10 | Step 23 | $\bar{X}$ |
|---|---|---|---|
| Days from Internode Elongation to Heading (C) | - 24.56** | - 29.11 | 24.4 |
| Lodging date 5 | - 43.59** | - 20.09 | 2.2 |
| Days from Emergence to IE (B) | - 44.21** | - 306.02 | 19.1 |
| Height | 6.12** | 5.49** | 85.6 |
| Combination (A + C + D) | 11.59** | 182.33 | 75.4 |
| Head Length | 50.90** | 49.55** | 6.0 |
| Lodging date 1 | - 23.62** | - 16.57** | 2.0 |
| Number of Plants per 1.2 m sample | 4.35** | 5.70** | 39.6 |
| Lodging date 8 | - 19.32** | - 3.23 | 6.1 |
| Number of Heads per 1.2 m sample | - 1.14** | - 1.24** | 116.2 |
| Number of Secondary Tillers per 1.2 m sample | | - 1.15 | 19.0 |
| Lodging date 4 | | - 14.94 | 3.7 |
| 1000 Kernel Weight | | 3.71 | 38.1 |
| Test Weight | | 3.66 | 57.7 |
| Lodging date 7 | | - 19.66 | 3.0 |
| Lodging date 2 | | - 14.89 | 2.0 |
| Habit at Internode Elongation | | - 8.54 | 2.8 |
| Lodging date 3 | | - 7.50 | 1.6 |
| Combination (A + C) | | - 212.41 | 30.7 |
| Days from Emergence to Heading (B + C) | | 220.53 | 43.5 |
| Days from IE to Ripe (C + D) | | - 173.78 | 69.2 |
| Lodging date 6 | | - 2.44 | 3.4 |
| Days from Seeding to IE (A + B) | | 37.02 | 25.3 |
| Intercept | 738.69 | 728.32 | |
| $R^2$ | 0.65 | 0.66 | |

** Significant at the 1 per cent level

into the equation. In this case, however, the equation was slightly altered from Table XXXII as growth periods C and D were replaced with the growing period (B + C) and the combination (A + C + D). All other variables that were entered as contributing to yield remained the same as Table XXXII. Introduction of these remaining variables into the equation resulted in an increase of 1% in the variation of yield.

It should be noted that height and period D (or a corresponding combination) were the only variables in common that were included for all three years. In addition, number of heads, head length, number of plants, and lodging, were included in common as being responsible for grain yield in the two field years.

# DISCUSSION

## I. HOMOGENEITY OF LINES

Lack of homogeneity, shown to be present in twenty of the thirty-two families, was first detected when the material was grown in a growth chamber in the winter of 1971-72. Here, the material when received was grown as the thirty-two samples with five replicates of supposedly genetically identical material. When significant differences were found within a number of samples it was suggested that the material be analyzed using two separate procedures:

1. Where the material was treated as thirty-two different samples with five replicates grouped to form means of these thirty-two families.
2. Supposing genetic differences between the replicates within a family, each line was treated as a separate sample and analyzed as ungrouped data.

This method of analysis was performed for all three years' material, and all results from the grouped and ungrouped data were compared. As the two sets of results differed in many instances, it was concluded that genetic differences were present within some of the families, and the ungrouped analysis was accepted. The conclusion was further supported by the application of a Duncan's analysis to the means of the two 1974 replicates. Here, lines showing genetic differences from their families for specific characters were isolated.

This lack of homogeneity was not detected when the material was first selected from the World Barley Collection, as the samples were entered as genetically pure lines. It was not until the material was grown either under controlled conditions or in a northern environment that the differences became evident. Faris and Guitard (1969) and

Guitard (1960), working with the barley varieties Olli and Vantage, found interactions of the varieties with photoperiod and temperature, affecting the length of the growth phases as well as the yield components. It is suggested that this interaction with northern photopesiods and temperatures has allowed genetic differences that were not evident further south to become clear. A comparison of Table II and Appendix I shows that many of the lines displaying a larger number of within family differences are of tropical origin (Ethiopia, Turkey, and Iran).

## II. RELATIONSHIPS OF GROWTH PERIODS AND STAGES

### i. Period of Emergence

A comparison of the ranges, means and variances of the growth periods showed some interesting differences among the three years. Period A began this sequence of differences by displaying the smallest range between the families in 1974. The mean number of days for emergence in this year was smaller as well. A comparison of the mean daily temperatures for period A among the years showed that the growth-room and 1973 field material had temperatures of 15.5°C and 16.7°C, and showed a much greater genetic variability between the families. In 1974, however, there was a mean daily temperature of 10.1°C accompanied by a loss of variability betwen the families (all families emerged over a period of three days). Faris (1967) has stated that time to germinate is extremely sensitive to different temperatures, with lower temperatures (below 12°C) magnifying the importance of varietal differences. This is in direct opposition to the reduction of variability found in the lower air temperatures of 1974. As the material for 1974 was grown under field conditions, it is likely that environmental factors such as soil temperature and moisture content played an overriding

role in determining the reduced variability. Coefficients of variation for this period remained low (<1.5%), indicating that most of the variability was accounted for by the different families. Associations between the growthroom and field years for this period are also quite low, a factor which may be explained by variation in such environmental variables as seeding depth and soil moisture and temperature.

Faris (1967) has indicated that a short period from seeding to emergence is desirable in northern climates, as this leads to earlier establishment and earlier maturation of the crop. However, in the present case, correlations for period A with total time to mature were low for all three years. There was a significant and positive relationship present between the lengths of periods A and D. It seems here that varieties [illegible] longer to emerge also tend to have a longer ripening period. Relationships are lacking between the time to emerge and the length of the periods of floral development, which would indicate that the emergence time does not influence the floral development of the plant to any great extent. Faris (1967) indicated that different varieties tend to retain their ranking in germination time over a large range of temperatures. Therefore, it was of interest to discover whether the families in this project would retain their ranking over the three years, and whether they would retain this ranking in the length of period D as well. It was found that the families retained their ranking in period A for the three years. However, upon comparison with period D it was found that, while a few of the families retained the top or bottom positions in common with period A, generally the pattern of ranking was not maintained for the three years.

Correlations between time to emerge and yield were non-significant with the exception of the 1974 field data (Table XIII).

ii. Period of Vegetative and Floral Development

Period B also displayed a large decrease in the number of days over which it ranged among the three years. The longest ranges here were shown in the growthroom and the 1973 material. There was a dramatic reduction in range in 1974, though the mean number of days taken by period B was similar in 1972 and 1974. This is reflected in the higher correlations between growthroom and 1973 material for this period. The 1973 material showed a much longer mean for period B. These differences cannot be readily explained by temperature variation, because mean daily temperatures for the period over the three years were similar at 15.5°C, 14.3°C, and 14.1°C, respectively. However, a late frost that occurred about one week after emergence in 1974 could have produced the effect of shortening the length of this period for some of the families.

As period B includes the period of growth up to inflorescence initiation, it is likely that the length of this period could have a significant effect on the yield of the crop by affecting the number of kernels per head (Willey and Holliday, 1971; Faris and Guitard, 1969; and Rawson, 1970, 1971). The results have indicated that in the years 1972 and 1974, when the mean number of days taken by Period B were almost identical, there were significant associations between the length of this period and the yield. However, in 1972, the relationship was positive, while in 1974 it was negative. Though the 1973 mean was much greater, correlations with yield were low and insignificant. A comparison of total number of days from seeding to internode elongation (A + B) shows that there were four fewer days in 1974 than in 1972, due to earlier

emergence. An explanation may be the short range of time over which period B occurred in 1974 with the completion of floral initiation being affected in some families by a slight vernalization requirement and/or interaction between temperature and photoperiodic response to the low temperatures and late frost (Rawson, 1970, Syme, 1973). This is supported by Marcellos and Single (1971) and Doyle and Marcellos (1974) when they tested varieties of spring wheat in Australian winter conditions (June to October). They found high correlations between temperature and photoperiod and the duration of the pre- and post-initiation phases, with later planting (lower temperatures) giving an overall reduction in the period of development.

Coefficients of variation for period B were highest in the growth chamber (>15%), then became quite low in the field, indicating that variability shown among the families for this period is reduced by field conditions.

Relationships between period B and the other growth periods were generally quite low, with the exception of a significant association with period C. This correlation was positive and fairly strong in 1972 and 1973, but was weakened to a large extent in 1974.

Growth period C again showed the largest range in 1972 and then dropped to similar values for the field years. Here again, mean temperatures for this period were similar in the three years with values of 15.5°C, 14.8°C, and 15.6°C, respectively. In 1973 there was a much lower mean number of days for this period, though the range and variance were only slightly lower than in 1974. Though the mean temperature associated with this period is slightly lower, extremely high temperatures (up to 32.0°C) were experienced in the third week of June, which may have had the

effect of hastening anthesis. This is supported by Halse and Weir (1970) who showed that high temperatures accelerated development to initiation and anthesis in wheat.

Associations of period C with the other growth periods are generally low and negative with the exception of the previously mentioned correlation with period B. Associations with total growing time are highly significant, with extremely high values shown in the two field years. As period C is defined as the period of floral development (after initiation) up to heading (which in barley occurs just after anthesis), it is in many cases regarded as the most important of the growth periods in their relationships with yield. Willey and Holliday (1971) stated that this period, as part of the pre-heading phase affected yield by altering the capacity of the ear to accumulate carbohydrates, determined by number of grains per ear. Rawson (1970) showed that the period from floral initiation to terminal spikelet formation, which is included in period C, is important in determining the yield of the cultivars (wheat) that have no vernalization response. In this study the length of period C had similar significant but fairly low associations with yield. The 1974 relationship, however, was negative. Relationships of this period with head length in 1972 and 1000 kernel weight were generally stronger than those shown by any other growth period.

As growth periods B and C together comprise the total period of floral development of a crop, many writers include them together as the pre-heading phase (Period B + C in this study)(Thorne et al., 1968; Willey and Holliday, 1971). In this study the length of both the periods had a high association with total time to maturity, but their individual contributions varied from year to year, as in 1972 period B had the

strongest association, while in 1973 and 1974 the greatest contribution was supplied by period C. Therefore it is not surprising that the combined relationship of (B + C) with total time was almost identical in all three years. Also, a look at the ranges covered by the two periods for the three years reveals some interaction between them, for the sum of these ranges in each case is far greater than those covered by the combined period (B + C).

Period C showed the greatest amount of variation of any of the growth periods or stages with CV's being extremely high (>20%) for all three years. The variation that was shown by period B in the growth chamber dropped in the field years, while the variability shown by period C remained extremely high in the field. The interaction between period B and C mentioned before became evident in the combined phase (B + C), for variability in the growth chamber dropped, while values in the field maintained a value somewhere between B and C. Also, periods C and (B + C) showed the most consistent relationships when the three years were compared (Table XVI).

Aksel and Johnson (1961) found a close relationship between the length of pre- and post-heading phases. They associated a long first phase (sowing to heading) with a short second period (heading to ripe) and vice versa. This strong association did not occur in the present experiment, as the only negative significant relationship with period D occurred in 1973, and it was not extremely high. Aksel and Johnson (1961), Beech and Norman (1971), and Rao (1972) all showed that the length of the pre-heading phase accounted for a significant portion of the variation in cereal yield. These strong relationships were not found in the present study because associations of the length of the pre-heading phase (B + C and A + B + C were almost identical) with

yield were significant only in 1972 and 1974. Also, the 1974 associations were negative (correlations between B + C and yield were 0.36**, 0.12 and -0.40**, respectively). Thus it seems that only the growthroom material supported this assumption, and then not to any great degree. Associations with head length and kernel weight were all low with significance occurring only in 1973 with kernel weight. Total time to head (A + B + C) showed a lower relationship with time to maturity in 1972 and similar values in 1973 and 1974, though in all three years there was a strong positive relationship between these two variables, supporting the close association found by many writers, among them Crumpacker and Allard (1962) and Frey (1954).

iii. Post-heading Period

As period D, which includes the assimilation and ripening phases of the crop is the longest, it would be the most likely to show the greatest variability in length. As mentioned previously, Aksel and Johnson (1961) found an inverse relationship between the length of the seeding to flowering period and the post-heading period. Faris (1971) also found a strong negative correlation between the same two periods. This association was found to be much weaker in the present study, thus giving a possible explanation of the lower amount of variation found in this growth period; (CV values being lower than both period B and C). Mayr (1969) showed that total radiation requirements in spring wheat were variety-specific before heading, but after heading showed no differences among the varieties. This could result in reduced variability in the post-heading phase among the families.

Another possible explanation for the reduced variation found in period D may be provided by Walpole and Morgan (1971). They showed that different barley varieties

could have similar yielding ability and take a similar length of time from flowering to ripening, but would show different behavior in each of three sub-phases in the ripening period. Therefore variation among the families could be reduced by a possible interaction between these sub-phases.

There was again a large reduction in the range for period D from the growthroom material to the field material, though the means were similar for the three years. It seems that here again, genetic variability among the families that showed up in the growthroom environment was greatly reduced under field conditions. This reduction cannot be readily explained by temperature as the mean daily temperatures for period D were similar at 15.5°C, 15.3°C, and 15.2°C respectively, for the three years.

Associations of period D with total time to mature were fairly high and significant in 1972 and 1974, but very low in 1973. As correlations between heading time and total time to ripen were extremely high, especially in 1973, it could be possible that the length of period D is dependent to a large extent on the heading time of the variety. Malhotra and Jain (1972), along with numerous other writers, have also reported this close association between heading time and maturity. If the crop is given ample time to express its full growing potential, such as in the growthroom or by the slightly earlier heading that occurred in 1974, it could be possible that the length of period D would have a major effect on time to maturity. If, however, the length of period D is limited by a late heading date or other environmental conditions such as an early frost, then it would show a lesser effect on the total time to maturity. This would provide a possible explanation for the low relationship in 1973, and also for the low associations found among the three years for this period. It should be noted also

that in many cases in 1974 ripening was hastened by severe lodging. The effect of this is discussed in part V.

## III. MORPHOLOGICAL AND YIELD CHARACTERS

As evidenced previously with the growth phases, the material displayed its greatest variability in yield potential in the growthroom. When exposed to a field environment in 1973 and 1974, the amount of variation was practically halved. Ranges and means for yield cannot be compared here because different plot sizes were used for each year, but it became obvious that the potential variability in yield in many of the samples was reduced by field conditions. Syme (1972) could find little relationship between the yield of single plants in a greenhouse and the same varieties grown in plots under field conditions, and suggested that in the field environmental stresses frequently shortened the growing season, thus limiting the straw yield and reducing the grain yield of later maturing varieties. However, he did have high correlations in days to ear emergence, height and grain weight between the two environments. This seems to hold true for days to ear emergence and height in the present study as there was no drastic drop in variability shown here by transference to field conditions, such as was seen in yield. Also, kernel weight, test weight, number of heads and habit show very little difference in variability between the two field years.

Inspection of Table XVI will show that the yield results from the present test almost duplicate those of Syme. Here also, correlation coefficients are extremely low when the yield of single plants in the growthroom is compared to plot yields in both 1973 and 1974. On the other hand, a comparison of days to ear emergence shows extremely consistent relationships between the years. Height, however, has a lower relationship

(though still significant) between the growthroom and the field, and a high association between the two field years.

The highest and most constant correlations with yield were provided by height, followed closely by head length. Also highly significant in the two field years was the number of plants per 1.2 meter sample. In 1973 the yield components kernel weight, test weight, and number of heads, along with habit, showed close associations with yield. However, in 1974 there was no association at all between these variables and yield. Reasons for this are unknown but may be attributed to the loss of yield associated with the heavy lodging occurring in that year.

Among the closest associations for all three years was that provided by height and head length. Both these characters have been closely associated with yield in the literature (Faris and Guitard, 1969; Khadr, 1971; Bhatt 1973), though their method of contribution to yield and the interaction between them is often debated. Hsu and Walton (1971) found a positive correlation between ear length and spikelet and kernel number per ear in wheat, though in 1969 Walton stressed that some measurement of the compactness of the head and glume size was needed as an indicator of the photosynthetic area of the head to accurately predict contribution to yield. Also, a well extruded head produced by increased height would reduce the amount of shading by the canopy allowing a greater photosynthetic contribution by the ear.

Though the amount of variability in height remained low (CV $\leq$ 15%) in the growth chamber and was only slightly lower in the field, the range of heights dropped by 10 cm in transferring to the field, and the means were reduced by 17 and 24 cm. Thus field conditions produced generally shorter plants with fewer extremes in height. There

seemed to be little if any effect to the head length produced by the change in environments; the range, means and amount of variation remained similar over the three years. The only other major associations incurred by head length were negative relationships with the number of heads and the number of secondary tillers in 1974. Fonseca et al. (1968) and Smoček (1969) showed similar negative relationships between the number of ears and the number of grains per ear.

Though mean kernel weight was slightly greater in 1974, its only high association with yield occurred in 1973. Ranges and variability among families dropped slightly in 1974, but values remained fairly constant. Also in 1973 kernel weight showed positive associations with test weight; height; and the number of heads, secondary tillers and plants. Bhatt (1973) found similar positive relationships between kernel weight, height and spike number. In 1974, however, the only major relationship of kernel weight was with habit at internode elongation.

The relationships shown by habit (or leaf and tiller spread at Internode Elongation) are not consistent between the two years, for in 1973 it is correlated with yield and height, and in 1974 with 1000 kernel weight. Research has been done to associate leaf angle with yield (Smoček, 1969) and it is possible that the angle of the leaf created by the habit of the plant at this stage could influence the photosynthetic efficiency of the plant, thus affecting yield in 1973 and kernel weight in 1974. Behavior of the families in regard to their habit remained fairly consistent between the two years showing little difference in the ranges, means and CV's. Because there was severe lodging in many cases at the time of heading, it was impossible to assess the habit at this stage. As there is some association with yield in the earlier stages, it might prove

profitable to measure the leaf and tiller spread at heading on material grown under greenhouse conditions. These data would reveal any continued associations of the habit between these two stages and could possibly clarify the relationship with yield.

The test weight showed very little variability (CV's < 15%) in both 1973 and 1974. Means were similar though the range was greatly reduced in 1974. Any differences here, though they seem to be slight, could possibly be due to the different methods of measurement and sample sizes utilized in the two years. Test weight showed a positive correlation with yield and 1000 kernel weight in 1973, but had no such relationship in 1974. Reasons for the lack of association in 1974 are not known.

The final yield component includes the number of plants, number of heads, and the number of secondary tillers per unit area in 1973 and 1974. Positive associations were found between number of plants and number of heads; also between number of heads and number of secondary tillers. In 1973 there were highly significant positive correlations between all these variables and kernel weight, which supports the findings of Bhatt (1973). It is of interest to note that in both the field years there was a positive association between number of plants and yield, while number of heads and yield were significant only in 1973.

The only other relationships of significance were the negative associations of height and head length with the number of secondary tillers. As these two variables showed no relationships with lodging on any occasion, their association with the production of secondary tillers must be due to some other factor besides lodging.

Behavior among the three density variables (number of heads, plants and secondary tillers) proved to be quite different in the two field years. The number of

heads per unit area proved to be the most consistent with a slight increase in range and means, and the amount of variability remaining similar. On the other hand, the number of plants per unit area increased greatly in range, means, and amount of variability in 1974. It should be noted that difficulty was experienced in accurately measuring this character as problems were encountered in separating the plants and their respective tillers from each other. There was a large decrease in 1974 in both the range and the mean number of secondary tillers, possibly as a result of environmental conditions. This was demonstrated when the amount of variability experienced between the lines was almost doubled in 1974 (CV's 48.1 in 1973 and 91.0 in 1974).

## IV. MULTIVARIATE ANALYSIS

The use of factor analysis in the study of agriculture has only gained acceptance in the last few years. The technique was found effective for reducing a large number of correlated variables into a small number of main factors, thus making it easier to study the dependence relationships among certain variables. In 1972 Waddington employed this method to investigate relationships between environmental variables and yield in forages. Walton (1971 and 1972) used this method to study the relationships between yield and its components in wheat.

A form of analysis that is more commonly employed in studying the relationships of yield with different variables is the stepwise multiple regression. This method has been used to study the dependency structures of yield in wheat (Syme, 1972); rice (Rao, 1972) and barley (Malhotra and Jain, 1972).

It was Walton (1971) who paired these two forms of analysis to provide complementary ways of studying the data. He found that factor analysis indicated the relationships among yield components and morphological structures, while the stepwise regression analysis indicated importance of the components of yield. This complementary pairing of analysis is carried out in the present study in order to detect relationships among growth periods and stages, morphological characters and yield.

Growthroom: The behavior shown by the growth periods when they were included with all their combinations in a factor analysis, indicated a fairly clear separation of behavior among the phases. The most prominent differences are shown in 1972 when each growth period, together with its appropriate combinations, is clearly placed in separate factors, indicating that each of the individual growth periods displays some form of behavior that is independent of the others. The major proportion of the total was shown by the first two factors, which included periods D and C and their combinations, with period D accounting for over half of the variability. The contributions of periods A and B were relatively minor.

A stepwise regression of these growth periods on yield shows that period D is the major contributor to yield, with the four growth periods accounting for 28% of the variation in yield. Inclusion of all periods and phases did not increase the contribution to yield, but showed the major contributor was the total growing time after emergence, with the time to emergence included as having a negative but still significant effect. Period D is still included but has lost its significance when all variables are entered.

The addition of height and head length to the four growth periods in the factor analysis created a slight difference in the groupings. Here, periods B and C were

grouped together in a single factor, while periods A, D and head length gave strong loadings in separate factors. The regression analyses, however, showed that the inclusion of morphological characters increased the amount of yield variation accounted for to 44%. Periods D and A still are included as the most important growth periods, but the greatest contributor to yield is height.

When all the combinations of growth periods were included with morphological characters, period D remained the largest single factor with 49% of the total variance. The grouping of periods B and C along with height would indicate that both these growth periods had a high association with the height of the plant. The stepwise regression showed that the total growing period from emergence had the greatest influence on yield, followed by height, which was the only variable that retained significance in the final equation. Periods A and D were again the only separate growth periods retained in the equation as having any influence on yield.

It is of interest to note that the inclusion of the combinations of growth periods and stages in this data was useful in the factor analysis, as it clarified the interrelationships among the growth periods. However, these combinations served little, if any, useful purpose in the regression equations as they accounted for no additional variation in yield, and served only to confuse the matter.

1973: In this field year, the differences among growth periods are not as clear-cut as in the growthroom. Periods B and C and their combinations are grouped together to account for the largest portion of the variability, followed by period D and its combinations in the second factor. However, with the addition of morphological characters and lodging, period A was included with period D in a single factor. Yield components

and yield are grouped together in the third factor. This holds true when the four growth periods are included in the matrix with the morphological characters and lodging.

One difference revealed by the regression analysis was that the proportion of variability in yield accounted for by the four growth periods increased by more than 1.5 times in the two field years compared to the growthroom. In 1973, 43% of the yield was accounted for by the growth periods, with period D being the largest single contributor.. Inclusion of all periods and stages did little to clarify matters, for they did not produce any additional contribution to yield. Also, the period that included flowering and ripening (C + D) was included as the major contributor to yield, thus offering little change from the previous equation. When the morphological characters and lodging were included with the four growth periods, the variability in yield accounted for rose to 83%. Here the major contributor to yield was the number of heads per sample, with period D included as the second most important variable. As the addition of the combinations into the equation produced little change, it is evident that here again, they are of little use in this form of analysis.

1974: In this field year the factor analysis did not reveal clear-cut separations among the growth periods. Entering all stages and combinations into the matrix revealed a general grouping of those variables containing some part of the complete period of floral development (B or C) making up the first factor. The second contained periods A and D, thus again showing some relationship between the time to emerge and the ripening period. These relationships remained similar after the addition of the lodging data and morphological components into the matrix. However, when the four growth periods were entered along with the lodging data and morphological and yield components, there seemed to be no clear-cut pattern emerging. Therefore in this case the utilization of combinations aids in the clarification of the groupings.

It is of interest to note the similarities found for the two field years in the factor analysis, for the groupings were remarkably similar in content. In both years a single factor was composed of the combinations containing either period B or C, thus showing that in the field at least, it is fairly difficult to separate the different phases of floral initiation and development. It is also noteworthy that periods A and D were grouped together in the two field years, thus showing some similarities in behavior. Reasons for this behavior, as mentioned previously (in multiple correlations), remain unknown. One point previously described in the results indicated that in both 1973 and 1974 the yield components, number of plants, number of heads, and 1000 kernel weight, were grouped together. Also, the lodging data retained a specific pattern for both years.

Although the amount of variation in yield accounted for by the growth periods in the regression remained almost identical in the two field years, the major contributor to yield in 1974 changed from period D in the previous years to period B. The length of the growth period had a very strong negative effect on yield - one which remained unchanged with the addition of combinations of periods. However, the introduction of lodging data and morphological characters shifted the emphasis so that period C had the primary influence on yield (also negative), followed by lodging on date 5 and period B. The fact remains though, that there is a shift of importance from the period of ripening (shown in the two previous years) to the period of floral development. The two yield components included as significantly affecting yield were the number of plants and the number of heads per sample. One possible influence on this change in behavior in 1974 could be environmental conditions: heavy lodging occurred throughout the

season, thus delaying the heading and ripening times. Also, in many cases, the length of period D was influenced by the arrival of fall frosts - a long period of floral development created by lodging and meteorological conditions resulted in a limited period of time remaining for ripening. Thus, in some cases, a sample was harvested green, as it refused to ripen in the cooler fall weather.

## V. LODGING

As lodging in cereals is a very real problem in northern Alberta, and thus a detriment to obtaining maximum yields, periodic recordings of lodging severity were taken during the two field years. Regression equations showed that on two occasions in 1973 and three occasions in 1974, lodging played a significant role in affecting the grain yield. These results are supported by numerous examples in the literature, among them Laude and Pauli (1956) who found that test weight and 1000 kernel weight in barley and wheat were affected by lodging. Brady (1934) working with oats, and Esechie et al. (1977) with sorghum, both showed that resistance to lodging is genetically inherited and can vary between varieties. That this holds true in the present experiment was shown by the highly significant differences between treatments in the Analysis of Variance in 1974. As the analysis progressed, it became evident that the lodging behavior of the material changed as the plants matured. This was first indicated in the factor analysis when loadings for both years clearly separated the early lodging behavior (before heading) from the later lodging. The CV's showed a large amount of variability among treatments with the earlier observations, but dropped as the crop developed. This change in behavior was also indicated by broad sense heritabilities which were highest with the first lodging date, showed a gradual decline to just after heading, then remained fairly constant for the remainder of the growing season.

In the present study, simple correlations between yield and lodging were extremely low in both the pre- and post-heading phases in 1973. In 1974, however, all recordings showed a highly significant negative effect on yield. Lodging dates 1, 2, and 3 all occurred in the period between internode elongation and heading; dates 4, 5, and in many cases, 6, occurred during the heading period (up to a week after); and dates 7 and 8 occurred during the ripening period (because a large variability had already shown up by heading time, there is some overlap present). Thus it can be seen that the three most important lodging dates (as shown in the regression tables) occurred at crucial times in the crop's development, as described by Laude and Pauli (1956) and Day (1957). As correlations between yield and all yield components were high and significant in 1973, it could be assumed that they were not greatly affected by the lodging, thus creating the low relationship between yield and lodging.

Significant correlations found between the individual growth periods A and B and lodging could be interpreted as the length of the growing period affecting the severity of lodging at a certain time. Therefore the stage of development that the plant has reached at the time of a storm could have a significant effect on its susceptibility to lodging. For example, a positive and significant association was described between the length of the early growth periods and the severity of lodging in period C. This observation was supported by Gardener and Rathjen (1975) who stated that lodging and yield depression in barley were greatest in the later flowering cultivars with their longer juvenile growth phase, greater number of tillers and leaves per tiller, and longer leaves. Total time to maturity showed significant associations with lodging. Lodging that occurred before heading time showed a positive relationship with the total growing time, while that occurring after heading had a negative association. This could be explained by

referring to the observations of Neenan and Spencer-Smith (1975) who showed that lodging resistance is affected by the maturity of the straw. Also, it has been shown that later varieties were generally more resistant to severe lodging and loss of yield (Esechie et al., 1977; Larson and Maranville, 1977, with sorghum). Though the length of period D is not greatly affected by lodging (with one exception) it would seem that if lodging occurred after heading time, seed set and ripening would be hastened by the reduction in supply of assimilates, thus influencing the time to maturity.

From observing the wide amount of variability shown by the material in this project, it became obvious that breeding for lodging resistance is possible. However, as mentioned earlier in the literature review, it has still not been fully determined what characters are involved in this quality.

## VI. RECOMMENDATIONS FOR SELECTION OF CHARACTERS

### i. Growth stages and periods

One of the major objectives of this project was to study the relationships between the growth periods and stages, as well as their associations with several morphological characters, in order to develop varieties that would be better adapted to our northern climate. It has been stated previously in the literature review that such an achievement, though difficult to accomplish, is not impossible (Thorne et al., 1968). The aim of this study therefore was to find which growth stage or period, if any, would be most receptive to manipulation, all the time keeping in mind the minimum sacrifice of yield.

The factor analysis results (especially those from the growth chamber, 1971/72) showed that the life-span of a crop can be divided quite clearly into four separate growth periods that are largely independent of each other. Therefore manipulation of one growth

period could occur without seriously affecting the length of the other growth periods. Though the material grown in the field shows increased inter-relationships between periods B and C, this manipulation should still be possible.

In order that the most effective manipulation occur, the growth period involved must show a high variability between varieties, and must possess a high enough heritability that any genetic manipulation with its length would be retained in future generations. Also, there must be a sufficient number of days to provide ease of manipulation in the growth period itself. Period A does not fit these qualifications, for though it demonstrates a fairly high heritability, it is the shortest of all growth periods and possesses the smallest amount of variability. Also, correlations with total time to maturity are low and non-significant.

Therefore it would follow that manipulation must occur in either the developmental period up to flowering (B, C, or both) or the ripening period after heading (D). It is at this point that differences between the growth chamber and field results show up, as there seems to be distinctive behavior differences between the two environments. In the growth chamber it was period B that had the closest relationship with total time to maturity, while in the field it was period C. The greatest amount of variability was shown by period C for all three years, but at the other end of the scale, the least amount was shown by period A in the growthroom and period D in the field.

Differences between the environments also showed up in the relationships of growth periods and yield. In 1972, period B had the highest correlation with yield, while in the field years, period D showed the highest positive correlations with yield (in 1974 the highest correlation was period B, but the effect on yield was negative).

Broad sense heritabilities taken in 1974 indicate that period C has the highest heritability at 0.897, with periods A and B being similar but lower, and period D being non-significant. Also, correlations comparing the three years indicate that period C has the most consistent behavior in all three environments. Therefore it would be logical to conclude that the growth period that would be best to manipulate (based on three years' data) is period C as it displays the highest genetic variability, is stable, and yet does not possess the greatest influence on yield.

As mentioned previously, the distinct separation between the growth periods that is evident in the growthroom material is not as obvious in the field. Some form of compensation or interaction between periods B and C present in the field material would possibly be due to suppression of genetic variation due to environmental conditions. Therefore, if a detailed study of the behavior of separate growth phases is required, it would be advisable to raise the material in the growthroom. However, since the aim is towards overall adaptation, the material must be grown in a field environment to confirm that any changes made would be maintained.

If adjustments are to be made to period C, which covers the time from initiation to anthesis, the yield components affected would be the number of fertile florets and the number of ears. However, the described effect seems to be less than that produced by changes in period B which affect all three components, and period D, which affect mainly kernel weight (Thorne et al., 1968; Faris and Guitard, 1969; Willey and Holliday, 1971).

The regression results show that in all three years the active growing time and, in the field, the individual growth periods rank extremely high in total contribution

to yield. Thus, shortening one of the periods would allow more time for ripening and, as a result, increase kernel weight.

As mentioned in the literature review, the length of any growth stage up to heading can be affected by photoperiod or temperature. Also, there is evidence (Grafius and Thomas, 1971) of an oscillatory nature of the yield components produced by changes in the growth periods. If such is the case, it might be advisable to study the use of longer growth periods (produced by varying sequences of the original growth periods) in order to manipulate their lengths without worrying about the compensation and interaction shown between the smaller growth periods.

If manipulation of the longer periods is to be attempted, the previously discussed objectives of selection must be kept in mind. Almost all of these longer periods have extremely high correlations with total time from seeding to ripe, and so adjustment of any of these is bound to alter the time to maturity. However, one must keep in mind that because all the growth periods are a part of the total growing time, they will be involved in interactions among each other and the total time. Thus partial correlations are created that could produce a serious bias in the results.

The periods (A + B + C) and (B + C) show the greatest consistancy of behavior between the three years (Table XVI), and also, along with period (B + C + D), have the greatest heritabilities in 1974. The greatest variation in all three years is produced by period (B + C) followed by (A + B + C). However, the variability for these periods is much lower than that shown by the individual growth periods B and C. This is probably due to the effect of compensation between growth periods mentioned above. Correlations with yield are not as consistent as those produced by the separate growth periods with

significance for all three years shown only by period (B + C + D). Even so, some of the individual correlations with yield produced by the combinations may be slightly higher. Regression analysis showed that, for 1972, periods (B + C + D) and (A + B + C) do have a greater effect on yield than any of the individual periods. However, in the field years 1973 and 1974, the longer growth periods had very little influence on yield.

Since selection for earliness is at present generally done at the time of heading (period A + B + C), which is one of the longe iods selected, the only other choice of one of the growth periods would be (B + C), which includes the time from emergence to heading. This period showed the highest variability of all the combinations, had fairly stable behavior, and a high heritability. Also, its effect on yield would be the least of all the combinations.

However, the recommendation for selection of a growth period for manipulation would remain as the single period C. This individual period gives a greater variability to work with and fulfils the other selection requirements to a much better degree without adding the complicating factor of partial correlations (there is a small interaction between any single growth period and the total time as it is a part of the whole, but this involvement is a lot less complicated that that created by the longer periods).

ii. Selection of morphological characters

As results for the morphological characters varied among the three years, it is difficult to select a character from the material in this experiment that would consistently show a positive effect on yield. The only morphological characters that did show consistent positive associations with yield were height, head length, and number of plants per 1.2 meter sample. The regression equations showed that in the growthroom height made the most important contribution to yield, while in 1973 it was the number of heads

per 1.2 meter sample, followed by 1000 kernel weight, head length and height. In 1974 the most important influence on yield was produced by lodging, followed by height and head length. The highest amount of variability and also the highest heritabilities were produced by height and head length. Though these were the only two morphological characters that were compared in all three years, height showed high associations between the two field years but lower associations in comparing the growth-room to the field. Head length showed fairly consistent but not extremely close behavior among the three years, but appeared unrelated to yield in this experiment because of the large variation found in the density of seeds per head in the different genotypes. Therefore, in the present project the character that seems to be the most useful to manipulate to the advantage of yield is the height of the plant.

iii. Recommendations for future tests

As this project has been carried out, a number of questions have been raised that could affect the performance of future tests. One major problem encountered was the poor adaptability of the large diversity of material to the Alberta environment. Therefore, some unexpected problems were encountered. One of these was at the very beginning of the test when light and temperature regimes caused genetically diverse behavior in material that was supposed to have been homogeneous. As a result, each sample from 1972 was treated as a separate line for the remainder of the test. Therefore, if unfamiliar material is being used in future tests, it may be advisable to test for genetic purity at the very beginning.

Another problem created by the use of unadapted material was the susceptibility of many of the lines to severe lodging, thus influencing the results. Therefore,

one character that should exert a strong influence on selection locally would be lodging resistance. A problem is encountered here as there is a conflict between the aim of the project - to produce earlier maturing varieties - and the fact that lodging-resistant varieties also tend to be later maturing (Esechie et al., 1977). However, it was shown in the present project that the length of period C had the highest correlations with lodging (before heading). These correlations were higher than at any other stage, thus showing that more resistant varieties had earlier flowering and a longer ripening period. Therefore, a shortening of period C to achieve earliness would have the dual effect of increasing lodging resistance. Also, in this respect, a measurement of culm thickness (an indicator of straw strength) could be advantageous in future testing.

One other recommendation for future testing would be to study the habit (leaf and tiller spread) at heading time. Since this character at internode elongation showed a fairly high association with yield in 1973, it would be of interest to discover if it carried through to a later stage and remained constant throughout the stages. This character would have to be studied under greenhouse or growthroom conditions, because, in the present study, measurement at heading time was prevented by lodging in field conditions.

# CONCLUSIONS

The main objective of this project was to make a detailed study of the morphological growth stages of spring barley (Hordeum vulgare L.). This was done in order to discover if it would be possible to reduce the time taken to maturity without the attendant sacrifice in yield, a necessity in the relatively short growing season experienced in northern Alberta.

Early in the study it was discovered that the thirty-two lines selected showed signs of heterozygosity. Thus, the experiment was expanded to 144 lines from the thirty-two original families, in the process accommodating any heterogeneity present.

Factor analysis showed that the four major growth periods retained separate identities and each behaved relatively independently of the others, though some dependencies were discovered in the field between period B (emergence to internode elongation) and period C (internode elongation to heading). The growth period selected as best for manipulation in order to achieve earliness was period C, as it displayed the largest amount of genetic variability. This period was fairly stable in its behavior as evidenced by continuously high correlations among the three environments; it also showed a high heritability in 1974 and yet had a relatively low correlation with yield. Problems expected from the selection of this growth period would probably occur from its interrelationships with period B in the field.

Longer growth periods were derived from sequential combinations of the original four periods. Of all of these, the only one showing any signs of being acceptable for manipulation is period (B + C) which includes time from emergence to heading. Of all the combinations, this one shows the greatest consistency of behavior among the

three years and the highest heritabilities. It also shows the largest amount of variability, but this is much lower than that shown by either of the single growth periods B or C. In the long run, the selection of combinations of growth periods, whether sequential or not, did not prove very effective, as their major function in the analysis seemed to be clarification of the relationships among the growth periods in the factor analysis. Regression results did not include any of these combinations as major contributors to variation in yield, whereas the single growth periods were shown to be quite important in this respect.

Ford and Thorne (1975) have stated that grain yield is usually controlled by source and sink, but one or the other could predominate in a particular situation. This seems especially true in the present study, for of the morphological characters studied, consistent and high positive associations with yield were only experienced with the height. Head length followed with correlations that were considerably lower, though still significant. The regression results showed that in 1972 the greatest portion of yield variation was explained by height; in 1973 it was number of heads per sample and 1000 kernel weight; and in 1974 it was lodging and height. Head length was included in all three equations but showed less importance.

The results in both field years (especially 1974) seem to have been affected by lodging as the material, to a large extent, does not seem well adapted to local conditions. By recording detailed notes on the lodging of each line it became clear that the lodging behavior differed before and after heading, with the most severe effects on yield occurring at the time of heading.

Because the material was grown in both growthroom and field conditions, differences between the two environments were quite obvious. With a few major exceptions, genetic variability among the lines showed a decrease upon transfer to field conditions. This was confirmed by comparing the three years' data for each variable. Simple correlations showed low relationships between the growthroom and each of the field environments, and high associations between the two field years. Exceptions to this were provided by the growth periods B and C, and their combinations. Associations for yield between the growthroom and field were close to zero, while between the field years there was a higher relationship of $r = 0.46$.

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## APPENDIX I

### ORIGINS OF THE 32 FAMILIES SELECTED FOR THE STUDY

| Line # | Variety or Cross | Origin World Barley Collection | Original Seed Source | Name | Country of Origin |
|---|---|---|---|---|---|
| 1. | CI 6552 | USDA | Aberdeen Idaho | Vega | Sweden |
| 3. | CI 6943 | " | " | | Afghanistan |
| 4. | CI 7054 | " | " | Velvon 5 | Utah, USA |
| 5. | CI 7211 | " | " | Abyssinian 25 | Ethiopia |
| 6. | CI 7271 | " | " | | Iran |
| 7. | CI 7273 | " | " | | Ethiopia |
| 8. | CI 7852 | " | " | | Turkey |
| 9. | CI 7859 | " | " | | Turkey |
| 10. | CI 8108 | " | " | | Wisconsin, USA |
| 13. | CI 9784 | " | " | | Ethiopia |
| 14. | CI 9794 | " | " | | Ethiopia |
| 15. | CI 10268 | " | " | | Ethiopia |
| 18. | CI 10579 | " | " | | Canada |
| 19. | CI 10639 | " | " | | Canada |
| 26. | CI 10726 | " | " | | Iran |
| 27. | CI 10773 | " | " | | Japan |
| 29. | CI 10844 | " | " | Floya | Ethiopia |
| 30. | CI 11187 | " | " | Baladi 16 | Egypt |
| 31. | CI 11567 | " | " | Mulyan | Argentina |
| 32. | CI 11574 | " | " | Himlayense 3645 | Germany |
| 34. | CI 11624 | " | " | Ragusa 6-9 | Bulgaria |
| 38. | CI 12017 | " | " | Cyprus Black | Cyprus |
| 39. | CI 12262 | " | " | | Iran |
| 41. | CI 12393 | " | " | Szekacs Tak | Hungary |
| 44. | CI 12474 | " | " | Cenad 395 | Bulgaria |
| 46. | CI 13032 | " | " | | Ethiopia |
| 47. | CI 13085 | " | " | | Ethiopia |
| 49. | Olli | | Beaverlodge | | Canada |
| 51. | Galt | | " | | Canada |
| 52. | Jubliee | | " | | Canada |
| 53. | Vantage | | " | | Canada |
| 54. | Early Russian Fargo No. 0-765 | | " | | Russia |

# APPENDIX II

## CONTROL CULTIVARS USED IN 1973 AND 1974

| | 1973 | 1974 | |
|---|---|---|---|
| 1. | Olli | Olli | |
| 2. | Galt | Galt | |
| 3. | Gateway-63 | Gateway-63 | |
| 4. | Windsor | Windsor | |
| 5. | Bonanza | Bonanza | |
| 6. | Conquest | Conquest | |
| 7. | Paragon | Paragon | |
| 8. | Jubilee | Jubilee | |
| 9. | | Hiproly | |
| 10. | | Steptoe | |
| 11. | | H35-5047 | (Conquest x M65-94) |
| 12. | | H12-5070 | (Olli x M64-69) |
| 13. | | H12-5072 | ( " " ) |
| 14. | | H12-5296 | ( " " ) |
| 15. | | H12-5342 | ( " " ) |

N. B. Entries 11-15 are short strawed cultivars derived from the University of Alberta breeding program, using short straw sources obtained from Dr. D. Rasmussen, Minnesota.

## APPENDIX III

## COMPARISON OF SCALES FOR MEASURING THE GROWTH STAGES OF CEREALS

| Zadoks Scale* | | Feekes Scale | Present Study |
|---|---|---|---|
| 00 | dry seed | | Seeding |
| 09 | Leaf at coleoptile tip | | Period A |
| 10 | First leaf through coleoptile | 1 | Emergence |
| 19 | 9 or more leaves unfolded | Seedling Growth | |
| 20 | Main Shoot only | | Period B |
| 29 | Main Shoot and 9 or more tillers | Tillering 2, 3 | |
| 30 | Pseudo stem erection | 4-5 | |
| 39 | Flag leaf ligule just visible | Stem Elongation 9 | Internode Elongation (First node detectable) |
| 40 | | | |
| 49 | First awns visible | Booting 10 | Period C |
| 50 | First spikelet of inflorescence just visible | 10.1 | |
| 59 | Emergence of inflorescence completed | 10.5 | Heading (50% of head is visible) |
| 60 | Beginning of anthesis | 10.51 | |
| 69 | Anthesis complete | | |
| 70 | Early milk | Milk development 11.1 (Early milk | Period D |
| 79 | Late milk | | |
| 80 | Early dough | | |
| 89 | Hard dough | 11.2 | Ripe (hard dough) |

* J. C. Zadoks, 1975. A Decimal Code for the Growth Stages of Cereals. Barley Research Notes; September, 1975

** W. Feekes, 1941. De Tarwe en haar milieu. Uerslagen Technische Tarwe Commissie, 17: 560-561