



A GENETICAL ANALYSIS OF YIELD AND YIELD  
COMPONENTS IN AN 8-PARENT DIALLEL  
CROSS OF SPRING BARLEY  
(Hordeum vulgare, L.)

by

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ABSTRACT

An 8 x 8 diallel experiment involving parental and F<sub>2</sub> progenies was conducted in the field at the Uyole Agricultural Centre, Mbeya, Tanzania in the 1977-78 growing season. The aim was to obtain information on the magnitude and type of genetic variability for yield and its components, to estimate the magnitude of the various genetic components and to investigate the nature and magnitude of the correlations between yield and its components.

Results indicate that additive and non-additive variation was present for all characters measured. The non-additive portion was greater than the additive portion for all characters except number of ears per plant. Dominance was found for all characters and it was the main source of non-additive variation. Average degree of dominance for the characters measured varied from partial dominance to overdominance.

Epistasis was found to be small, and it was detected in the characters plant height, number of grain per ear, grain yield per plant and 1000 grain weight.

Overall heterosis was found in the characters number of days to heading, plant height, ear length, grain yield per plant and 1000 grain weight. However, its magnitude and direction was specific to the cross.

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Heterosis for yield was generally associated with heterosis for the yield components, particularly number of ears per plant, number of grains per ear, earliness and plant height. Maternal effects were found for grain yield per plant and 1000 grain weight.

Estimates of narrow sense heritability showed that all characters, except plant height, had values greater than 40%. Number of ears per plant showed the highest value (93.0%) while plant height had the lowest (24.3%).

High yield per plant and high 1000 grain weight were associated with dominance, while lateness and high number of grains per ear were associated with recessiveness.

Correlation studies showed that the characters number of ears per plant, plant height, ear length, grain yield per plant and 1000 grain weight were positively intercorrelated. Number of grains per ear was negatively correlated with number of ears per plant and 1000 grain weight. Number of days to heading showed significant negative correlation with all characters except ear length and number of grains per ear.

The implications of the results to barley improvement are discussed.

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## 1. INTRODUCTION

Barley (Hordeum vulgare, L.) is the fourth most important grain cereal in the world (JANICK et al., 1974). Leading world producers are the Soviet Union, France, United Kingdom, United States and Canada. Others are Turkey, India and Morocco. In 1976, barley occupied 93.5 million hectares and grain production amounted to 189.7 million metric tons (FAO, 1976a). Most of the grain is used for animal feed. About a third is used for making malt which is mainly used in the brewing industry (JANICK et al., 1974).

Presently, barley ranks sixth in importance among the cereals in Tanzania after maize, sorghum, millets, rice and wheat. FAO (1976a) estimated the area under commercial barley in Tanzania at 2000 hectares and an annual grain production of about 2000 tons. Despite its present low hectarage, the crop is likely to be important in the future because its demand is growing rapidly.

The major proportion of the barley produced in Tanzania is used for malting. Substantial amounts are also used for human consumption, especially in the higher mountainous areas around the Mporoto hills in the Southern Highlands. Insignificant amounts are currently used for livestock feed.

Most of the barley used in the country is now

imported, so that it is contributing substantially to the foreign exchange drain. In 1976, Tanzania imported 204 metric tons of barley worth US \$33000 (FAO, 1976b). In order to avoid the dependence on foreign sources of supply and loss of foreign exchange, all of the barley requirements should be produced within the country.

Attempts for barley improvement in Tanzania have suffered big setbacks since the first introduction. One of the major reasons has been the lack of adequate research in the country. Research and Proctor, varieties which were bred in Australia and Britain respectively have remained the standard East African malting types. These varieties have low-medium yield, are late maturing and are susceptible to the common barley diseases.

The fulfilment of the National objective of self-sufficiency in this crop can be achieved if yields per hectare and the area under cultivation can be increased. This will require, among other things securing of more productive and agronomically desirable varieties. The varieties must also be widely adapted and able to give high yields consistently. This may be achieved by improvement of present varieties or substituting these for better types.

Crop improvement in the world has been achieved through one or more of the following conventional approaches: The introduction of better varieties from

other places, the selection from land varieties or the introduced varieties, and hybridization followed by selection.

In Tanzania, introduction could be expected to bring sizable immediate improvement in barley production. However, experience from elsewhere has shown that it is not easy to find a variety which is "tailor made" for a certain type of condition when it was bred to fit a different set of conditions. Over the last few decades, breeders around the world have concentrated on breeding crops to suit their own specific areas and uses.

The second approach is also not very appropriate to Tanzania. There are neither land varieties to select from nor a long history of barley cultivation in the country. Reselection from existing cultivars is therefore unlikely to produce worthwhile improvements.

Hybridization followed by selection, then, is perhaps the most appropriate. Desirable attributes found in different varieties from the world collections can be combined in new varieties by hybridization. By this method, new varieties can be produced to fit new environments.

The success of any such programme and the synthesis of better genotypes requires a proper understanding of the genetic basis for the improvement of yield and other

important traits. Various methods are currently available for investigating the genetical properties of potential breeding material (KEARSEY, 1965). Of these, the diallel method has been extensively used (MATZINGER, 1963). Apart from helping the breeder in choosing parents for breeding, these methods also guide the breeder in his choice of the breeding procedure.

Another important aspect in yield improvement is the relationship between yield and yield subcharacters. These relationships help the breeder in his selection programme, for although the final goal is high yield and/or quality, certain aspects of plant morphology may enable easier and faster improvement in yield than when selection is done on the basis of yield alone.

At present information on the variability, mode of inheritance and type of gene action conditioning yield and its components is conflicting. Similarly, the magnitudes and nature of correlations between yield and its components are not very clear.

A thorough knowledge of such relationships, among others, will provide a more objective approach towards the attainment of the set breeding goals.

The objectives of the present study are therefore to:

- (i) Obtain information on the magnitude of genetic variability for yield and

its components in selected lines under local conditions.

- (ii) Estimate the magnitude of the various genetic and environmental components influencing yield and its components.
- (iii) Determine the nature and magnitude of the correlations between yield and its component traits.

## 2. LITERATURE REVIEW

Extensive research has been done in different parts of the world on the genetics of yield and its components in barley and considerable literature is available on the subject. However, as far as the author is aware, no such studies have been done in Tanzania. The following is a sample review of published work. It covers the techniques which have been followed in breeding for yield; the mode of inheritance, gene action and heritability of yield and its components and the correlation between characters.

### 2.1. Selection Procedures for Yield Improvement

The main objective of most plant breeding programmes has been to increase yield. The selection procedures used for yield improvement are usually based on one of two models. In the first model, yield is considered to be a single complex character. It has therefore been suggested (AASTVEIT, 1961) that selection should be primarily on the basis of yield. This author considers the interaction of the genotype and the environment as a single characteristic.

The alternative model considers yield to be a product of several subcharacters (components).

According to this model, it should be possible to improve overall yield by assembling in one variety desirable genes governing several subcharacters. Consequently, some workers have analysed these subcharacters which contribute directly or indirectly to yield and which may be more simply inherited. The merits of the two approaches of breeding for yield improvement in barley and other crops have been reviewed by among others, BOYCE et al., (1947), FRANKEL (1947), WILLIAMS (1959), AASTVEIT (1961), ADAMS (1967), GRAFIUS et al., (1976a), SIDWELL et al., (1976) and RASMUSSEN and CANNEL (1970).

The general conclusion arising from the above studies has been that both approaches are useful for the overall success of the programme. In the first case, varieties may show large differences in the components but not so in grain yield and vice versa. There is therefore a need of analysing yield separately. On the other hand genetic analysis, choice of parents for hybridization and selection work can greatly be eased if investigations are done on the subcharacters. However, such a program can only be successful if the components have high heritability and are independent (no linkage or pleiotropy).

Moreover, the components should be positively correlated, physiologically unrelated or related in a positive manner.

## 2.2 Mode of inheritance and gene action for yield and its components

Current interest in varietal improvement of self-pollinated crops like barley, lies mostly in the production of purelines. The technique is based upon fixation of additive gene action and fixable gene interactions (AASTVEIT, 1961; 1964).

Dominance and non-fixable epistasis cannot be utilized in this case, but their existence, direction and magnitude is valuable for the planning and execution of breeding programs. On the other hand where possibilities of producing hybrid barley are being sought, information on the above is invaluable. It is therefore important to specify the different types of gene action influencing yield and its components.

Genetic studies in barley have revealed the presence of both additive and non-additive gene action for the inheritance of yield and its components (FEJER and FEDAK, 1975b; AREVALO et al., 1974; AASTVEIT, 1961; UPADHYAYA and RASMUSSEN, 1967; CHAUDHARY et al., 1974). The relative magnitudes

of additive versus non-additive gene action have differed considerably depending on the source of material and the environments in which they were grown. Further, their relative magnitude is indicative of the extent to which the lines have been selected (GARDENER, 1963, after SPRAGUE and TATUM, 1942).

Most of the non-additive gene action which has been reported for yield and the components was attributed to dominance (ABO-ELENEIN et al., 1975; AASTVEIT, 1961; FEJER and FEDAK, 1975b; AREVALO et al., 1974; RIGGS and HAYTER, 1973). Epistasis has generally been considered to be unimportant (AASTVEIT, 1961), although it was found to significantly affect heading date and number of ears per plant (AASTVEIT, 1961). ABO-ELENEIN (1975) reported epistasis for grain weight.

Unlike in cross-pollinated crops, where the use of hybrids is quite advanced, production of hybrids in self-pollinated crops is relatively a new innovation. This has been mainly due to alleged low hybrid vigour in the latter and the absence of effective and cheap ways of producing hybrid seed. Recent evidence however, indicates that yield heterosis may be considerable. Moreover, ways of producing hybrid seed by the use of

genetic male sterility are also being perfected (HAGBERG et al., 1975; HOCKETT, 1975; RAMAGE, 1975; WEIBE, 1975).

In barley heterosis has been reported by AREVALO et al., (1974); AASTVEIT (1961); FOSTER (1975); UPADHYAYA and RASMUSSEN (1967); FEJER and FEDAK (1975a) and NASR and KHAYRALLAH (1976). Similar results have been reported in wheat by HASSANIEN et al., (1974); LEE (1974); HALLORAN (1975a) and HRASKA (1975); in Sorghum by LINNICK (1974); RUBAIHAYO and MAKUMBI (1976) and KAMBAL et al. (1976) and in garden peas by GRITTON (1975). The magnitudes of heterosis reported for yield have varied considerably. Most authors, however, have reported greater heterosis where diverse parents, with low mean for the character were used.

The type of gene action responsible for heterosis is a subject of much discussion. FEJER and FEDAK (1975a), AASTVEIT (1961), AREVALO et al. (1974) and HALLORAN (1975a) attributed it to dominance and/or overdominance. Other authors (HALLORAN 1975b) reported heterosis to be due to epistasis.

Investigation of possible association between means of characters and dominance or recessiveness revealed that high grain yield, plant height, grain weight and ears per plant to be mostly associated with dominance (HALLORAN, 1975a, b; FEJER and FEDAK, 1975a, AREVALO et al., 1974 and LAU, 1974). HALLORAN (1975a) reported association of high number of grains per ear with recessiveness.

Maternal effects have often been reported to be unimportant in plants. Many authors however, have reported the presence of reciprocal differences in different crops for example barley (FEJER and FEDAK, 1975b and CHAUDHARY et al., 1974) and in wheat (EL-HADDAD, 1974 and HRASKA, 1975). Reciprocal differences have also been reported <sup>in</sup> Sorghum (LINNICK, 1974; RUBAIHAYO and MAKUMBI, 1976) and in water melon (SAGHAN and NATH, 1976). AASTVEIT (1961) reported no reciprocal differences in barley and GRITTON (1975) did not find any maternal effects in garden peas.

### 2.3. Estimates of Heritability

Estimates of heritability of the different characters have varied considerably. They have been influenced by the breeding material used and

the type of environment in which they were grown. In addition, they were affected by the method of computation and the units employed in reporting (i.e. whether heritability in the broadsense or narrow sense). For this reason, it has been difficult to compare heritability values directly.

In self-pollinated crops, like barley, it is the additive variability which is utilized and consequently, it is heritability in the narrow sense which is of interest. Most studies have shown grain yield and number of ears per plant to have low heritability (MANZYUK et al., 1975 and DUWAYIRI, 1974). Grain weight, number of grains per ear, plant height, heading date and ear length have been reported to be quite highly heritable (DUWAYIRI, 1974, MANZYUK et al., 1975).

#### 2.4 Correlation of Yield With its Components

A fairly large number of studies have been done to investigate the relationship between yield and its components in barley, but the correlations have not been consistent in either direction or magnitude.

Among the three primary yield components (number of ears per plant, number of grains per

ear and grain weight), number of ears has been found to be most positively correlated with yield (RASMUSSEN and CANNEL, 1970). AUSTENSON and WALTON (1970) and SIDWELL et al., (1976) reported similar results in wheat. FEJER and FEDAK (1975b) and CROOK and POEHLER (1971) reported no correlation between grain weight and yield. The latter also reported no correlation between grain weight and heading date, plant height, number of ears per plant and number of grains per ear. RUTGER et al., (1967) reported no correlation between yield and any of the components.

The causes of the discrepancies which have been reported concerning the relationship between yield and its components are not well understood. It is possible that they may have a genetic basis, a physiologic basis or both.

ADAMS (1967), working with common beans (Phaseolus vulgaris, L.) suggested that grain yield components were independently inherited characters. He speculated that the negative associations often observed between the components were due to competition for growth substances by the sequentially developing yield components. According to this hypothesis, plants may differ greatly in the components but show no difference

in yield. This is thought to be due to the ability of the components to compensate each other. The role of component compensation has also been discussed by GRAFIUS and THOMAS (1971); HALLORAN (1975a); WILLIAMS (1959); GRAFIUS et al., 1976 a, b.) and UPADHYAYA and RASMUSSON (1967). Most of these authors have shown component compensation to be an important phenomenon.

TANDON et al. (1970) reported the presence of a genetic association between the yield components. They suggested that the genetic association between yield and number of ears per plant was due to linkage, and that between grain weight and number of grains per ear was due to pleiotropy. The findings of TANDON et al. (1970) suggested that it is possible to break the association between yield and number of ears per plant. On the other hand it is not possible to break the relation between grain weight and number of grains per ear because it is affected by the same gene or block of genes.

### 3. MATERIALS AND METHODS

#### 3.1. Materials:

Seven of the eight lines which were used for this study were obtained from a barley collection which is maintained by the Crop Husbandry Department, the Royal Agriculture and Veterinary College, Højbakkergård, Denmark. They were selected from 573 lines which were grown for observation at the Uyolet Agricultural Centre, Mbeya, Tanzania in the 1975-76 growing season. The eighth line, Research, is currently one of the standard varieties used in East Africa. The lines selected originated from various geographical regions and were picked on the basis of contrasting genetic background, morphology, yield and yield components. A more detailed description of the lines is given in Table 1.

All possible crosses (including reciprocals) were made by hand emasculation and pollination in a glasshouse at the Agricultural University of Norway, ÅS, NLH in the winter of 1977. There were fifty six crosses in all.

The  $F_1$ 's so obtained were grown in a glasshouse at ÅS, NLH in the summer of 1977 in order to get  $F_2$  seed. The seed was harvested in October

Table 1: Origin, pedigree and selected characteristics of the lines used for the study.<sup>1</sup>

LINE	ORIGIN	PEDIGREE	NO. OF BIRDS IN BIRDS	STANDARDIZATION	YIELD	ORIGIN WEIGHT
Research <sup>2</sup>	(P <sub>1</sub> ) Australia	Taylor x Plumage Aviator	2	H	H	H
Dady	(P <sub>2</sub> ) Netherlands	(Aglo x Kenda x Aviole var.)	2	H	H	L
Asplund	(P <sub>3</sub> ) Sweden	Selection from a mixed population	6	H	H	L
Doston	(P <sub>4</sub> ) Norway	Opal B x Mandin	2	H	H	H
Jet	(P <sub>5</sub> ) Ethiopia	-	2	H	L	H
Oderbrucker	(P <sub>6</sub> ) Germany	-	6	L	H	L
Herzo	(P <sub>7</sub> ) Norway	from a natural cross Asplund x mandin	6	L	H	L
GI5791	(P <sub>8</sub> ) Ethiopia	Selection from Taylor collection, Uppsala	2	H	H	H

<sup>1</sup> Information from various sources

<sup>2</sup> Currently one of the standard eating varieties in East Africa

P<sub>1</sub>, P<sub>2</sub>, ..... P<sub>8</sub> = Designation of the parental lines Research, Dady, ..... GI 5791 respectively used in this study.

H = High; L = Medium; T = Low

- No information available

1977, and was treated with "Panogen" Mercury compound.

Material for this investigation consisted of the eight parents and their fifty-six F<sub>2</sub> crosses.

### 3.2. Methods:

The trial was conducted in the experimental fields at Uyole Agricultural Centre, Mbeya, Tanzania in the 1977-78 growing season. The Centre is located 8° 55' S and 32° 33' E at an altitude of about 1800 meters above sea level. The soil is a loamy clay originating from volcanic pumice. Pyrethrum had been grown the previous season.

The experiment was a randomized complete block with three replicates. Thirteen seeds, each seed to a hole were spaced 15 cm. within the row with the aid of a measured planting stick. The rows were 25 cm. apart made with a marking board. The parental entries had one row per replicate, while the F<sub>2</sub>'s had two. Sowing was done on the 2nd of March 1978, which is the optimal planting time of this crop in the area.

Weeding was first done by spraying with MCPA at 1.0 kg./ha. at the 4-leaf stage of barley. This was followed by two clean weedings by hand.

Fertilization was done with Triple superphosphate and Calcium Ammonium Nitrate. Triple superphosphate at a rate of 20 kg.P/ha, was incorporated into the soil in the last harrowing before planting. Calcium Ammonium Nitrate at a rate of 20 kg. N/ha, was broadcast by hand 4 weeks after planting. Copper as Blitox 50, at a rate of 1.0 kg./ha, was sprayed in order to correct copper deficiency, which has been reported in this area (NILSSON, 1974; MATTSOON and MÄRMI, 1976). No attempts were made to control diseases and pests.

Records were taken on individual plants and then averaged to give means for analysis. The characters measured were:

- (i) Date of heading - Number of days from sowing until the awns were first visible.
- (ii) Ears per plant - Number of ears bearing seed at harvest.
- (iii) Plant height - The height from the soil surface to the neck of the ear of the tallest tiller.
- (iv) Ear length - Length from the neck of the ear to the tip of the furthest fertile spikelet.
- (v) Grains per ear - Number of grains per ear

of the tallest tiller at harvest.

- (vi) Grain yield - weight of air-dry grain per plant.
- (vii) Grain weight - Two samples of 200 grains each were obtained from seed composited from about 10 plants from each entry. Their average weight was multiplied by five to obtain 1000 grain weight.

### 3.3. Analysis:

Diallel analysis has extensively been used for investigating the genetical properties of groups of homozygous parental lines. The theory and practice underlying its use is detailed in HAYMAN (1954 a, b), JINKS (1954, 1956) and MATHER and JINKS (1971) among others. The method provides valuable information on the existence and magnitude of additive and dominance variation in the parental lines. It also provides information on the direction of dominance, order of parental lines with respect to dominant genes and may also detect non-allelic gene interaction.

The method is based on several assumptions (HAYMAN, 1954b; JINKS 1954, 1956; KEARSEY, 1965):

- (i) Diploid individual
- (ii) Normal segregation with no linkage

- (iii) Homozygous parents
- (iv) No multiple allelism
- (v) No epistasis
- (vi) No differences between reciprocal crosses

Briefly, the method involves crossing the parental lines in all possible combinations including selfs, so that if  $n$  lines are used, then  $n^2$  progeny families are obtained. The progeny families are grown, and these provide data from which means, variances and covariances are calculated.

The statistics so obtained can be used to test the adequacy of the additive - dominance (diallel) model in describing inheritance of a character in the group of lines under study. Further, the statistics can be used to estimate genetic and environmental parameters. These are  $D$ , measuring the additive genic component,  $H_1$ ,  $H_2$ , and  $F$  measuring dominance and  $E$  measuring the environmental component.

From these components, the degree of dominance, symmetry of gene distribution and heritability can be estimated.

a. Means:

The expected means for parental and  $F_2$

progenies for a character showing polygenic inheritance is according to the notation of MATHER and JINKS, 1971:

$$P_1 = M + (D)$$

$$P_2 = M - (D)$$

$$\bar{F}_2 = M + \frac{1}{2}(H)$$

where  $P_1$ ,  $P_2$  are the high<sup>and</sup>/low parent respectively

$M$  = Overall mean

$D$  = Additive gene effect

$H$  = Dominance deviation, and can take either sign

b. Variations:

Table 2 shows the expected variances and covariances for the Parental and  $F_2$  progenies. The variance ( $V_r$ ) and the parent - offspring covariance ( $W_r$ ) of members of an array are very important statistics and bear characteristic relationships. These relationships have been used in various ways:

- (i) Testing adequacy of the additive - dominance model in describing inheritance in the material under study: Variation of  $W_r - V_r$  over arrays is expected to be constant if the model is adequate and vice versa (HAYMAN, 1954 b; WHITEHOUSE et al., 1958). If  $W_r - V_r$  shows heterogeneity a change of scale of the data

Table 2: Expectation of variance and covariances for the Parental and  $F_2$  Generation (JINKS, 1956)

STATISTIC	PARENTS	$F_2$
Environmental variance, $E_2$	$E_2$	$E_2$
Variance of Parental means, $V_p$	$D + E_2$	
Mean variance of arrays, $\bar{V}_r$		$1/4D + 1/16H_1 - 1/8F + E_2$
Variance of array means, $V_r$		$1/4D + 1/16H_1 - 1/16E_2 - 1/8F + 1/nE_2$
Mean Parent-offspring covariance of arrays, $\bar{W}_r$		$2D - 1/8F + 1/nE_2$

may be done (e.g. log transformation) to try to see if the heterogeneity could be reduced. Alternatively, parents whose arrays cause the heterogeneity may be removed from the diallel tables and the data reanalysed (HAYMAN, 1954b). This procedure is done until the  $W_r - V_r$  no longer show heterogeneity.

- (ii) Determining the cause of non-additive variation. When the data has satisfied the requirements of the model, the sums  $W_r + V_r$  of the different arrays are similar only if additive gene action is operating. However, if  $W_r + V_r$  do not show constancy over arrays there is an indication that non-additive gene action is present.
- (iii) Showing the degree of dominance and the relative dominance of parental lines: The degree of dominance is shown by the position at which the regression line cuts the  $W_r$  axis. The regression line cuts the  $W_r$  axis above the origin, at the origin and below the origin if there is incomplete, complete and over-dominance respectively. The relative dominance of parental lines is shown by their position

along the line of regression of  $W_r$  on  $V_r$ . Parental lines with low  $W_r$  and  $V_r$  contain a greater proportion of dominant genes. Those with high  $W_r$  and  $V_r$  contain a preponderance of recessive genes for the character.

- (iv) **Detection of epistasis:** Epistasis is usually indicated by the regression line of  $W_r$  on  $V_r$  being significantly different from 1.0. Slopes of less than 1.0 are usually associated with epistasis of the complementary type while those above 1.0 are associated with epistasis of the duplicate type (ALLARD, 1956).
- (v) **Testing for association of mean performance with dominance or recessiveness:**  
Correlations of  $W_r + V_r$  with the corresponding parental means,  $Y_r$  over arrays give information on the relationship between mean performance and dominance or recessiveness. A significant positive correlation indicates association of high mean of a character with recessiveness and vice versa.

c. Analysis of Variance:

Analysis of variance of the diallel can be made if the data has satisfied conditions on which the diallel model is based. According to HAYMAN (1954a) the main effects can be partitioned into

the following components:

A - measures additive variation

B - measures dominance deviation. The dominance component can be further partitioned thus:

$B_1$  - measures direction of dominance (heterosis)

$B_2$  - measures symmetry of genes at loci showing dominance

$B_3$  - measures non-additive variation specific to the cross (corresponds to Specific combining ability (GRIFFING, 1956)).

C - measures reciprocal differences due to the maternal parent

D - measures reciprocal differences due to non-maternal causes.

F - measures the difference between families.

When the experiment is replicated, significance of these components is usually tested against their block interactions. When the experiment is not replicated, all the main effects are tested against the D component. They may also be tested against the pooled block inter-action with families, if Bartlett's test shows homogeneity of variances.

d. Estimation of the genetic and environmental components, degree of dominance, symmetry of gene distribution and heritability

Estimation of the genetic and the

environmental parameters,  $D$ ,  $H_1$ ,  $H_2$ ,  $F$  and  $E_2$  is done by substituting the observed variances and covariances in the expected equations shown in Table 2. For example:

$$V_p = D + E_2$$

$$D = V_p - E_2$$

$$F = 4V_p - \delta W r - 4\frac{(n-2)}{n}E_2$$

The degree of dominance is estimated from the relation  $(H_1/D)^{1/2}$ . A value greater than 1.0 indicates overdominance. A value less than 1.0 indicates incomplete dominance. A value of 1.0 shows complete dominance.

The sign and magnitude of  $F$  shows the relative proportion of dominant and recessive genes in the parental lines. It is positive, if dominants are in excess, and negative if recessives are in excess. If it is 0 dominants and recessives are in equal proportion.

An estimate of the symmetry of distribution of alleles is given by the relation  $\frac{1}{2} H_2/H_1$ . If  $u$  and  $v$  are the alleles with increasing and decreasing effects respectively, equal distribution of these alleles among the parents is indicated if their mean value,  $\overline{uv}$  is at a maximum value of 0.25.

This is a value when their frequencies are  
 $u = v = 0.5$ .

As stated before, it is the additive variation which is of major interest in self-pollinated crops. Hence heritability in the narrow sense is calculated following

CRUMPACKER and ALLARD (1962) as:

$$h^2(NS) = \frac{1/4D}{1/4D + 1/4H_1 - 1/4F + E_2} \times 100 \text{ For the } F_1.$$

For the  $F_2$ , the equation may be modified thus:

$$h^2(NS) = \frac{1/4D}{1/4D + 1/16H_1 - 1/8F + E_2} \times 100$$

e. Relationship between characters:

Simple phenotypic correlations between the progeny means of the different characters were calculated by conventional variance and covariance procedures. The significance of the correlation coefficients were tested according to Table A 11 in SNEDECOR and COCHRAN (1967).

f. Tests of Significance:

In tests of significance of mean squares and correlation coefficients, \*, \*\* and \*\*\* indicate significance at  $P < 0.05$ ,  $P < 0.01$  and  $P < 0.001$  respectively.

#### 4. RESULTS

##### 4.1. General Assessment:

Meteorological data during the growing season is shown in APPENDIX A. The weather at emergence and the early stages of seedling growth was good. After emergence some seedlings were attacked by barley fly (Hylemya arambourgi). Some of these seedlings recovered, but others did not.

In March and early April it was very rainy and humid. This could have caused the exceptionally high incidence of net blotch (Helminthosporium teres) on the barley in that season. There was a clear difference in severity of the disease on the different entries (APPENDIX B).

From about the middle of April, rainfall began to decrease sharply, and at the end of April, stopped completely. This coincided with the onset of heading in most entries. Since moisture is important for grain filling, the late maturing entries could have been adversely affected in this respect.

Closely related to the above was the early onset of leaf rust of barley (Puccinia hordei). This disease is favoured by warm dry weather. There was a difference in severity of attack between the

entries (APPENDIX B).

Some plants appeared to have been damaged by the herbicide. This had the effect of disturbing the development of the ear and the boot. The leaves forming the boot did not open and inside it the ear was curled. This prevented or delayed awn and ear emergence.

A few plants, which were very bushy, were seen in the experimental material. These were randomly distributed and could not be attributed to any known cause. As far as possible plants which showed obvious abnormalities or which deviated very much from the rest were excluded in the calculation of the means.

At harvest, the weather was very dry and windy. Many entries were ready for harvesting at the same time. Since the harvesting operation could not cope with the maturity, some ears (whole or part) snapped from the plants.

#### 4.2. Means, variability and heterosis

The complete data for each parental and  $F_2$  progeny (reciprocals included) mean averaged over blocks is shown in APPENDIX C. Table 3

shows the overall means for the parents and the  $F_2$  crosses.

The magnitude of the standard errors when expressed as percentages of the overall means, indicated that grain yield per plant was the most variable character. Number of ears per plant and number of grains per ear were also quite variable. Number of days to heading was the least variable character. Plant height, ear length and 1000 grain weight also showed low variability.

Comparison of the overall means of the Parents and the  $F_2$ 's (Table 3) showed that the two sets of means differed, at least numerically. This indicates heterosis. Further analysis revealed that except for number of days to heading, heterosis in the other characters was towards higher means. Heterosis for the number of days to heading was towards earliness.

A more detailed analysis of heterosis (APPENDIX D-1 to D-4) showed that the magnitude of heterosis for the different characters differed considerably. Grain yield per plant exhibited the highest mean heterosis (36.2% and 12.7%

Table 3: Overall means and standard errors for parental and F<sub>2</sub> progenies in the 8 x 8 diallel experiment

	No. of days to heading	No. of ears per plant	Plant height (cm)	Ear length (cm)	No. of grains per ear	Grain yield per plant (g)	1000 grain weight (g)
Overall mean	63.30	12.18	79.40	7.85	32.51	13.47	49.36
S.D. as % of mean	10.6	33.6	10.8	12.9	30.6	46.3	17.2
Parental Mean	65.96	10.96	72.25	7.25	29.70	10.32	48.50
F <sub>2</sub> Mean	62.83	12.36	80.42	7.94	32.92	13.93	49.49
F <sub>2</sub> - P	-3.08*	1.40	8.17***	0.69****	3.22	3.61**	0.99

above the mid-parents and high Parents respectively. Grain weight exhibited the lowest value (2.1% and - 10.0% above the mid-parents and high parents respectively. The other characters showed intermediate values. However, within a character, the magnitude and direction of heterosis was not the same between the different crosses (APPENDIX D-1 to D-4). Some crosses showed positive heterosis while others showed negative heterosis and others revealed no heterosis.

Heterosis for yield was associated with heterosis for number of grains per ear, number of ears per plant, plant height and earliness (APPENDIX D-5).

#### 4.3. Testing for goodness of fit of data to the model

Analysis of variance of  $W_R - V_R$  (Table 4) for testing the conformity of the data to the additive - dominance model indicated that the model was adequate for the description of inheritance in all characters measured except plant height. Plant height showed heterogeneity of  $W_R - V_R$  over arrays ( $P < 0.001$ ), indicating that this model was not adequate. When the original data was

Table 4: Mean squares from the analysis of variance of  $W_r - V_r$  and  $W_r + V_r$  for yield and yield components in the 8 x 8 diallel experiment

Source of variation	Deg- of freedom	No. of days to heading	No. of ears per plant	Plant height original data	Log transformed	Ear length	No. of grains per ear	Grain yield per plant	1000 grain weight
33									
$W_r - V_r$ Blocks	2	205.99 ***	9.32	1498.76 ***	572.25 *	0.0354	15.41 **	100.00	218.53
$W_r - V_r$ Arrays	7	16.77	8.38	765.90 **	135.00	0.0046	3.99	33.17	126.32
Error	14	15.32	12.84	109.71	116.85	0.0163	1.57	28.15	98.36
***									
Blocks	2	96.03 ***	136.30	4037.88 ***	2101.93 **	0.3750	4.97 #	1938.92 **	725.56
$W_r + V_r$ Arrays	7	1047.71 ***	265.44	3487.26 ***	962.03 #	0.4206	84.20 #	1214.38 #	1967.28
Error	14	114.79	105.80	466.65	249.84	0.1438	24.94	416.56	1228.76

logarithmically transformed ( $\log_{10}$ ) and reanalysed, the model was found to be adequate.

Significant  $W_r/V_r$  regressions whose slopes did not differ from unity were obtained for plant height, number of days to heading, number of ears per plant and ear length. For number of grains per ear, grain yield per plant and 1000 grain weight the  $W_r/V_r$  regression coefficients differed significantly from unity, probably indicating the presence of epistasis.

Further analysis of  $W_p + V_p$  (Table 4) revealed the presence of non-additive genetic variation for all the characters except for number of ears per plant and 1000 grain weight. The non-additive genetic variation is most probably attributed to dominance.

#### 4.4. Analysis of variance:

Results of the analysis of variance of the diallel tables for yield and its components is shown in Table 5. The main effects were tested against their block interactions.

Additive gene action (A) was found for all the characters measured. Dominance variation

(B) was also significant for all the characters.

Further partitioning of the dominance component indicated significant heterosis ( $B_1$ ) for number of days to heading, Plant height, ear length and grain yield per plant. Comparison of the overall means of the parents and the  $F_2$  crosses (Table 3) shows that overall heterosis was in the direction of early heading while for the other characters it was towards higher yield, taller plants and longer ears. At loci exhibiting dominance, asymmetry ( $B_2$ ) was shown for heading date, number of ears per plant, number of grains per ear and grain yield per plant only. Non-additive gene action not attributed to dominance ( $B_3$ ) was shown in all characters except plant height.

Reciprocal differences attributed to maternal causes (C) were present for grain yield per plant and 1000 grain weight. Differences between reciprocal crosses not attributed to maternal causes (D) were found in the character ear length. For all the characters examined the differences between families were highly significant (Table 5,

Table 5: Mean squares from the analysis of variance of the 8 x 8 diallel experiment for yield and yield components

Source of Variation	Degrees of freedom	No. of days to heading	No. of ears per plant	Plant height	Ear length	No. of grains per ear	Grain yield per plant	1000 grain weight
A	7	1034.14 ***	333.40 ***	0.0252 *	21.22 ***	20.50 ***	765.60 ***	1507.85 ***
B	28	28.11 ***	9.40 ***	0.0030 ***	0.73 ***	0.87 ***	28.43 ***	33.05 ***
B <sub>1</sub>	1	199.64 ***	41.09 ***	0.0369 ***	9.89 ***	2.22 ***	213.27 ***	20.50 ***
B <sub>2</sub>	7	35.15 ***	8.14 *	0.0000	0.15 ***	0.60 ***	19.83 ***	12.95 ***
B <sub>3</sub>	20	17.76 ***	8.25 *	0.0024	0.47 ***	0.61 ***	19.19 ***	40.71 *
C	7	4.38	4.93	0.0004	0.08 *	0.10	8.62 *	20.41 *
D	21	4.40 ***	4.24 ***	0.0003 ***	0.34 ***	0.13 ***	7.29 ***	4.30 ***
T	63	129.40 ***	43.18 ***	0.0047 ***	2.81 ***	2.63 ***	101.09 ***	185.93 ***
Blocks	2	4.19	10.67 ***	0.0050	0.32	0.92	153.29 ***	239.48 ***
Block x A	14	5.48	2.61	0.0086	0.19	0.34	6.79	10.32

Table 5: continued

Source of Variation	Degrees of Freedom	No. of days to heading	No. of ears per plant	Plant height	Ear length	No. of grains per ear	Grain yield per plant	1000 grain weight
Blocks x B	56	3.66	3.68	0.0015	0.10	0.15	5.60	18.55
Blocks x B <sub>1</sub>	2	4.88	6.50	0.0001	0.01	0.28	4.24	15.02
Blocks x E <sub>2</sub>	14	5.10	1.81	0.0014	0.15	0.17	2.08	9.39
Blocks x B <sub>3</sub>	40	3.09	4.19	0.0016	0.09	0.14	6.89	21.93
Blocks x C	14	2.36	2.43	0.0010	0.06	0.09	2.70	5.76
Blocks x D	42	2.88	4.20	0.0003	0.16	0.17	7.28	7.66
Blocks x T	126	3.46	3.59	0.0013	0.13	0.17	5.97	12.53
Total	191	45.01	16.73	0.0028	1.02	0.99	38.39	72.14

item T). However, the response to environments of the parents and the  $F_2$  groups were generally similar. This is indicated by the similar magnitude of the Block x A and Block x B mean squares.

4.5 Estimation of genetic and environmental components, symmetry of gene distribution, degree of dominance and heritability

Estimates of the genetic and environmental components as derived from the expected relationships (Table 2) are shown in Table 6. Also shown are the estimates of the degree of dominance, symmetry of gene distribution and heritability.

The relative magnitudes of the genetic components differed considerably. The additive component ( $D$ ) was smaller than the dominance component ( $H_2$ ) for all characters measured except number of ears per plant.

The relative proportion of dominant and recessive genes as shown by the value of  $F$  indicates that dominant genes were in greater proportion than recessives in conditioning number of ears per plant ( $F$  positive). Recessive genes were in greater proportion than dominants for the other characters ( $F$

Table 6: Estimates of components of genetic variance, degree of dominance, asymmetry of gene distribution and heritability for yield and its components in the 8 x 8 diallel experiment

Character	$\mu$	$H_1$	$H_2$	$D$	$\Sigma$	$(H_1/D)^2$	$\overline{W}$	$h^2$ (MS)
No. of days to heading	67.70	103.50	90.68	-24.53	1.15	1.24	0.22	61.3%
No. of ears per plant	35.29	18.44	27.68	13.48	1.20	0.72	0.38	93.0%
Plant height	102.57	546.23	548.00	-323.40	18.00	2.31	0.25	24.3%
Ear length	166.19	206.54	230.74	-55.07	4.17	1.11	0.44	65.4%
No. of grains per ear	161.35	159.70	234.33	-0.37	5.67	1.03	0.35	45.6%
Grain yield per plant	39.25	36.13	130.90	-53.85	1.99	1.43	0.38	41.0%
1000 grain weight	120.71	56.18	180.06	-35.53	4.19	0.68	0.80	71.3%

negative). The environmental component (E) was smaller than the genetic components.

The estimate of the distribution of alleles indicated that except for number of days to heading and plant height, negative and positive alleles were unequally distributed among the parental lines ( $\bar{uv} \neq 0.25$ ). In most cases, the mean values of  $uv$  were greater than 0.25.

Estimates of the degree of dominance indicated incomplete dominance for number of ears per plant and 1000 grain weight ( $(H_1/D)^2 < 1.0$ ). Number of grains per ear showed complete dominance ( $(H_1/D)^2 = 1.0$ ). Number of days to heading, plant height, ear length and grain yield per plant showed over-dominance ( $(H_1/D)^2 > 1.0$ ).

Narrow sense heritability estimates for all characters were generally high. The highest estimate, 93% was shown for number of ears per plant while plant height had the lowest value (24%).

#### 4.6. Graphical analysis of $W_r$ , $V_r$ :

Regression graphs of  $W_r$  on  $V_r$  for the characters measured are shown in FIGS. 1 - 7. Regression lines for all characters had slopes

which were significantly different from zero, indicating presence of dominance in all characters. In addition,  $W_r/V_r$  regressions for the characters plant height (untransformed data), grain yield per plant and 1000 grain weight had slopes which were significantly different from 1.0, indicating presence of epistasis. When a change of scale (logarithmic transformation) was done for plant height, the slope of the regression line for this character was also not significantly different from 1.0.

The degree of dominance is shown by the position at which the regression line cuts the  $W_r$  axis. The regression lines for all the characters except plant height and ear length cut the  $W_r$  axes significantly above the origin, indicating partial dominance. Plant height and ear length showed complete dominance.

The relative dominance of the parental lines is shown by their position along the  $W_r/V_r$  regression line, the parents closest to the origin having a preponderance of dominant genes, while those which are furthest have an excess of recessive genes. The relative dominance of the parental lines differed for the different characters. The ranking of

the parental lines in order of decreasing dominance was:

No. of days to heading	P <sub>8</sub> , P <sub>5</sub> , P <sub>4</sub> , P <sub>2</sub> , P <sub>3</sub> , P <sub>6</sub> , P <sub>1</sub> , P <sub>7</sub>
No. of ears per plant	P <sub>5</sub> , P <sub>7</sub> , P <sub>6</sub> , P <sub>3</sub> , P <sub>2</sub> , P <sub>8</sub> , P <sub>1</sub> , P <sub>4</sub>
Plant height	P <sub>8</sub> , P <sub>5</sub> , P <sub>1</sub> , P <sub>3</sub> , P <sub>2</sub> , P <sub>4</sub> , P <sub>6</sub> , P <sub>7</sub>
Ear length	P <sub>8</sub> , P <sub>4</sub> , P <sub>2</sub> , P <sub>1</sub> , P <sub>7</sub> , P <sub>5</sub> , P <sub>3</sub> , P <sub>6</sub>
No. of grains per ear	P <sub>4</sub> , P <sub>1</sub> , P <sub>2</sub> , P <sub>3</sub> , P <sub>6</sub> , P <sub>5</sub> , P <sub>7</sub> , P <sub>3</sub>
Grain yield per plant	P <sub>8</sub> , P <sub>5</sub> , P <sub>7</sub> , P <sub>6</sub> , P <sub>2</sub> , P <sub>3</sub> , P <sub>4</sub> , P <sub>1</sub>
1000 grain weight	P <sub>1</sub> , P <sub>8</sub> , P <sub>2</sub> , P <sub>4</sub> , P <sub>6</sub> , P <sub>7</sub> , P <sub>3</sub> , P <sub>5</sub>

4.7. Association of mean performance with dominance or recessiveness

Correlation of  $\bar{A}_r + \bar{V}_r$  with the corresponding parental means,  $\bar{Y}_r$  (Table 7) gave positive and significant correlation coefficients for number of days to heading and number of grains per ear ( $P < 0.01$ ). This indicates association of lateness and high grain number with recessiveness.

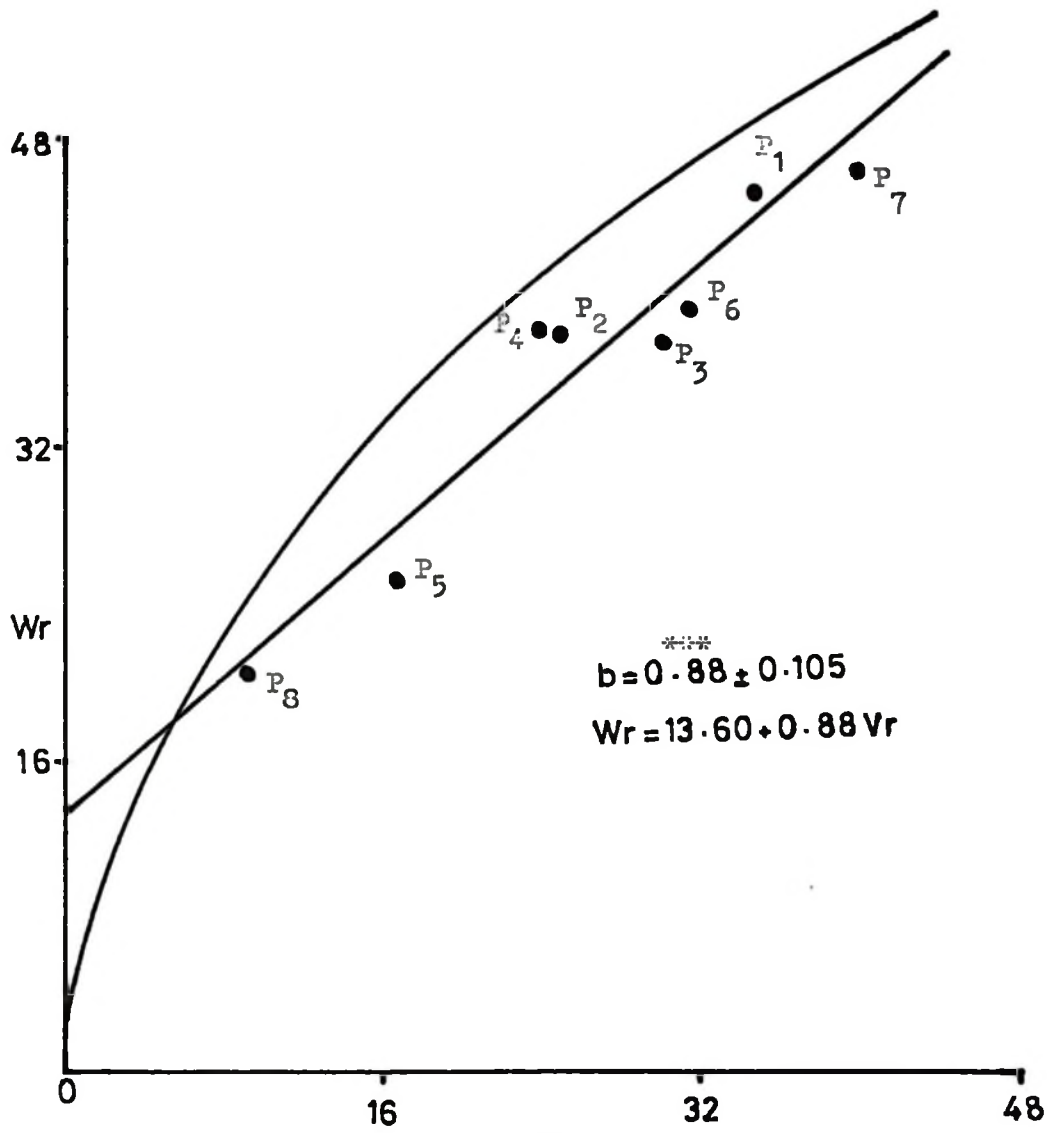


FIG. 1:  $W_r, V_r$  graph for number of days to heading.

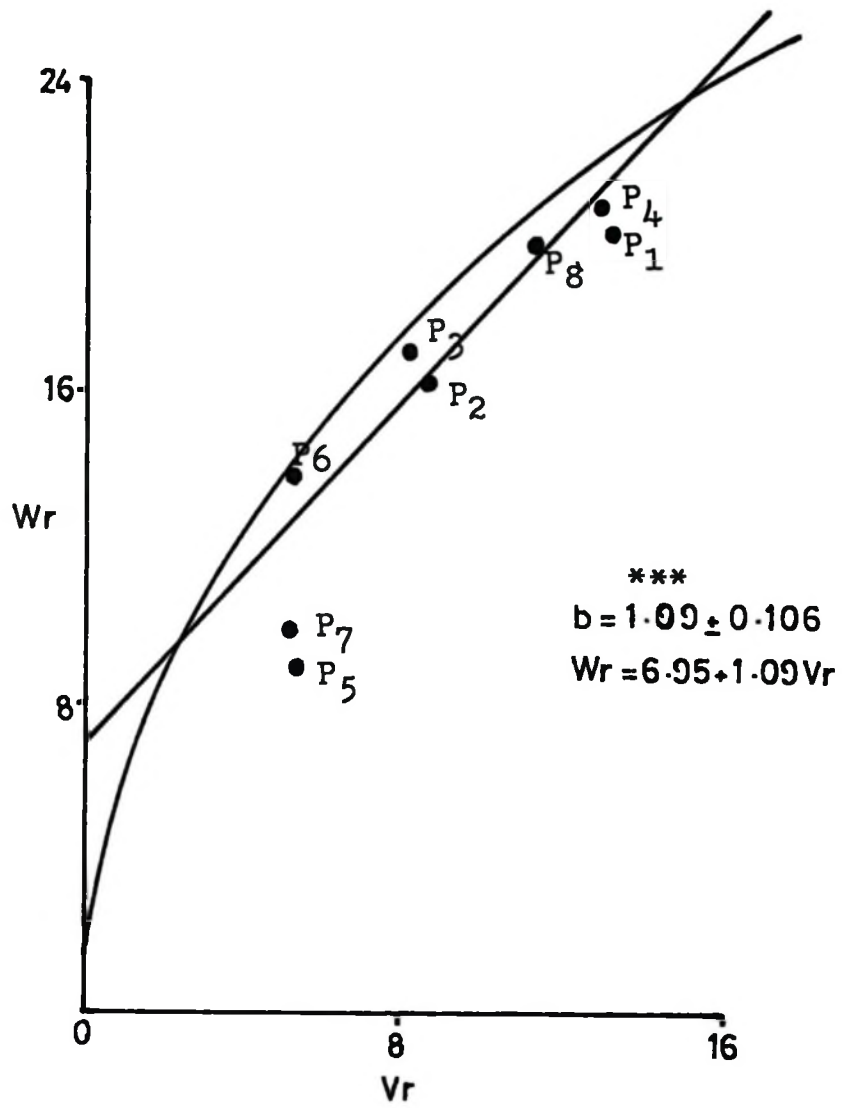


FIG. 2:  $W_r$ ,  $V_r$  graph for number of ears per plant

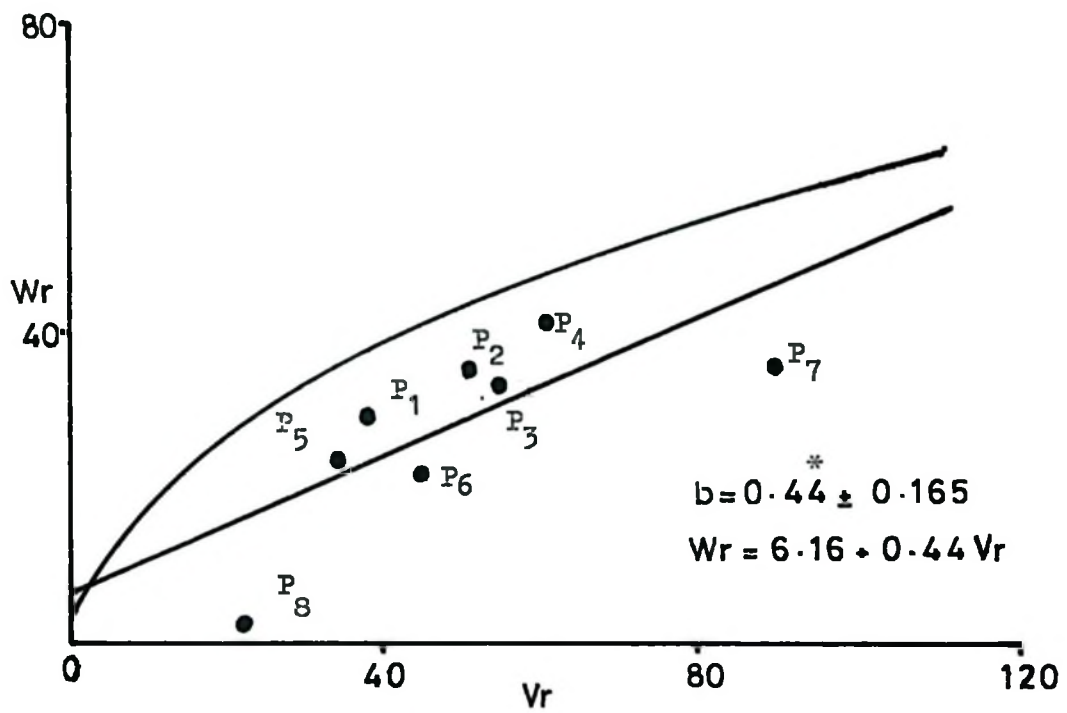
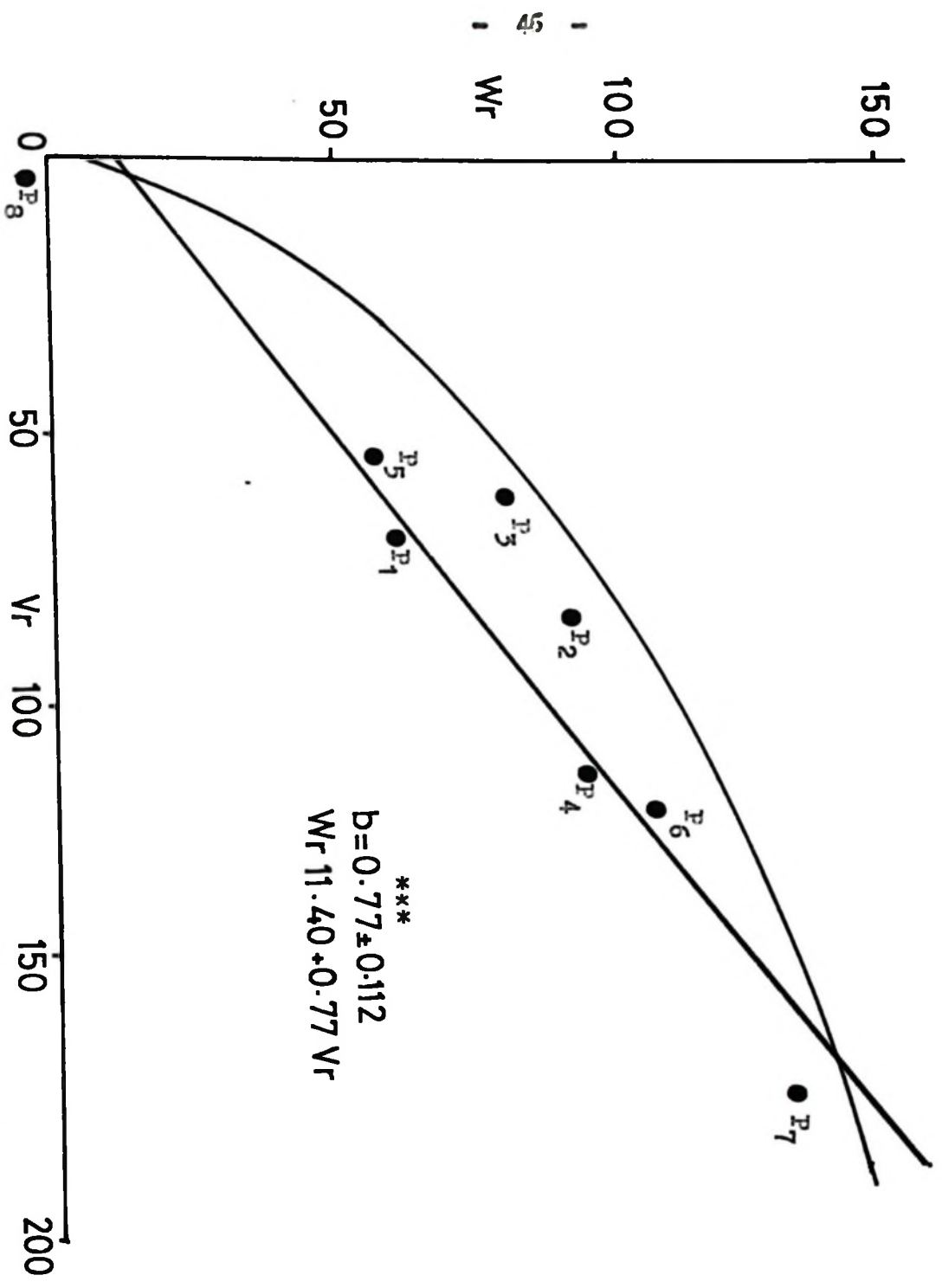


FIG. 3a:  $W_r, V_r$  graph for plant height  
(original data).



2. 4. 1981 12. 2. 1981 (for p1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000)

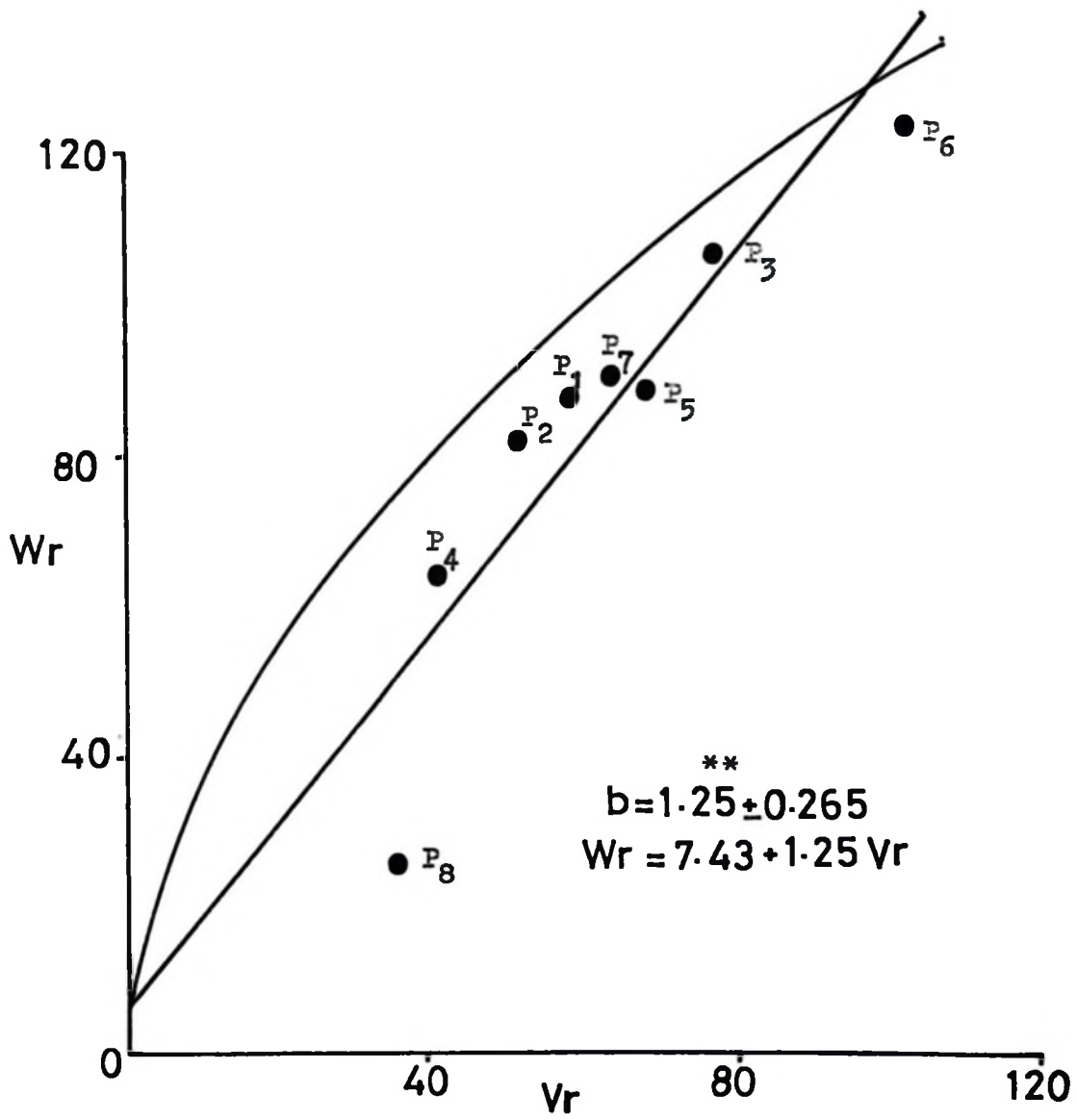


FIG. 4:  $W_r, V_r$  graph for ear length

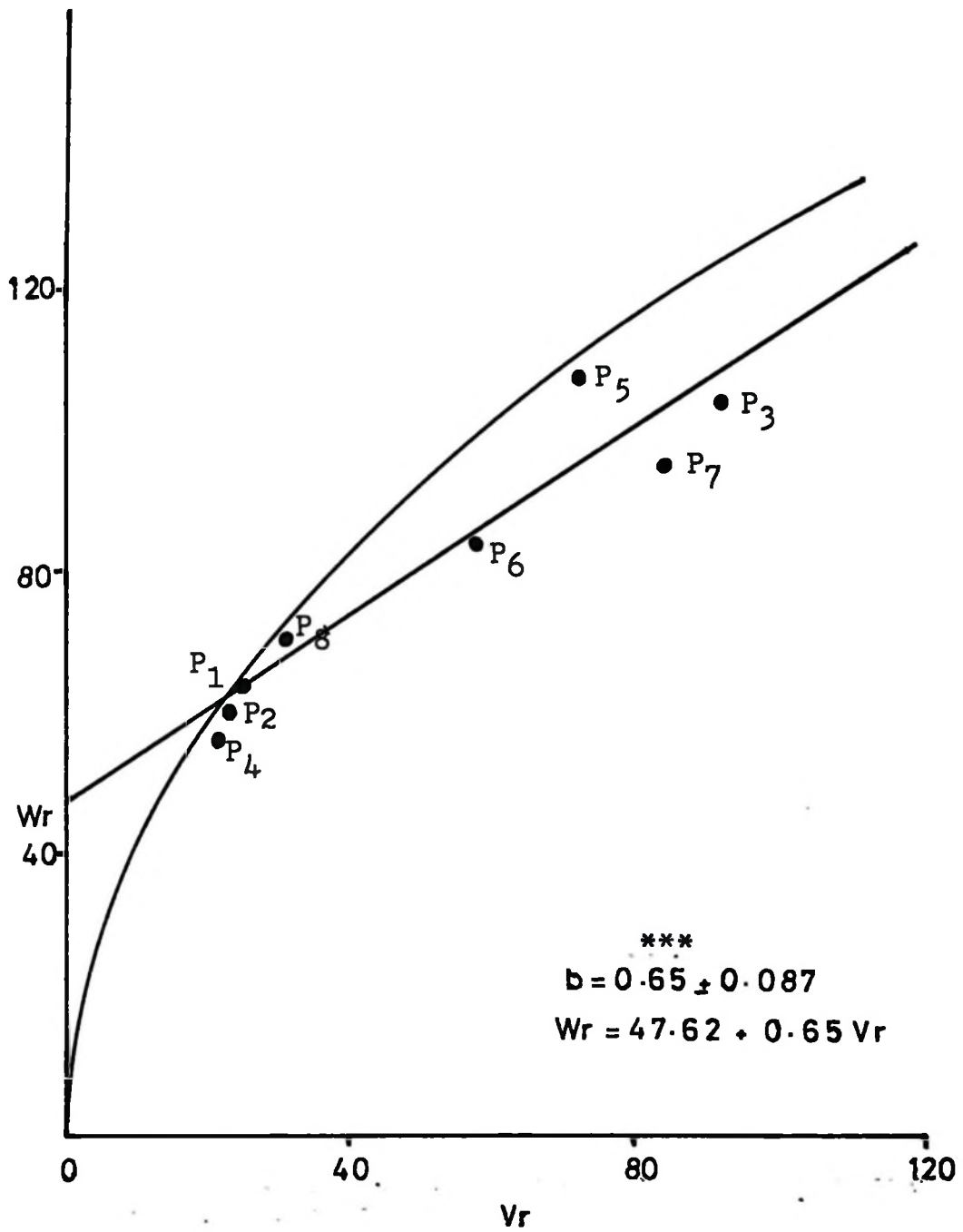


FIG. 5:  $W_r$ ,  $V_r$  graph for number of grains per ear

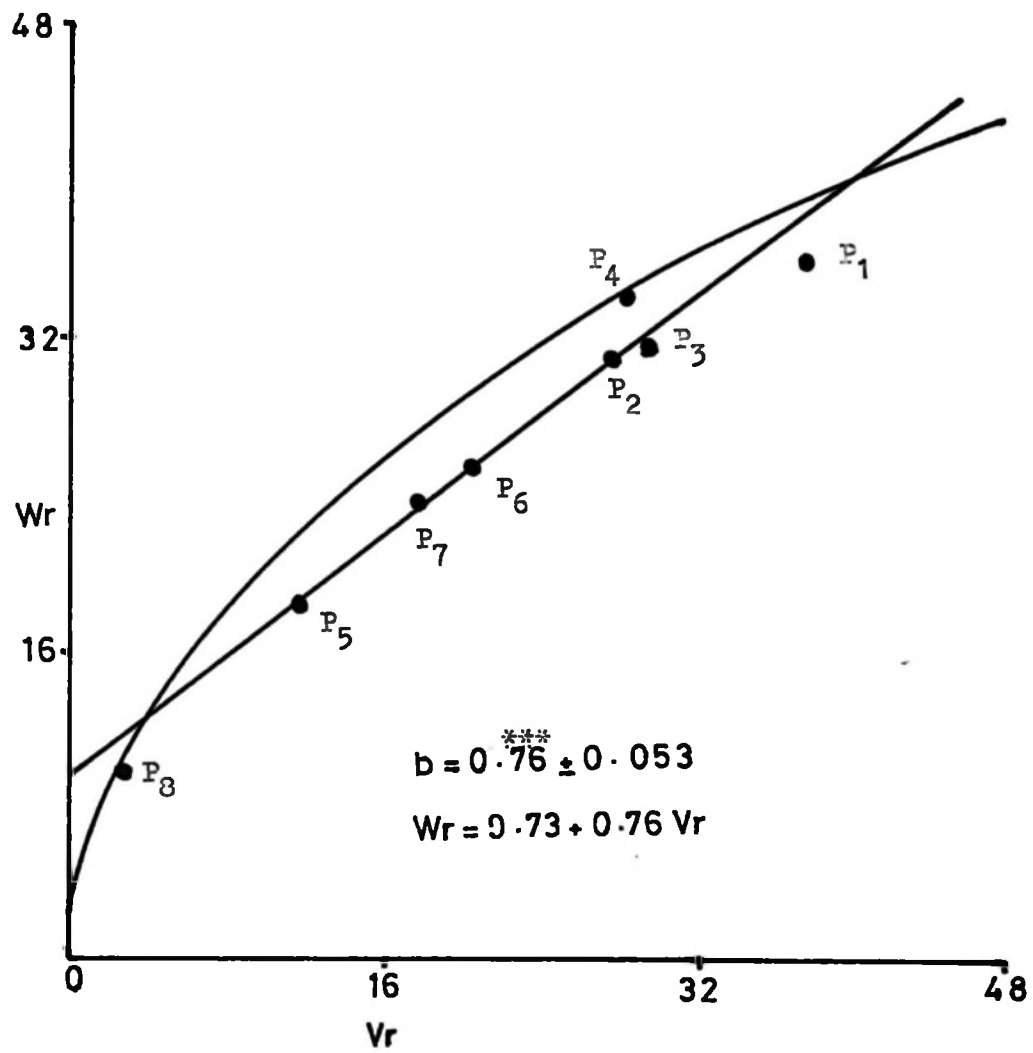


FIG. 6:  $W_r$ ,  $V_r$  graph for grain yield per plant

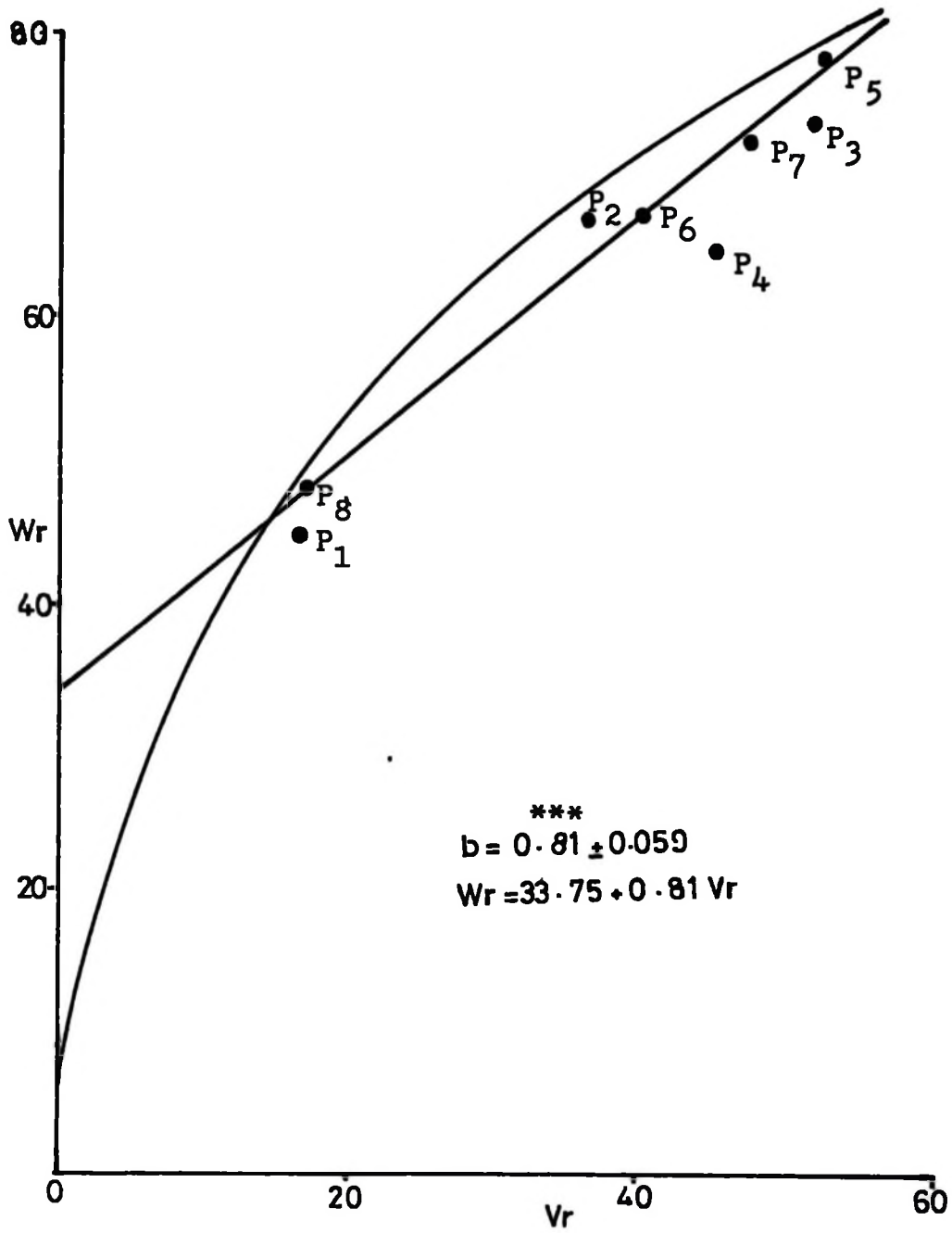


FIG.7:  $W_r$ ,  $V_r$  graph for 1000 grain weight

Grain yield per plant and 1000 grain weight gave significant negative correlation coefficients ( $P < 0.01$  and  $P < 0.05$  respectively), indicating association of high grain yield per plant and high grain weight with dominance.

There were no other significant associations of performance with dominance and recessiveness.

#### 4.3. Association between characters:

Table 8 shows the correlation coefficients between means of all possible pairs of characters. There was a complete positive intercorrelation among the characters number of ears per plant, plant height, ear length, grain yield per plant and 1000 grain weight. The number of days to heading was negatively correlated with all of the above characters except ear length and number of grains per ear.

The number of grains per ear was negatively correlated with the number of ears per plant, ear length and 1000 grain weight. All other correlation coefficients were not significant.

Table 7: Simple correlation coefficients (r) between  $V_1 + V_2$  and the parental mean,  $V_1$ , for yield and its components in the 8 x 8 diallel experiment

Character	r
Number of days to heading	0.61**
Number of ears per plant	0.06
Plant height	-0.36
Ear length	-0.35
Number of grains per ear	0.67**
Grain yield per plant	-0.51**
1000 grain weight	-0.42*

Degrees of freedom = 22

**Table 8: Simple phenotypic correlation coefficients between yield and its components in the 8 x 8 diallel experiment**

	No. of ears per plant	Plant height	Ear length	No. of grains per ear	Grain yield per plant	1000 grain weight
No. of days to heading	-0.70**	-0.85**	-0.23	0.02	-0.81**	-0.40**
No. of ears per plant		0.64**	0.62**	-0.36**	0.87**	0.63**
Plant height			0.44**	0.12	0.82**	0.33**
Ear length				-0.67**	0.45**	0.85**
No. of grains per ear					0.23	-0.81**
Grain yield per plant						
1000 grain weight						0.42**

Degrees of freedom = 62

## 5. DISCUSSION

The main purpose of studies on the genetics of yield is to provide information which will guide the plant breeder in his endeavour to produce superior varieties. In the present study, the mode of inheritance of yield and its components was investigated by the diallel scheme of analysis. The reliability of the information obtained from such analysis depends on how well the assumptions on which it is based (Page 19) are fulfilled, and various methods have been developed for this purpose (HAYMAN, 1954 a, b; JINKS, 1954, 1956; MATHER and JINKS, 1971).

In this study, the conformity of the data to the additive-dominance model was examined, before further analysis, by testing the homogeneity of  $W_r - V_r$  values over arrays (Table 4). The test showed the model to be adequate for all characters measured except for plant height. On  $\log_{10}$  transformation of data for plant height, the model was found to be adequate.

The reason for the failure of the model for plant height seems to be the presence of non-allelic gene interaction or experimental error. Since the data transformation resulted into the conformity of the data to the model and to the improvement in the  $W_r/V_r$  regression coefficient, the gene interaction was probably of a

generalised type (WHITEHOUSE et al., 1958).

For the characters, number of grains per ear, grain yield per plant and 1000 grain weight, the  $W_r/V_r$  regression coefficients differed significantly from unity, thus indicating the presence of gene interaction. The type of gene interaction can be identified by transformation (as shown above) or by omission of one or more of the deviant parental arrays. For example, for grain yield the omission of array of parent 1 improved the regression coefficient from  $b = 0.76 \pm 0.053$  to  $0.88 \pm 0.033$ . Similarly for number of grains per ear the regression coefficient improved from  $b = 0.65 \pm 0.087$  to  $1.01 \pm 0.293$  on omission of arrays of parent 3 and 7. These results indicate that gene interaction of the localized type (WHITEHOUSE et al., 1958) were present for these characters.

Although the omission of certain parents is not an essential feature of the analysis, the exercise helps to identify interacting parents. In this work, this was not done for all the characters and the two examples given above only help to point out such possibilities.

The assumptions on diploidy of organism and homozygosity of parental lines are undoubtedly fulfilled. All cultivated barleys, including Hordeum vulgare, L. have evolved at the diploid level ( $2n = 14$ )(JANICK et al., 1974). Also, all lines used for this study were purelines,

some of which having been released as early as the beginning of this century. Hence, ignoring occurrence of some mutations, seed mixture and the fact that the crop is almost wholly self-fertilized, contamination can be assumed to be minimal and the lines to be reasonably homozygous.

The last assumption, absence of maternal effects, is generally fulfilled for most characters. Small but significant maternal effects were found for grain yield per plant and 1000 grain weight (Table 5, item C).

From the foregoing discussion, it is apparent that the material is amenable to diallel analysis. Results as obtained from this work are therefore discussed in relation to barley improvement. It should however be clear that these results are only applicable to the material examined, and caution should be taken to adopt these results to other material and environments.

The material studied showed wide phenotypic variability in all the characters measured particularly in grain yield, ears per plant and number of grains per ear (Table 3). This is not surprising considering the wide genetic and morphological diversity of the lines.

A casual glance at the means (Table 3) shows that except for the character days to heading, the overall means of the  $F_2$  crosses were greater than those of the

parents, indicating the presence of residual heterosis in  $F_2$ . However, within a character the magnitude and direction of heterosis was specific to the cross (APPENDIX D 1 to D4). Overall heterosis occurred more where gene effects were predominantly in one direction (unidirectional) than when the effects were in opposition (APPENDIX D-1 to D-4). In the latter case, positive and negative effects tend to cancel each other.

The role of maternal effects on the amount of heterosis was generally found to be small (Table 5). For grain yield per plant and 1000 grain weight higher heterosis was obtained if high yielding parents with high grain weight are used as females in crossings.

Judging from the overall magnitude of heterosis in  $F_2$ , there is an indication that heterosis for characters of economic importance, including grain yield, would be considerable in  $F_1$ . This would obviously tempt the breeder to produce  $F_1$  hybrids to exploit this phenomenon. However, before this decision is made, there is need to examine the magnitude and extent of heterosis in the  $F_1$  hybrids and also to explore the feasibility of producing them.

Partitioning of the total variation (Table 5,6) indicated that most of the observed variation was

genetic in origin. Further, both additive and non-additive genetic variation were important in all characters measured. Similar results were obtained from Table 4. The non-additive portion was greater than the additive portion for all characters except for number of ears per plant (Table 6).

Estimates of heritability indicated considerable additive genetic variation in most characters (Table 6). Number of ears per plant showed the highest heritability estimate ( $h^2 = 93.0\%$ ), but this is not typical for this character (cf. the value of 29% reported by RUTGER et al. 1966). This may have arisen as a result of an unidentified systematic cause in the data collection. The low estimate for plant height may partly indicate lack of variability in the lines studied, or large influence of the environment on this character. It could also be a result of the change of scale.

On the other hand, the relatively high magnitude of non-additive variation suggests that most of the lines have been fairly intensely selected for the characters (GARDENER, 1963, after SPRAGUE and TATUM, 1942). This is especially so for the characters number of grains per ear, grain yield per plant and grain weight. In these characters, significant dominance and epistasis were found.

Dominance was the more important source of non-additive variation and the average degree of dominance varied from partial to overdominance (Table 6; FIGS. 1-7). It is interesting to note that the  $W_r/V_r$  method failed to reveal overdominance for number of days to heading, plant height, ear length and grain yield per plant, which were shown by  $(H_1/D)\frac{1}{2}$ , (Table 6).

The estimates of the average degree of dominance as obtained from the genetic components were in some cases higher than those obtained by the  $W_r$ ,  $V_r$  regressions (cf. Table 6 and FIGS. 1-7). This may be due to the fact that the components are estimated from some statistical relationships, whereas the information from the  $W_r$ ,  $V_r$  regression analysis is from observed statistics. Further, the difference would have followed from the lower  $W_r/V_r$  regression coefficients for some of the characters. In both cases however, the estimates are exaggerated if there is gene asymmetry in parents, residual heterozygosity, epistasis or linkage (HAYMAN 1954; JINKS 1954, 1956; MATHER and JINKS, 1971).

The order of dominance of parental lines differed for the different characters (FIGS. 1-7). This partly suggests that the characters are controlled by different genes.

Results of investigation of the relationship

between mean of a character and the degree of dominance (Table 7) showed most of the characters examined to be associated with dominance. This has an important bearing on the effectiveness of selection, especially in early generations. For example, selection for a character would be futile in the  $F_2$  generation if it is associated with dominance or non-fixable epistasis. The problem will be aggravated if the character has low heritability.

For example, it was found in this study that grain yield per plant was associated with dominance and had a relatively low heritability (Table 6, 7). Selection for this character, especially in early generations would not be effective because of the masking effect of dominance, other non-fixable gene action and the environment. Consequently, in order to increase chances of recovering high yielding segregates in later generations, a large proportion of the population has to be selected. This reduction in the selection intensity will lead to a slow progress.

On the other hand selection for earliness and tillering ability would be much easier and considerable progress would be obtained. This is because these characters were shown to be associated with recessiveness and that these characters had high heritability values.

Selection for characters which have high heritabilities but associated with dominance, or characters which are associated with recessiveness but with low heritabilities would lead to intermediate rates of progress. Such will be the case in the selection for high number of grains per ear, high grain weight, ear length and shortness.

The correlation between characters indicated strong negative relationships between the three sequential primary components of yield; number of ears per plant, number of grains per ear and 1000 grain weight. This result may partly lend support to the findings of ADAMS, 1967; ELSOUSSON and GARNEL, 1970; GRAFIUS et al., 1976a,b that the negative correlations are due to competition. However number of ears per plant and 1000 grain weight were positively correlated with yield, indicating that their effects were more than enough to offset the negative effects arising from low number of grains per ear.

The implications of the results from this work on the breeding of barley depend on the breeding goals. Most breeding programmes aim at improving yield; but, often such studies are also designed to improve other characters of economic importance, for example quality, earliness, plant height and resistance to pests, diseases and lodging.

Aspects of quality and resistance to diseases, pests or lodging have not been dealt with in this study. This however does not mean that these factors had no large influence on the characters measured. For example, the attack of the barley by the barley fly (Hylemya arambourgi) is usually followed by excessive tillering; however, it takes sometime before new tillers are formed. Since records were taken on individual plants, irrespective of the gaps, these factors could affect the records of number of ears per plant, number of days to heading and grain yield per plant. Plant space is known to have a considerable influence on tillering and hence grain yield per plant.

The differential reaction of the different genotypes to the diseases would have corresponding influence on some of the characters examined. Where for example the reaction of two genotypes to disease is similar, a late maturing variety would be exposed to disease for a longer time than an early genotype. This would affect the relative performance of the two genotypes. Similar effects on performance of late and early maturing varieties would be obtained in response to moisture stress.

Often the breeder has to make a choice between the production of purelines or hybrids. Important prerequisites for the production of hybrids have been

earlier considered, and will not be further discussed here.

In the production of purelines, the aim is to get lines which are extreme in the character in question. This is achieved by fixation of additive genes and additive - additive interactions (AASTVEIT, 1961, 1964). Results of this study show that the possibility of recovering lines which have higher means than the higher parents for most characters is rather small. The type of gene action controlling these characters is mainly of additive and non-fixable, non-additive type. Therefore in the course of a few generations of inbreeding the lines which will be recovered will have means which are intermediate between the two parents.

For number of grains per ear, grain yield per plant and grain weight there is the possibility that such extreme lines could be recovered, since epistasis was found for these characters. However, for this to happen, this epistasis should be of the complementary, homozygous - homozygous type (AASTVEIT, 1961, 1964).

Another aspect is whether selection should be done directly for the character under consideration, or if it is necessary to devise some indirect methods. Estimates of heritability (Table 6) indicate that selection for

most individual characters, including grain yield, would be effective. Apparently the study suggests that selection will not be effective for plant height ( $h^2_{NS} = 24.3\%$ ). The results of Table 6 and Table 8 suggest that faster progress in yield would be obtained through selecting for higher number of ears per plant or early heading. This would be achieved as the two characters, namely earliness and number of ears per plant are positively correlated with yield (Table 8) and have high heritabilities (Table 6).

Where it is desired to improve several characters, a decision has to be made whether improvement will be achieved by selecting for one character at a time or whether simultaneous improvement of several characters is possible. The study shows that it is possible to get simultaneous advance in two or more of the characters, earliness, high tillering ability, grain yield and grain weight. These characters were positively intercorrelated (Table 8). However, much will depend on how close these characters are linked or whether they are pleiotropically controlled.

Selection in early generations ( $F_2$  and  $F_3$ ) is not likely to be effective. This follows from the presence of considerable non-fixable, non-additive variation and residual heterosis in the  $F_2$  material. Further,

selection will be complicated by the fact that higher means of some characters are associated with dominance (Table 7). It would therefore be desirable to delay selection until the  $F_4$  generation. By this time the effects of non-fixable genetic variation will have diminished.

In order to ease the handling of the hybrid material, the crosses could be grown in bulk in  $F_2$  and  $F_3$ . Selection can then be initiated in the  $F_4$  generation and the conventional pedigree method of selection can be followed.

The results of this work suggest that selection within certain crosses (crosses with parent 8) would be rewarding. Evidence for this conclusion is provided by the outstanding array performance for four of the important characters, namely grain yield, earliness, tillering ability and grain weight (APPENDIX C). From array number 8 it was also evident that the cross  $P_8 \times P_1$  was the best with respect to yield. The breeder working with this material would probably benefit by paying particular attention to this cross in future generations.

While this study has given much indication for the presence of heterosis, the need for further examination of this phenomenon in  $F_1$  hybrids has been

expressed. In addition to this the procedure for producing the  $F_1$  seed needs to be evaluated under Tanzanian conditions. It seems therefore efforts to produce superior purelines should continue while the feasibility of producing hybrids is being investigated.

Since there is much indication that superior inbred lines could be obtained, the material has been kept and will be handled along the guidance provided by this study.

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## 7. APPENDIX

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APPENDIX A: Meteorological data for The Uyole Agricultural Centre,  
Uyole, for the 1977 - 78 growing season

Month	Rainfall (mm)		Temperature (°C)			15.00 hrs. % Relative Humidity	Total Evaporation(mm)
	Total	No. of days	Max	Min.	Mean		
October	4.3	3	27.0	13.4	20.4	48	229.5
November	99.8	9	25.1	13.7	19.4	59	169.0
December	229.3	23	23.3	14.1	18.6	74	138.8
January	100.4	21	22.3	14.7	18.5	78	93.8
February	104.4	19	23.4	14.1	18.8	78	104.2
March	252.1	24	22.6	14.5	18.6	81	129.9
April	88.2	16	23.2	12.7	17.9	71	131.5
May	0.4	1	22.9	9.2	16.1	61	143.5
June	4.8	2	22.0	8.2	15.1	66	122.6
July	0.0	0	21.9	5.8	13.8	51	146.8
August	0.0	0	24.3	7.4	15.8	46	189.2
September	3.1	1	26.2	9.8	18.0	42	234.2

Latitude : 8° 55' S

Longitude: 32° 33' E

Altitude : 1800 m. a.s.l.

↕ Duration of the experiment

APPENDIX B: Assessment of severity of attack by  
the leaf diseases (score 0-9).  
Average over blocks and reciprocals

Parent or Cross	Leaf rust ( <u>Puccinia</u> <u>hordei</u> )	Net blotch ( <u>Helminthosporium</u> <u>teres</u> )
P <sub>1</sub>	4.7	5.0
F <sub>2</sub>	2.0	6.0
P <sub>3</sub>	7.3	6.3
P <sub>4</sub>	6.7	5.7
P <sub>5</sub>	8.7	7.0
P <sub>6</sub>	5.0	6.0
P <sub>7</sub>	8.0	7.0
F <sub>8</sub>	9.0	7.8
P <sub>1</sub> x P <sub>2</sub>	1.6	6.2
P <sub>1</sub> x P <sub>3</sub>	4.4	6.9
P <sub>1</sub> x P <sub>4</sub>	4.4	5.5
P <sub>1</sub> x P <sub>5</sub>	6.3	6.2
P <sub>1</sub> x P <sub>6</sub>	4.5	6.5
P <sub>1</sub> x P <sub>7</sub>	5.0	6.8
P <sub>1</sub> x P <sub>8</sub>	4.4	7.5
P <sub>2</sub> x P <sub>3</sub>	2.5	7.0
P <sub>2</sub> x P <sub>4</sub>	1.5	6.5
P <sub>2</sub> x P <sub>5</sub>	5.4	6.7
P <sub>2</sub> x P <sub>6</sub>	4.5	6.9
P <sub>2</sub> x P <sub>7</sub>	2.5	6.7
P <sub>2</sub> x P <sub>8</sub>	3.9	7.0
P <sub>3</sub> x P <sub>4</sub>	7.0	6.0
P <sub>3</sub> x P <sub>5</sub>	7.2	7.3
P <sub>3</sub> x P <sub>6</sub>	6.0	6.7
P <sub>3</sub> x P <sub>7</sub>	7.0	6.3
P <sub>3</sub> x P <sub>8</sub>	5.8	7.7

## APPENDIX B: continued

Parent or Cross	Leaf rust ( <u>Puccinia</u> <u>hordei</u> )	Net blotch ( <u>Helminthosporium</u> <u>teres</u> )
P <sub>4</sub> x P <sub>5</sub>	7.9	5.3
P <sub>4</sub> x P <sub>6</sub>	5.5	6.2
P <sub>4</sub> x P <sub>7</sub>	6.3	6.5
P <sub>4</sub> x P <sub>8</sub>	5.9	6.8
P <sub>5</sub> x P <sub>6</sub>	7.2	7.2
P <sub>5</sub> x P <sub>7</sub>	7.3	7.5
P <sub>5</sub> x P <sub>8</sub>	8.2	8.0
P <sub>6</sub> x P <sub>7</sub>	5.0	6.5
P <sub>6</sub> x P <sub>8</sub>	6.2	7.2
P <sub>7</sub> x P <sub>8</sub>	6.0	8.2

APPENDIX C: Means of Parental and F<sub>2</sub> progenies, averaged over blocks, for yield and yield components in the 8 x 8 diallel experiment

Parent or Cross	No. of days to heading	No. of ears per plant	Plant height (cm)	Ear length (cm)	No. of grains per ear	Grain yield per plant (g)	1000 grain weight (g)
Research (P <sub>1</sub> )	78.0	8.7	67.0	7.33	25.7	9.54	54.58
Dmlr (F <sub>2</sub> )	71.7	12.0	65.3	7.27	23.3	8.08	46.84
Asplund (F <sub>3</sub> )	66.0	8.3	75.3	5.27	52.0	10.87	29.76
Domen (F <sub>4</sub> )	66.3	6.3	69.3	8.50	17.3	4.04	55.82
Jet (P <sub>5</sub> )	63.0	12.0	69.7	7.47	18.3	8.12	52.32
Oderbrüker (P <sub>6</sub> )	69.7	8.3	74.3	7.17	34.0	8.25	41.31
Herse (P <sub>7</sub> )	63.7	7.0	72.3	5.73	45.3	8.19	41.24
GI 5791 (P <sub>8</sub> )	49.3	25.0	84.7	9.27	21.3	25.47	66.13
P <sub>2</sub> x P <sub>1</sub>	72.7	11.3	71.3	7.80	26.0	9.91	51.84
P <sub>3</sub> x P <sub>1</sub>	69.7	11.3	77.7	7.07	37.7	11.30	45.34
P <sub>4</sub> x P <sub>1</sub>	69.7	11.3	77.0	8.60	22.7	9.72	53.92
P <sub>5</sub> x P <sub>1</sub>	62.3	15.7	81.7	8.53	25.0	15.89	57.30
P <sub>6</sub> x P <sub>1</sub>	68.0	9.0	79.3	8.40	33.7	8.04	46.76

APPENDIX G: continued

Parent or Cross	No. of days to heading	No. of ears per plant	Plant height (cm)	Ear length (cm)	No. of grains per ear	Grain yield per plant (g)	1000 grain weight (g)
P <sub>7</sub> x P <sub>1</sub>	68.3	10.0	73.7	6.97	34.0	9.61	49.28
P <sub>8</sub> x P <sub>1</sub>	58.3	20.0	86.7	8.90	29.0	27.11	56.88
P <sub>1</sub> x P <sub>2</sub>	73.3	9.3	70.3	8.00	22.3	7.79	53.98
P <sub>3</sub> x P <sub>2</sub>	69.0	13.0	70.7	7.07	37.0	13.50	37.18
P <sub>4</sub> x P <sub>2</sub>	69.0	11.7	67.7	8.10	23.7	9.60	52.71
P <sub>5</sub> x P <sub>2</sub>	63.0	14.7	78.0	8.60	24.7	14.15	54.39
P <sub>6</sub> x P <sub>2</sub>	65.0	13.7	80.0	8.17	28.9	12.03	49.02
P <sub>7</sub> x P <sub>2</sub>	66.7	10.7	76.7	7.10	34.3	10.69	44.89
P <sub>8</sub> x P <sub>2</sub>	57.3	19.7	86.7	9.03	28.3	24.75	56.72
P <sub>1</sub> x P <sub>3</sub>	69.3	8.3	74.0	7.20	34.0	8.72	48.64
P <sub>2</sub> x P <sub>3</sub>	69.0	11.3	75.7	6.90	35.0	10.53	47.08
P <sub>4</sub> x P <sub>3</sub>	64.0	10.0	76.7	7.73	31.3	8.55	48.23
P <sub>5</sub> x P <sub>3</sub>	58.7	11.7	84.3	7.13	41.0	14.68	42.13
P <sub>6</sub> x P <sub>3</sub>	56.0	10.0	81.0	7.43	55.7	15.31	36.98
P <sub>7</sub> x P <sub>3</sub>	69.7	7.0	72.7	5.70	54.3	9.57	33.55

APPENDIX C: continued.

Parent or Gross	No. of days to heading	No. of ears per plant	Plant height (cm)	Ear length (cm)	No. of grains per ear	Grain yield per plant (g)	1000 grain weight (g)
P <sub>8</sub> x P <sub>3</sub>	54.0	17.0	95.0	7.50	37.0	25.36	48.51
P <sub>1</sub> x P <sub>4</sub>	70.7	8.7	70.3	8.07	23.3	8.17	56.53
P <sub>2</sub> x P <sub>4</sub>	69.0	14.0	69.3	8.03	19.7	9.49	51.60
P <sub>3</sub> x P <sub>4</sub>	66.3	9.0	76.3	7.30	29.3	7.83	42.21
P <sub>5</sub> x P <sub>4</sub>	59.7	11.7	80.0	8.77	20.7	9.35	53.24
P <sub>6</sub> x P <sub>4</sub>	65.0	8.0	82.0	8.00	30.3	7.16	47.45
P <sub>7</sub> x P <sub>4</sub>	62.7	9.3	73.3	8.47	31.3	8.82	46.99
P <sub>8</sub> x P <sub>4</sub>	55.3	18.0	91.7	9.47	25.7	22.69	62.05
P <sub>1</sub> x P <sub>5</sub>	63.7	13.7	81.0	8.63	26.3	14.75	54.66
P <sub>2</sub> x P <sub>5</sub>	64.3	15.0	77.3	8.70	24.3	13.32	52.61
P <sub>3</sub> x P <sub>5</sub>	59.3	14.0	80.3	6.63	42.3	16.32	40.33
P <sub>4</sub> x P <sub>5</sub>	60.0	13.7	75.7	8.30	23.7	11.21	54.47
P <sub>6</sub> x P <sub>5</sub>	55.7	12.3	86.7	8.03	37.7	15.49	44.96
P <sub>7</sub> x P <sub>5</sub>	58.3	10.0	80.7	6.87	39.0	12.16	40.70
P <sub>8</sub> x P <sub>5</sub>	52.0	17.0	87.7	8.70	23.7	20.52	62.09

APPENDIX C: continued

Parent Or Cross	No. of days to heading	No. of ears per plant	Plant height (cm)	Ear length (cm)	No. of grains per ear	Grain yield per plant (g)	1000 grain weight (g)
P <sub>1</sub> x P <sub>6</sub>	68.3	9.3	83.3	8.43	32.0	10.51	52.95
P <sub>2</sub> x P <sub>6</sub>	68.0	11.0	76.0	7.80	29.7	9.30	47.25
P <sub>3</sub> x P <sub>6</sub>	69.0	8.3	76.3	6.77	49.7	10.64	37.33
P <sub>4</sub> x P <sub>6</sub>	65.7	8.3	78.7	8.87	31.7	8.01	53.92
P <sub>5</sub> x P <sub>6</sub>	58.0	12.3	86.7	8.10	39.0	15.29	44.80
P <sub>7</sub> x P <sub>6</sub>	65.0	9.3	80.7	7.07	50.0	13.71	38.97
P <sub>8</sub> x P <sub>6</sub>	54.0	15.3	94.3	9.80	35.7	22.10	53.36
P <sub>1</sub> x P <sub>7</sub>	68.3	11.3	79.0	7.73	31.7	9.62	50.32
P <sub>2</sub> x P <sub>7</sub>	69.3	8.3	68.7	7.43	26.0	6.26	45.18
P <sub>3</sub> x P <sub>7</sub>	66.7	8.7	70.7	5.80	56.0	12.00	32.29
P <sub>4</sub> x P <sub>7</sub>	67.0	9.0	72.7	7.40	34.3	9.52	45.19
P <sub>5</sub> x P <sub>7</sub>	57.0	10.7	88.0	6.90	41.3	13.79	40.87
P <sub>6</sub> x P <sub>7</sub>	66.7	9.3	78.0	7.30	46.0	11.93	40.69
P <sub>8</sub> x P <sub>7</sub>	51.0	13.7	96.0	7.73	36.0	20.86	56.42

†

APPENDIX C: continued

Parent or Cross	No. of days to heading	No. of ears per plant	Plant height (cm)	Ear length (cm)	No. of grains per ear	Grain yield per plant (g)	1000 grain weight (g)
P <sub>1</sub> x P <sub>8</sub>	57.7	16.7	90.3	3.57	23.3	23.06	59.59
P <sub>2</sub> x P <sub>8</sub>	57.3	20.3	85.0	9.13	23.7	23.63	56.58
P <sub>3</sub> x P <sub>8</sub>	53.3	15.0	92.7	7.90	37.7	22.27	52.72
P <sub>4</sub> x P <sub>8</sub>	57.0	16.7	84.3	9.73	24.3	18.90	62.54
P <sub>5</sub> x P <sub>8</sub>	53.3	18.0	85.7	3.70	23.7	21.12	59.96
P <sub>6</sub> x P <sub>8</sub>	52.7	15.0	97.3	9.03	34.3	21.33	54.16
P <sub>7</sub> x P <sub>8</sub>	50.3	14.3	90.3	8.00	35.3	21.83	54.90

APPENDIX D-1: Percentage heterosis of the F<sub>2</sub>'s for number of days to heading <sup>1</sup> (average over blocks and reciprocals)

Cross	Heterosis over Mid-parent	Heterosis over Early parent	Heterosis over Late parent
P <sub>1</sub> x P <sub>2</sub>	-2.5	1.8	-6.4
P <sub>1</sub> x P <sub>3</sub>	-3.5	5.3	-10.9
P <sub>1</sub> x P <sub>4</sub>	-2.3	5.9	-10.0
P <sub>1</sub> x P <sub>5</sub>	-10.6	0.0	-19.2
P <sub>1</sub> x P <sub>6</sub>	-7.7	-2.2	-12.6
P <sub>1</sub> x P <sub>7</sub>	-3.7	7.2	-12.4
P <sub>1</sub> x P <sub>8</sub>	-8.9	17.6	-25.6
P <sub>2</sub> x P <sub>3</sub>	0.1	4.5	-3.8
P <sub>2</sub> x P <sub>4</sub>	0.0	4.1	-3.8
P <sub>2</sub> x P <sub>5</sub>	-5.5	1.1	-11.2
P <sub>2</sub> x P <sub>6</sub>	-5.9	-4.6	-7.3
P <sub>2</sub> x P <sub>7</sub>	0.4	6.8	-5.3
P <sub>2</sub> x P <sub>8</sub>	-5.3	16.2	-20.1
P <sub>3</sub> x P <sub>4</sub>	-1.5	-1.2	-1.7
P <sub>3</sub> x P <sub>5</sub>	-8.5	-6.3	-10.6
P <sub>3</sub> x P <sub>6</sub>	-0.3	2.6	-2.9
P <sub>3</sub> x P <sub>7</sub>	5.1	7.1	3.3
P <sub>3</sub> x P <sub>8</sub>	-6.9	8.9	-18.6
P <sub>4</sub> x P <sub>5</sub>	-7.3	-4.9	-9.7
P <sub>4</sub> x P <sub>6</sub>	-3.8	-1.4	-6.2
P <sub>4</sub> x P <sub>7</sub>	-0.2	1.9	-2.1
P <sub>4</sub> x P <sub>8</sub>	-2.8	14.0	-15.2
P <sub>5</sub> x P <sub>6</sub>	-14.3	-9.7	-18.4
P <sub>5</sub> x P <sub>7</sub>	-9.0	-3.4	-9.4
P <sub>5</sub> x P <sub>8</sub>	-6.2	6.9	-16.3
P <sub>6</sub> x P <sub>7</sub>	-1.2	3.5	-5.5

## APPENDIX D-1: continued

Gross	Heterosis over Mid- parent	Heterosis over Early parent	Heterosis over Late parent
P <sub>6</sub> x P <sub>8</sub>	-10.3	8.3	-23.4
P <sub>7</sub> x P <sub>8</sub>	-10.3	2.8	-20.4
Mean	-4.8	3.1	-10.9

<sup>1</sup>Early heading is usually the desirable characteristic.

APPENDIX D-2: Percentage heterosis of the F<sub>2</sub>'s for number of ears per plant and plant height (average over blocks and reciprocals)

Cross	Number of ears per plant		Plant height	
	Heterosis over Mid-parent	Heterosis over high parent	Heterosis per Mid-parent	Heterosis over high-parent
P <sub>1</sub> x F <sub>2</sub>	-1.0	-14.2	6.9	5.7
P <sub>1</sub> x F <sub>3</sub>	15.3	12.6	6.6	0.8
P <sub>1</sub> x F <sub>4</sub>	33.2	14.9	8.1	6.3
P <sub>1</sub> x F <sub>5</sub>	41.3	22.5	19.0	16.3
F <sub>1</sub> x F <sub>6</sub>	8.2	5.7	15.0	9.4
F <sub>1</sub> x F <sub>7</sub>	35.4	23.0	9.6	5.7
P <sub>1</sub> x F <sub>8</sub>	8.9	-26.4	16.6	4.5
P <sub>2</sub> x F <sub>3</sub>	19.6	1.7	4.1	-2.8
P <sub>2</sub> x F <sub>4</sub>	40.2	7.5	1.8	-1.2
P <sub>2</sub> x F <sub>5</sub>	24.2	24.2	15.1	11.5
P <sub>2</sub> x F <sub>6</sub>	21.6	3.3	11.7	5.0
F <sub>2</sub> x F <sub>7</sub>	0.0	-20.8	5.7	0.6
F <sub>2</sub> x F <sub>8</sub>	8.1	-20.0	14.5	1.4

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APPENDIX D-2: continued

Cross	Number of ears per plant		Plant height	
	Heterosis over Mid-parent	Heterosis over High parent	Heterosis per Mid-parent	Heterosis over High-parent
P <sub>3</sub> x P <sub>4</sub>	30.1	14.4	5.8	1.6
P <sub>3</sub> x P <sub>5</sub>	26.5	7.5	13.5	9.3
P <sub>3</sub> x P <sub>6</sub>	10.8	10.8	5.2	4.5
P <sub>3</sub> x P <sub>7</sub>	2.6	-4.8	-2.8	-4.8
P <sub>3</sub> x P <sub>8</sub>	-4.2	-36.0	17.4	10.9
P <sub>4</sub> x P <sub>5</sub>	28.0	5.8	12.1	11.8
P <sub>4</sub> x P <sub>6</sub>	12.3	-1.2	12.0	8.2
P <sub>4</sub> x P <sub>7</sub>	37.3	31.4	3.1	1.0
P <sub>4</sub> x P <sub>8</sub>	10.8	-30.6	14.3	3.9
P <sub>5</sub> x P <sub>6</sub>	20.6	2.5	20.8	16.7
P <sub>5</sub> x P <sub>7</sub>	9.5	-13.3	13.9	16.7
P <sub>5</sub> x P <sub>8</sub>	-5.4	-30.0	12.3	2.4
P <sub>6</sub> x P <sub>7</sub>	20.8	12.0	8.3	6.9
P <sub>6</sub> x P <sub>8</sub>	-9.0	-39.2	20.5	13.1
P <sub>7</sub> x P <sub>8</sub>	-12.5	-44.0	13.7	10.0
Mean	15.8	-2.9	11.2	6.3

APPENDIX D-3: Percentage heterosis of the F<sub>2</sub>'s for ear length and number of grains per ear (average over blocks and reciprocals)

Cross	Ear length		Number of grains per ear	
	Heterosis over Mid-parent	Heterosis over High-parent	Heterosis over Mid-parent	Heterosis over High-parent
F <sub>1</sub> x F <sub>2</sub>	3.2	7.8	-1.2	-5.3
P <sub>1</sub> x F <sub>3</sub>	15.3	-2.6	-7.7	-31.0
P <sub>1</sub> x P <sub>4</sub>	5.3	-1.9	7.0	-10.5
P <sub>1</sub> x F <sub>5</sub>	15.9	14.9	25.9	7.3
P <sub>1</sub> x F <sub>6</sub>	16.1	14.3	10.0	-3.2
F <sub>1</sub> x F <sub>7</sub>	12.0	0.3	-7.3	-27.4
P <sub>1</sub> x F <sub>8</sub>	7.1	-4.1	23.0	12.5
P <sub>2</sub> x F <sub>3</sub>	11.5	-3.9	4.5	-30.3
F <sub>2</sub> x F <sub>4</sub>	2.3	-5.1	6.9	-6.9
F <sub>2</sub> x P <sub>5</sub>	17.4	15.3	17.8	5.2
P <sub>2</sub> x P <sub>6</sub>	13.7	9.9	0.7	-15.0
P <sub>2</sub> x P <sub>7</sub>	12.2	0.3	12.0	-33.3
P <sub>2</sub> x P <sub>8</sub>	9.8	-2.0	27.3	22.3
F <sub>3</sub> x P <sub>4</sub>	9.1	-11.5	-12.7	-41.7

APPENDIX D-3: continued

	Ear length		Number of grains per ear	
	Heterosis over 146-parent	Heterosis over High-parent	Heterosis over 146-parent	Heterosis over High-parent
P <sub>3</sub> x P <sub>5</sub>	8.0	-7.9	18.5	-19.8
P <sub>3</sub> x F <sub>6</sub>	14.1	-1.0	22.6	0.1
P <sub>3</sub> x F <sub>7</sub>	4.5	0.3	13.3	5.2
P <sub>3</sub> x P <sub>8</sub>	5.9	-16.9	1.9	-23.1
F <sub>4</sub> x P <sub>5</sub>	6.9	0.5	24.7	21.3
F <sub>4</sub> x P <sub>6</sub>	7.7	-0.7	20.6	-8.8
F <sub>4</sub> x P <sub>7</sub>	11.5	-6.6	4.3	-27.6
P <sub>4</sub> x P <sub>9</sub>	8.0	3.6	29.5	17.4
P <sub>5</sub> x F <sub>6</sub>	10.2	8.0	46.6	12.9
P <sub>5</sub> x P <sub>7</sub>	4.4	-7.8	26.4	11.3
P <sub>5</sub> x P <sub>8</sub>	3.9	-6.1	19.7	11.3
P <sub>6</sub> x P <sub>7</sub>	11.5	0.3	20.9	6.0
P <sub>6</sub> x P <sub>8</sub>	14.6	1.6	26.4	2.9
P <sub>7</sub> x P <sub>8</sub>	4.9	-15.1	6.6	-21.6
Mean	9.2	-0.5	15.0	-7.0

APPENDIX D-4: Percentage heterosis of the F<sub>2</sub>'s for grain yield per plant and 1000 grain weight. (Average over blocks and reciprocals)

Cross	Grain yield per plant		1000 Grain weight	
	Heterosis over Mid-parent	Heterosis over High-parent	Heterosis over Mid-parent	Heterosis over High-parent
P <sub>1</sub> x P <sub>2</sub>	0.5	-7.2	4.3	-3.1
F <sub>1</sub> x P <sub>3</sub>	-1.9	-7.9	11.4	-13.9
P <sub>1</sub> x P <sub>4</sub>	31.5	-6.2	0.1	-1.1
F <sub>1</sub> x F <sub>4</sub>	72.5	60.6	4.7	2.6
P <sub>1</sub> x P <sub>6</sub>	4.3	-2.7	4.0	-8.6
P <sub>1</sub> x P <sub>7</sub>	8.5	0.8	3.9	-8.8
P <sub>1</sub> x P <sub>8</sub>	43.5	-1.5	-3.5	-11.9
P <sub>2</sub> x P <sub>3</sub>	25.8	10.5	10.0	-10.1
P <sub>2</sub> x P <sub>4</sub>	57.6	18.2	1.6	-6.6
P <sub>2</sub> x P <sub>5</sub>	69.7	69.2	7.9	2.3
P <sub>2</sub> x P <sub>6</sub>	30.7	29.3	9.2	2.8
P <sub>2</sub> x P <sub>7</sub>	4.2	3.5	3.4	2.8
P <sub>2</sub> x P <sub>8</sub>	44.2	-5.0	0.3	-14.3
P <sub>3</sub> x P <sub>4</sub>	9.9	-24.6	5.7	-19.0
P <sub>3</sub> x P <sub>5</sub>	63.3	42.6	0.5	-21.2

APPENDIX II-4: continued

Cross	Grain Yield per plant		1000 Grain weight	
	Heterosis over Mid-parent	Heterosis over Mid-parent	Heterosis over Mid-parent	Heterosis over Mid-parent
P <sub>3</sub> x P <sub>6</sub>	35.7	15.4	4.6	-10.0
P <sub>3</sub> x P <sub>7</sub>	13.2	-0.3	-7.3	-20.2
P <sub>3</sub> x P <sub>8</sub>	31.1	-6.5	5.6	-23.5
P <sub>4</sub> x P <sub>5</sub>	59.2	26.7	4.2	1.0
P <sub>4</sub> x P <sub>6</sub>	23.5	-3.0	4.2	-9.1
P <sub>4</sub> x P <sub>7</sub>	56.0	12.0	-5.0	-17.4
P <sub>4</sub> x P <sub>8</sub>	40.9	-18.4	2.2	-5.3
P <sub>5</sub> x P <sub>6</sub>	44.1	36.6	-4.1	-14.2
P <sub>5</sub> x P <sub>7</sub>	59.2	50.5	-12.3	-22.0
P <sub>5</sub> x P <sub>8</sub>	24.0	-18.3	3.0	-7.7
P <sub>6</sub> x P <sub>7</sub>	56.0	55.4	-3.5	-3.6
P <sub>6</sub> x P <sub>8</sub>	24.9	-14.7	0.1	-14.7
P <sub>7</sub> x P <sub>8</sub>	26.8	-15.2	3.7	-15.8
Mean	36.2	12.7	2.1	-10.0

APPENDIX B-9: simple correlation coefficients  
between heterosis for yield and  
heterosis for the yield components

Character	r
Number of days to heading	-0.45*
Number of ears per plant	0.45*
Plant height	0.41*
Ear length	-0.02
Number of grains per ear	0.68**
1000 grain weight	-0.35

Degrees of freedom = 26

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