

THE UNIVERSITY OF MANITOBA

GROWTH CHARACTERISTICS OF SIX WHEAT CULTIVARS
UNDER NORMAL AND SPACED PLANTING

by

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A dissertation submitted to the Faculty of Graduate Studies of
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ABSTRACT

The objective of this study was to compare the growth characteristics of a group of adapted wheat cultivars having different yield potential under normal field conditions and under spaced plant conditions.

Measurements in normal density may reveal the causes of yield differences, assisting the breeders in selecting parents or parental combinations. Measurements under spaced conditions may permit the identification of correlations that could assist in selection procedures in F_2 single plant nurseries.

Two completely randomized block designs of six wheat (*Triticum aestivum* L.) cultivars were conducted, one under normal density, the other in spaced plant condition. Measurements of grain yield, dry matter, harvest index, relative growth rate, leaf area index, leaf area duration, net assimilation rate, crop growth rate, tiller number and kernel weight were taken.

The cultivars differed in grain yield, harvest index, leaf area duration, grain/leaf area ratio, number of tillers and kernel weight.

The variation in leaf area duration after ear emergence accounted for 79% of the variation in grain yield.

No correlation was found between grain yield in spaced plant and yield under normal density. The same occurred between dry matter and leaf area per plant in spaced condition and the corresponding values in normal density.

The harvest index of spaced plants was significantly correlated with grain yield in normal density.

The number of tillers per plant in spaced condition was correlated with the maximum number of tillers produced in the season in normal density but not with the final number of heads per square meter.

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1. INTRODUCTION

A knowledge of the characters underlying differences in yield between cultivars can be important to plant breeders when selecting parents and parental combinations. Such information may also be useful in construction selection indices or in breeding according to ideotype models.

Selection for grain yield in wheat, as in most of the other crops, has been empirical. If we ask why a new variety with the same maturity and degree of disease resistance as an old one yields more, usually there is no clear answer (Donald, 1963). Perhaps it yields more because it has more heads, a greater number of grains per head, or larger seeds, which is the same as saying that it yields more. We select the high yielding lines in segregating populations, but we do not breed for it in a very precise manner. We usually "cross the best with the best and hope for the best". The same idea was stated by Shebeski (1967) when he said that: "all F_2 plants retained by the breeder irrespective of the basis for selection are random for yield".

The problem is not new. As early as 1923 Engledow and Wadham (quoted by: Syme, J. R., 1972; Hsu, P. and P. D. Walton, 1970; Lupton, F. G. H. *et al.*, 1967) stressed the need for plant breeders to make detailed studies of growing crops and to apply the knowledge so gained to selection within hybrid populations.

Subsequent workers considered such morphological characters as ear number, number of grains per ear, and 1000 grain weight. These characters must be considered as manifestations of yield rather than

as the physiological basis of yield (Lupton *et al.*, 1967).

In more recent years several workers have undertaken analysis of growth, making comparative studies between high and low yielding cultivars. The first important review of the topic was made by Watson (1952). Later, Thorne (1966) reviewed the physiological aspects of grain yield in cereals and, in 1972, Wallace and coworkers reviewed the physiological genetics of crop yield.

Many workers have proposed selection for morphophysiological characters (Yap, T. C. *et al.*, 1972; Stoskopf and Reinbergs, 1966; Jennings, P. R., 1964) alone or in combination or their incorporation into selection indices. Donald (1968a, b) proposed the breeding of crop ideotypes, i.e. plant models with characteristics known to influence photosynthesis, growth and grain production. The practical application of this approach has not been very extensive. The success of the I.R.R.I. in the Philippines in the release of the IR8 rice cultivar is one indication of its application (Wallace *et al.*, 1972).

The objective of this study was to compare the growth characteristics of a group of adapted wheat cultivars having different yield potential. Measurements under normal field conditions may reveal the cause of the yield differences and measurements made under spaced condition may permit a correlation to be identified that could assist in selection procedures.

2. LITERATURE REVIEW

2.1 Selection for Yield Under Spaced Plant Conditions

The traditional methods of breeding in self-pollinated crops are based on the production of genetic variability through artificial crosses and selection in the segregating populations.

As far as characters of high heritability are concerned (like disease resistance, height, maturity, etc.) this selection has been successful. This is an indirect way of breeding for yield because these characters permit the manifestation of the genotypic potentiality for grain production; but for yield itself the results are not so clear. In general, the selection for yield in single plants has been ineffective in producing high yielding lines in later generations.

Palmer (1952) working with a wheat cross between parents that differed significantly for three yield components, selected the 75 highest yielding plants in F_2 and F_8 populations. The progenies were sown in a two row plot with two replications and the data for yield and yield components recorded. The selection for grain yield per plant failed to be expressed in the yield per plot in the succeeding generation, or in any of the components of yield.

Frey (1962) made "good", random, and "poor" selections in the F_2 of two oat crosses grown as spaced plants. The "good" selections were vigorous, had many large panicles, and in general, were phenotypically desirable. The seed of each plant was increased in F_3 and yield tested in F_4 . In one of the crosses the mean yields of the three categories were equal and in the other the "poor" selections yielded lower than

the random or "good" in one year out of two. He repeated the selection procedure on F_5 spaced plants and again all categories yielded the same.

Working with barley, Atkins (1966), in a F_3 spaced nursery made 25 "good", 25 "poor" and 25 random selections. The "good" selections were vigorous, with many tillers and large seeds. He tested the derived lines for grain yield under field conditions for three years. The mean yield was highest for the "good" group, but the mean differences between groups were very small, and the relative ranking of the three groups changed with years. The variability for grain yield was greatest within the random group.

McGinnis and Shebeski (1968) compared F_3 lines from selected and randomly sampled F_2 plants from a spaced nursery. Three different breeders were successful in visually selecting for high yielding F_2 plants but the correlations between F_2 plant yield and F_3 plot yield were not significant.

Knott (1972) tried to reduce environmental variability in order to increase the heritability of yield in a F_2 spaced plant nursery of eight wheat crosses, by choosing a uniform block of land and having a uniform distance between plants. The F_3 lines from selected and unselected F_2 plants were yield tested. Although selection had a statistically significant effect, the effect was not large enough to be of practical value in wheat breeding.

We can conclude that there is little relationship between the yield of spaced plants and the yield in subsequent generations under normal density. A possible explanation for this is that grain yield has low heritability, as has been shown in many cases (Fonseca *et al.*, 1968; McNeal, 1960; Knott, 1972). It is also possible that the characters

that enhance grain yield of a spaced plant are not necessarily the same that enhance grain yield under normal field density. On this point, Syme (1972) has interesting results: studying single-plant characters as a measure of field plot performance of 49 cultivars of the Fifth International Spring Wheat Yield Nursery he found that the single plant grain yield of the cultivars was not significantly correlated with the mean plot yield. We shall return to this point.

2.2 The Components of Yield

The complexity of grain yield as a character for selection induced its subdivision into components, namely: number of heads per unit area, number of grains per head and 1000 grain weight.

Woodworth (1931) was one of the first to advocate the use of yield components in breeding programs. He reported positive correlations between the components and yield in wheat and other crops, and the lack of significant correlations among the components themselves. Although he realized that the data was inadequate, he proposed as a breeding method the measurement of yield components in parental lines and the use of specific crosses to combine the yield components.

Grafius (1956) also suggested the possibility of working with yield components. He represented yield as the volume of a rectangular parallelepiped whose three dimensions are determined by the three components of yield. He postulated that it should be easy to increase the volume (yield), by increasing the shortest dimension of the parallelepiped.

There are many reports that the components of yield are positively correlated with yield. However, the results of correlation studies

among the components themselves are variable.

Palmer (1952) working with wheat found a negative correlation between the seed weight and seed number per plant.

Fonseca *et al.* (1968) in a study of a seven-parent dialled cross between winter wheat cultivars found that the three components of yield were highly correlated with grain yield, but that any progress in breeding by selection for components of yield, rather than yield *per se*, may be limited by the strong negative correlation between number of spikes and number of kernels per spike. In other words, as plants develop additional spikes, these spikes are progressively smaller. The negative correlations between kernel weight and number of spikes, and kernel weight and number of kernels per head were smaller but still significant. An important consideration of the authors is whether these relationships are genetic or simply result from limitations of the total physiological capacity of the plants.

Stoskopf and Reinbergs (1966) studied the relationships between the components and grain yield of oats and barley under Ontario conditions. They found a negative correlation between tillers per plant and grain number per head.

Chaudhry *et al.* (1970) working with wheat found negative correlations between the number of grains per ear and the number of tillers per plant.

The results from a five-parent diallel cross greenhouse study by Hsu *et al.* (1970) indicated that wheat grain yield was correlated with the number of ears per plant and the number of grains per ear. Among the yield components there was a negative correlation between kernel number per ear and kernel weight and a positive correlation between ear

number and kernel number per ear.

Hsu and Walton (1971) studied a diallel set of crosses between five spring wheat cultivars and found that the simple correlations between yield per plant and the three primary components were positive and consistent in the greenhouse and field; but between the components there was a negative correlation between ear number and kernel weight.

A study of the correlations between yield and yield components in wheat was made by Singh *et al.* (1970). The 20 cultivars used showed a significant positive correlation between grain yield and its components. Again, tiller number and 1000-grain weight were negatively correlated.

Nass (1973) in a two-year study with 22 cultivars of spring wheat found that: kernel weight and yield per ear were associated; kernel weight was not associated with ears per plant; and yield per ear and ears per plant were negatively associated.

Adams (1967), who found negative correlations between the yield components in field beans (*Phaseolus vulgaris*), stated that these negative correlations are widespread among major crop plants. As examples he cited: Williams (1959) who found a negative correlation between fruit number per plant and fruit weight in tomatoes; Leng (1963), with data from a large number of lines and hybrids, indicated a predominance of negative correlations among yield components in corn; Hatfield *et al.* (1965) arrived at the same conclusion also with corn.

According to Adams a genotypic correlation may derive from genetic linkage, from pleiotropy, or from developmental relationships between components that are only indirectly the consequence of gene action. In beans, the components of yield are believed to be genetically independent. This conclusion is based on the observation that in spaced

plant nurseries and in other noncompetitive or nonstress situations the component correlations are generally near zero.

An example of what is implied in such developmentally induced relationships occurs when two developing structures of a plant compete for a common, possibly limited, nutrient supply. If one structure is favored over the other in the amount of nutrient received, a negative correlation may arise between them. McAlester and Krober (quoted by Adams, 1967) showed a marked response in seed weight in soybeans, offsetting artificial removal of pods. Seed yield was affected only slightly by a drastic reduction in pod number.

Rasmusson and Cannell (1970) presented results from a selection experiment in barley in which the selection criteria were yield and its morphological components among F_4 families. Selection for number of heads yielded results similar to those observed when selection was for yield itself. The selection for kernel weight was highly effective in altering yield in one of the two populations. The yield was reduced in one population when selection was practiced for number of kernels per head. The authors explained this negative response by genetic linkage. The genotypes of the parental cultivars and the response to selection in this population provided the basis for this conclusion. The parental combination of characters remained together, suggesting that the genes which condition the component phenotypes are linked.

Adams and Grafius (1971) gave another interpretation to this negative response based on an oscillatory response of components due to the sequential nature of component development and a limitation of environmental resources.

From a practical plant breeding point of view the two interpretations

have different consequences. In one case the objective is to break the unfavorable linkages and to identify the superior recombinations. In the other it is necessary to put emphasis on increasing the flow of environmental resources throughout the period of need by the components.

Palmer (1952) working with wheat found that the selection for mean weight of the individual grain in single plants was effective, but, like number of grains per plant and grain weight were negatively correlated, this selection was not useful in increasing yield.

According to Bhatt (1972) the inheritance of kernel weight is not complex. He found a tetragenic control in two crosses of spring wheat. His results agree with those of Sharma and Knott (1964).

Sun *et al.* (1972) found a large amount of additive genetic variance for kernel weight, reflected in high heritability in six spring wheat crosses. This indicates that substantial progress can be made using standard selection schemes in the development of pure lines of desired kernel weight. Fonseca *et al.* (1968) also found high heritability for kernel weight.

Knott and Talukdar (1971) transferred high seed weight from the spring wheat cultivar "Selkirk" to "Thatcher" by backcrossing. On the average, the backcross lines with high seed weight outyielded Thatcher, even though the number of seeds produced declined. This data agree with Adams' (1967) conclusion that yield tends to be stabilized by compensation among yield components. However, on this occasion the compensation was not complete.

Summarizing the literature it is apparent that the components of yield are in most cases highly correlated with yield. However, in many cases there is a negative correlation between component and when this

happens the selection for yield through the components is ineffective.

Adams (1967), and later Adams and Grafius (1971) developed the compensation theory. The components of yield are formed in a sequence. First the number of heads is determined, later the number of grains per head and finally the weight of the grain. These developing structures may compete for any supply, and if one component is favored, the others will be depressed.

Murata (1969) divided the process of yield-formation into the following three phases:

- a. Formation of organs for nutrient absorption and photosynthesis.
- b. Formation of flower organs and "yield-containers", and
- c. Production, accumulation and translocation of "yield-contents".

If the "yield-contents" that a canopy can produce and effectively translocate are in excess of the "yield-container" capacity (i.e. the yield components) the selection for yield components can be effective. But, when the yield limitation is the capacity of the canopy to produce and translocate "yield-contents", selection through the components will be ineffective. It is here that negative correlations occur, because the "yield-contents" are limited and the components compete for their use.

Differences between species occur in this regard. For instance, according to Matsushima (quoted by Murata, 1969) an upper limit of kernel growth is imposed in rice by the size of the hulls which is determined one week before heading. Thus, it is very likely that the capacity of the "containers" may be a limiting factor in rice. In

wheat this is not the case. Thorne (1966) found in some cultivars yearly deviations as high as 50% in 1000-grain weight. This means that the last developing component is a very plastic structure. This reduces the possibility that the yield container may be an important limiting factor in wheat.

A point related to the analysis of yield components that we very often forget is that our objective is the yield per unit of land and not the yield per plant. The wheat plant, in a normal density of sowing, is under very high competitive stress (Donald, 1963). Its yield is only a small fraction of that possible under spaced conditions. The plant that produces well in this extreme situation is the one we wish to select.

In this competitive stress there is competition for water, nutrients and light, not only between plants, but between tillers of the same plant and flowers of the same head. For instance, Bingham (1967) has found that the percentage of tillers that survived to form ears in three winter wheat cultivars is only 27.4% with low N and 31.5% with high N of the total number produced. This means that the limitation is not the genetic capacity of the plant to produce tillers but their survival under this competitive situation.

2.3 Growth Analysis

Simultaneously with the study of the effectiveness of breeding for yield through its components, there have been attempts to explain yield in terms of plant growth and development.

Yield depends ultimately on photosynthesis or on the balance between photosynthesis and respiration. The size of the photosynthetic

apparatus, its efficiency and the capacity to translocate the photosynthetic products to the economic parts are important.

The parameters normally estimated in growth analysis are: net assimilation rate (NAR), leaf area index (LAI), relative growth rate (RGR), harvest index (HI), and complementary to these are, leaf area ratio (LAR), leaf area duration (LAD) and crop growth rate (CGR). (See Watson, 1952; Wallace *et al.* 1972; and for mathematical assumptions Radford, 1967.)

As Wallace *et al.* (1972) pointed out growth analysis usually ignores the weight and the role of the root system, since this information is very difficult to obtain. But the root system is an important component of yield and there are differences between cultivars. For instance, Hurd (1968) showed that there are not only differences in the weight of the root systems among wheat cultivars, but that root growth patterns are different and also that roots respond in different ways to moisture stress. Lupton and Bingham (cited by Wallace *et al.*, 1972) also found that the roots of the high-yielding semidwarf winter wheats are heavier, longer and extend to greater soil depths than roots of other cultivars

2.3.1 The net assimilation rate

In growth analysis, the mean dry weight of the plants and the mean leaf areas are obtained at the beginning and at the end of a period of plant growth. With these two basic measures all the growth parameters are calculated.

The net assimilation rate (NAR) is the dry weight accumulated per unit of leaf area per unit of time. The NAR is not a pure measure of

photosynthesis; it reflects the excess of dry matter (DM) gained by photosynthesis over the loss by respiration (Watson, 1952). It only takes into account the top part of the plant and ignores the increase in DM that occurs in the root system. NAR is only an approximate measure of net photosynthesis because it includes the weight gain due to mineral uptake, and not only the CO_2 fixation (Bettery and Buzzel, 1971).

The NAR is conventionally expressed on the basis of leaf area, but photosynthesis also occurs in other parts of the plant, such as the stems, sheaths and ears. When we estimate NAR on the basis of leaf area we are overestimating the efficiency of the laminae in producing DM, and if there are differences among cultivars in the relation of leaf area to sheath area, we are misinterpreting any relative comparison.

From a plant breeding point of view relative differences between cultivars in NAR are of interest, whereas seasonal and environmental influences on NAR are of lesser value.

Nevertheless, the relative variation of NAR and LAI (leaf area index) can be important. Since NAR changes very little with the age of the plant (McKey, 1966) but has a marked seasonal variation, it is important that high NAR coincide with a high LAI to get the maximum productivity.

Watson (1947), in a study of the differences in NAR between crops, found that the cereals have lower values than the root crops (sugar beet and potatoes) and that among cereals, wheat has a lower value than barley. Comparing three wheat cultivars (Square head's Master,

Yeoman, and Victor) during two years, he found no differences in NAR.

In later work, Watson *et al.* (1958) found no significant differences in NAR between barley cultivars. It is worthwhile to point out that in this case their values were smaller than in other reports because they included leaf sheath area which practically doubles the LAI values.

In an experiment designed to illustrate differences in photosynthetic activity between wheat cultivars, Lupton (1961) estimated the differences in NAR during six intervals prior to ear emergence. The photosynthetic area measured to calculate NAR included leaves, leaf sheaths and stems. He found significant differences between cultivars.

Buttery and Buzzel (1972) working with soybeans observed significant differences ($P < 0.05$) in NAR among cultivars in two out of five tests (each test included at least 21 cultivars). Phenotypically, NAR was inversely correlated with LAR (leaf area ratio) and positively correlated with SLW (specific leaf weight). The heritability of NAR was 54%. They found that selection for yield and other agronomic characteristics had resulted in an increase in NAR and SLW, coupled with a decrease in LAR, L (leaf area per plant), W (plant dry weight) and S/R (shoot/root ratio) but with no obvious effects on RGR or RLGR (relative leaf growth rate). These cultivars had been selected in breeding programs at eight locations in U.S.A. and Canada during the past 30 years.

So far, very few consistent differences in NAR within species have been reported. A possible explanation for this may be the difficulty in estimating NAR, particularly as it relates to the true and total

photosynthetic area of the crop.

2.3.2 The leaf area index and the leaf area duration

Because the agricultural yield is usually measured in terms of weight of crop per unit area and not per plant it is appropriate to express the leaf area of a crop on the same basis. Watson (1947) introduced the term leaf area index (LAI) for this measure of leaf area.

Because many of the first studies failed to show differences in NAR, and since DM yield is a function of leaf area and NAR, differences in total DM have frequently been related to differences in leaf area.

The persistence of leaf area in time is as important as mean magnitude of leaf area in total DM production. The leaf area duration (LAD) of a crop is a measure of its ability to produce and retain leaf area throughout its life (Watson, 1952).

The mean yield of dry matter for wheat and other crops grown over several seasons at Rothamsted were found to be approximately proportional to their mean LAD (Watson, 1947).

From the point of view of grain yield the leaf area duration after ear emergence is one of the growth parameters that frequently has been found correlated with yield.

Most of the carbohydrate in the grain comes from photosynthesis after ear emergence (see Thorne, 1966 for review of the topic). Some carbohydrate is accumulated in the stems and leaf sheaths, and later translocated to the grain but this source makes only a small contribution to DM accumulation in the grain (Murata, 1969; Thorne, 1966).

Thorne and Watson (1955) studied the effect of N on yield and leaf

area of wheat and found that the principal effect of N (applied early or late) was an increase in leaf area duration after ear emergence and increased yield.

Fisher and Kohn (1966) varied the time of sowing and the amount of fertilizer applied in order to study the relationship of grain yield with vegetative growth and post-flowering leaf area in wheat. They found a positive correlation between grain dry weight and LAD after flowering for all treatments.

Welbank, French and Witts (1966) testing three wheat cultivars with two nitrogen levels (63 and 126 kg/ha), found that the grain yield was nearly proportional to the leaf area duration during grain development.

In a study of the effect of N on LAI, LAD, NAR and grain yield of wheat, Khalifa (1973) found that the variations in grain yield were mainly a function of the effects of the treatments on LAD after ear emergence.

Not all the photosynthetic area after ear emergence has the same importance in producing carbohydrates. The relative contribution of the different parts of the shoot probably depends on the nutrition of the plant, the environment and the cultivar (Thorne, 1966). Leaves, sheaths and stems below the flag leaf node usually contributes little, probably about 15% of the final grain weight (see Thorne, 1966, for a review of this topic).

In this regard, Spiertz *et al.* (1971) found that a greater part of the variance in grain yield could be explained from the combined LAD value of the flaf leaf and the peduncule, and they got an improvement

in the correlation if they included the LAD value of the ears.

Welbank *et al.* (1966) also found that variations in the LAD above the flag leaf node explained the differences between treatments in a wheat trial better than the LAD of all the green parts.

In a study of the relationship between photosynthetic area and grain yield per plant in wheat Voldeng and Simpson (1967) carried out shading treatments on high- and low-yielding lines. Their results indicated that the ear and the flag leaf contributed the major share to grain dry weight.

Hsu and Walton (1971) studied the relationship between yield and the morphological structure above the flag leaf node. Working with a complete diallel set of crosses between five wheat cultivars they found that ear length and flag leaf breadth influenced yield and its components significantly.

Jennings and Shibles (1968) studies the genotypic differences in photosynthetic contribution of plant parts to grain yield in oats. They used two cultivars and the contribution of the different parts was estimated by shading and removal techniques. The results (presented in Table 1) show the contribution to grain yield from the different parts and also the differences between cultivars. The cv. A-475 possessed about 50% more photosynthetic area in the panicle than cv. Goodfield. The great differences in photosynthetic efficiency of tissues below the flag leaf blade may be associated with the differences in leaf disposition: the more erectophile leaf canopy of Goodfield allowing better light penetration.

Both genotypes showed that the contribution per unit of tissue area of the panicles is greater than the other tissues. The authors

suggested several reasons for this:

1. Panicles receive higher light intensity over a longer period of the day,
2. are closer to the storage site,
3. persist in activity over a longer period.

We can draw two important conclusions from this work: first, that the contribution of the different parts of the plant to grain yield estimated on single plants can not be generalized to field conditions, and secondly, differences between cultivars are possibly associated with differences in the structure of the canopy.

Table 1. (After Jennings and Shibles, 1968)

| | <u>Contribution to grain yield</u> | |
|--------------------------|------------------------------------|-------------------------------|
| | <u>Cultivar A-465</u> | <u>Cultivar Goodfield</u> |
| Panicle | 63% | 38% |
| Leaf sheath and stems | 15% | 26% |
| Flag leaf blade | 18% | 10% |
| Other leaves | 4% | 26% |

It is not only the size of the photosynthetic apparatus after ear emergence that is important for grain yield but also its efficiency in producing dry matter and in translocating it to the grain.

Watson, Thorne and French (1963) proposed the use of the ratio of grain dry weight to LAD after ear emergence (grain-leaf ratio = G) as a measure of efficiency. They did not find differences in G between

winter and spring cultivars, but found greater values for new relative to old cultivars.

Thorne, Welbank and Blackwood (1969) compared the growth and yield of six dwarf Mexican cultivars with two tall European cultivars. The semidwarf cultivars had yields equal to or slightly below the taller European cultivars, but the grain-leaf ratio, G , of the shortest cultivars was 50% greater.

2.3.3 Relative growth rate and leaf area ratio

The relative growth rate (RGE) is the dry matter accumulated per unit of plant dry weight per unit of time. From a physiological point of view the RGR is a function of the leaf area ratio and NAR ($RGE = LAR \times NAR$). Leaf area ratio (LAR) is the leaf area per unit of plant dry weight.

Absolute differences in LAR between cultivars (Wallace *et al.* 1972) were almost constant throughout growth, and the LAR of all the cultivars declined steadily with time.

Wallace and Munger (1965) studied the physiological basis for yield differences between several dry bean (*Phaseolus vulgaris*) cultivars. Within two types of beans the higher yielding cultivar had both the larger leaf area and the larger leaf area ratio.

2.3.4 Harvest index

The harvest index (HI) is the relation between the economic yield and the total plant dry weight expressed as a per cent. The HI represents the physiological capacity (often termed sink power or sink capacity) to mobilize photosynthate and to translocate it to organs

having economic values (Wallace *et al.*, 1972).

Vogel, Allan and Peterson (1963) found that new semidwarf wheat selections (at two N levels) had a straw-grain ratio from 1.5 to 1.7, in comparison with the commonly grown tall cultivars Brevor and Omar, with values ranging from 1.9 to 2.3, and for the oldest cultivars the values ranged from 2.4 to 3.0.

Working with eleven dry bean cultivars, Wallace and Munger (1966) found that the HI varied from 53% to 67%, and that the correlation between HI and grain yield was not good.

Van Dobben (quoted by Wallace and Munger, 1966) compared five wheat cultivars, each of which was a leading variety for some part of the period beginning in 1902 and ending in 1955. The prominent cultivar of 1902 had a grain-straw of 0.51 whereas the leading variety of 1955 had a grain-straw ratio of 0.66.

In a study of a number of selections from the wheat breeding program at the University of Guelph, Sing and Stoskopf (1971) reported a considerable variation in HI. The average value for winter wheat was 39%, with a range from 28 to 46%. The dwarf selections of winter wheat had higher values than the taller selections or the check cultivars "Genesee" and "Talbot". The HI was positively correlated with grain yield.

Syme (1970) compared WW15, a new Australian semidwarf selection, with other Mexican and Australian cultivars. He found a high positive correlation between grain yield and HI.

Single plant characters were used as a measure of field plot performance by Syme (1972). He used the mean field plot yield of 49

cultivars (see p. 6) as the dependent variable and characters measured on single plants grown in a glass house as the independent variables. In a stepwise regression analysis with 16 single plant characters, the HI (of single plants) accounted for 71.7% of the variability in the mean field plot yield of the 5th International Spring Wheat Yield Nursery.

2.4 Plant and Canopy Morphology

The plant morphology, the basic element of the canopy structure, can affect photosynthesis, principally through light interception and utilization, and hence productivity.

NAR, CGR, LAD and other growth analysis parameters can be influenced by plant morphology, and from a practical plant breeding point of view it is, obviously, easier to select for a "plant type" than for these other measurements.

Jennings (1964) was one of the first to discuss plant type as a breeding objective. On the basis of comparisons between high and low-yielding rice cultivars he proposed a desirable plant type: short, narrow, erect, thickened leaves; short and sturdy culms and short and dense panicles.

Later MacKey (1966), Tanner *et al.* (1966) and Donald (1968a, b) advocated the selection of morphological characters that enhance yield.

Donald (1968a, b) introduced the term "ideotype" for the conceptual model of any crop plant and he described in detail the wheat ideotype.

Later several workers studied the correlation and inheritance of many of these morphological characteristics, particularly the parts of the plant above the flag leaf node (Yap and Harvey, 1972; Walton, 1971a, b

and 1972; Saghir *et al.*, 1968; Nass, 1973; Hsu and Walton, 1970, 1971; Chang and Tagumpay, 1970).

In the following sections the morphological characteristics of the wheat crop plant that have been more commonly discussed in breeding work are reviewed.

2.4.1 Height

The advantage of a short stem in reducing lodging is well established. Vogel *et al.* (1963) advocated the use of semidwarf wheat to avoid lodging and facilitate the application of high amounts of fertilizer, particularly nitrogen to irrigated wheat. The spread of the Mexican semidwarf type cultivars throughout the world is an indication of the success of this practice under dryland conditions as well.

The direct effect on yield of reducing the height is not so well known. Casidy (1965) used the frequent reverse mutation of one of the four genes for height in sorghum to establish isogenic lines. In three cultivars with the four dwarf genes, the effects of Dw3 (tallness) was to increase the yield, the number of heads per plant, the kernel weight and the test weight.

McNeal *et al.* (1972) reported on the agronomic response of short, medium and tall wheat genotypes in different environments. They compared three plant height classes within the cultivar Centana. Each height class (61 cm, 76 cm and 91 cm respectively) was a composite of 4 selected lines from a bulk population created by the fifth backcross of the cross: Norin 10/Brevor, 14/6 Centana to Centana. The tests were conducted at 22 locations the first year and at 17 the second. The medium height always had the highest yield, with only one exception.

The short lines were always lower in yield, suggesting that there is a point beyond which plant height cannot be reduced without losing yield.

A possible explanation for this (Donald, 1968) is that reduction in height is a reduction in the vertical interval between successive leaves, and on an extremely short stem may induce shading of all but the top leaves.

The stems are also photosynthetic organs, and particularly the peduncule, remain green till near maturity.

2.4.2 Leaf inclination and leaf size

The leaves are the most important structures of canopy morphology. Watson and Wits (1959) found that although the NAR of wild and cultivated sugar beets was similar, the cultivated beets produced much more dry matter at high LAI than the wild ones. They attributed this difference to leaf orientation.

In a comparison between 3 high and 3 low-yielding barley cultivars, Tanner and Gardener (1965) found that the high yielding lines had narrow upright leaves while the low yielding ones had wide, drooping leaves. According to the authors the narrow, upright leaves permit light to penetrate further down into the leaf canopy thus exposing a greater leaf area to direct sunlight. This increase in photosynthetic surface is reflected in a greater maximum rate of DM accumulation in the higher yielding cultivars (292 lb/day compared with 243 lb/day for the low-yielding cultivar per acre).

Tanner *et al.* (1966) ranked the material in the wheat, oat, and barley nurseries at the Ontario Agricultural College, at Guelph, for

yield using only the characteristics leaf angle and leaf width. Approximately 300 cultivars and strains were evaluated as high, medium or low yielders. In this way, they properly categorized all but two of the 50 highest yielding strains.

Pearce, Brown and Blaser (1967) studied the effect on photosynthesis of leaf angle. Flats of barley were seeded at 3 different rates and tilted at 0° , 30° , and 60° from the horizontal. When the first leaf had developed the flats were returned to horizontal for measurements of photosynthesis, light penetration and LAI. The differences in leaf angle produced differences in net photosynthesis (Pn) and these differences increased as LAI increased. The vertical leaves had a higher Pn and allowed more light to penetrate at high LAI than horizontal leaves.

A backcross-derived isogenic single cross corn hybrid carrying the Lg2 gene for erect leaf produced 40% more grain than its counterpart with normal (horizontal) leaves. Pendleton *et al.* (1968) also found that tying the leaves of a commercial corn hybrid to support them in a more vertical position produced an increased yield.

Duncan (1971) studied the effect of leaf angle on photosynthesis using computer simulation. His results indicated that if the plant canopy has a LAI below 3.0, leaf angle has little practical significance, but if the LAI is 5.0 or more, the leaf angle may be quite meaningful.

Russell (1972) compared single cross diallels of 5 erect-leaf (liguled) and 5 horizontal leaf maize inbred lines at two row widths and three stand densities. The linear yield response of the two hybrid groups to increased stand density were different ($P < 0.01$): the linear

regression coefficients were 0.35 and 2.70 for the erect-leaf and horizontal-leaf groups respectively. The author suggested that with the germ plasm presently available a breeder should not restrict his selection to plant types that have a distinctly erect-leaf orientation. He did not estimate LAI, but concluded that the values are below 7.0, even at the highest density.

The attenuation of light in a canopy apparently follow the Bouguer-Lambert law:

$$I = I_0 e^{-kl}$$

where I and I_0 refer to the illumination on a horizontal surface within and above the canopy respectively; k is the extinction coefficient, and l is the leaf area index from the top of the canopy. Variations in k have been related to variations in canopy structure, especially leaf angle (Loomis and Williams, 1969).

Loomis, Williams and Duncan (1967) cited as an example the work of Hayashi and Ito, who compared light distribution characteristics of 14 rice cultivars. " k " for the cultivars varied from 0.46 to 0.77, and was negatively correlated ($r = -0.72$) with leaf angle and leaf thickness (in rice, thick leaves tend to be narrow) and positively with plant height (tall plants have lax leaves).

Apparently small leaves are advantageous in communities under high illumination because they permit a better distribution of the light (Donald, 1968).

2.4.3 The ear

Very little is known about the relationship between grain yield and the capacity of the ear to accumulate carbohydrate in wheat.

According to Thorne (1966) there is evidence from other species that the size of the sink affects the production and movement of carbohydrates.

The demand of the ear for carbohydrates can affect how much moves to them: it can be increased by shading the ear or decreased by removing some spikelets from the ears (Thorne, 1966).

According to Grundbacher (1963) the cereal spike is a site of photosynthesis which contributes about 30% of the carbohydrate accumulated in the grain. The variation in this aspect can be great, not only between cultivars but also from season to season, plus the variations due to the techniques used in the estimations (Lupton *et al.*, 1966).

Thorne (1966), Grundbacher (1963) and Donald (1968) reviewed most of the work relative to the contribution of the ear to grain yield and concluded that a large ear is not only important from the point of view of the photosynthetic contribution but also for the sink capacity. Many florets is also a basic requisite for yield since the yield "containers" can be a limiting factor.

The importance of the awn is well known. Grundbacher (1963) reviewed the physiological function of the cereal awn. Later workers confirmed the positive contribution of this organ to grain yield.

Derera and Stoy (1973) found that cultivars differed in the amount of C^{14} assimilated in the awns. These differences were strongly associated with the length, thickness and weight of awns. The morphological characteristics of the awn indicated significant genotypic differences and it seems they can be used as selection criteria. Furthermore, efficient awns should also complete their growth shortly after anthesis, and at the same time, remain effective during late ontogenesis.

McKenzie (1972) did not find a positive contribution of the awns to grain yield. He reciprocally backcrossed Thatcher (an awned cv) and Lee (awned). The presence of awns decreased the yield. The author's explanation is the possible presence of deleterious linkages.

3. MATERIALS AND METHODS

Six wheat cultivars were used in this study: Selkirk, Manitou, Glenlea, Era, Pitic 62 and Yecora 70.

Selkirk is a hard, red, spring cultivar, released in 1953 by the Laboratory of Cereal Breeding, Agriculture Canada, Winnipeg. Its principal feature is its resistance to race 15 B of stem rust (Cereal News, 1953).

Manitou is also a hard, red, spring wheat. It is a Thatcher back-cross, with Kenya Farmer, PI 170925 (a red Egyptian type) and Frontana the donor parents of rust resistance genes (Campbell, 1967).

Glenlea is the first Canadian spring utility wheat, produced primarily for nonmilling use. Its yield is superior to the other Canadian bred cultivars (Evans *et al.*, 1972).

Era is a hard, red, spring, semidwarf wheat, released by the Minnesota Agricultural Experimental Station. Its semidwarf character was introduced via a selection obtained from Montana (Heiner *et al.*, 1971).

Pitic 62 is a spring, semidwarf wheat, with partial light sensitivity developed by the INIA and CIMMYT programs in Mexico. (INIA and CIMMYT programs, 1972.)

Yecora 70 is a triple dwarf spring cultivar, released by the Mexican program in 1970 (CIMMYT, 1970).

A summary of the origin and pedigree of the six cultivars is presented in Table 2.

Table 2. Origin and Pedigree of the Six Wheat Cultivars

| Cultivar | Origin | Pedigree ⁽¹⁾ |
|-----------|-----------------------------|---|
| SELKIRK | Canada C.D.A. (Winnipeg) | McMurachy / Exchange // 3* Redman |
| MANITOU | Canada C.D.A. (Winnipeg) | Frontana / 7* Thatcher // Kenya Farmer / 6* Thatcher /3/ PI 170925 / 6* Thatcher |
| GLENLEA | Canada U. of M. | Bage / 2* Pembina // CB 100 (2) |
| ERA | U.S.A. Minnesota | II-55-10/4/ Pembina/ II-52-329/3/ II-53-38/III-58-4/II-53- 546 (3) |
| PITIC 62 | Mexico INIA-CIMMYT | Yaktana 54 // Norin 10 / Brevor 26 - 1C |
| YECORA 70 | Mexico INIA-CIMMYT | CIANO "S" // Sonora 64 / Klein Rendidor /3/ Siete Cerros "S" |

(1) The pedigree is written according to Purdy *et al.*, 1968.

(2) CB100 is a Mexican strain having the cvs Sonora 64, Tezanos Pintos Precoz, and Nainari 60 in its pedigree.

(3) Includes in its pedigree Frontana, Thatcher, Mida, Kenya 117 A, Kenya 58, Lee, Newthatch and a Polk sib.

Two trials were conducted and in both the design was a completely randomized block, with three replications. The trials were sown on the experimental area of the Plant Science Department, University of Manitoba, Winnipeg, in the spring of 1973. In one trial (TRIAL A) the six cultivars were sown at normal density (approximately 270 viable seed/m²) with a conventional farm seeder. The distance between rows was 18.4 cm and the plot size was 69 m². In the other trial (TRIAL B) the same six cultivars were sown at a very low density and thinned to produce a distance between plants at 25 cm in rows 18.4 cm apart. The trials were sown May 14th, 1973 and emergence took place on May 24.

Samples of plant material were collected on the following six dates: 12th and 23rd of June, 4th, 15th and 26th of July and the 6th of August, referred to as samples 1 through 6 respectively. On each date the sample consisted of two subsamples per plot from Trial A of 0.762 m² on the first date and 0.449 m² on the others. From Trial B, 15 plants per plot were taken for samples 2 and 3, and 10 plants on the other dates.

For grain yield four subsamples per plot, of 1.1 m², were taken from Trial A, and 50 plants per plot in Trial B. Simultaneously, a final sample was taken from both trials for total dry matter and number of heads.

In each subsample the plants were pulled, the roots separated and the following measurements taken:

- ___ number of plants (on two occasions)
- ___ number of tillers
- ___ total dry matter (DM) from a sub-subsample (dried 48 hours at 80°C)

— from 100 at the beginning, and later from 50 random tillers, the dry matter of the green areas of the different parts (leaves, flag leaf, sheaths and exposed stem, peduncules and heads) was calculated.

And at the appropriate time the following measurements were made: grain yield, number of spikelets per ear, 1000 grain weight, ear emergence (the day that 50% of the ears have emerged in each plot), the day that LAI fell to zero, visually estimated, and height.

From these basic measurements all the other parameters were calculated. The growth measurements were calculated following Radford (1967) and Watson (1952).

The photosynthetic area was estimated using the linear regression between leaf area and leaf weight (Milthorpe, 1956). Regression lines for all plant parts at three times, when the plants were 28, 51 and 72 days old respectively were fitted to photosynthetic area and dry weight.

The leaf lamina area/dry weight regression was determined at each of these three times on a sample of 10 tillers per cultivar, ranking from the shortest to tallest. Because the regression coefficient and the elevations were similar for all cultivars a common equation was used. The leaf lamina area was recorded as the surface of one side of the lamina estimated by attaching the leaf to a paper, spraying it with paint and calculating the clear area. The leaves were dried and weighed.

The area of the green sheath and exposed stem and peduncules were calculated in the same way, by considering these tissues as cylinders, and their equivalent "leaf area" was taken as half the surface area of the cylinder (Fisher and Khon, 1966). Thorne (1959) reported that the rate of apparent photosynthesis in the leaf sheath and in the lamina of

barley, compared on the above area basis, seemed about equal. By measurements of the diameter at the bottom and at the top of the stem and peduncules, the average diameter of these tissues were calculated.

They were dried and the corresponding regression lines were fitted.

The green head area was estimated by the product of length and breadth (of the middle spikelet) of one side (Khalifa, 1973) and its average "leaf area" per tiller estimated in the same way as the other tissues.

The relation of awn area and awn dry weight was also calculated and used to correct the regression equation of head area/head dry weight of the three awned cultivars: Era, Pitic 62 and Yecora 70.

The average photosynthetic or "leaf area" of each of these parts per tiller was calculated and multiplied by the number of tillers per square meter to obtain the leaf area/m². The summation of all these areas provided the total LAI.

4. RESULTS AND DISCUSSION

4.1 General Observations

Some variation in plant population occurred in spite of the steps taken to secure uniform sowing. Pitic 62, in particular, had a lower number of plants than the other cultivars. Table 3 summarizes the mean values for plant population at sampling time 1 and 3 (Also see Appendices Nos. 4.1.1 and 4.1.2).

Table 3. Plant population

| <u>Cultivar</u> | No. of plants/m ² | |
|-----------------|------------------------------|------------------------|
| | sample <u>No. 1</u> | sample <u>No. 3</u> |
| Selkirk | 271 a* | 246 a |
| Manitou | 246 ab | 244 a |
| Era | 239 ab | 241 a |
| Yecora 70 | 235 b | 218 ab |
| Glenlea | 229 b | 215 ab |
| Pitic 62 | 196 c | 197 b |

* = Duncan's Multiple-range test;
5% level.

In general the growth and development of the crop was normal and moisture was not limiting. Between sampling time 5 and 6, a heavy infection of leaf rust, *Puccinia recondita*, appeared. Table 4 reports the range of infection for the cultivars in both trials.

Table 4. Leaf rust infection, in per cent

| <u>Cultivar</u> | <u>Trial A</u> | <u>Trial B</u> |
|-----------------|----------------|----------------|
| Selkirk | 60 - 80 | 40 - 60 |
| Manitou | 80 - 100 | 60 - 80 |
| Era | tr - 10 | tr - 5 |
| Yecora 70 | 10 - 20 | tr - 10 |
| Glenlea | - | - |
| Pitic 62 | 40 - 60 | 20 - 40 |

Because of the effect of the rust epidemic the susceptible cultivars (Selkirk, Manitou and Pitic 62) and the more resistant ones (Yecora 70, Era and Glenlea) are discussed separately. Unfortunately, the degree of infection, although similar, is not as severe in the B trial. No other diseases were observed.

The cultivars differ considerably in height. Table 5 shows the average of 9 estimations of height in Trial A.

Table 5. Height and days from emergence to heading

| <u>Cultivar</u> | <u>Height cms.</u> | <u>Days from emergence to heading</u> |
|-----------------|------------------------|---|
| Selkirk | 99 | 47 |
| Manitou | 104 | 48 |
| Era | 87 | 50 |
| Yecora 70 | 67 | 42 |
| Glenlea | 110 | 48 |
| Pitic 62 | 95 | 55 |

The number of days from emergence to mid-heading (50% of the plot headed) is also reported in Table 5. The cultivars are similar in this respect, except Yecora 70 and Pitic 62 which are one week earlier and later, respectively.

4.2 Grain Yield

At harvest, four subsamples of 1.1 m^2 were taken from each plot, to estimate the grain yield. Table 6 shows the mean grain yield for the six cultivars in Trial A (Also see Appendix 4.2.1).

Table 6. Trial A - grain yield

| <u>Cultivar</u> | <u>Grain yield kg/ha</u> |
|-----------------|------------------------------|
| Yecora 70 | 3855 a* |
| Glenlea | 3507 ab |
| Era | 3153 b |
| Selkirk | 2626 c |
| Manitou | 1984 d |
| Pitic 62 | 1769 d |

* = Duncan's Multiple-range
test; 5% level.

The three rust resistant cultivars outyielded the susceptible ones. The low yield of Pitic 62, a potentially high-yielding genotype, can be ascribed to the late heading and subsequent disease buildup.

Yecora 70 significantly outyielded all the cultivars except Glenlea. The yield of Glenlea and Era did not differ significantly.

A different pattern occurred with the grain yield of the spaced plants. Table 7 shows the average grain yield per plant of 150 plants of each genotype. (Also see Appendix 4.2.2.)

Table 7. Trial B - grain yield

| <u>Cultivar</u> | <u>Grain yield</u> <u>gm/plant</u> |
|-----------------|---------------------------------------|
| Glenlea | 22.88 a* |
| Era | 16.99 b |
| Yecora 70 | 16.28 bc |
| Pitic 62 | 14.22 cd |
| Selkirk | 13.24 d |
| Manitou | 10.13 e |

* = Duncan's Multiple-range test;
5% level.

Again the resistant cultivars outyielded the susceptible; but among the resistant group Glenlea had a significantly higher yield per plant than Era or Yecora 70.

If we take into consideration only the resistant cultivars, there was no significant correlation between grain yield in normal density and grain yield per plant under spaced conditions ($r = -0.07$). The small number of genotypes used makes any generalization dangerous, but thinking only in terms of the genotypes tested, the grain yield per plant under spaced conditions is not an indication of how that genotype is going to perform under normal density.

Several workers (Palmer, 1952; Frey *et al.*, 1962; Atkins, 1966; McGinnis *et al.*, 1968; Knott, 1972) found no correlation between grain yield as spaced plants and plot yield in subsequent generations of the derived lines. The low heritability of grain yield of spaced plants has been given as one reason for this lack of correlation (Knott, 1972). By using the same genotype in normal density and spaced plant conditions, and by taking the average of a large number of plants, to overcome the environmental variability of grain yield of isolated plants, (see Appendix 4.2.2) a lack of correlation still exists which cannot be ascribed to the low heritability of grain yield.

These results agree with those of Knott (1972), who failed to increase the correlation between F_2 spaced plant yield and F_3 line yield by reducing the environmental variability of the F_2 nursery. The results also agree with those of Syme (1972) who found that the grain yield of the cultivars as single plants was not significantly correlated with the mean plot yield.

This means that the factors that enhance grain yield in single plants do not necessarily enhance grain yield under normal density. Later data are going to corroborate this statement.

As Donald (1963) reported the grain yield of a plant under field density is only a small fraction of that under spaced condition. In this study the grain yield per plant under field density varies from 6 to 11% of that of the spaced plants. This is an indication of the competitive stress that the plants are subjected to under field conditions.

4.3 Dry Matter Yield

The DM increased continuously until the last sample data, approximately 12 days before harvesting.

The average increase in DM during the season in Trial A is shown in Fig. 1. At the beginning of the season there were clear differences between varieties, but these differences disappeared in samples 3, 4 and 5. In the last two samples (6 and 7) differences reappear, but we can associate these to the disease reaction of the cultivars, as differences do not occur between susceptible (Selkirk, Manitou, Pitic 62) or resistant cultivars (Era, Yecora 70 and Glenlea) (see Appendices 4.3.1 up to 4.3.7).

A different pattern appears when the plants are spaced. The general evolution is similar, but at the end of the season the plant DM yield of the 3 resistant cultivars was quite different (see Fig. 2 and Appendices 4.3.8 up to 4.3.13).

Table 8 shows the final DM/m^2 in Trial A and the DM/plant in Trial B. Again the disease may disturb the analysis, because the degree of infection was not equal in both trials; but, if we take into consideration only the healthy cultivars, there are significant differences between DM production per plant in spaced condition, but not under normal density.

There is no correlation between DM/m^2 in normal density and DM per plant in spaced condition ($r = +0.58$). In both conditions Glenlea had the highest DM yield. It is surprising that in spite of the difference in height between Glenlea and Yecora 70 there was no significant difference in DM/m^2 in normal density between these two varieties. In

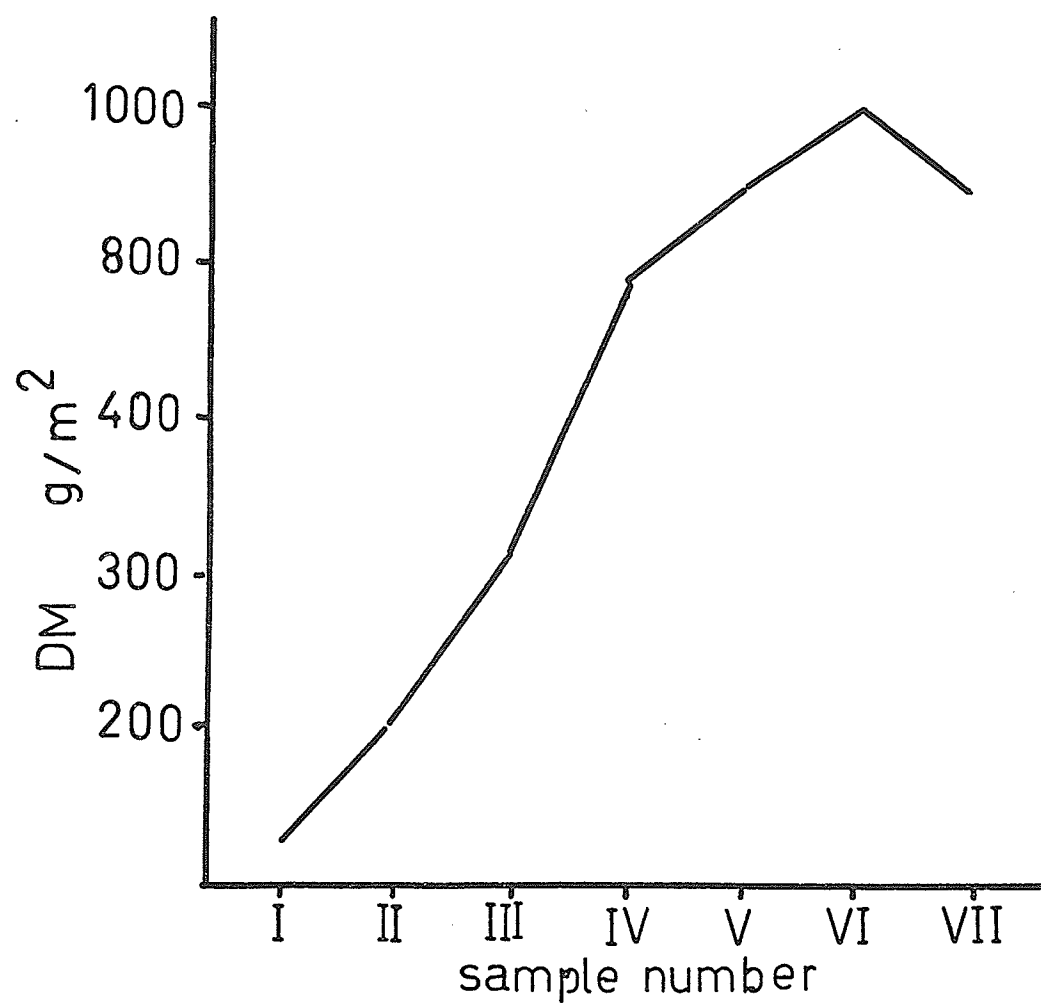


FIG.1. TRIAL A. AVERAGE
DRY MATTER PRODUCTION

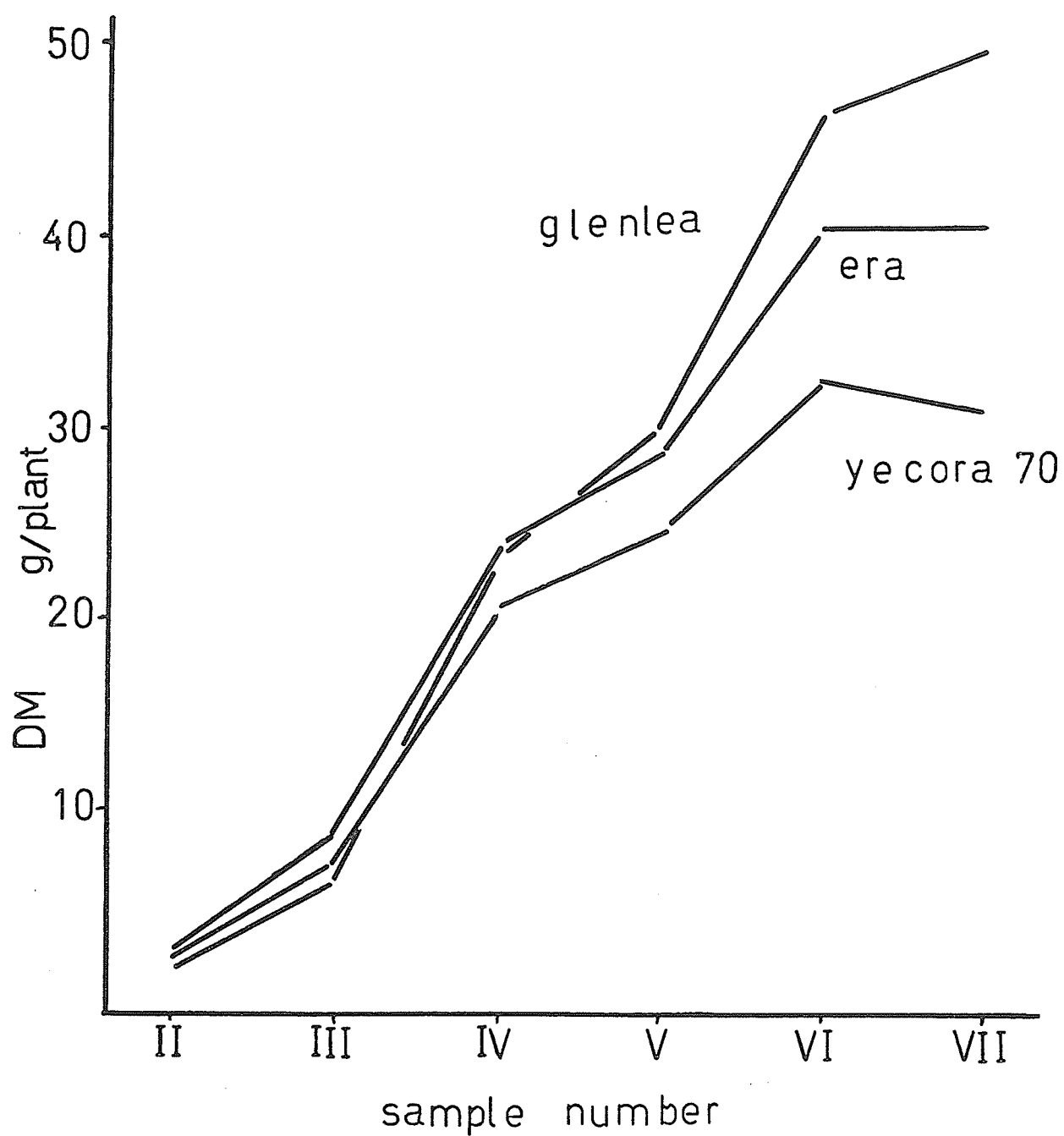


FIG.2. DRY MATTER PER PLANT
IN SPACED CONDITION

spaced plants Glenlea had the highest and Yecora 70 the lowest DM production. A pattern similar to this occurred with grain yield.

Table 8. DM at the end of the season

| <u>DM/m², gm</u> <u>Trial A</u> | <u>DM/plant, gm</u> <u>Trial B</u> |
|---|---------------------------------------|
| G* = 1018 a# | G = 48.93 a |
| E = 927 ab | P = 43.93 b |
| Y = 904 abc | E = 40.37 bc |
| P = 851 bc | S = 37.73 cd |
| M = 826 bc | M = 33.57 de |
| S = 797 c | Y = 31.67 e |

* = G = Glenlea, E = Era, Y = Yecora 70,
P = Pitic 62, M = Manitou, S = Selkirk.

= Duncan's Multiple-range test; 5% level.

4.4 Harvest Index

The HI in normal density and in spaced plants was calculated using the average values for DM and grain yield in both situations. Table 9 shows the mean HI values in both trials.

The HI is a measure of the capacity of the genotype to produce and translocate photosynthate to the grain. The HI of the susceptible cultivars is a meaningless value, because the disease affects the photosynthetic area and it also has a sink effect.

Table 9. Harvest Index

| <u>Cultivar</u> | <u>HI in normal density</u> | <u>HI of spaced plants</u> |
|-----------------|---------------------------------|--------------------------------|
| Selkirk | 32.93 | 35.09 |
| Manitou | 24.02 | 30.18 |
| Era | 34.01 | 42.09 |
| Yecora 70 | 42.63 | 51.41 |
| Glenlea | 34.43 | 46.76 |
| Pitic 62 | 20.79 | 32.37 |

Yecora 70, the triple dwarf, has the highest HI, with a value similar to that reported in the literature for the dwarf Mexican cultivars. Era and Glenlea have a lower HI than Yecora, but are similar to each other, in spite of the differences in height.

In the previous section it was shown that there is no correlation between DM and grain yield per plant in spaced condition and DM and grain yield per hectare in normal density. In spite of this, the correlation between HI of spaced plants and grain yield/ha in normal density is significant and very high: $r = 0.97$ and increases to 1.00 when we take into consideration only the resistant cultivars.

Again, any generalization can be dangerous due to the small number of genotypes used, but these results agree with those of Syme (1972) who studied single plant characters as a possible measure of field plot performance and found that the HI of single plants account for 71.7% of the variability of the mean field plot yield of 49 cultivars. It may be worthwhile to study the correlation between HI of F_2 single plants

and the grain yield of the F_3 derived lines. Since the HI of single plants is easy to measure, a large F_2 population could be screened and only those with a high HI tested in F_3 , if this correlation is maintained in segregating populations.

4.5 Relative Growth Rate

The RGR is a measure of the dry matter production efficiency of the crop per unit of dry weight. RGR is a function of the NAR and the leaf area per unit of dry weight (LAR).

There were no significant differences in RGR between cultivars. Significant differences in a measure of this nature are difficult to obtain in field experiments due to the large error variance. Nevertheless, on two occasions, the analysis of variance gave F test significance at the 10% level. This may be an indication of differences in RGE between cultivars. A consideration of the RGR trends is interesting. The RGR decreased steadily during the season, except at the end, where there was a small increase (Fig. 3). The decrease is apparently related to a decrease in LAR (leaf area ratio) as seen from the regression lines fitted to leaf area and leaf weight per tiller at three dates (Fig. 4).

Between sampling dates 3 and 4 a change in the relative order of RGR mean values occurred. This fact is sustained by changes in NAR and CGR at the same time (Section 4.8 and 4.9). A possible explanation is that Pitic 62, Era and Yecora 70 have a better distribution of light through their canopy, increasing the average NAR and consequently the RGR and CGR. At the beginning of the season is no competition for light,

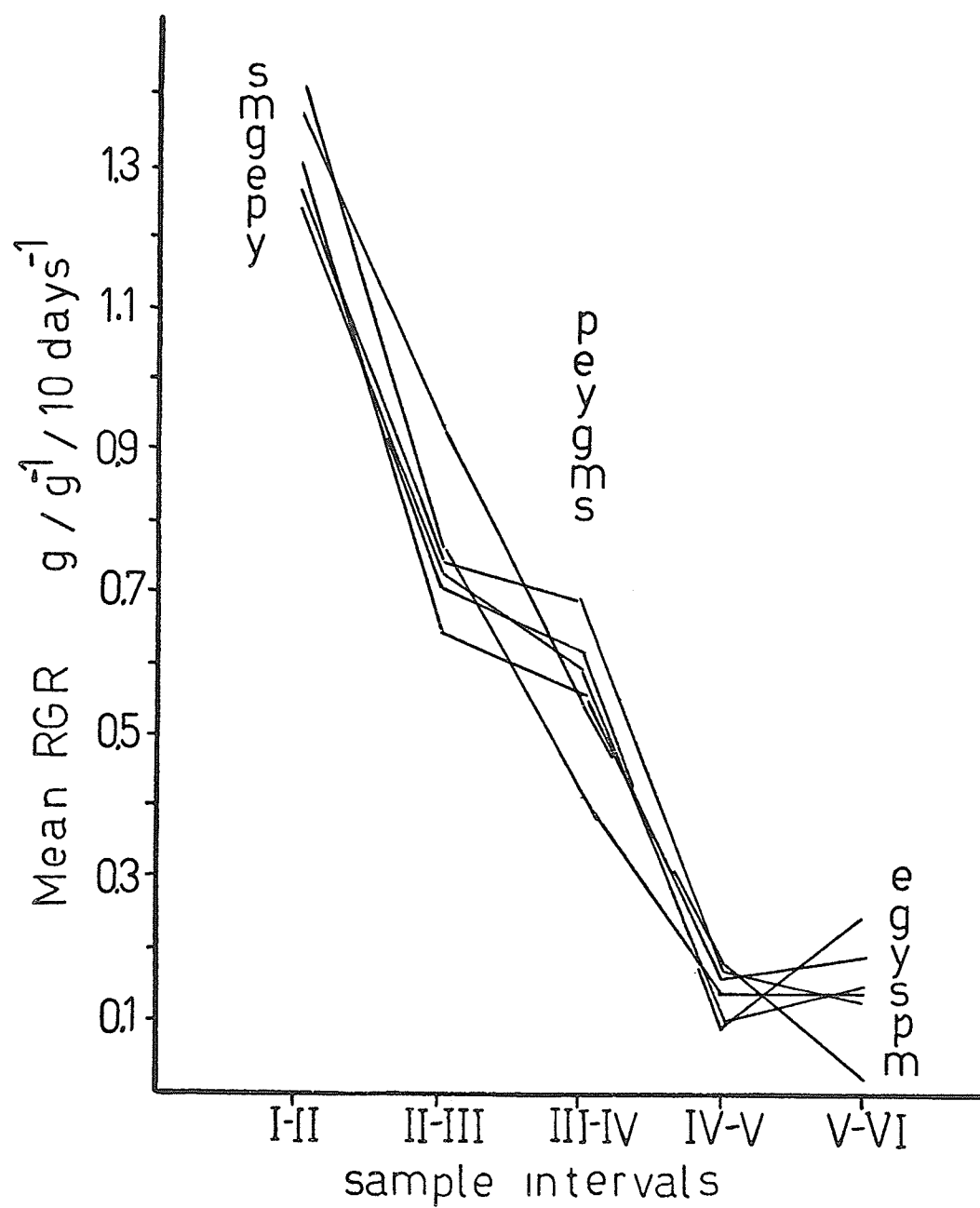


FIG. 3. RELATIVE GROWTH RATE

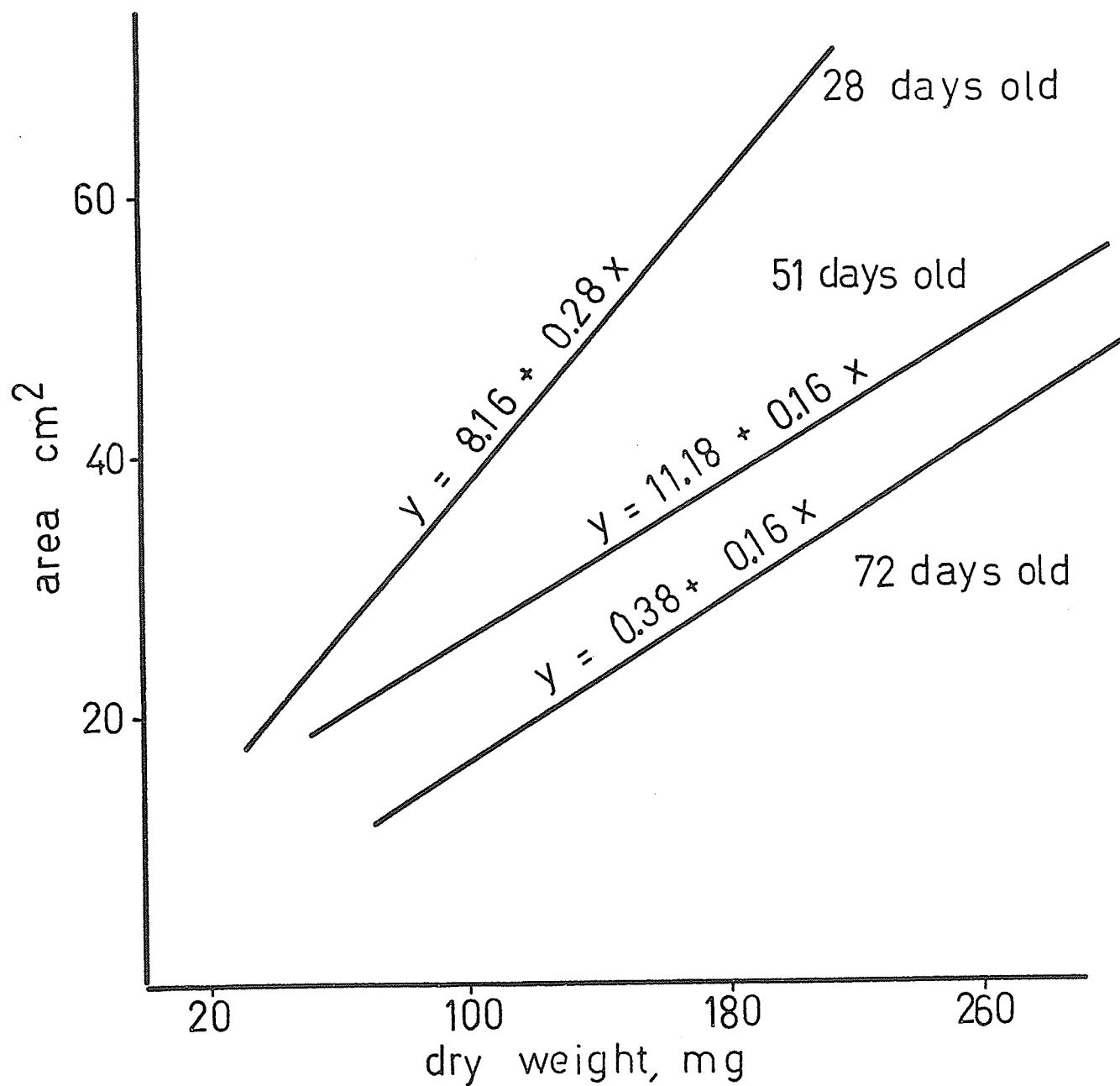


FIG. 4. RELATIONSHIP BETWEEN TOTAL LEAF DRY WEIGHT AND TOTAL LEAF AREA PER TILLER

but later competition begins, and the best expression of this phenomenon is the death of tillers (Section 4.10). In some varieties, the structure of the canopy is not very efficient in the interception of light, and for this reason the photosynthesis of the lower leaves is limited, reducing the average NAR.

At the end of the season there is a small increase in RGR of the resistant cultivars. The increase is also associated with an increase in NAR discussed later (Section 4.8).

In spaced plants, as expected, the variation is even greater, and no significant differences were found between cultivars.

4.6 Leaf Area Index

Traditionally, leaf area was estimated by considering only the area of the leaves. When the importance of the other parts of the plant as photosynthetic organs was recognized, the problem of measuring these areas on a photosynthetic basis arose.

In this study the photosynthetic area of the stems and peduncles were estimated as half the surface area of the relevant cylinder, on the basis of the data reported by Thorne (1959) with barley. The area of the green head was estimated from the product of the length and breadth of one side, following Khalifa (1973). This is, indeed, a very arbitrary decision, since the length of the glumes can vary from variety to variety as can the density of spikelets. The errors made in this estimation can be important since the photosynthetic importance of the heads is quite well recognized. In the absence of data to support any decision, the area of the awns was also estimated as half

the surface of a cylinder.

The regressions between area and dry weight of each component part were estimated three times during the season. Fig. 4 plots total leaf area versus dry weight per tiller. The inclination of the lines changes with time. It is obvious that as the leaves become older the area per unit of dry weight becomes smaller. Since the LAI in sample I and II was estimated with the first equation, sample III and IV with the second equation, and sample V and VI with the third equation, it follows that in the odd samples the areas were underestimated and in the even samples overestimated. This indicates the need to check the regressions for every sample.

Table 10 reports the change in total LAI during the season. In sample II, when the crop was only 31 days old, very high LAI values were observed. In fact, Glenlea and Yecora 70 achieved their maximum LAI at this early stage.

Table 10. Change in total LAI during the season

| Variety | Sample number | | | | |
|-----------|---------------|------|------|------|------|
| | II | III | IV | V | VI |
| Selkirk | 5.34 | 5.85 | 4.02 | 3.69 | 1.36 |
| Manitou | 4.24 | 4.93 | 4.56 | 3.56 | 1.74 |
| Era | 4.96 | 5.73 | 5.41 | 3.84 | 3.11 |
| Yecora 70 | 5.11 | 4.81 | 5.06 | 4.03 | 2.13 |
| Glenlea | 5.50 | 5.08 | 4.66 | 4.61 | 3.07 |
| Pitic 62 | 4.87 | 5.72 | 5.12 | 4.30 | 3.04 |

This can be ascribed to the high tiller production of all the varieties in the early stage of growth (see Section 4.10) and subsequent loss of them due to competition for light.

Selkirk, Manitou, Era and Pitic 62 achieve their maximum LAI in sample III, when the crop is 42 days old.

The differences in maximum LAI among varieties is very small. The differences between the two extreme cultivars, Selkirk with a maximum LAI of 5.85 and Manitou of 4.93, is less than one LAI unit. There is no significant correlation between maximum LAI and grain yield ($r = -0.06$).

The contribution of every plant part of this total LAI is shown in Table 11. In spite of the differences in height, leaf size, head size, and number of tillers per m^2 among the varieties, the similarities in the contribution of the different parts to the total LAI are striking. Some differences, however, attract immediate attention. If we take into consideration sample V, at the middle of the grain filling period, the low contribution of the head to the photosynthetic area of Glenlea, in comparison with Yecora 70 or Era, is worth citation (Table 11). Glenlea has bigger heads than Yecora 70, but it cannot compensate for the absence of awns and the low ear number per m^2 .

Table 12 corroborates the obvious fact that the LAI is a function of the leaf area per tiller and the number of tillers per m^2 . As will be seen later (Section 4.10), in the absence of severe water or nutrient stress, the final number of tillers is a function of the capacity of the crop to use the available light. This corroborates the earlier statement that the capacity to produce photosynthates and the "container"

Table 11. Contribution of leaves, flag leaves, stems, peduncules and heads to the total LAI (in per cent)

| | | Sample number | | | | |
|-------------|---|---------------|-----|----|----|----|
| | | II | III | IV | V | VI |
| Leaves | S | 83 | 79 | 32 | 18 | 0 |
| | M | 85 | 78 | 32 | 35 | 0 |
| | E | 86 | 82 | 40 | 30 | 0 |
| | Y | 84 | 75 | 27 | 36 | 0 |
| | G | 83 | 82 | 38 | 36 | 18 |
| | P | 88 | 84 | 48 | 41 | 0 |
| Stems | S | 17 | 21 | 22 | 25 | 13 |
| | M | 15 | 22 | 23 | 28 | 36 |
| | E | 14 | 18 | 18 | 21 | 19 |
| | Y | 16 | 25 | 19 | 21 | 10 |
| | G | 17 | 18 | 21 | 24 | 17 |
| | P | 12 | 16 | 18 | 21 | 29 |
| Flag leaves | S | | | 27 | 27 | 0 |
| | M | | | 25 | 25 | 0 |
| | E | | | 26 | 21 | 28 |
| | Y | | | 27 | 27 | 20 |
| | G | | | 24 | 29 | 30 |
| | P | | | 22 | 24 | 24 |
| Peduncules | S | | | 10 | 19 | 47 |
| | M | | | 11 | 20 | 37 |
| | E | | | 8 | 16 | 21 |
| | Y | | | 10 | 18 | 33 |
| | G | | | 9 | 16 | 19 |
| | P | | | 8 | 15 | 21 |
| Heads | S | | | 8 | 11 | 40 |
| | M | | | 9 | 11 | 28 |
| | E | | | 11 | 18 | 32 |
| | Y | | | 17 | 15 | 37 |
| | G | | | 8 | 8 | 16 |
| | P | | | 3 | 11 | 25 |

capacity are not independent structures in the crop.

Table 12. Photosynthetic area per tiller
in normal density at sample V

| <u>Variety</u> | <u>Area, cm²</u> |
|----------------|-----------------------------|
| Selkirk | 70.02 |
| Manitou | 59.83 |
| Era | 73.70 |
| Yecora 70 | 62.48 |
| Glenlea | 95.84 |
| Pitic 62 | 84.98 |

It also explains some apparent contradictions in the literature. It has been demonstrated, principally with studies on isolated plants, that an important part of the carbohydrates that go to the grain comes from the photosynthesis in the flag leaf. This can induce us to look for plants with big flag leaves. On the other hand, the workers who studied the efficiency of light interception demonstrated the need for small, up-right leaves. The importance of the flag leaves can be related to structural position on the plant, and it is the actual flag leaf area per unit of land, and not the size of the individual flag leaf, that is important. Small leaves can result in a better LAI and/or a better utilization of the incident light, improving in this way the photosynthetic production.

Regression lines have not been calculated between leaf area and leaf weight in spaced plants. There are reasons to believe however that they are different from that in normal density. In spite of this, and because we are more interested in relative than in absolute values, the leaf area (leaves plus flag leaves) per plant in Trial B was calculated, using the same equations as in normal density.

Table 13. Leaf area index (leaves + flag leaves) in normal density and leaf area per plant in spaced condition at sample IV

| <u>Cultivar</u> | <u>LAI (leaves + flag leaves) Trial A</u> | <u>Leaf area per plant² Trial B, dm²</u> |
|-----------------|---|--|
| Selkirk | 2.36 | 7.07 |
| Manitou | 2.59 | 7.80 |
| ERa | 3.56 | 9.14 |
| Yecora 70 | 2.77 | 4.01 |
| Glenlea | 2.89 | 10.76 |
| Pitic 62 | 3.61 | 9.87 |

This comparison was made with the data from sample IV because it is the first sample after ear emergence. There is no significant correlation ($r = 0.57$) between LAI in normal density and leaf area per plant in spaced condition. There is also no correlation between leaf area per tiller at normal density and leaf area per tiller in spaced plant condition ($r = 0.26$) at sample IV. This means that the leaf area of an isolated plant is not an indication of its potential LAI at normal density, supporting the lack of correlation in grain yield and DM yield

between spaced plants and normal density.

4.7 Leaf Area Duration

The character related to leaf area that is often correlated with grain yield is leaf area duration after ear emergence.

Fig. 5 shows the average relationships between leaf area duration and grain yield. The total photosynthetic area was taken into consideration for the calculation of the LAD. There is a significant correlation ($P < 0.02$) between LAD and grain yield ($r = 0.89$). In this case it was assumed that the principal effect of the rust infection was a reduction in the leaf area. This is not totally true because the fungus has also a sink effect. Furthermore, the determination of what is a green leaf in an infected crop is an arbitrary decision. If we take out the susceptible cultivars the correlation increases ($r = 0.98$) with significance at the 10% level.

Considering the six cultivars, 79% of the variation in grain yield can be explained by variation in LAD. It would be interesting to see if the calculation of LAD on the basis of flag leaves, peduncules and heads increases this percentage. Unfortunately, because we took samples only every 10 days, this calculation cannot be made precisely.

Fig. 6 shows the LAD of two contrasting cultivars, Selkirk and Yecora 70. Yecora flowered approximately one week before Selkirk and achieves its maximum LAI after heading.

An early ear emergence, a late maximum LAI and a delayed senescence appeared to be a positive feature in any cultivar. Nevertheless, particularly the early flowering, needs to be tested more years before making

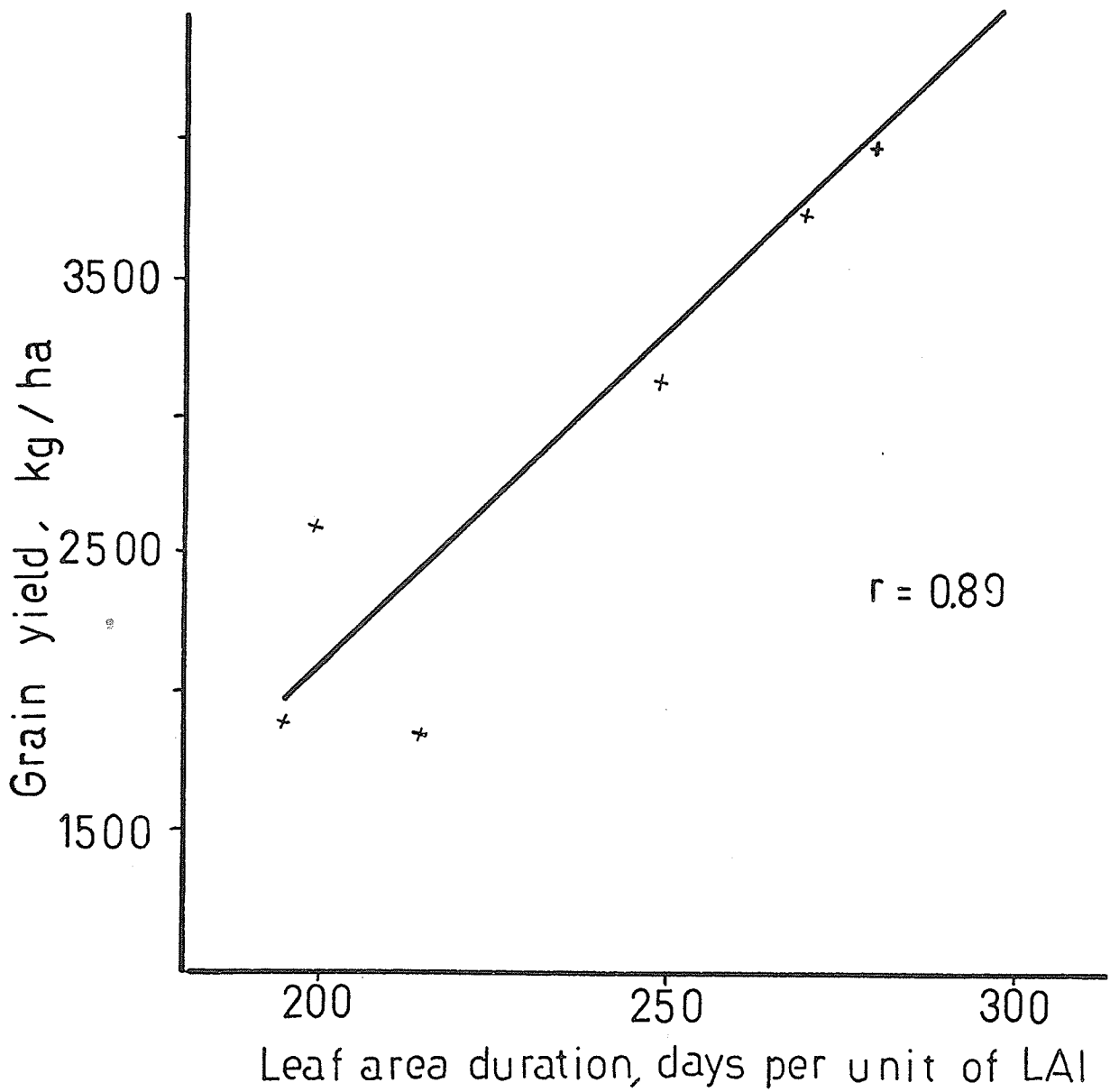


FIG.5. RELATIONSHIP BETWEEN LEAF AREA DURATION AND GRAIN YIELD

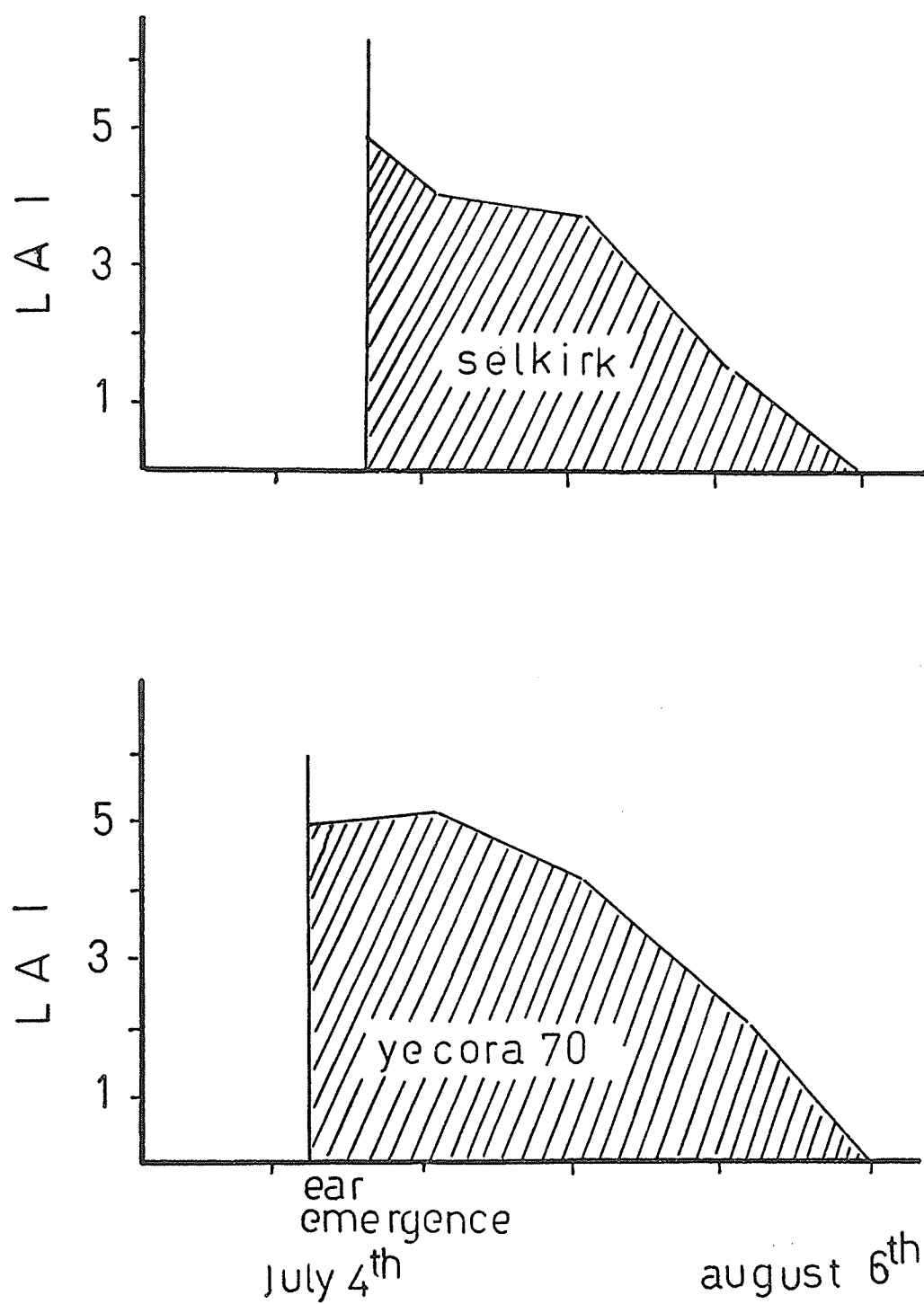


FIG. 6. LEAF AREA DURATION
OF SELKIRK AND YECORA 70

a general statement because the seasonal variation can change its effects.

The ratio, grain dry weight to LAD after ear emergence, has been proposed as a measure of the efficiency of the "leaf area" to produce and translocate photosynthates to the grain (grain/leaf area ratio = G). The plant can also compete for light after ear emergence, though less than before (Thorne, 1966). Differences in leaf angles and leaf size can produce changes in NAR. Ear photosynthesis can differ among cultivars and also the efficiency to produce and translocate carbohydrates to the grain from the other parts of the plant. The mistake made in the estimation of the "leaf area", particularly the green ear area, can also be a factor that accounts for differences in G.

Table 14. Grain yield, leaf area duration after ear emergence, LAD, and grain:leaf ratio, G, of the three resistant cultivars

| <u>Cultivar</u> | <u>Grain yield</u> <u>gm/m²</u> | <u>LAD</u> <u>weeks</u> | <u>G</u> <u>gm/week⁻⁷</u> |
|-----------------|---|----------------------------|---|
| Era | 315.3 | 35.31 | 8.88 |
| Yecora 70 | 385.5 | 40.07 | 9.62 |
| Glenlea | 350.7 | 38.67 | 9.07 |

The grain:leaf area ratio, G, of Yecora 70 is greater than that of Era and Glenlea, which have more similar values (Table 14). This result agrees with that of Watson *et al.* (1963) and Thorne *et al.* (1969) who found that the new semidwarf cultivars tend to have greater G values than the "old type" cultivars. In this case, apparently Era

has not inherited this characteristic from its semidwarf parent,

The LAD per plant in spaced condition has not been calculated due to the lack of information on the ratio dry weight to leaf area in single plants. Nevertheless, on the basis of the results of the last section, it is quite improbable that any positive correlation exists between LAD in isolated plants and in normal density.

4.8 Net Assimilation Rate

The NAR has been estimated taking into account the total photosynthetic area of the plant. The mean NAR was calculated in four intervals (from samples II - III up to samples V - VI) (See Fig. 7).

Only in the first interval are there significant differences in NAR among cultivars. Manitou has a significantly greater NAR than all the other cultivars.

The principal reason for the lack of significant differences can be ascribed to the experimental error, i.e., in a measure of this sensitivity, DM produced per unit of photosynthetic area per unit of time, increase tremendously. The coefficient of variation was 19%, 31%, 67% and 41% in the intervals II - III, III - IV, IV - V and V - VI, respectively. To avoid this it is clearly necessary to reduce the plot size as much as we can (in our case the size was 69 m^2) and to use an extremely uniform field (this was not our case, with parts of the field having had different crops in previous years). Also the estimation of the photosynthetic area was subjected to many experimental errors.

Another problem in the calculation of the NAR is on what leaf area basis is the estimation made. There is a lack of documentation in the

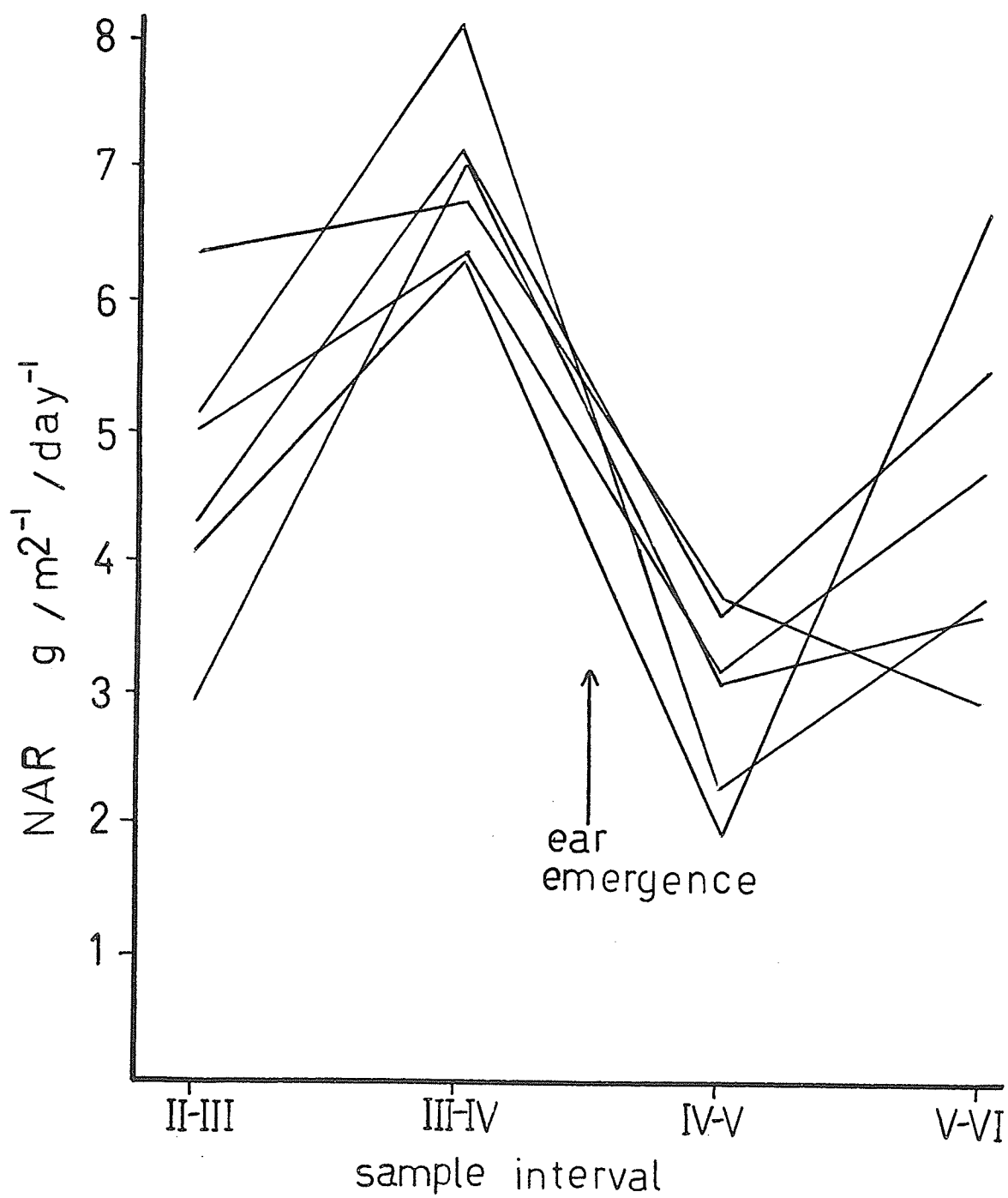


FIG. 7. NET ASSIMILTION RATE

literature in this aspect. All the considerations that were made in Section 4.6 in reference to the calculation of the photosynthetic area are valid here.

In spite of this, some interesting things appeared. Firstly, there is a clear seasonal variation common to all the cultivars (Fig. 7). There is an increase between intervals II - III and III - IV, that can probably be ascribed to an increase in temperature.

The competition for light, that reduces the average NAR by poor illumination of the bottom leaves and the high night temperatures that increase the loss by respiration can probably be factors that explain the subsequent decrease in NAR.

Nalborczyk (personal communication) also found an increase in NAR during the grain-filling period, particularly in years with no water limitations. There is no explanation for this. Since at this time only the top parts of the plants are green the light is not a limiting factor for photosynthesis. The night temperatures are slightly lower. But perhaps other "internal" factors are also responsible for this increase of efficiency at the end of the season.

Secondly, some differences among cultivars, although not significant, are consistent with the RGR and CGR data. The maximum NAR is achieved between samples III and IV. Here cultivars like Yecora 70, Pitic 62 and Glenlea have a higher NAR than the others. Also during this interval the maximum CGR is achieved, and the same cultivars have the top values. If we look at the RGR data (Fig. 3) we see that, in this interval, there is a change in the order of the RGR values of the cultivars, Selkirk and Manitou now have the lower values. Since a change in RGE can be explained by a change in LAR or in NAR, and since an inter-

action between LAR and time is difficult to explain, these results support the idea that actual differences in NAR among the cultivars exist and that we only need more precise experiments to detect them.

4.9 Crop Growth Rate

The CGR data (increase in DM per unit of time per unit of land) are shown in Fig. 8. There are significant differences in the intervals I - II and V - VI. In this last interval the CGR values are clearly affected by the rust.

The maximum CGR is achieved during the interval III - IV. As we said before (see Section 4.8), although not statistically significant, the differences in CGR in this period agree with the NAR and CGR values.

Let us compare two cultivars, Yecora 70 and Selkirk. Selkirk achieves its maximum LAI in sample III with 5.85, decreasing to 4.02 in sample IV (Table 10). Yecora has a value of 4.81 in sample III increasing to 5.06 in sample IV. Yecora also has a higher NAR and RGR in the interval between samples III and IV (Figs. 3 and 7). These factors can explain the fact that while Yecora 70 continues increasing its CGR between samples II - III and III - IV, Selkirk decreases.

There is no clear evidence in the literature (Shibles and Weber, 1965; William *et al.*, 1965) that there is an "optimum LAI", i.e., the LAI at which the CGR reaches a maximum and later declines with further increase in LAI. In some cases the CGR reaches a maximum and remains constant with further increase in LAI. If this also happens in wheat it is an indirect evidence that there are no "parasitic" leaves in the canopy. With the design of this experiment it was impossible to detect an "optimum LAI". But, what is clear from the data, is that the LAI at

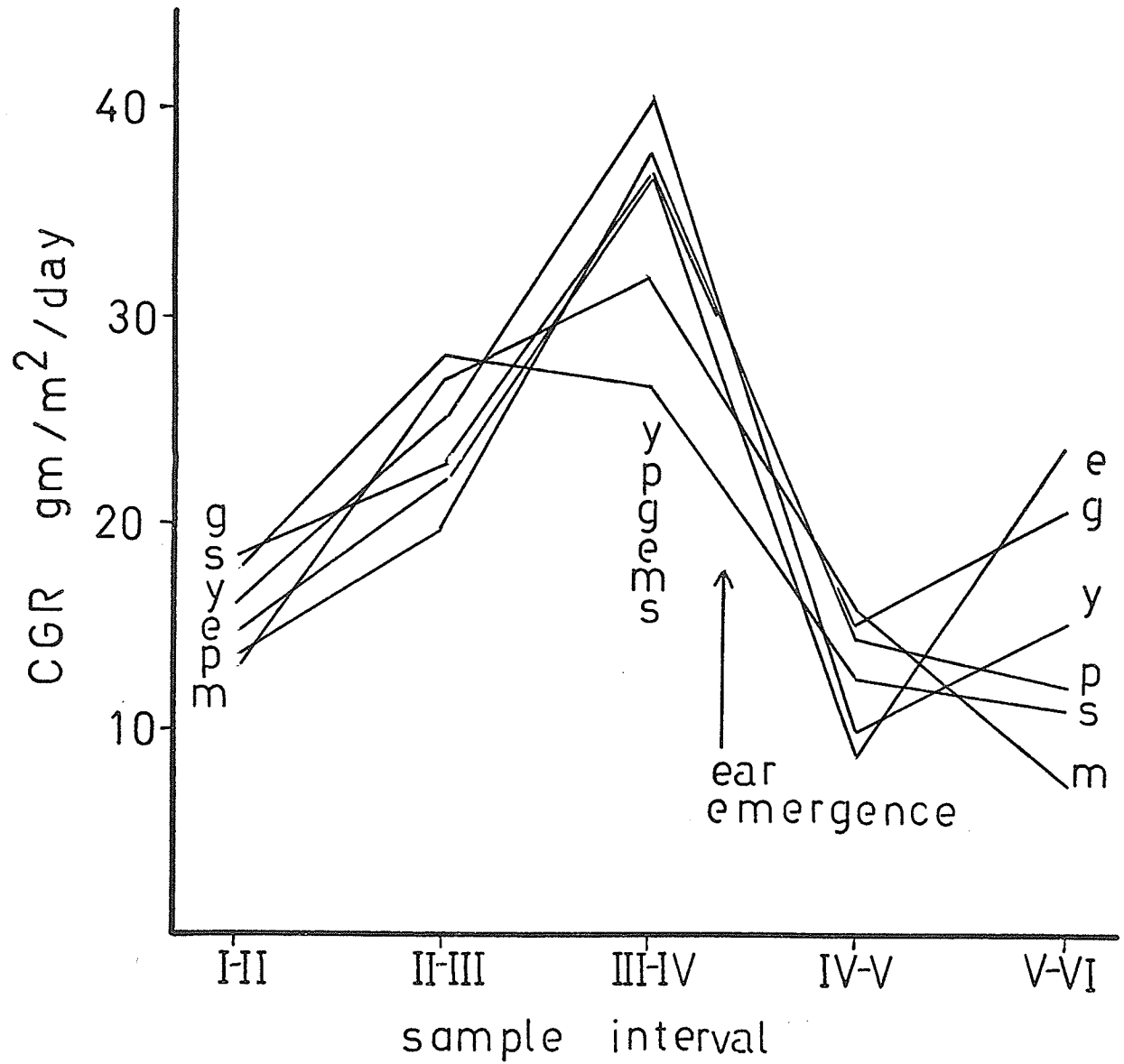


FIG. 8. CROP GROWTH RATE

which the CGR reach a maximum is not the same for all the cultivars. This is indirect evidence that there are possible differences between the cultivars in the use of light.

4.10 Tiller Number and Ear Number

The normal practice is to estimate the number of tillers per plant by counting the number of plants at the beginning of the season and the number of heads per unit area at harvest.

The evolution of the number of tillers during the season is important from the point of view of the knowledge of the structure of the canopy. As early as sample I, when the crop is only 20 days old, the number of tillers varied from 550 to 700 per m^2 . All cultivars achieved maximum tiller number at sample II. Later, the number declined rapidly to sample IV, remained practically constant in sample V, and a further small decline in sample VI to achieve the final number of heads.

Fig. 9 shows the average number of tillers for all the cultivars and the data for two extreme varieties. Selkirk achieved the highest number of tillers in sample II and one of the lowest number of heads at harvest, and Yecora 70, with the low maximum number of tillers in sample II achieved the highest number of heads at the end of the season.

The loss of tillers ranks from 46.6% up to 67.2% (Table 15). The correlation between the maximum number of tillers that a cultivar can achieve and the final number of heads/ m^2 is not significant ($r = 0.50$). There is also no significant correlation between the per cent tiller loss and the maximum number of tillers. The same happens between the final number of heads/ m^2 and grain yield ($r = 0.09$).

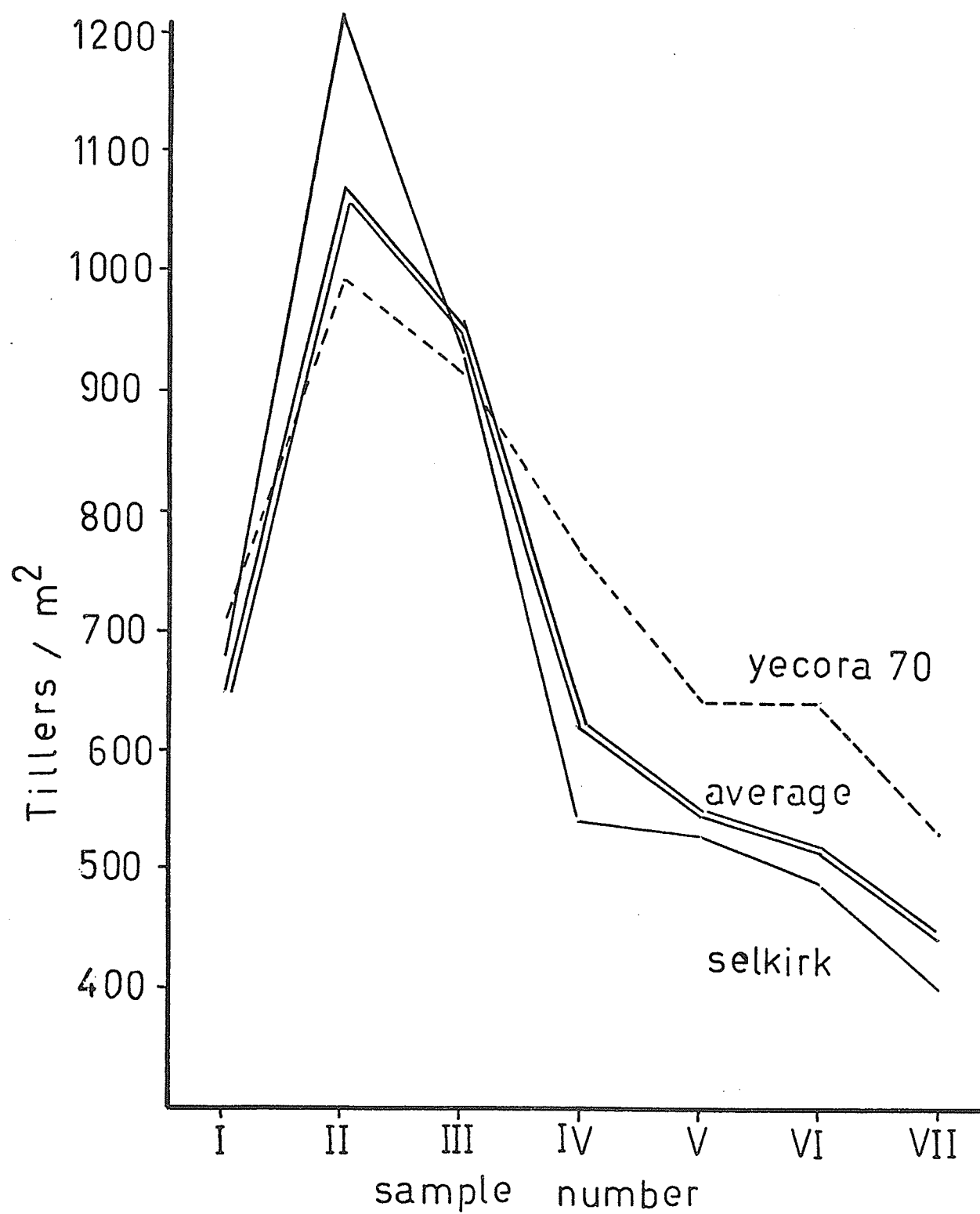


FIG. 9. EVOLUTION OF THE NUMBER OF TILLERS

Table 15. Number of tillers/m² at sample II, number of heads at harvest, percentage of tillers lost and heads per plant in Trial A

| <u>Variety</u> | <u>No. tillers/m² sample II</u> | <u>No. of heads/m² at harvest</u> | <u>% tiller loss</u> | <u>Heads/ plant</u> |
|----------------|--|--|--------------------------|-------------------------|
| Selkirk | 1201 | 401 | 66.6 | 1.60 |
| Manitou | 1130 | 508 | 55.0 | 2.08 |
| Era | 1112 | 439 | 60.5 | 1.82 |
| Yecora 70 | 986 | 526 | 46.6 | 2.41 |
| Glenlea | 788 | 320 | 59.3 | 1.49 |
| Pitic 62 | 1128 | 369 | 67.2 | 1.72 |
| L.S.D. | 107 | 59.35 | - | - |

A different pattern occurs with the evolution of the number of tillers in spaced plant conditions (Fig. 10). There is not the tiller reduction that occurs in normal density.

Table 16. Number of heads per plant in spaced condition

| <u>Variety</u> | <u>Heads/plant</u> |
|----------------|--------------------|
| Pitic 62 | 16.65 a* |
| Era | 16.43 a |
| Selkirk | 15.71 a |
| Manitou | 15.28 a |
| Yecora 70 | 13.28 b |
| Glenlea | 12.45 b |

* = Duncan's Multiple-range test; 5% level.

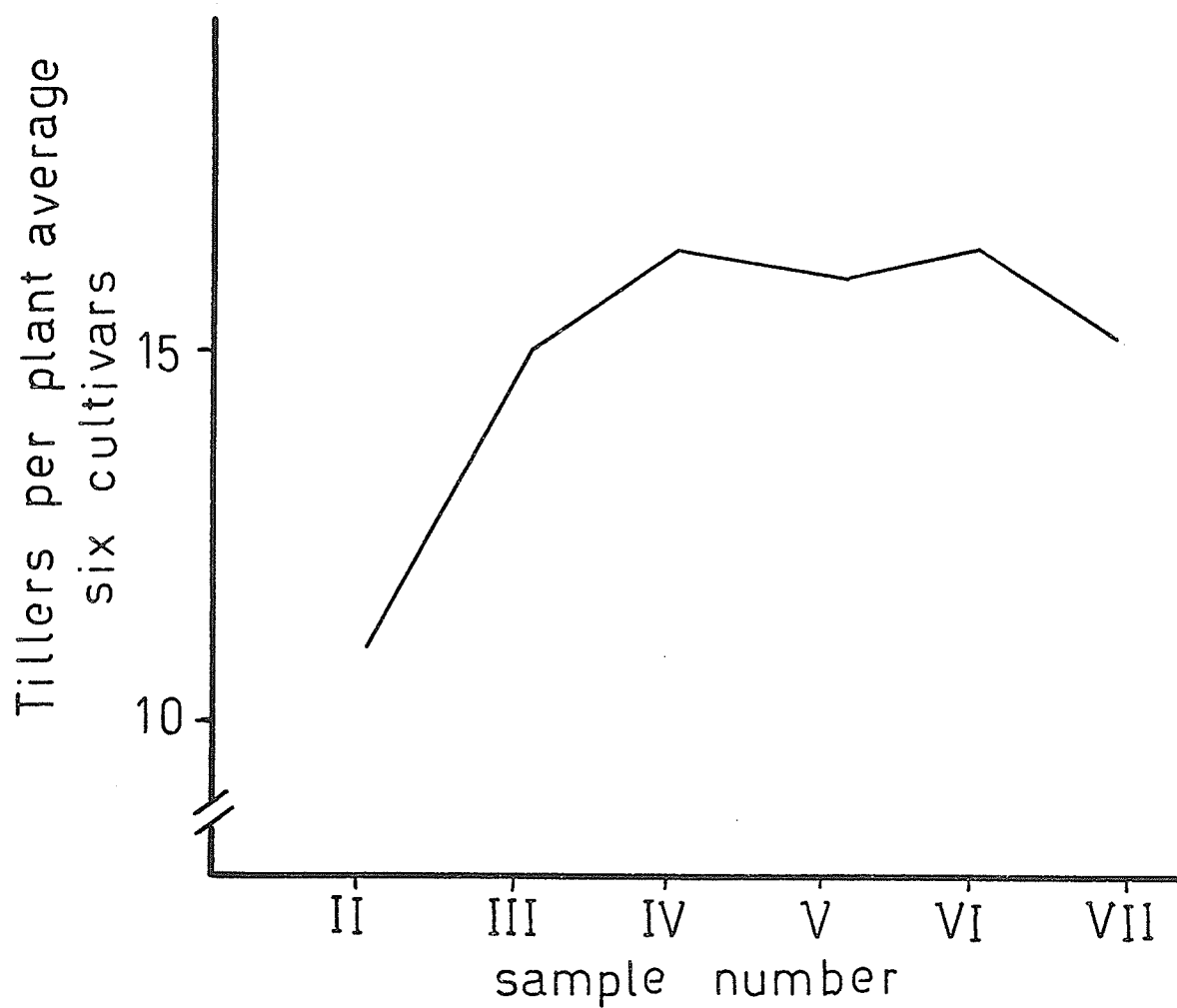


FIG. 10. EVOLUTION OF THE NUMBER OF TILLERS IN SPACED PLANTS

There are significant differences in the number of tillers bearing heads per plant in spaced condition (Table 16). We can assume that this is an expression of the potentiality of the genotype to produce tillers under the environmental conditions of the experiment. The correlation between the number of heads per plant in spaced condition and the number of heads per m^2 in normal density is not significant ($r = 0.16$), but the correlation between the number of heads/plant in spaced condition and the maximum number of tillers that a cultivar can achieve in normal density is significant at the 10% level ($r = 0.79$). Since the production of heads was not affected by the rust infection all cultivars were taken into consideration.

In spaced plants there is no competition for light (at least to the same degree that occurs in normal density) and, for this reason, the survival of tillers is high. In normal density the competition for light is intensive, and the survival of tillers is very low.

The final number of heads in a crop is not a function of the potentiality of the genotype to produce tillers but of the efficiency of the canopy in relation to light interception and utilization.

The heavy loss of tillers agree with the results of Thorne (1962) and Bingham (1967). Since the seed density used in Trial A is quite near the optimal (at least for that year and for the cultivar Glenlea^{*}) we can suppose that in order to achieve the highest grain yield the plants have to be put in an extremely competitive situation.

(*) Grebermarianm, Hailu. 1974. Master's Thesis. University of Manitoba, Plant Science Department.

The severe loss of tillers also indicates that there is a loss of water, light and part of the nutrients from these sterile tillers that do not produce grain.

These results tend to agree with Donald's proposal of the unicum plant type in wheat. Without entering this topic, that involves other aspects, such as different productivity of primary versus secondary or tertiary tillers, prior and more important than the number of tillers is the morphology of these tillers.

A genotype that in isolation produces 2 or 3 tillers can be more productive in normal density than one that produces 15 or 20 tillers. The number of heads in normal density will depend on the factors that reduce light competition. Large horizontal leaves are going to compete highly for light and many tillers will die (Glenlea). The contrary is true for small and upright leaves (Yecora 70). The grain yield is going to be a function of the photosynthetic area per unit of land after ear emergence (if we assume similarity in the efficiency of the photosynthetic process and translocation). In this aspect, apparently many small leaves can accomplish a better LAD than a few big ones; at least in high productivity systems. In our case, and with the grain level we obtained, Glenlea is an example that this is not necessarily true. But, if we want to continue increasing yield perhaps a different morphology is needed.

4.11 Kernel Weight

Table 17 shows the kernel weight for the six cultivars.

Table 17. 1000-grain weight; Trial A

| <u>Variety</u> | 1000-grain weight | |
|----------------|-------------------|----|
| | <u>gm</u> | |
| Glenlea | 44.28 | a* |
| Yecora 70 | 38.24 | b |
| Selkirk | 37.56 | b |
| Era | 31.52 | c |
| Manitou | 28.32 | cd |
| Pitic 62 | 25.56 | d |

* = Duncan's Multiple-range test;
5% level.

Among the three resistant cultivars, Glenlea has a higher kernel weight than Yecora 70 or Era. Berdahl *et al.* (1972), on the basis of their data postulated that large leaves favor higher kernel weight and that small leaves favor production of more culms, which concurs with the above data. Since large leaves are associated with reduced tiller number, the LAD per head is going to be greater in the large leaved cultivars as shown in Table 18.

Table 18. Leaf area duration per head in Trial A

| <u>Cultivar</u> | LAD |
|-----------------|----------------------|
| | <u>days per head</u> |
| Era | 0.56 |
| Glenlea | 0.84 |
| Yecora 70 | 0.53 |

Perhaps, the exact basis of comparison is not the head but the individual kernel, because the number of kernels per head is going to also affect the final kernel weight. The important fact here, is that this is another example that shows us that the "yield components" or, as perhaps we should say, the "yield containers" are not an independent structure, but quite dependent, on the canopy morphology.

5. CONCLUSIONS

The value of a study of the characters underlying differences in yield among cultivars is that it may assist in selecting parents and parental combinations. In this study, the rust infection caused serious damage, particularly affecting information about Pitic 62, a potentially high-yielding cultivar.

Since the performance of any cultivar is strongly affected by environmental conditions, the lack of replications in years and locations clearly restrict the conclusions that can be drawn from these data.

The cultivars studied differ in grain yield. Some characteristics appear to be associated with these differences, as follows:

1. The rust resistant cultivars had different HI. Yecora 70 had a higher value than Era and Glenlea. Very little is known about this measure of efficiency, but it no doubt is an important characteristic to incorporate.
2. In the growth analysis measures, RGR, NAR, and CGR, there were no significant differences between cultivars. There is, however, a strong indication that actual differences exist and that the lack of significance is due principally to experimental error.
3. The maximum LAI that the cultivars achieved are quite similar. Supporting previous reports, the LAD values were different and significantly correlated with grain yield.
4. An early ear emergence and a delayed maximum LAI were factors that contributed to the high LAD of Yecora 70.

5. There were differences among cultivars in the grain/leaf ratio. Yecora 70 had a higher value than the other resistant cultivars. The same comments regarding HI are valid here.
6. The loss of tillers ranked from 46 to 67% of the maximum number produced in the season. The degree of survival was related to the competitive ability of the genotype, principally in the use of light. Yecora 70 was the best cultivar in this aspect.
7. There were several indirect indications, i.e., delayed maximum LAI, low loss of tillers, high CGR values, etc., of the importance of small leaves.
8. Glenlea, with its typical large leaves, compensated its small number of heads with large LAD per tiller, increasing in this way the kernel weight. The compensation, however, was not completed, and it was outyielded by Yecora 70.
9. In general, the results indicate, that theoretically at least, we can hope for genetic recombination of positive features in a cross such as Yecora 70 x Glenlea.

The comparison of the performance of a genotype in spaced conditions and in normal density has proved to be a useful method of getting information about the possibilities of selecting single plants. In this regard the following points are pertinent:

1. No correlation exists between grain yield of spaced plants and yield under normal density. The characters that enhance yield in spaced plants are not the same as those that are important in field stands.

2. There is no significant correlation between DM and leaf area per plant of spaced plants and the corresponding values in normal density.
3. There is a positive correlation between HI of spaced plants and grain yield at normal density. The next step is to determine if this correlation remains in segregating populations by comparing the HI of F_2 plants with the grain yield of F_3 derived lines.
4. There was no significant correlation between the number of heads per plant in spaced condition and the final number of heads per m^2 in normal density. But a significant correlation was found between the number of heads per plant in spaced condition and the maximum number of tillers that a cultivar can achieve during the season. Assuming that in the spaced plant condition there is not much competition for light and that the number of heads per plant is an expression of the genetic potentiality to produce tillers, it is postulated that the final number of heads per unit of land in normal density that a cultivar can achieve is not the expression of its potential to tiller but of its efficiency in the interception and use of light.

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A P P E N D I X

APPENDIX 4.1.1

Plant Population — Means per Cultivar — SAMPLE NO. 1

| No. of Plants/m ² | | | |
|------------------------------|-----|-----|-----|
| S. (1) | 268 | 254 | 260 |
| | 213 | 225 | 214 |
| <u>Means</u> | | | |
| M. | 251 | 225 | 234 |
| | 223 | 311 | 214 |
| E. | 274 | 256 | 299 |
| | 260 | 290 | 244 |
| Y. | 234 | 277 | 205 |
| | 229 | 245 | 220 |
| G. | 214 | 240 | 208 |
| | 253 | 238 | 220 |
| P. | 174 | 190 | 210 |
| | 207 | 205 | 189 |

E = 271 a (2)
 M = 246 ab
 S = 239 ab
 Y = 235 b
 G = 229 b
 P = 196 c
 General mean = 236
 C.V. = 7.0%

(1) S = Selkirk, M = Manitou, E = Era, Y = Yecora 70, G = Glenlea, P = Pitic 62.

(2) Duncan's Multiple-range Test; 5% level.

APPENDIX 4.1.2

Number of Plants — SAMPLE NO. 3

| No. of Plants/m ² | | | |
|------------------------------|------------|------------|------------|
| S. | 296 247 | 256 256 | 227 196 |
| M. | 261 254 | 233 249 | 236 229 |
| E. | 263 241 | 256 216 | 229 243 |
| Y. | 274 178 | 207 229 | 229 192 |
| G. | 214 185 | 225 267 | 223 174 |
| P. | 232 209 | 203 200 | 163 174 |

Means

S = 246 a

M = 244 a

E = 241 a

Y = 218 ab

G = 215 ab

P = 197 b

General mean = 227

C.V. = 10.0%

APPENDIX 4.2.1

TRIAL A. Grain yield

| | gm per subsample | | | |
|-----------|------------------|-----|-----|-----------------------------|
| | I | II | III | |
| Selkirk | 315 | 268 | 305 | <u>Means: gm/subsample</u> |
| | 350 | 258 | 358 | Y = 432.16 a* |
| | 291 | 267 | 251 | G = 393.16 ab |
| | 280 | 329 | 261 | E = 353.50 b |
| Manitou | 225 | 155 | 244 | S = 294.41 c |
| | 242 | 164 | 244 | M = 222.41 d |
| | 217 | 228 | 238 | P = 198.41 d |
| | 212 | 232 | 268 | |
| Era | 419 | 344 | 391 | * = Duncan's Multiple range |
| | 400 | 330 | 368 | Test; 5% level. |
| | 300 | 323 | 350 | C.V. = 19% |
| | 333 | 343 | 341 | |
| Yecora 70 | 441 | 407 | 462 | |
| | 493 | 417 | 416 | |
| | 435 | 411 | 386 | |
| | 444 | 461 | 413 | |
| Glenlea | 478 | 377 | 408 | |
| | 459 | 344 | 419 | |
| | 358 | 350 | 391 | |
| | 386 | 407 | 341 | |
| Pitic 62 | 162 | 92 | 328 | |
| | 114 | 220 | 243 | |
| | 180 | 110 | 255 | |
| | 175 | 226 | 276 | |

APPENDIX 4.2.2

TRIAL B. Grain Yield per Plant

| | gm/plant | | | |
|-----------|----------|-------|-------|-----------------------------|
| | I | II | III | |
| Selkirk | 14.54* | 12.47 | 13.82 | <u>Means: gm/plant</u> |
| | 13.49 | 11.27 | 15.18 | |
| | 15.35 | 13.36 | 13.77 | |
| | 13.75 | 12.74 | 10.01 | |
| | 12.90 | 11.67 | 14.30 | |
| Manitou | 9.82 | 10.62 | 10.45 | G = 22.88 a* |
| | 9.96 | 8.97 | 9.17 | E = 16.99 b |
| | 10.27 | 9.01 | 12.74 | Y = 16.28 bc |
| | 10.62 | 8.92 | 10.68 | P = 14.22 cd |
| | 10.66 | 8.31 | 11.68 | S = 13.24 cd |
| Era | 15.33 | 19.48 | 18.53 | M = 10.13 e |
| | 16.28 | 17.25 | 18.79 | General mean = 15.62 |
| | 13.99 | 23.64 | 16.74 | C.V. = 19% |
| | 14.60 | 17.46 | 17.16 | * = Duncan's Multiple-range |
| | 12.57 | 15.29 | 17.77 | test; 5% level. |
| Yecora 70 | 13.25 | 18.49 | 17.62 | |
| | 13.11 | 17.84 | 15.63 | |
| | 15.86 | 15.95 | 16.25 | |
| | 15.53 | 18.71 | 16.27 | |
| | 14.43 | 17.25 | 17.99 | |
| Glenlea | 14.23 | 22.35 | 26.01 | |
| | 22.90 | 23.72 | 23.17 | |
| | 22.00 | 24.66 | 25.65 | |
| | 24.78 | 20.67 | 22.41 | |
| | 23.95 | 21.83 | 24.87 | |
| Pitic 62 | 14.73 | 14.72 | 15.92 | |
| | 11.64 | 14.78 | 15.23 | |
| | 11.80 | 12.98 | 11.97 | |
| | 16.53 | 15.25 | 16.18 | |
| | 13.41 | 11.63 | 16.49 | |

* = Each subsample is the average of the grain yield of 10 plants.

APPENDIX 4.3.1

TRIAL A — Dry matter — SAMPLE No. 1

| | DM — gr/m ² | | | (block number) |
|------|------------------------|----------------|----------------|----------------------|
| | I | II | III | |
| S(1) | 43.15 37.71 | 71.43 62.50 | 80.36 66.96 | |
| | | | | <u>Means (2)</u> |
| | | | | G = 66.47 a |
| M | 37.20 32.74 | 41.67 50.60 | 47.62 40.18 | Y = 64.73 a |
| | | | | S = 60.35 a |
| E | 52.08 52.08 | 59.52 56.55 | 66.96 53.57 | E = 56.79 a |
| | | | | P = 53.32 ab |
| Y | 56.55 46.13 | 80.36 61.01 | 62.50 81.85 | M = 41.67 b |
| | | | | General mean = 57.22 |
| G | 46.13 59.52 | 80.36 63.99 | 74.40 74.40 | C.V. = 13% |
| P | 38.69 43.15 | 53.57 53.57 | 74.40 56.55 | |

(1) S = Selkirk, M = Manitou, E = Era, Y = Yecora 70, G = Glenlea, P = Pitic 62.

(2) Duncan's Multiple-range test. Values with different letters differ significantly at 5% level.

APPENDIX NO. 4.3.2

TRIAL A — Dry matter — SAMPLE NO. 2

| | DM — gr/m ² | | | |
|---|------------------------|-----|-----|--------------------|
| S | 205 | 236 | 222 | |
| | 234 | 300 | 232 | |
| | | | | <u>Means</u> |
| M | 136 | 177 | 221 | G = 245 a |
| | 136 | 186 | 160 | S = 233 a |
| E | 206 | 219 | 176 | Y = 223 ab |
| | 166 | 209 | 236 | E = 203 bc |
| Y | 198 | 248 | 259 | P = 185 cd |
| | 198 | 241 | 192 | M = 170 d |
| G | 210 | 279 | 269 | |
| | 211 | 237 | 262 | General mean = 210 |
| | | | | C.V. = 8% |
| P | 129 | 209 | 192 | |
| | 170 | 225 | 182 | |

APPENDIX NO. 4.3.3

TRIAL A — Dry matter — SAMPLE NO. 3

| | DM — gr/m ² | | | |
|---|------------------------|-----|-----|--|
| S | 946 | 510 | 493 | |
| | 353 | 686 | 456 | |
| | | | | <u>Means</u> |
| M | 462 | 440 | 441 | S = 516 |
| | 410 | 428 | 418 | Y = 471 |
| E | 372 | 453 | 424 | G = 469 |
| | 420 | 379 | 451 | M = 433 |
| Y | 527 | 493 | 499 | E = 416 |
| | 378 | 515 | 417 | P = 377 |
| G | 480 | 415 | 576 | |
| | 402 | 412 | 530 | General mean = 447 |
| | | | | C.V. = 14% |
| P | 358 | 384 | 350 | |
| | 413 | 380 | 377 | There is no significant difference at 5% level. |

TRIAL A — Dry matter — SAMPLE NO. 4

| | DM — gr/m ² | | | |
|---|------------------------|------|-----|---|
| S | 771 | 791 | 779 | |
| | 767 | 773 | 803 | |
| M | 698 | 688 | 785 | Means |
| | 779 | 801 | 750 | |
| E | 770 | 761 | 779 | Y = 874 |
| | 738 | 797 | 778 | G = 820 |
| Y | 977 | 930 | 780 | S = 780 |
| | 893 | 864 | 801 | E = 770 |
| G | 776 | 1117 | 810 | P = 758 |
| | 763 | 794 | 662 | M = 750 |
| P | 851 | 762 | 726 | General mean = 792 |
| | 638 | 861 | 707 | C.V. = 10% |
| | | | | There is no significant difference at 5% level. |

TRIAL A — Dry matter — SAMPLE NO. 5

| | DM — gr/m ² | | | |
|---|------------------------|------|------|---|
| S | 721 | 933 | 894 | Means |
| | 933 | 1059 | 891 | |
| M | 810 | 973 | 810 | Y = 968 |
| | 941 | 994 | 885 | G = 956 |
| E | 847 | 868 | 944 | S = 905 |
| | 855 | 902 | 706 | P = 903 |
| Y | 976 | 1093 | 956 | M = 902 |
| | 882 | 961 | 942 | E = 854 |
| G | 964 | 907 | 1031 | General mean = 915 |
| | 902 | 970 | 979 | C.V. = 6% |
| P | 922 | 965 | 917 | There is no significant difference at 5% level. |
| | 867 | 972 | 774 | |

APPENDIX NO. 4.3.6

TRIAL A — Dry matter — SAMPLE NO. 6

| | DM — gr/m ² | | | |
|---|------------------------|------|------|---------------------|
| S | 856 | 1155 | 944 | <u>Means</u> |
| | 987 | 1109 | 1033 | G = 1153 a |
| M | 1046 | 1054 | 875 | Y = 1117 ab |
| | 969 | 1061 | 848 | E = 1087 ab |
| E | 1122 | 1091 | 1149 | P = 1032 ab |
| | 945 | 1174 | 1040 | S = 1014 ab |
| Y | 1217 | 1041 | 1214 | M = 975 bc |
| | 1084 | 1247 | 903 | General mean = 1063 |
| G | 1199 | 1172 | 1176 | C.V. = 7% |
| | 1146 | 1130 | 1099 | |
| P | 1172 | 1051 | 987 | |
| | 935 | 1047 | 1004 | |

APPENDIX NO. 4.3.7

TRIAL A — Dry matter — SAMPLE NO. 7

| | DM — gr/m ² | | | |
|---|------------------------|------|-----|--------------|
| S | 770 | 849 | 716 | <u>Means</u> |
| | 800 | 865 | 786 | G = 1018 a |
| M | 885 | 913 | 883 | E = 927 ab |
| | 818 | 786 | 777 | Y = 904 ab |
| E | 1133 | 790 | 977 | P = 851 b |
| | 874 | 802 | 988 | M = 826 b |
| Y | 1009 | 940 | 810 | S = 797 b |
| | 915 | 916 | 839 | C.V. = 11% |
| G | 1028 | 1083 | 988 | |
| | 1044 | 1057 | 915 | |
| P | 846 | 1036 | 781 | |
| | 772 | 731 | 942 | |

APPENDIX NO. 4.3.8

TRIAL B — Dry matter — SAMPLE NO. 2

| | DM — gr/plant | | | Means |
|----|---------------|-----|-----|---------------------|
| S. | 1.6 | 2.6 | 2.3 | G = 2.73 a |
| M. | 1.3 | 1.7 | 1.7 | Y = 2.53 a |
| E. | 1.7 | 1.8 | 1.7 | P = 2.33 ab |
| Y. | 1.7 | 3.3 | 2.6 | S = 2.17 abc |
| G. | 2.4 | 2.9 | 2.9 | E = 1.73 bc |
| P. | 2.4 | 2.2 | 2.9 | M = 1.57 c |
| | | | | General mean = 2.18 |
| | | | | C.V. = 15% |

APPENDIX NO. 4.3.9

TRIAL B — Dry matter — SAMPLE NO. 3

| | DM — gr/plant | | | Means |
|----|---------------|-----|-----|---------------------|
| S. | 4.9 | 7.7 | 7.7 | P = 8.67 a |
| M. | 5.9 | 6.5 | 5.0 | G = 8.13 ab |
| E. | 4.9 | 6.7 | 7.0 | Y = 7.30 abc |
| Y. | 5.6 | 8.7 | 7.6 | S = 6.77 bc |
| G. | 7.1 | 8.8 | 8.5 | E = 6.20 c |
| P. | 8.8 | 9.7 | 7.5 | M = 5.80 c |
| | | | | General mean = 7.14 |
| | | | | C.V. = 12% |

APPENDIX NO. 4.3.10

TRIAL B — Dry matter — SAMPLE NO. 4

| | <u>DM — gr/plant</u> | | | <u>Means</u> |
|----|----------------------|------|------|--|
| S. | 23.1 | 40.6 | 20.3 | S = 28.0 |
| M. | 16.1 | 15.1 | 16.4 | E = 23.8 |
| E. | 32.3 | 19.7 | 19.4 | G = 23.1 |
| Y. | 5.8 | 36.2 | 21.7 | Y = 21.2 |
| G. | 24.5 | 23.3 | 21.6 | P = 20.6 |
| P. | 13.8 | 18.9 | 29.2 | M = 15.8 |
| | | | | General mean = 20.63 |
| | | | | There is no significant difference at 5% level. |
| | | | | C.V. = 41% |

APPENDIX NO. 4.3.11

TRIAL B — Dry matter — SAMPLE NO. 5

| | <u>DM — gr/plant</u> | | | <u>Means</u> |
|----|----------------------|------|------|--|
| S. | 25.9 | 28.5 | 30.0 | P = 33.70 |
| M. | 30.0 | 31.1 | 26.2 | G = 30.53 |
| E. | 30.6 | 23.1 | 31.4 | M = 29.10 |
| Y. | 24.7 | 21.9 | 27.7 | E = 28.37 |
| G. | 30.6 | 30.8 | 30.2 | S = 28.13 |
| P. | 32.6 | 43.0 | 30.2 | Y = 24.77 |
| | | | | General mean = 29.10 |
| | | | | There is no significant difference at 5% level. |
| | | | | C.V. = 17% |

APPENDIX NO. 4.3.12

TRIAL B — Dry matter — SAMPLE NO. 6

| | DM — gr/plant | | | Means |
|----|---------------|------|------|----------------------|
| S. | 37.2 | 36.2 | 41.6 | P = 47.50 a |
| M. | 29.5 | 31.7 | 36.6 | G = 46.93 a |
| E. | 41.2 | 36.7 | 43.2 | E = 40.37 b |
| Y. | 31.2 | 31.1 | 36.1 | S = 38.33 b |
| G. | 43.7 | 46.6 | 50.5 | Y = 32.80 c |
| P. | 43.3 | 53.1 | 46.1 | M = 32.60 c |
| | | | | General mean = 39.76 |
| | | | | C.V. = 7% |

APPENDIX NO. 4.3.13

TRIAL B — Dry matter — SAMPLE NO. 7

| | DM — gr/plant | | | Means |
|----|---------------|------|------|----------------------|
| S. | 35.5 | 39.1 | 38.6 | G = 48.93 a |
| M. | 33.2 | 32.2 | 35.3 | P = 43.93 b |
| E. | 40.7 | 42.4 | 38.0 | E = 40.37 bc |
| Y. | 33.2 | 32.9 | 28.9 | S = 37.73 cd |
| G. | 48.2 | 49.0 | 49.6 | M = 33.57 de |
| P. | 39.6 | 43.5 | 48.7 | Y = 31.67 e |
| | | | | General mean = 39.37 |
| | | | | C.V. = 7% |