EARLY GENERATION SELECTION FOR YIELD POTENTIAL IN *VICIA FABA* L.

by

Monika Magdalena Lulsdorf

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ABSTRACT

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Two crosses, Ackerperle x Star Czyzowskich (AS) and Herz Freya x Star Czyzowskich (HS), and two generations (F2 and F4) of fababeans (*Vicia faba* L.) were used to evaluate the effectiveness of the honeycomb and index selection methods for the identification of spaced plant yield potential. The study was conducted at the University of Manitoba Point Field Laboratory in 1983 and 1984.

For the honeycomb method, 200 plants of each cross and generation were sown in such a way that each plant was surrounded by six other plants at equal distance. Plants were selected if they yielded higher than all six surrounding neighbours.

For the index method, 200 plants of each cross and generation were grown in a rectangular grid pattern with 60 cm interplant spacing. The selection index used was yield (top 50% of the population) plus TDM (top 50% of the population) plus HI (top 50% of the population).

In order to evaluate both methods, plants of each cross and generation were selected at random and used to generate check populations.

The yield test of each derived cross and generation was grown in an 81 entry lattice designs with the honeycomb, selection index and random selections each comprising one third of the lattice entries.

Analysis of the yield tests of material from the Ackerperle x Star Czyzowskich F4 populations (AS4) indicated that the honeycomb selections significantly outyielded the mean of the random and the index selections by 7.6 % and 6.9 %, respectively.

In yield tests of material from Herz Freya x Star Czyzowskich F2 populations (HS2), the index selections significantly outyielded the mean of the random and the honeycomb selections by 7.8 % and 7.0 % respectively.

No other significant mean yield differences were observed for any cross or generation.

Response to selection was also determined by comparing the number of entries from each selection method in the top 15 % and 20 % of the population. The honeycomb design was found to be effective in AS4 and HS2. However, it was only slightly superior to the random method in HS4 and was not effective in AS2.

The index method was superior in AS2 and HS2. However, it was only slightly better than the random procedure in HS4 and was not effective in AS4.

It was concluded that both the honeycomb and the index method were not sufficiently superior to random selection to justify the work involved in their application. However, further testing is necessary to draw general conclusions.

LIST OF TABLES

LIST OF FIGURES

Figure Page

CONTENTS

Appendix page

Chapter I

INTRODUCTION

Vicia faba L. is commonly known as fababean as well as broad, horse, Windsor, field and tick bean (Presber 1972). From archaelogical findings Schultze-Motel (1972) concluded that this species has been cultivated from the very early Neolithic period. Ladizinski (1975a) considers Afghanistan to have been the centre of origin, whereas Cubero (1974) suggested that fababeans originated in the Near East and spread from there to Europe, North Africa, Ethiopia and India.

V. faba belongs to the *Leguminosae* family and is a diploid species with 2n = 12 chromosomes. Hanelt *et al.* (1972) proposed that *Vicia bithynica* and *Vicia narbonesis* are closely related to fababeans in view of their common morphological characters. Chooi (1971) however showed that their respective nuclear DNA content and size is completely dissimilar. Additionally, Ladizinski (1975 b) and Abdalla and Gunzel (1979) found that the electrophoretic protein pattern of fababeans differed from that of other *Vicia* species. Interspecific crosses have failed (Bond 1976) and consequently Cubero (1982) suggested the assignment of a separate sub-genus to *V. faba* .

Muratova (1931) further classified *V. faba* into the ssp. *paucijuga* and *eu-faba*. The latter is divided into the large seeded var. *major*, the intermediate var. *equina* and the small seeded var. *minor*.

Two-thirds of the world production is grown in China. There as well as in the Mediterranean, Western Asia and Latin America the major types are predominant. In Europe, the Nile Valley, Ethiopia, Afghanistan, India and North America the small seeded varieties are widely cultivated (Hawtin and Hebblethwaite 1983). Thus *Vicia faba* production spreads from about 9 ° N to more than 50 ° N and from near Sea Level to more than 2000 meters (Clark 1980, Saxena 1982).

Fababeans were introduced into Canada in the early 1970s due to an increase in vegetable protein prices (Furgal and Evans 1980). In addition to having a high protein content of 22 % to 38 % on a dry matter basis, *Vicia faba* is also relatively rich in the essential amino acid lysine (Griffiths and Lawes 1978, Lafiandra *et al*. 1979). It is, therefore an appropriate livestock feed. The small seeded varieties are well suited for industrial protein extraction and processing techniques, whereas the large seeded types are basically used for human consumption (Lawes 1980).

Another advantage of this crop is seedling frost hardiness which makes early seeding a safe practice. Conventional farm equipment can be used for its cultivation. Fababeans improve the usual fibrous root crop rotation system because of their large and deep growing tap roots. Additionally, this crop suffers from relatively few pests and diseases. Since this legume is living in symbiosis with *Rhizobium* bacteria, it is capable of fixing appreciable quantities of atmospheric nitrogen (Chapman and Peat 1978, Lawes 1980).

Licensed small seeded varieties in Manitoba are Ackerperle, Aladin, Diana, Herz Freya, Outlook and Pegasus. They are erect growing, annual plants with one or only few tillers. On average, these varieties need 100 to 120 days to reach maturity. Because of the indeterminate growth habit, this crop bears pods along the length of its stem, starting 20 to 25 cm from the ground to a full length of 85 cm to 100 cm according to the Field Crop Recommendations.[1]

Fababeans are partially autogamous with an average amount of cross-fertilization of about 35 % depending on variety and environmental factors (Bond and Poulsen 1983). For Manitoba, McVetty and Nugent-Rigby (1984) reported 8.5 % to 60 % natural cross pollination.

To avoid losses due to shattering the crop is swathed when the lower pods begin to blacken. An average yield of 3380 kg/ha to 3650 kg/ha is obtained in Manitoba plot scale yield trials[1]. In contrast, commercially grown fababeans yield 1600 kg/ha on average with yield fluctuations ranging from about 500 kg/ha to over 5400 kg/ha in Manitoba (Platford _et al_. 1981).

Keatinge and Shaykewich (1977) concluded that high soil moisture stress severely reduces yield, especially if it occurs during the early phases of reproductive development. Additionally, competition between the vegetative and reproductive phases and the need of insects for cross-pollination and self-pollination (tripping effect) contribute to this yield instability (Poulsen 1975). Therefore, increasing yield and yield stability are the major goals in _Vicia_ _faba_ breeding.

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[1] Manitoba Agriculture Publication 1984

In order to solve these problems plant breeders use mass selection, bulk pedigree methods, recurrent selection and a range of specially developed breeding methods (Hawtin 1981, Lawes _et_ _al_. 1983).

A common factor between these methods is that selection for yield is usually delayed until later generations (not prior to F5) when the amount of seed available per line is large enough to plant replicated yield trial plots. It is very difficult to recognize high yielding lines because yield is a quantitatively inherited trait where many genes are involved and where considerable interaction between genotype and environment may confound selection. Heterozygosity and heterosis in early generations are other reasons why selection for yield is delayed.

Late generation selection for yield potential, as outlined above, requires additional labour and land and delays the development and release of cultivars when compared to early generation selection. Therefore this study was conducted to assess the possibility of early generation selection for yield potential in _Vicia_ _faba_ L. in order to improve the efficiency of breeding methods.

The specific objectives of this investigation were:

1. To determine whether selection for yield potential in spaced plants of F2 or F4 generations of _Vicia_ _faba_ L. was possible.
2. To compare the efficiency of the honeycomb screening design selection method with the yield - total dry matter - harvest index selection index method for the identification of F2 and F4 generation spaced plant yield potential.

Chapter II

LITERATURE REVIEW

2.1 EARLY GENERATION SELECTION

Early generation selection is defined as the evaluation of yield potential of a genotype as early as possible after hybridization (Allard 1960). The fundamental idea of this selection principle is that the frequency of a superior genotype is greater in early generations than in later ones. Consequently, the chance of finding the genotype which includes all the desired alleles in either the homozygous or heterozygous condition decreases in later generations (Shebeski 1967, Shebeski and Evans 1973, Sneep 1977).

However, Allard (1960) as well as many other plant breeders have concluded that selection for quantitatively inherited characters such as yield is futile in early generations due to the masking effect of heterosis, the segregation due to heterozygosity, and the large environmental influence (Grafius _et al_. 1952, Leffel and Hanson 1961, Luedders _et al_. 1973, Knott and Kumar 1975, Nass 1983).

Hence, commercial breeders prefer to select visually in early generations because many plants or many lines can already be discarded on the basis of simply inherited traits and general agronomic appearance. But selection intensity has to be kept low in order to avoid discarding valuable genotypes. Consequently, plant breeders who delay selection until later generations or who make too few selections from the experimental material, will have to settle for genotypes with less desirable genes than possible. Additionally, early elimination of undesired lines or plants would increase the efficiency of use of breeding facilities (Shebeski 1967, Shebeski and Evans 1973, Sneep 1977).

The effectiveness of early generation selection depends on the breeder's ability to identify high yielding genotypes or families which maintain this character in subsequent generations. Therefore, success depends on a high correlation between the performance of genotypes or families selected in F2, F3, or F4 and the performance of their progeny in later generations (Allard 1960, O'Brien _et al_. 1979a). However, such a correlation has to be interpreted with some caution because the correlation coefficient tends to be higher when the genetic variation is larger (Bhatt 1980, Spitters 1979).

Early generation selection for yield starts in F2 on a single plant basis and on a family basis as early as F3.

2.2 SINGLE PLANT SELECTION

Plant breeders attempt to select for yield on a single plant basis because each plants represents a distinct genotype. Visual assessment of single plants is considered a fast screening technique in order to reduce large population sizes.

McGinnis and Shebeski (1968) reported that visual selection of well-tillered vigorous F2 plants is advantageous in comparison to random selection.

Frey (1962) studied the effectiveness of visual selection in oat crosses. He observed that the yielding ability of the derived oat lines was associated with criteria used in the visual assessment. However, the phenotypic expression of single plants was so confounded with environmental influences that visual selection was ineffective.

Knott (1972) tried to improve the efficiency of breeding for yield by reducing environmental variability in the F2 generation and thus increase heritability. Visual selection resulted in a slightly positive effect. Nevertheless, the ranges of good and poor plants overlapped considerably. Therefore he concluded that effective yield testing should be done on a plot basis rather than on individual plants.

Another approach in predicting yield potential would be the direct measurement of single plant grain yield. However, many authors have agreed that evaluation of single plant yield was ineffective because they found no or only a very low significant correlation between F2 plant and F3 plot yield (Escuro et al. 1963, Shebeski 1967, Utz et al. 1973, Pernas 1974, Hanson et al. 1979).

In contrast, Skorda (1973) reported highly significant correlations between F2 plant and F3 plot yield for both crosses (r=0.848** and r=0.871**). He concluded that randomization, use of nearly commercial seeding rates, replication, use of control varieties, and the actual measurement of yield rather than visual selection was a worthwhile procedure.

2.3 HONEYCOMB METHOD

Fasoulas (1973) developed the 'honeycomb design' as a method for early generation yield selection of spaced plants.

This design consists of a planting pattern in which each plant is surrounded by six other plants at equal distance, thus forming a hexagon. The central plant is selected if it outyields all six surrounding neighbours.

The honeycomb method tries to reduce the masking effect of soil heterogeneity. This is based on the idea that nearby plots are more similar in soil fertility, structure, and moisture than those further apart (Smith 1938). Therefore, if plants are compared in relatively small areas, for example a hexagon, environmental differences due to soil gradients are considerably minimized. Hence, if a plant yields more than its six immediate neighbours, then this can be mainly attributed to its genetic superiority rather than because it happens to grow on a highly fertile spot (Fasoulas 1973).

Elimination of competition is the second idea on which Fasoulas' theory is based upon. However, many plant breeders concluded that selection should be carried out at commercial seeding density because single plant performance under wide spacing is not necessarily related to performance under close spacing (Allard 1960, Hamblin and Donald 1974, Spitters 1979, Simmonds 1981).

In contrast, Fasoulas (1973,1979) has argued that varieties are monogenotypic in nature and therefore intragenotypic competition within varieties leads to an equal sharing of the available environmental resources. Hence, yield is evenly suppressed due to coincidence of developmental stages and needs and the yields of single spaced plants should rank correlate with desired plot yield.

On the other hand, in early generations each plant from a specific cross represents a different genotype. If different genotypes are closely planted there is an unequal sharing of environmental resources because their developmental stages and needs are different. Consequently, strong competitors gain advantages and prevent weaker genotypes from expressing their maximal genetic potential. Fasoulas (1973,1979) further reasoned, that selection of strong competitors may not be advantageous because competitive ability is not necessarily associated with high yielding ability.

In 1980, Niehaus reported that durum wheat lines selected according to the honeycomb method performed 4.2 % better than randomly selected F2 lines. However, no correlation between F2 grain yield per plant and F4 plot yield was found.

Similarily, Mitchell _et_ _al_. (1982) used the honeycomb design to select for high and low yielding F2 plants of three durum wheat crosses. The average response to single plant selection was 4 % of the mean in solid seeded plots. The authors concluded that Fasoulas' method is not sufficiently superior to mass selection to justify the extra work involved in its application.

Recently, Lungu (1984) confirmed that the honeycomb method is effective for wheat in improving yield. Progenies of plants selected for high yield outyielded the progenies derived from low yielding plants by 12.9 % on average and outyielded the mean yield of the check variety Glenlea by 5.5 % on average.

Rye (Secale cereale L.) is the only other crop in addition to wheat where the honeycomb method has been applied (Bos 1981). The goal of the selection was to decrease culm length while maintaining or improving grain yield. Three generations of continued honeycomb selection resulted in plants with a reduced culm length and an increase in yield of 4.3%. The author concluded that the efficiency of this method is disappointing and that the cause for this is the environmental diversity within the hexagon.

2.4 SELECTION ON A PLOT YIELD BASIS

The F3 is the first generation after hybridization in which plot yield trials can be conducted, although the available amount of seed allows only either replicated single rows or bigger, unreplicated plots. The efficiency of selection is usually reported as the correlation between yield of F3 (or F4) plots and their derived progenies in later generations.

McKenzie and Lambert (1961) determined the relationship between the performance of barley lines in the F3 and their progeny in the F6 generation. In this study, the F3 lines were tested in unreplicated single row plots. However, the results for both crosses (r=0.313** and r=0.543**) indicated that only a small part of the variation in yield in the F3 was associated with the variation in the F6 generation. Therefore they concluded that, especially for crosses between varieties differing very little in yield genes, early generation selection based on unreplicated plots was not a reliable method.

Similarily, Knott and Kumar (1975) found low but significant correlations between F3 and their derived F5 progenies (r=0.29** and r=0.14**) when they tested the F3 in single row plots with three replicates. Even though selection based on F3 yields had some positive effect, the authors doubted that it was worth the labour involved.

In an attempt to overcome the difficulties concerning yield testing, Frey (1965) recommended the use of hill plots for selection in cereals. But neither Utz _et al_. (1973) nor O'Brien _et al_. (1979b) could confirm the advantage of hill plots over row plots.

Utz _et al_. (1973) reported variable and low correlations between F3 hill plots and the yield of row plots in F5 and F6. Hence, they advocated a mild indirect selection via kernel number per head, kernel number per fertile spikelet, 1000-kernel weight, and head number per plot for wheat.

The results of studies by O'Brien _et al_. (1978) and by Knott (1979) indicated that the effectiveness of early generation yield selection was influenced by the amount of environmental variation among generation means, and the amount of genotypic and genotype x environmental variation.

Therefore, if selection efficiency is to be improved, the amount of environmental variation has to be reduced in order to increase the correlation between phenotypic expression and genotype (Simmonds 1981).

According to Fasoulas (1973), soil heterogeneity and intergenotypic competition were the two major factors responsible for the masking of the genotype in observations of individual phenotypes.

2.5 SOIL HETEROGENEITY

Knight (1983) estimated that 80% of the variation in yield is due to environmental heterogeneity and error.

LeClerg (1966) recognized soil heterogeneity as one of the principal sources which confounds selection procedures. The variation in soil fertility creates variability in the expression of phenotypes which decreases the breeder's ability to recognize desired genotypes.

As early as 1938, Smith observed that even apparently uniform fields varied extensively in soil fertility. Hence, variation in soil fertility caused variation in yield. However, it was evident that this soil heterogeneity was rather systematic and thus nearby plots were generally more alike than those further apart.

Consequently, several plant breeders have frequently studied the use of control plots for selection and testing in order to reduce the confounding environmental variation (Pritchard 1916, Shebeski 1967, Briggs and Shebeski 1968, Knott 1972). This method is based on the expression of yield of each line as a percentage of an adjacent control and the use of the control plots as a covariate for adjustment of soil heterogeneity. DePauw and Shebeski (1973) applied this method on F3 lines of wheat. The correlation coefficient obtained between F3 lines and F4 bulk means was r=0.59** and between F3 lines and F5 family means was r=0.56*. Hence, the authors concluded that replicated microplots and frequent controls should be used in order to select efficiently for quantitative characters in early generations.

A modification of the check plot method for adjusting yield is the use of moving means as suggested by Richey (1924,1926) and later by Townley-Smith and Hurd (1973). Here yield was adjusted by subtracting the mean yield of a number of adjacent plots from the plot yield.

Townley-Smith and Hurd (1973) compared the efficiency of adjustment of repeated controls with the efficiency of moving mean adjustment in yield trials of wheat. Their findings indicate that the moving mean of adjacent plots gives superior control over the experimental error.

Another method dealing with soil heterogeneity was proposed by Gardner in 1961. He stratified the field into small areas of 40 corn plants each and then selected the 10% highest yielding plants in each stratum. This method is also known as 'grid selection'. This resulted in a 3.9 % gain per year over the yield of the original corn variety.

Bos (1981, 1983a) applied grid selection in rye. However, the response to grid selection was disappointing. The author suggested that selection of a fixed instead of a variable number of plants per grid, and the arbitrary ways of choosing size, shape and orientation of the grids are reasons for the small response.

Fasoulas (1973) observed that the effects of soil heterogeneity could be reduced if plants were grown under highly improved growing conditions because he found that a stress-free environment differentiated the yielding ability of genotypes much better than a stress environment.

In 1964, Frey investigated the effect of stress and non-stress environments on selection efficiency in oats. He came to the conclusion that non-stress conditions resulted in the retention of oat strains with a wide adaptation reaction, whereas the stress condition did not. However, the progress in mean yield from selection was small but about equal for both sets of selection conditions.

Similarily, McVetty and Evans (1980a) reported that selection efficiency in the F2 increased only slightly when wheat plants were grown in a stress free environment.

2.6 COMPETITION

The elimination of competition between plants is the second idea which Fasoulas (1973) proposed for improving the efficiency of early generation selection.

Competition is defined as the interference which occurs

> "when each of two or more organisms seeks the measure it wants of any particular factor or thing and when the immediate supply of the factor or thing is below the combined demand of the organisms"

(Donald 1963).

The environment of a plant consists of physical growth factors and neighbouring plants. They compete for the same resources, for example water, nutrients, and light which are usually limited.

Fasoulas (1973) reasoned that because each genotype in a selection nursery is different from the other, this may lead to an unequal sharing of those limited growth requisites. Hence, if phenotypes are evaluated in a mixed population, the weak competitive genotypes are underestimated, whereas the strong competitors are overestimated. As a result of this intergenotypic competition, the performance in the selection nursery may be poorly related to yielding ability under normal agricultural conditions.

The relation between the performance of genotypes grown in heterogeneous populations, and their performance when grown in monoculture was studied by numerous researchers.

From their experiments with wheat and barley, some researchers have concluded that there is a positive relationship between the competitive ability of genotypes when grown in mixture, and their respective yielding ability when grown in monoculture (Harlan and Martini 1938, Jensen and Federer 1965, Blijenburg and Sneep 1975, Spitters 1979).

On the other hand, Jennings and de Jesus (1968) reported for rice and Khalifa and Qualset (1974) reported for wheat a negative correlation between competitive ability and yield. In their experiments they used varieties with contrasting height and different plant types.

In contrast, Sakai (1955) concluded from a study with mixtures and pure stands of 12 barley varieties that there is no sign of association of competitive ability and yield.

One reason why these inconsistent relationships between competitive ability and monoculture yield are found is due to the difficulty to determine what 'competitive ability' really is. In the experiment of Jennings and Aquino (1968) with rice, light was the limiting growth factor.

Consequently, 'strong competitors' were determined by a better early vegetative growth which promoted light interception.

In a study with barley, Lee (1960) found that the 'strong competitor' had a more rapid and denser root growth, and in the environment where the investigation was carried out, the area was rather dry and the soil generally thin. Therefore, this dense and rapid root growth gave the 'strong competitor' the advantage over the 'weak competitor'.

Many researchers have tried to connect competitive ability with certain plant characteristics. Sakai (1961) reported that competitive ability has a genetic basis, but because the range of plant characters that can affect competition is so wide and diverse, it seems to be improbable that any uniform heritability pattern will emerge for competitive ability (Donald 1963).

In order to avoid this dilemma, plant breeders either grow plants widely spaced and thus select without the influence of competition, or try to find characters related to yield which are slightly or not at all affected by competition such as 1000 grain weight or grain yield per tiller (Valentine 1982).

2.7 SELECTION AND SPACE PLANTING

Fasoulas (1981) concluded that

> "once exceptional genotypes have been evaluated and selected in the absence of competition, their superior performance under intragenotypic competition is secured".

The effect of wide spacing on the performance of a genotype has been widely studied, and differential responses of genotypes to spacing have been reported.

For example, Baker and Briggs (1982) showed that single plant selection for yield in barley was effective at plant spacings near 40 x 40 cm. Hamblin et al. (1978) also concluded that selection efficiency was better at low density than at high density.

In contrast, Hamblin and Evans (1976) demonstrated that dry beans selected at low density do not necessarily perform well at crop density.

Similarily, Spitters (1979), Kelker and Briggs (1979) and Chebib et al. (1973) reported that wide plant spacing removed the effect of intergenotypic competition but introduced bias due to different abilities of genotypes to respond to wide spacing.

Chebib et al. (1973) showed that errors introduced by wide plant spacing were much greater than the degree to which competition confounded selection. They suggested that sowing seeds of approximately the same seed size together in close-planted nurseries would increase the effectiveness of single plant selection.

However, Knight (1983) reported that emergence, area available to a plant and competition from neighbours together accounted only for 20% of the variation in yield. The remaining 80% consisted of environmental heterogeneity (e.g. soil fertility and structure) and error.

2.8 INDIRECT SELECTION FOR YIELD

Direct selection for yield is difficult due to low heritability and due to confounding effects of either competition or differential response to wide plant spacing.

In 1956, Grafius proposed that indirect selection for yield might be of value. The success of this method generally depends on:

1. strong association of yield with the character selected for
2. its genetical independence of, or positive correlation with yield
3. the character being highly heritable
4. being simpler inherited than yield itself
5. if selected under wide spacing, then the trait should maintain this character under close spacing
6. if selected under normal density, then the trait should not be affected by competition.

Many workers have found associations between components of yield or morpho-physiological attributes and yield itself.

For example, Valentine (1982) studied the merits of indirect selection for yield in early generations of 14 barley cultivars. His results indicated that selection for characters like grain yield, dry matter, ear weight and numbers of grains on a single plant basis were strongly confounded by intergenotypic competition. Therefore, the author concluded that selection for those characters should be delayed until later generations. However, plant height, ear weight/tiller, grain yield/tiller, number of grains/tiller, and 1000-grain weight are hardly affected by competition and thus selection for those traits could start in the F2 generation. Harvest index and number of tillers per plant were found to be intermediate between both groups.

Donald and Hamblin (1976) suggested in their review that biological yield and harvest index might be valuable criteria for selection of single spaced plants in early generations.

The biological yield of a plant is the total yield of plant material, usually excluding the roots. It is also called total dry matter (TDM) or productivity. Total dry matter accumulation is expected to provide an integrated account of the ability of a genotype to exploit its environment (Donald and Hamblin 1976).

Harvest index (HI) is defined as the ratio of economic yield to total biological yield and is a measure of the plants ability to move photosynthate from non-economic to economically important parts of the plant (Donald and Hamblin 1976).

Pernas (1974) compared growth characteristics of a group of adapted wheat cultivars having different yield potential under close and wide plant spacing. He found no correlation between total dry matter of spaced plants and plants grown at normal density. However, harvest index of spaced plants was significantly correlated (r=0.97*) with grain yield at normal density.

In contrast, Okolo (1977) investigated the same problem but found no correlations between harvest index of single F2 plants from four wheat crosses and their respective F3 and F4 plot yields. However, highly significant correlations were obtained between biological yield of single F2 plants and their derived F3 and F4 bulks.

Similar results were obtained by Monde (1981) in an experiment with barley.

These inconsistent reports were elucidated by the investigation of McVetty and Evans (1980b). They showed that in tall populations, single spaced plants should be selected for productivity, whereas in short cultivars, harvest index is an effective selection criteria.

However, Baker and Gebeyehou (1982) found that the relationship among grain yield, biological yield and harvest index grown at high density depends on the level of productivity. Under low levels of productivity a positive relationship between harvest index and biologial yield may exist while under high levels of productivity this relationship may be reversed. Hence, grain yield could consistently be positively correlated with productivity but may show varying relationships with harvest index.

Similarily, Whan et al. (1982) and Nass (1983) came to the conclusion that improving grain yield in wheat at approximately normal density using harvest index, has no greater effectiveness than selection for yield directly.

Early generation selection has not been applied to Vicia faba L. yet. However, all methods decribed have in common selection that takes place either under competition or at wide plant spacing. Therefore, the effects of competition and plant spacing on yield and yield related traits of fababeans are reviewed in the following, as are criteria for indirect selection in fababeans.

2.9 COMPETITION AND PLANT SPACING IN FABABEANS

Hodgson and Blackman (1956,1957) studied the influence of density on the pattern of development in *Vicia faba* L.. With increasing density from 11 to 67 plants per square meter, the number of pods per plant and the extent of branching fell progressively but there was no significant change in either seed size or number of seeds per pod. Consequently, seed production was solely governed by the number of mature pods formed. The primary effect of increasing density was to depress the number of nodes on the lower half of the stems which produced mature pods.

They concluded that the production of mature pods depends on integrated effects of internal physiological factors, and external environmental conditions on the development which has gone forward from the early vegetative growth.

Hodgson and Blackman (1957) suggested that the effects of increasing density might be due to altered competition within the plant rather than to mutual shading.

Similarily, Sprent *et al*. (1977) concluded from their shading experiments that irradiance was not a major limiting growth factor in *Vicia faba* L., because they found the effects of shading and density were essentially independent.

In fababeans, indeterminate growth results in the apex remaining a significant sink during and after the flowering period. This leads to competition between reproductive and vegetative organs (Lawes et al. 1983).

The upper regions of the plant are preferentially supplied with water and thus also with food, since water stress is known to affect photosynthesis and translocation, and since pods obtain much of their carbon from subtending leaves. Therefore, Sprent et al. (1977) concluded that moisture stress retards growth, and that an adequate water supply is essential for pod retention in Vicia faba L..

Keatinge and Shaykewich (1977) confirmed that high soil moisture stress has a major impact on reducing the yield of fababeans in the Canadian prairie environment, especially if the stress occurred during the early stages of reproductive development. A multiple regression analysis showed that accumulated soil moisture stress above 100 mm, which is quite common under Manitoban conditions, markedly reduced total dry matter production. Furthermore, if water stress was not a limiting factor then suboptimal ambient temperatures and soil temperatures limited total dry matter production and thus yield.

Day et al. (1979) reported a remarkable lack of response of fababeans to planting density because they did not find significant differences in yield between 18 and 98 plants per square meter. This compensation worked through number of seeds per plant, rather than seed weight, which remained relatively constant. The authors also pointed out that fababeans did not suffer from nitrogen deficiency because the nodules have the potential to meet a considerable higher nitrogen demand, and applying nitrogen fertilizer to well-nodulated beans did not improve yield.

Similarily, Igwilo (1982) suggested that a limited supply of nitrogen within the plant was not responsible for producing fewer mature pods per plant as density increased but that other internal factors were responsible.

As already mentioned, Donald and Hamblin (1976) suggested TDM and HI as selection criteria of spaced cereal plants. Consequently, Keller and Burkhard (1981) studied the relationship between plant density and structure of yield in different growth types of _Vicia faba_. The authors found that harvest index was relatively stable as density increased from 10 plants per square meter up to 80 plants per square meter. However, in their experiment the production of increased dry matter was correlated with an increase in yield even for very high densities. Therefore, the authors concluded that the _Vicia faba_ L. ideotype should have a high total dry matter per unit area combined with a high harvest index.

Furthermore, Neal and McVetty (1984) reported that the spaced plant characteristic yield per plant (r=0.747***), TDM per plant (r=0.686**) and HI per plant (r=0.474*) were correlated with plot yield in an experiment with spring fababeans.

2.10 INDEX SELECTION

In search for indirect selection criteria, Bond (1966) conducted a diallel experiment with lines of *Vicia faba* L.. The author found that a high number of pods/node seemed to be determined by recessive genes in contrast to most other yield components. Seed yield showed overdominance while components of yield showed additive type of gene action. Number of pods, number of seeds, pods per node and seed weight were all correlated with yield. Consequently, Bond (1966) concluded from the mode of gene action and the correlation with yield that selection for yield components could be done with much greater precision than for yield itself.

Other investigations have pointed out that the number of podded nodes/plant (Magyarosi and Sjodin 1976) or seeds/plant, pods/node and pods/flower (Cubero and Martini 1981) were also important characters influencing yield.

However, negative correlations between yield and yield components were also observed. For example, pods per plant was found to be negatively correlated with seeds per pod (Ishag 1973) and Poulsen (1977) reported that seeds per pod was negatively correlated with seed weight.

Similarily, Vries (1979) observed inconsistent correlation coefficients between seed yield per plant on the one hand and plant length, grain weight, number of seeds, pods and pod bearing nodes per plant on the other hand.

This indicates that yield component compensation restricts the use of yield components as selection criteria in Vicia faba L. as was previously mentioned for other crops. Therefore, Vries (1979) suggested that selection for characters which are closely related to the production and distribution of assimilates might be a solution.

Yassin (1973) reported that yield per plot was closely and positively related with number of pods/plant (r=0.986***) and yield/plant (r=0.763*). But he also observed a negative correlation between yield per plot and 1000 seed weight (r= -0.773**). Similarily, the number of pods per plant and seed weight were closely and negatively correlated (r= -0.940***).

Consequently, Yassin (1973) concluded that selection based on indices would be more efficient than selection for one character at a time or several characters independently. Hence, the author proposed that a selection index which gives proper weight to different characters such as seed yield, number of pods per plant or seed weight seems to be the best way to improve yield in fababeans.

Neal and McVetty (1984) suggested total dry matter production and pods per plant as valuable parameters for selection especially for Western Canada because these traits were closely and positively correlated with yield. However, harvest index was not suggested for use as a selection criteria because in a regression analysis, HI accounted only for 1% of the variation in yield.

In order to elucidate the inheritance of yield and agronomic characters of spring fababeans a diallel experiment was conducted by Kao

(1984) at the University of Manitoba. In this study yield expressed the greatest extent of heterosis with an average of 30.7% *** above the higher parent, whereas TDM and HI showed 16.4% *** and 8.1% ** respectively. The author concluded that heterosis for yield resulted from both increased TDM and HI. Therefore, it was suggested that selection for TDM and HI might be effective means in order to obtain high yielding lines.

In contrast, Sprent *et al*. (1977) observed in their experiment that TDM was lower in 1975 than in 1974, but yield was higher in 1975. This indicates that photosynthetic potential may not limit yield.

Similarily, Thompson and Taylor (1981) showed that improved TDM production was not always correlated with an increase in yield because the proportion of total dry matter utilized for seed production (harvest index) was consistently lower from plants grown at high fertility. They concluded from their investigation that highly fertile growing conditions promoted vegetative growth at the expense of reproductive growth which suggested a way of introducing selection pressure for improved harvest index.

Improving yield of fababeans via selection for harvest index was also proposed by Dantuma *et al*. (1983).

In summary, there are contradictionary results reported as to the usefulness of parameters for selection. However, from the literature review it can be concluded that two methods of early generation selection for yield potential in *Vicia faba* L. merit further investigation: the honeycomb method and the index method. The studies by Thompson and

Taylor (1981), by Neal and McVetty (1984) and by Kao (1984) in particular suggest that an index consisting of yield per plant, total dry matter per plant and harvest index per plant might be useful in predicting yielding ability of *Vicia faba* L. genotypes.

Chapter III

MATERIALS AND METHODS

3.1 MATERIALS

The materials used in this study consisted of two crosses derived from three spring fababean cultivars (*Vicia faba* L.). For each cross, Herz Freya x Star Czyzowskich (HS) and Ackerperle x Star Czyzowskich (AS), two generations (F2 and F4) were produced, by selfing plants of the previous generation in the greenhouse. Table 1 shows the key to the abbreviations used in 1983 and 1984.

Star Czyzowskich originated from Poland whereas Ackerperle and Herz Freya originated in the Federal Republic of Germany.

Ackerperle and Herz Freya are licenced for production in Canada and perform well in Manitoba. According to the Field Crop Recommendations[2] Herz Freya yields 5 % more on average than Ackerperle. In 1972, Star Czyzowskich was tested by Seitzer (1973) and yielded 5 % more than Ackerperle.

On average, Ackerperle has the smallest seeds with a thousand seed weight of 361g, while Star Czyzowskich and Herz Freya have a thousand seed weight of 394g and 406g respectively. The protein content of the seeds is very similar at approximately 29-30% on a dry matter basis.

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[2] Manitoba Agriculture Publication 1984

Table 1. Key to the abbreviations of crosses, generations and selection methods in 1983 and 1984.

		Abbreviations
Crosses:		
Ackerperle x Star Czyzowskich		AS
Herz Freya x Star Czyzowskich		HS
Generations:		
selected in F2		2
selected in F4		4
Selection Methods:		
Honeycomb Selection		H
Index Selection		I
Random Selection		R
Lattice Design:		
Group (Replicate)	1 - 3	RNUM
Block	1 - 9	BLK
Treatment (Entries)	1 - 81	LNUM

Star Czyzowskich was reported as the tallest cultivar whereas Herz Freya is medium and Ackerperle is the shortest in relation to the other two varieties. According to the Field Crop Recommendations[3] and Seitzer (1973), Herz Freya is a few days earlier maturing (102 days on average) than Ackerperle (110 days) and Star Czyzowskich (117 days).

The parents were chosen because of their different genetical background and their good yielding ability.

3.2 FIELD STUDY IN 1983

On April 21st, 1983 the experiment was seeded with a hand cornplanter along with Rhizobium leguminosarum inoculum at the University of Manitoba Point Field Laboratory.

For the honeycomb design, 256 seeds from each cross and generation (therefore four populations) were planted in a hexagonal pattern with 60 cm interplant spacing according to Fasoulas (1973). The field layout is shown in Figures 1 and 2.

For the index selection method, 224 seeds from each cross and generation (therefore four populations) were seeded in a rectangular grid pattern with 60 cm interplant spacing. The field layout is shown in Figures 3 and 4.

In both methods two seeds were planted in some holes and the plants were later used for filling gaps. The entire experiment was bordered with Herz Freya guard rows. Plants were sown in Red River clay soil and

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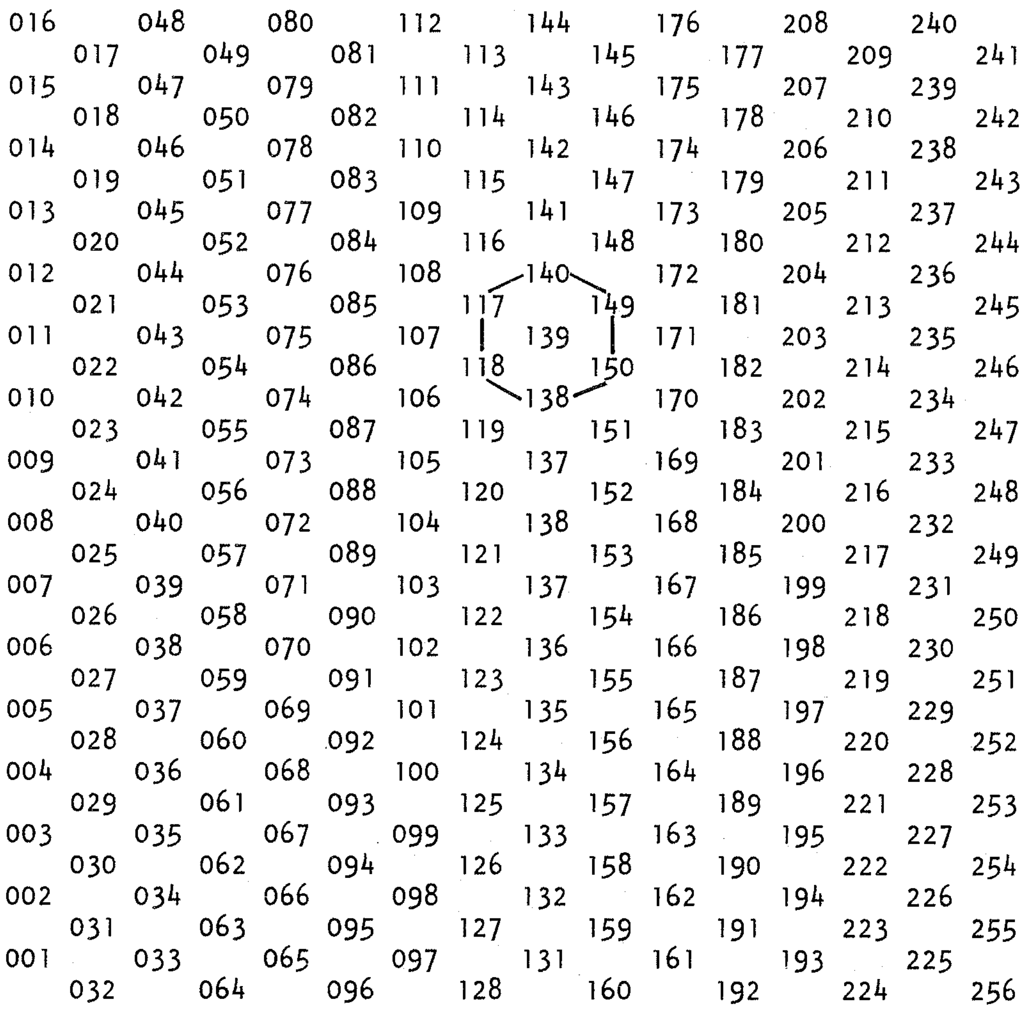
[3] Manitoba Agriculture Publication 1984

Figure 1. Field layout of the honeycomb design for one population in 1983.



016		048		080		112		144		176		208		240	
	017		049		081		113		145		177		209		241
015		047		079		111		143		175		207		239	
	018		050		082		114		146		178		210		242
014		046		078		110		142		174		206		238	
	019		051		083		115		147		179		211		243
013		045		077		109		141		173		205		237	
	020		052		084		116		148		180		212		244
012		044		076		108		140		172		204		236	
	021		053		085		117		149		181		213		245
011		043		075		107		139		171		203		235	
	022		054		086		118		150		182		214		246
010		042		074		106		138		170		202		234	
	023		055		087		119		151		183		215		247
009		041		073		105		137		169		201		233	
	024		056		088		120		152		184		216		248
008		040		072		104		138		168		200		232	
	025		057		089		121		153		185		217		249
007		039		071		103		137		167		199		231	
	026		058		090		122		154		186		218		250
006		038		070		102		136		166		198		230	
	027		059		091		123		155		187		219		251
005		037		069		101		135		165		197		229	
	028		060		092		124		156		188		220		252
004		036		068		100		134		164		196		228	
	029		061		093		125		157		189		221		253
003		035		067		099		133		163		195		227	
	030		062		094		126		158		190		222		254
002		034		066		098		132		162		194		226	
	031		063		095		127		159		191		223		255
001		033		065		097		131		161		193		225	
	032		064		096		128		160		192		224		256

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Figure 2. Section of the honeycomb field layout in 1983.

Figure 3. Field layout of the index selection method in 1983.

016	017	048	049	080	081	112	113	144	145	176	177	208	209
015	018	047	050	079	082	111	114	143	146	175	178	207	210
014	019	046	051	078	083	110	115	142	147	174	179	206	211
013	020	045	052	077	084	109	116	141	148	173	180	205	212
012	021	044	053	076	085	108	117	140	149	172	181	204	213
011	022	043	054	075	076	107	118	139	150	171	182	203	214
010	023	042	055	074	087	106	119	138	151	170	183	202	215
009	024	041	056	073	088	105	120	137	152	169	184	201	216
008	025	040	057	072	089	104	121	136	153	168	185	200	217
007	026	039	058	071	090	103	122	135	154	167	186	199	218
006	027	038	059	070	091	102	123	134	155	166	187	198	219
005	028	037	060	069	092	101	124	133	156	165	188	197	220
004	029	036	061	068	093	100	125	132	157	164	189	196	221
003	030	035	062	067	094	099	126	131	158	163	190	195	222
002	031	034	063	066	095	098	127	130	159	162	191	194	223
001	032	033	064	065	096	097	128	129	160	161	192	193	224

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Figure 4. Section of the index field layout in 1983.

received only natural precipitation during the growing season.

Emergence started on May 9th 1983, and was quite uniform for the F2 and F4 generation. The plots were weeded by hand whenever necessary and were monitored for pests and diseases. At the beginning of June the whole experiment was treated once with chlordane against cutworms. Starting from mid June till the end of July all plots were treated six times with Pirimor insecticide in order to control virus-transmitting aphids. On June 24th, 1983 six soil samples were taken at 0-15 cm and 15-30 cm depth.

Throughout the growing season notes were taken on each plant. The parameters measured on each plant are presented in Table 2. Harvest started on August 9th, 1983 with the F2 populations which had ripened very uniformly. The F4 was harvested beginning on August 15th.

Each plant was cut at ground level, tagged, bagged and dried indoors. When the moisture content was 8-10%, the plants were weighed for total dry matter, threshed and weighed for yield. Harvest index was then calculated by dividing yield per plant by TDM per plant and multiplying by 100.

The total dry matter (TDM) refers to the total above ground dry weight of a plant including the seeds. However, when fababeans ripen they usually loose their leaves, which are consequently not included.

Yield per plant (YIELD) refers to the total weight of the seeds with a moisture content of approximately 8-10% .

Table 2. Parameters measured on single plants in 1983 and on plots in 1984.

Parameters	Unit of Measurement	Abbreviation
Date of Seeding	days	SEED
Date of Emergence	days	EMER
Date of Flowering	days	FLOW
Date of Maturity	days	MAT
Plant Height at Maturity	cm	HT
Seed yield (per plant or plot)	g	YIELD
Total Dry Matter (per plant or plot)	g	TDM
Harvest Index (per plant or plot)	%	HI
Number of Plants per Plot		STAND

3.3 SELECTION METHODS

Three selection methods were applied in 1983 : the honeycomb method, the index method and the random method.

In the honeycomb method, a plant was selected if it yielded higher than all six surrounding neighbours. Selection was only carried out if at least 4 surrounding plants were present, or in a few cases where this criteria could not be fullfilled, then they were selected if they yielded higher than the plants of the next closest hexagon. Selection intensity was 14.2 % .

The selection indeces used were yield (top 50% of the population), total dry matter (top 50% of the population), and harvest index (top 50% of the population). Selection intensity was approximately 12.5% if the three parameters are assumed to be independent. The number of plants selected was adjusted according to the number selected in the honeycomb method.

Approximately 15 % of the plants from each cross and generation were selected at random using a SAS random number generating program. These selections served as a check population for both selection methods.

For the F2 and F4 of both crosses 27 plants were selected from each population according to the three selection methods.

3.4 YIELD TEST IN 1984

From May 2nd to 4th, 1984 the yield experiment was seeded at the University of Manitoba Point Field Laboratory.

The field layout was a split-split-split plot design with the sub-sub-sub plots consisting of incomplete blocks. For the F2 and F4 the incomplete blocks consisted of a 9 x 9 lattice square design. The lattice designs were replicated three times. In the 9 x 9 lattices, each selection method had 27 entries randomly assigned to the plots.

Each plot consisted of a single 1 m row spaced 60 cm apart. 25 seeds per row were planted by hand and Rhizobium leguminosarum inoculum was applied at the same time. The seeds were spaced 4 cm apart within the row.

The whole experiment was bordered by Herz Freya guard rows. Similar to the previous year, this experiment was carried out in Red River soil clay and received only natural precipitation. Soil samples were taken on May 7th, 1984. Emergence started on May 22nd 1984, and was quite uniform. Weeding was done by hand when necessary and pests and diseases were monitored.

Throughout the growing season notes were taken on each plot. The parameters were measured for each plot and are presented in Table 2. Prior to harvest the number of plants per plot (STAND) was recorded. On August 9th, 1984 harvest started with cutting the plants of each plot at ground level. Then they were tagged, bound into sheaves and left in the field for 10 days in order to dry to approximately 10% moisture content.

Just prior to threshing, all plots of the second replicate from each lattice were weighed for TDM. Then all plots were threshed, yield measured and harvest index calculated as before.

3.5 STATISTICAL ANALYSIS

Basic statistics were calculated with the SAS computer programs available at the University of Manitoba (Helwig and Council 1979).

In order to compare the populations, means, standard deviations and standard errors were calculated for each variable of each cross and generation. In 1984, yield was adjusted for STAND using analysis of covariance (ANCOVA). All subsequent statistical analyses were performed with these adjusted yield values.

The yield test was analyzed as a lattice design for each derived cross and generation. The general linear models procedures were used for the analysis of variance (ANOVA) for a nested design, also for each derived cross and generation. In order to determine statistically different means, multiple comparisons were made among entries and among selection methods. Simple intra-generation and inter-generation correlation analyses were conducted to investigate relationships among plant and plot parameters.

The statistical analysis of the lattice design was carried out according to Cochran and Cox (1960) and all other statistical procedures were conducted according to Steel and Torrie (1980).

Chapter IV

RESULTS AND DISCUSSION

4.1 CHARACTERIZATION OF THE GROWING SEASONS

Monthly means for temperature and precipitation during the growing seasons of 1983 and 1984 are presented in Table 3. The 1983 growing season (May - August) was generally characterized by unusual warm and dry conditions. May was much drier and cooler than normal. Shortly after plants started emerging, low temperatures occurred which delayed emergence and restricted early plant development. Conditions changed in June with near normal temperatures and precipitation. Thus, plants grew rapidly and started flowering about 35 days from emergence. July was characterized by unusual hot and dry weather conditions that reached record highs and persisted into August. Thus, plants suffered from moisture stress during the hot afternoon hours. In conjunction with these conditions, plant growth halted early and maturing started about 80 days after emergence.

In 1984, the growing season was generally more favourable for fababean development. May was rather cool and dry. Therefore, seeding started about ten days later than in the previous year and plants emerged about 20 days after planting. June was characterized by an unusual high amount of precipitation of 223 mm but normal temperatures. In spite of the large number of thunderstorms, lodging was not a problem and very

Table 3. Monthly means for temperature and precipitation during the growing seasons of 1983 and 1984.

Temperature[1] °C	1983	1984	Long Term Average	Historical Extremes High	Historical Extremes Low
May	8.3	10.2	11.3	16	7
June	17.1	17.0	16.8	20	12
July	22.2	19.6	19.6	24	15
August	22.5	21.1	18.3	23	15

Precipitation[2] mm	1983	1984	Long Term Average	Historical Extremes High	Historical Extremes Low
May	15	28	66	162	1
June	76	223	80	256	3
July	52	31	76	197	13
August	32	20	75	180	3

[1] From Winnipeg International Airport

[2] From the University of Manitoba Point Field Laboratory.

few plots suffered from root rot. However, vegetative growth was promoted by the warm and wet conditions. Plants flowered around 35 days from emergence. Conditions changed in July and August such that these two months were relatively dry and warm. But because of the high amount of precipitation in June, plants did not suffer from moisture stress. Plants matured rather uniformly around 75 days after emergence.

Keatinge and Shaykewich (1977) concluded that high soil moisture stress, especially during the early phases of reproductive development, severely reduces yield. Similarily, high temperatures (above 20 °C) appear to exert a negative effect on crop growth. Both moisture stress and high temperatures occurred in 1983 whereas in 1984, conditions were more favourable for fababean growth and consequently for yield.

Soil samples were taken prior to planting in both years (Appendix Tables 1 and 2). The levels of all macronutrients were found to be adequate and no fertilizer was used in either year.

4.2 CHARACTERIZATION OF THE POPULATIONS

The populations selected according to the honeycomb procedure, were slightly earlier in emergence, flowering and maturity than the respective random populations (Tables 4 and 5). Mean height was approximately the same for both selection procedures, except for the Herz Freya x Star Czyzowskich Honeycomb F4 generation (HSH4) population which was taller than the Herz Freya x Star Czyzowskich Random F4 generation (HSR4) population. As expected, plants selected according to the honeycomb method had a higher mean yield in all generations in comparison to the random

Table 4. Means and ranges of characters measured on randomly selected single plants (N=27) for each cross and generation.

	ASR2			HSR2		
Variable	Mean	S.E.	Range	Mean	S.E.	Range
EMER	136.52	1.34	130-154	133.70	1.12	130-152
FLOW	175.81	0.71	168-186	166.37	1.03	160-182
MAT	217.15	0.55	210-221	212.56	0.71	200-219
HT	91.11	1.80	75-111	83.59	2.19	65-105
YIELD	51.70	1.92	33- 76	45.85	2.90	27- 76
TDM	121.70	6.32	77-200	97.41	5.50	52-169
HI	43.99	1.55	23- 60	48.07	2.01	22- 63

	ASR4			HSR4		
Variable	Mean	S.E.	Range	Mean	S.E.	Range
EMER	136.30	1.79	130-156	137.04	1.34	130-154
FLOW	175.81	1.39	160-189	168.93	1.40	160-184
MAT	220.63	1.36	210-230	218.00	1.19	210-230
HT	88.85	2.19	73-114	84.37	2.04	62-110
YIELD	43.30	2.29	30- 75	41.48	1.69	28- 58
TDM	134.96	10.35	61-253	117.30	8.25	58-218
HI	34.81	1.98	15- 61	38.84	2.37	16- 58

Table 5. Means and ranges of characters measured on single plants (N=27) which were selected according to the honeycomb method for each cross and generation.

	ASH2			HSH2		
Variable	Mean	S.E.	Range	Mean	S.E.	Range
EMER	134.89	0.86	130-150	132.00	0.61	130-138
FLOW	171.44	1.13	160-185	164.00	0.82	160-174
MAT	215.33	0.51	210-221	212.26	0.69	200-221
HT	92.19	1.56	80-113	83.81	1.59	72-100
YIELD	69.96	2.27	51- 95	76.81	2.39	53-105
TDM	144.56	5.75	97-207	145.81	4.55	90-188
HI	49.16	1.22	35- 59	53.19	1.28	30- 61

	ASH4			HSH4		
Variable	Mean	S.E.	Range	Mean	S.E.	Range
EMER	135.48	1.13	130-156	132.81	1.07	130-152
FLOW	173.74	1.10	164-190	165.67	1.07	160-185
MAT	217.04	0.95	212-230	217.19	1.08	210-230
HT	87.22	1.86	70-106	90.00	1.78	73-104
YIELD	69.48	3.79	35-118	77.67	3.73	50-133
TDM	147.63	7.41	94-235	158.85	7.88	90-268
HI	47.82	1.87	25- 60	49.87	1.68	34- 64

Table 6. Means and ranges of characters measured on single plants (N=27) which were selected according to the index method for each cross and generation.

	ASI2			HSI2		
Variable	Mean	S.E.	Range	Mean	S.E.	Range
EMER	135.26	0.92	130-150	131.48	0.82	130-150
FLOW	174.59	0.76	166-184	167.41	0.79	160-176
MAT	216.37	0.63	212-221	211.63	0.59	200-218
HT	88.74	1.28	73-102	78.37	1.74	60- 95
YIELD	71.48	2.82	49-122	54.70	2.94	42- 70
TDM	138.44	6.05	96-237	99.81	2.94	75-136
HI	52.01	0.79	45- 62	55.09	0.85	48- 63

	ASI4			HSI4		
Variable	Mean	S.E.	Range	Mean	S.E.	Range
EMER	136.15	1.38	130-156	133.56	1.06	130-146
FLOW	175.07	0.95	168-190	166.89	0.89	160-174
MAT	217.07	1.29	210-230	212.96	0.96	200-220
HT	85.30	1.69	70-101	82.89	1.92	65- 99
YIELD	71.67	3.71	45-117	53.93	2.48	35- 93
TDM	156.30	6.78	117-251	112.74	5.34	77-200
HI	45.81	1.28	35- 58	48.14	1.05	39- 58

selections. The superiority in yield was accompanied by a higher mean TDM and a higher mean HI (Tables 4 and 5). This reflects that higher yield depends on higher TDM and/or higher HI, as was concluded by Kao (1984).

Emergence, flowering and maturity of the index populations were slightly earlier or equal to the appropriate random populations as can be observed from the means and ranges (Table 6). In comparison to the random selections, the mean height was lower for all index populations. Plants in this group were selected according to an index consisting of yield, TDM and HI. Thus, the index populations are expected to have higher mean yields, higher mean TDM and higher mean HI. This fact is true except in HSI4 where the mean TDM was lower. However, this might be attributed to environmental effects, because all HSI populations had lower TDM than the HSH populations (Appendix Tables 3 and 4).

In 1984, emergence (Table 7) was later than in 1983 due to later seeding. However, it was faster and more uniform as can be observed from the ranges for this character, a reflection of the warmer temperatures in 1984. The number of days from emergence to flowering and to maturity were almost equal in both years. Similarily, there were hardly any differences in emergence, flowering and maturity between the two crosses. This is in accordance with the results reported by Kao (1984). The author found that phenological characters were minimally influenced by environment or by heterosis. Thus, narrow sense heritability of those traits was high.

In 1984, plants were generally taller than in the previous year. However, it was to be expected that plants would grow taller at higher density because they received less light. Kao (1984) reported that height had a moderate narrow sense heritability of 44.5% to 51.3% and heterosis for this trait was found to be 2.3%.

By definition, HI can only take values between 0% and 100%. Thus, HI allows direct comparisons without the influence of actual yield and TDM values. From Tables 6 to 7 it can be observed that HI did not vary extensively whether measured on single plants or plots. Additionally, it should be noted that HI was very similar in the F2 and F4 generation when compared within the same cross. Mean HI of the Herz Freya cross was slightly higher than in the Ackerperle cross (Table 7).

Table 7. Means and ranges of characters measured on families (N=81) in 1984 for each cross and generation respectively.

	AS284			HS284		
Variable	Mean	S.E.	Range	Mean	S.E.	Range
EMER	144.28	0.13	143-150	143.73	0.04	143-146
FLOW	181.16	0.18	172-190	176.09	0.22	170-184
MAT	223.15	0.21	214-227	215.39	0.24	210-224
HT	96.85	0.62	72-120	98.25	0.51	70-115
YIELD	251.23	3.80	86-393	303.89	3.77	122-438
TDM	452.50	14.19	160-800	609.14	14.63	270-870
HI	51.71	0.49	43- 72	54.01	0.49	44- 66
STAND	19.46	0.29	6- 26	23.21	0.14	13- 25

	AS484			HS484		
Variable	Mean	S.E.	Range	Mean	S.E.	Range
EMER	143.98	3.42	143-147	143.79	0.10	143-150
FLOW	181.94	0.06	172-186	176.26	0.29	168-190
MAT	219.91	0.14	210-227	217.56	0.28	210-227
HT	97.23	0.29	72-123	91.62	0.69	60-120
YIELD	281.66	0.45	106-385	244.28	4.44	51-460
TDM	583.33	12.34	250-820	416.00	12.27	200-680
HI	51.00	0.46	39- 62	54.68	0.54	46- 74
STAND	22.27	0.15	12- 25	21.97	0.19	10- 25

4.3 YIELD TRIALS

Yield was significantly associated with the number of plants per plot (STAND) for all trials except AS484. Therefore, yield was adjusted for STAND using analysis of covariance (Appendix Table 5). The subsequent analyses of variance (ANOVA) were conducted using adjusted yield values.

4.3.1 ANALYSIS OF VARIANCE

The yield trials were analysed as 9 x 9 lattice designs with 3 replicates for the F2 and F4 generations.

The coefficient of variation (C.V.) for the F2 and the F4 derived yield trials ranged from 10.61% to 15.34 % (Table 8), indicating that the yield trials were quite reliable, especially for the type of plot and number of replicates used.

In order to identify possible significant differences among selection procedures (i.e. honeycomb selection, index selection and random selection), a further analysis of variance with entries nested within selection methods was conducted. The analysis revealed that there were no significant differences between the selection methods in AS284 and in HS484 (Table 9). This implies that the honeycomb and the index procedure were not more effective in identifying high yielding plants in these specific crosses and generations than the random procedure. In contrast, highly significant differences were detected between selection methods in AS484 and in HS284.

Table 8. Analysis of Variance of the yield trial in 1984 for each derived cross and generation.

Cross	Gen.	Source of Var.	DF	MS	F+	C.V.
AS	2	Replicates	2	133,618.79		13.12
		Entries	80	4,950.35	4.330**	
		Blocks	24	2,077.62		
		Error	136	1,009.40		
AS	4	Replicates	2	23,154.04		11.26
		Entries	80	5,387.60	4.375**	
		Blocks	24	3,671.75		
		Error	136	903.57		
HS	2	Replicates	2	54,171.57		10.61
		Entries	80	6,429.95	6.290**	
		Blocks	24	3,585.94		
		Error	136	935.43		
HS	4	Replicates	2	190,284.15		15.34
		Entries	80	6,408.25	4.221**	
		Blocks	24	3,858.55		
		Error	136	1,276.16		

** Significant at the 0.01 level of probability.

\+ All F-values are adjusted F-ratios.

Table 9. Analysis of Variance for Entries Nested within Selection Methods.

Cross	Gen.	Source of Var.	DF	MS	F	C.V.
AS	2	Replicates	2	133,618.79	114.240***	13.61
		Sel. Methods	2	1,657.30	1.417	
		Entries	78	5,034.79	4.305***	
		Error	160	1,169.63		
AS	4	Replicates	2	23,154.04	17.557***	12.89
		Sel. Methods	2	10,757.44	8.157***	
		Entries	78	5,249.92	3.981***	
		Error	160	1,318.8		
HS	2	Replicates	2	54,171.57	40.639***	12.01
		Sel. Methods	2	13,086.11	9.817***	
		Entries	78	6,259.28	4.696***	
		Error	160	1,333.01		
HS	4	Replicates	2	190,284.15	114.387***	16.70
		Sel. Methods	2	2,913.58	1.751	
		Entries	78	6,497.86	3.906***	
		Error	160	1,663.51		

*** Significant at the 0.001 level of probability.

4.3.2 COMPARISONS OF MEANS

In order to determine which selection methods differed, an L.S.D. test of means was conducted for each cross and generation. In AS484 (Table 10), the mean of the honeycomb selections was significantly higher at the 1% level of probability than the mean of the random and the index selections. However, the mean of the index selections was not different from the mean of the random selections. The honeycomb selection group outyielded the random selection group by 7.6% and the index selection group by 6.9 %.

In HS284, the same L.S.D. test of means was applied and revealed that the mean of the index selections was significantly different at the 1 % level of probability from the mean of the random and the honeycomb selections. However, no significant differences were found between the mean of the honeycomb and the mean of the random procedure. The index selection group outyielded the random selection group by 7.8 % and the honeycomb selection group by 7.0 %.

In summary, both the honeycomb and the index selection method were effective in selecting high yielding plants which gave rise to high yielding progeny. However, both methods were only successful in a specific cross and a specific generation. Additionally, the increase in yield was rather small because considerable overlapping occurred as is obvious from the range of yield (Table 10) for each selection method. Similar disappointing results were reported by Niehaus (1980) and Mitchell _et_ _al_. (1982) for wheat and by Bos (1981) for rye.

Table 10. Overall means for yield of the honeycomb, index and random selections and L.S.D. Test of Means.

Cross	Gen.	Sel.Meth.	Mean	LSD 1%	Range (g/plot)
AS	2	H	252.20		191-380
		I	255.19		148-354
		R	246.30		171-319
AS	4	H	294.94**	14.88	208-355
		I	275.81		199-365
		R	274.23		208-340
HS	2	H	297.59	14.96	196-365
		I	318.52**		217-400
		R	295.56		208-345
HS	4	H	237.40		159-351
		I	247.07		169-336
		R	248.37		150-359

** Means are significantly different from the other two selection methods at the 0.01 level of probability.

4.3.3 RESPONSE TO SELECTION

The approach of comparing means in order to detect significant differences between selection methods is statistically correct. However, a plant breeder is less interested if the overall mean of a selection method differs from the mean of the random method because some overlapping between high yielding selections and random selections has to be expected. Hence, means might not be significantly different. Therefore, a breeder would also evaluate a selection method according to the number of families retained in the top 15 % or 20 % of the population. The adjusted mean yields of each entry, sorted according to crosses, generations and selection methods, and the L.S.D. values for comparing those means are shown in Appendix Tables 6 to 9. In order to allow comparisons, the number of families in the top 15 % and 20 % of each population were counted for each selection method and are set out in Table 11. The response to selection is also given in percent of the total number.

In population AS284, the honeycomb method did not identify more high yielding plants than the random method. In contrast, the index method identified 7 out of 13 high yielding families in the top 15 % and 7 out of 16 high yielding families in the top 20 % of the population. This is obviously better than the random method which contained 3 out of 13 and 5 out of 16 high yielding families in the top 15 % or 20 % of the population, respectively. Thus, the index method identified 54 % (top 15 %) or 44 % (top 20 %) of all high yielding families.

Table 11. Number of high yielding families for each selection method in the top 15 % and 20 % of the population.

Cross	Gen.	% top yield. progeny	total No.	Honeycomb No.	Honeycomb %	Index No.	Index %	Random No.	Random %
AS	2	15%	13	3	23%	7	54%	3	23%
		20%	16	4	25%	7	44%	5	31%
AS	4	15%	12	5	42%	3	25%	4	33%
		20%	16	9	56%	3	19%	4	25%
HS	2	15%	12	6	50%	5	42%	1	8%
		20%	16	6	38%	9	56%	1	6%
HS	4	15%	12	5	42%	4	33%	3	25%
		20%	16	5	31%	6	38%	5	31%
Total top		15%	49	19	39%	19	39%	11	22%
Total top		20%	64	24	38%	25	39%	15	23%
Total Cross									
AS		15%	25	8	32%	10	40%	7	28%
		20%	32	13	41%	10	31%	9	28%
HS		15%	24	11	46%	9	38%	4	31%
		20%	32	11	34%	15	47%	6	19%
Total Gen.									
F2		15%	25	9	36%	12	48%	4	16%
		20%	32	10	31%	16	50%	6	19%
F4		15%	24	10	42%	7	29%	7	29%
		20%	32	14	44%	9	28%	9	28%

In population AS484, the index method was not advantageous. In contrast, the honeycomb method identified 5 out of 12 or 9 out of 16 high yielding lines in comparison to 4 out of 12 and 4 out of 16 identified by the random method. Hence, the honeycomb method retained 42 % (top 15 %) or 56 % (top 20 %) of all high yielding families.

In population HS284, both selection methods were better than the random procedure. The honeycomb method selected 6 out of 12 and 6 out of 16 high yielding families. Thus, 50 % (top 15 %) or 38 % (top 20 %) of the high yielding progeny were retained using the honeycomb procedure. The index method identified 5 out of 12 and 9 out of 16 high yielding families. Therefore, 42 % (top 15 %) or 56 % (top 20 %) of the high yielding plants were identified by the index selection procedure.

In population HS484, both selection methods were only slightly better than the random procedure. The honeycomb method retained 5 out of 12 (top 15 %) or 5 out of 16 (top 20 %) high yielding families. The index method retained 4 out of 12 (top 15 %) or 6 out of 16 (top 20 %) top yielding progeny.

Furthermore, an overall evaluation reveals that both the honeycomb and the index selection method identified 19 out of 49 (top 15 %) and 24 or 25 respectively, out of 64 (top 20 %) high yielding plants. With regard to crosses, both methods showed rather similar results. Both were slightly better in the Herz Freya cross than in the Ackerperle cross when compared with the random method. Considering generations, the honeycomb method seemed to perform better in F4 whereas the index method performed better in F2. Kao (1984) reported that yield showed

30% to 40% heterosis in early generations whereas TDM and HI expressed 16.4 % and 8.1 % heterosis respectively. Heterosis decreases with subsequent generations by a factor of 1/2 in each generation. Consequently, it is not surprising that the honeycomb method, which was based on yield, performed better in F4 than F2. Since heterosis for TDM and HI was lower than for yield in F2, the index selection method may have been able to achieve better results in this generation. However, reasons for the ineffectiveness of the index method in F4 remain to be investigated.

4.3.4 ANOVA OF SPLIT-PLOT DESIGN

The entire experiment was reanalyzed as a split-split-split plot design in order to study statistically, interactions between crosses and selection methods as well as between generations and selection methods. There was a highly significant interaction between crosses and selection methods and a significant interaction between generations and selection methods (Table 12). This is not surprising because the honeycomb method was significantly different in AS484 whereas the index method was significantly different in HS284 from the other methods (Table 10). This analysis also confirms the results from Table 11.

Table 12. Split-Split-Split Plot Design with Lines Nested within Selection Methods.

Source of Variation	DF	MS	F
Replicates	2	122,650.84	12.62
Cross	1	14,183.51	1.46
Error I	2	9,715.42	
Generation	1	51,701.57	0.39
Cross x Generation	1	492,570.12	1.46
Error II	4	134,431.15	
Selection Methods	2	4,267.57	2.95
Cross x Sel. Meth.	2	12,469.12	8.63**
Generation x Sel. Meth.	2	8,190.41	5.67*
Cross x Gen. x Sel. Meth.	2	3,487.33	2.41
Error III	16	1,444.62	
Entries	312	5,760.46	4.21**
Error IV	624	1,369.36	

*,** Significant at the 0.05 and 0.01 level of probability.

4.4 SIMPLE CORRELATIONS

The index selection method consisted of the criteria yield, TDM and HI. In order to select successfully for improved yield, it is necessary to have a close relation between yield and TDM, yield and HI and either a zero or a positive correlation between TDM and HI. Additionally, correlations could provide some insight as to why selection criteria were successful in predicting a genotype's yielding ability. Therefore, intra-generation and inter-generation simple correlation analysis was conducted in order to study relationships between those traits.

4.4.1 INTRA-GENERATION CORRELATION ANALYSIS IN 1983

The correlation coefficients reveal that yield and TDM were moderately correlated in the AS cross (r=0.74*** and r=0.75***) but only slightly to moderately in the HS cross (r=0.26*** and r=0.49***) (Table 13). In the HS cross only 7 % to 24 % of the variation in yield was explained by the variation in TDM. This result is rather unexpected because TDM consists of approximately 50 % yield. Additionally, the index method was successful in selecting high yielding plants especially in this HSI population (Table 11) where the correlation coefficient was 0.26***. In 1983, the growing season was rather hot and dry especially in July. Hence, this had an impact on TDM production because vegetative growth was rather restricted.

In contrast, yield and HI per plant were closely correlated in both crosses (r=0.51*** to r=0.82***), (Table 13). The index method was comparatively successful in the AS2 population (Table 11). However, the

Table 13. Simple intra-generation correlations among characters measured on single plants for the index selection method.

Cross	Gen.	Character	TDM	HI
AS	2	YIELD	0.74***	0.51***
AS	4	YIELD	0.75***	0.82***
HS	2	YIELD	0.26***	0.79***
HS	4	YIELD	0.49***	0.76***
AS	2	TDM		-0.14
AS	4	TDM		0.38***
HS	2	TDM		-0.25***
HS	4	TDM		-0.01

*** Significant at the 0.001 level of probability.

correlation of single plant yield with HI/plant in this population was only moderate (r=0.51***).

Furthermore, the relationship between TDM and HI was slightly negative to slightly positive (Table 13). However, the low r^2 values indicate that only 0 % to 15 % of the variation in HI was explained by the variation in TDM. Therefore, simultaneous selection for TDM and HI should not result in compensation effects.

4.4.2 INTRA-GENERATION CORRELATION ANALYSIS IN 1984

Similar to 1983, simple intra-generation correlation analysis was conducted in order to study the relationship between yield per plot and TDM/plot, between yield/plot and HI/plot as well as between TDM/plot and HI/plot.

There was a strong correlation, significant at the 1% level of probability, between yield per plot and TDM per plot (Table 14) in each cross and generation. However, this is not surprising if one considers that approximately half of the measured TDM is in fact seed yield. Both Neal and McVetty (1984) and Kao (1984) have reported similar results. Kao (1984) concluded that TDM production might measure a genotype's ability to adapt to an environment. Thus, good adaptability would mean an increase in TDM and if HI remained constant, an increase in yield.

Neal and McVetty (1984) and Kao (1984) concluded that for producing high yield, both high TDM and high HI must coincide. However, no association between yield per plot and HI per plot was observed (Table 14). This is in contrast to the results obtained by Kao (1984). The author

Table 14. Simple intra-generation correlations among characters measured on plots for each cross and generation.

Cross	Gen.	Character	TDM	HI
AS	2	YIELD	0.96***	-0.01
AS	4	YIELD	0.91***	0.24*
HS	2	YIELD	0.93***	-0.09
HS	4	YIELD	0.94***	0.73
AS	2	TDM		-0.27*
AS	4	TDM		-0.16
HS	2	TDM		-0.44***
HS	4	TDM		-0.26*

*,***, Significant at the 0.05 and 0.001 levels of probability, respectively.

found that yield was highly correlated with HI and attributed HI to the genotype's ability to partition assimilates into seed yield. The correlations obtained in this experiment in 1983 and 1984 were reversed. However, this might possibly be attributed to the different weather conditions in both years. Similar to 1983, TDM/plot and HI/plot were slightly negative but significantly correlated (Table 14). However, this correlation is not very meaningful because the r^2 values ranged from 2.7% to 19.5 % which implies that more than 80 % of the variation in HI is not explained by the variation in TDM. This result was confirmed by Kao (1984). Therefore, the author concluded that selection for TDM and HI simultaneously should be possible.

4.4.3 INTER-GENERATION CORRELATION

An inter-generation simple correlation analysis was conducted to study the relationship between single plant characters and their respective plot characters.

No correlation between yield per plant and yield per plot was observed, except in the AS2 honeycomb population (Table 15). In view of this result, it is surprising that although the correlation was rather low in this population, the honeycomb method was not successful (Table 11). This result is in contrast to Neal and McVetty (1984) who reported that the best predictor of plot yield was spaced plant yield (r=0.747***).

Neal and McVetty (1984) also found a correlation between TDM per plant and plot yield (r=0.686**) and between HI per plant and plot yield

Table 15. Simple inter-generation correlations between single plant yield and plot yield.

Cross	Generation	Sel.Methods	r	r^2
AS	2	H	0.44*	20 %
AS	2	I	0.09	1 %
AS	4	H	0.04	0 %
AS	4	I	0.05	0 %
HS	2	H	0.18	3 %
HS	2	I	0.32	10 %
HS	4	H	0.31	14 %
HS	4	I	0.08	1 %

* Significant at the 0.05 level of probability.

(r=0.474*). Neither of these correlations could be confirmed in this experiment (Table 16). Both TDM per plant and HI per plant were not associated with yield per plot except in HS4, where the correlation was slightly negative. However, this was to be expected in view of the reverse correlations between yield and TDM as well as yield and HI in both years.

Additionally, neither TDM per plant and TDM per plot nor HI per plant and HI per plot were correlated (Table 16).

Table 16. Simple inter-generation correlations between single plant and plot characters for the index selection method.

Cross	Gen.	Character	Yield/ plot	TDM/ plot	HI/ plot
AS	2	TDM / Plant	0.06	0.27	-0.35
AS	4	TDM / Plant	0.11	0.23	-0.47*
HS	2	TDM / Plant	0.19	0.02	-0.35
HS	4	TDM / Plant	-0.42*	0.37	0.32
AS	2	HI / Plant	0.09	-0.28	0.21
AS	4	HI / Plant	-0.13	-0.15	0.07
HS	2	HI / PLant	0.17	0.06	0.22
HS	4	HI / Plant	-0.42*	-0.19	-0.17

* Significant at the 0.05 level of probability.

Chapter V

GENERAL DISCUSSION AND CONCLUSION

Early generation selection for yield has often been applied to cereal crops with various levels of success. However, no attempt has yet been made to apply these selection procedures to Vicia faba L.. Therefore, this study was conducted to determine the effectiveness of the honeycomb and the index method for the identification of spaced plant yield potential in early generations of fababeans. Both selection procedures were evaluated by comparing them with a group of randomly selected plants.

The results of this experiment revealed that the honeycomb and the index method were successful in predicting yield of spaced plants. However, the effectiveness of both methods depended on the generations. The analysis of variance indicated the presence of significant genotypic differences among the entries for yield (Table 8). Furthermore, significant differences were detected between selection methods in AS4 and HS2 (Table 9).

The L.S.D. test of means found that in AS4, the honeycomb method significantly outyielded the random and the index selections by 7.6 % and 6.9 % respectively (Table 10). In addition, response to selection was determined by comparing the number of entries from each selection method in the top 15 % and 20 % of the population. The honeycomb method was found to be superior in AS4 and HS2 (Table 11). However, this method was only slightly better than the random procedure in HS4 but was not effective in AS2.

The honeycomb method advocates direct selection for yield. In the F1 generation of fababeans, yield displayed 30 % to 40 % heterosis for yield which declined with a factor of 1/2 with each subsequent generation (Kao 1984). Consequently, the honeycomb method would be expected to perform better in the F4 than F2. However, this selection procedure was only effectively applied in one of the two F4 generations. The low or non significant correlations (Table 15) obtained between single plant yield and plot yield were probably due to genotype x environment interactions. The genotypes that perform well in one year do not necessarily perform well in another, especially if the years are very different. Similarly, Niehaus (1980) and Mitchell _et_ _al_. (1982) found no or only low correlations between single plant yield and progeny performance and attributed this to genotype x year interactions. In addition, genotype x density effects might have confounded selection procedures. Many plant breeders have reported that wide plant spacing might introduce bias due to different abilities of genotypes to respond to wide spacing (Chebib _et_ _al_. 1973, Hamblin and Evans 1976, Kelker and Briggs 1979, Spitters 1979).

Niehaus (1980), Bos (1981) and Mitchell _et_ _al_. (1982) reported similar moderate results for the honeycomb method. The authors thus concluded that this method does not justify the work required in its application. In contrast, Lungu (1984) obtained more positive results. The reason for this could be due to the fact that selection took place in F2 and F3. This higher selection response was obtained in comparison with a low yielding selection group. In contrast, progenies of the high yielding selections outyielded the plants of the check variety only by 4.24 % and 6.73 %.

Bos (1983 b) also concluded that the progress of selection might be greater at low levels of adaptation than at high levels of adaptation of the experimental material. Furthermore, the findings of Soetono and Donald (1980) and Soetono and Puckridge (1982) indicate that a comparison within a hexagon might also be biased because the phenotypes of the plants are mainly determined by their individual growing conditions and less influenced by their common environment.

Hence, this preliminary study is consistent with those other findings that the honeycomb method is not very effective in identifying high yielding fababeans, in order to warrant the work involved in the application of this method.

The L.S.D. test of means found that in HS2 the plants selected according to the index method significantly outyielded the random and the honeycomb selections by 7.8 % and 7.0 % respectively (Table 10).

Response to selection was also determined by comparing the number of entries from the index method with the other selection procedures (Table 11). The index method identified high yielding plants which gave rise to high yielding progeny in the F2 of both crosses. However, this selection procedure was only slightly better than the random method in HS4 and was not successful in AS4.

The index method selected for yield, TDM and HI. Both TDM and HI showed only 16.4 % and 8.1 % heterosis in F1 respectively (Kao 1984). Consequently, it might be expected that the index method would perform well in the F2 generation. The reason for the low response in the F4 remains a matter of speculation. It might be attributed to genotype x density interactions and genotype x year effects. Probably due to the remaining heterosis in F2, plants of this generation might have been better able than the F4 to adapt to the unfavourable growing conditions in 1983. Another reason for the low response of the index method in F4 could be due to the virus infection and the population size. The F4 was generally more affected by virus diseases than the F2. Thus, the population size for selection was smaller and might not have contained many plants with high yield potential.

Neal and McVetty (1984) reported that single plant yield was highly correlated with plot yield (r=0.747***). In addition, both TDM and HI of single plants were associated with plot yield (r=0.686** and r=0.474*). None of these results were confirmed in this experiment. In 1983, single plant yield was highly correlated with HI (Table 13), moderately high with TDM in the AS cross but there was only a slight association in the HS cross (Table 13). In contrast, yield per plot was highly correlated with TDM (Table 14) but not associated with HI per plot in 1984 (Table 14). Consequently, no or only low inter-generation correlations were found (Tables 15 and 16). These findings support the possibility that there might have been a confounding genotype x year interaction.

On the other hand, the results of the F2 confirmed that an increase in TDM and/or HI were indeed correlated with an increase in yield as was suggested by Keller and Burkhard (1981), by Neal and McVetty (1984) and by Kao (1984).

In conclusion, response to selection of the honeycomb or the index methods was moderate. However, selection and testing took place under very dissimilar growing conditions which might have had an impact on the level of success. The index method seems to be more effective in F2 whereas the honeycomb method tends to perform better in F4. In addition to the earlier generation (F2), the index method is more flexible because population size can be variable whereas the honeycomb method depends on a comparison of all plants. Hence, the index method could be combined with visual selection. This would enable plant breeders to remove obviously undesirable plants first and then to apply the index method. Thus, fewer plants would have to be harvested. This is an important feature because the index method requires the measurement of TDM which implies even more work than the honeycomb method.

The results of this experiment disagree with the general held view of Allard (1960) and many other plant breeders that selection for quantitatively inherited traits such as yield is futile in early generations. However, one has to keep in mind that selection and testing was carried out at one location and in one year only. The yield trial used small single row plots which might have reduced the accuracy of the results. Therefore, further testing and further experiments are necessary in order to be able to draw general conclusions about the effectiveness of the honeycomb and the index method.

LIST OF REFERENCES

Abdalla,M.M.F. and G. Gunzel 1979. Protein content and electrophoresis of seed proteins of certain Vicia faba L. stocks and their assumed ancestors.Zeitschrift f. Pflanzenzuchtg. 83: 148-154.

Allard,R.W. 1960. Principles of Plant Breeding. John Wiley and Sons, New York, pp. 115-128.

Baker,R.J. and K.G. Briggs 1982. Effects of plant density on the performance of 10 barley cultivars. Crop Sci. 22: 1164-1167.

Baker,R.J. and G. Gebeyehou 1982. Comparative growth analysis of two spring wheats and one spring barley. Crop Sci. 22: 1225-1229.

Bhatt,G.M. 1980. Early generation selection criteria for yield in wheat. Austr. Inst. Agric. Sci. J. : 14-22.

Blijenburg, J.G. and J. Sneep 1975. Selection in a mixture of 8 barley varieties grown in six successive years. I. Competition between the varieties. Euphytica 24: 305-315.

Bond,D.A. 1966. Yield and components of yield in diallel crosses between inbred lines of winter beans (Vicia faba L.). J. agric. Sci. Camb. 67: 325-336.

Bond,D.A.1976. Field Bean. In: Evolution of Crops. Ed. N.W. Simmonds, Longman Pub., New York, pp. 179-182.

Bond,D.A. and M.H. Poulsen 1983. Pollination. In: The Faba Bean (Vicia faba L.). Ed. P.D. Hebblethwaite, Butterworths, London, pp. 77-101.

Bos, I. 1981. The relative efficiency of the honeycomb selection and other procedures for mass selection in winter rye (Secale cereale L.). Doctoral Thesis, Agr. University, Dep. of Plant Breeding, Wageningen, Netherlands, 171pp.

Bos, I. 1983a. About the efficiency of grid selection. Euphytica 32: 885-893.

Bos, I. 1983b. Some remarks on honeycomb selection. Euphytica 32: 329-335.

Briggs,K.G. and L.H. Shebeski 1968. Implications concerning the frequency of control plots in wheat breeding nuseries. Can.J.Plant Sci. 48: 149-153.

Chapman,G.P. and W.E. Peat 1978. Procurement of yield in field and broad beans. Outlook on Agriculture 6: 267-272.

Chebib,F.S., S.B.Helgason and P.J.Kaltsikes 1973. Effect of variation in plant spacing, seed size and genotype on plant-to-plant variability in wheat. Zeitschrift Pflanzenzuchtg. 69: 301-332.

Chooi, W.Y. 1971. Variation in nuclear DNA content in the genus Vicia. Genetics 68: 195-211.

Clark, K.W. 1980. Faba Bean rhizobiology and agronomy. Fabis Newsletter 2: 5-7.

Cochran, W.G. and G.M. Cox 1960. Experimental Designs. John Wiley, Inc..

Cubero, J.I. 1974. On the evolution of Vicia faba L.. Theoret.Appl.Genetics 45: 47-51.

Cubero, J.I. 1982. Interspecific hybridization in Vicia. In: Faba Bean Improvement. Eds. G. Hawtin and C. Webb. I.C.A.R.D.A., Netherlands, pp. 91-108.

Cubero, J.I. and A. Martini 1981. Factorial analysis of yield components in Vicia faba. In: Vicia faba: Physiology and Breeding. Ed. R. Thompson. Martinus Nijhoff, Netherlands, pp. 139-151.

Dantuma, G., E. von Kittlitz, M. Frauen and D.A. Bond 1983. Yield, yield stability and measurement of morphological and phenological characters of faba bean (Vicia faba L.) varieties grown in a wide range of environments in Western Europe. Zeitschrift f. Pflanzenzuchtg. 90: 85-105.

Day, J.M., R.J. Roughley and J.F. Witty 1979. The effect of planting density, inorganic nitrogen fertilizer and supplementary carbon dioxide on yield in Vicia faba L.. J.agric.Sci.Camb. 93: 629-633.

DePauw, R.M. and L.H. Shebeski 1973. An evaluation of early generation yield testing procedure in Triticum aestivum. Can.J.Plant Sci. 53:465-470.

Donald, C.M. 1963. Competition among crops and pasture plants. Advances in Agronomy 15: 1-118.

Donald, C.M. and J. Hamblin 1976. The biological yield and harvest index of cereals as agronomic and plant breeding criteria. Advances in Agronomy 28: 361-405.

Escuro, P.B., J.C. Sentz and W.M. Myers 1963. Effectiveness of selection in F2 of crosses among related and unrelated lines of oats. Crop Sci. 3: 319-323.

Fasoulas, A. 1973. A new approach to breeding superior yielding varieties. Dep.Genet.Plant Breeding, Aristotelian Univ. of Thessaloniki, Greece, Publ. No.3, 42pp..

Fasoulas, A. 1979. The Honeycomb Field Design. Dep.Genet.Plant Breeding, Aristotelian Univ. of Thessaloniki, Greece, Publ. No.9, 70 pp..

Fasoulas, A. 1981. Principles and methods of plant breeding. Aristotelian Univ. of Thessaloniki, Greece, Publ. No.11, 147 pp..

Frey, K.J. 1962. Effectiveness of visual selection upon yield in oat crosses. Crop. Sci. 2: 102-105.

Frey, K.J. 1964. Adaption reaction of oat strains selected under stress and non-stress environmental conditions. Crop Sci. 4: 55-58.

Frey, K.J. 1965. The utility of hillplots in oat research. Euphytica 14: 196-208.

Furgal, F.J. and L.E. Evans 1980. Faba bean breeding in Manitoba. FABIS Newsletter 2: 22-23.

Gardner, C.O. 1961. An evaluation of effects of mass selection and seed irradiation with thermal neutrons on yield of corn. Crop Sci. 1: 241-245.

Grafius, J.E. 1956. Components of yield in oats: A geometrical Interpretation. Agronomy J. 48: 419-423.

Grafius, J.E., W.L. Nelson and V.A. Dirks 1952. The heritability of yield in barley as measured by early generation bulked progenies. Agronomy J. 44: 253-257.

Griffiths, D.J. and D.A. Lawes 1978. Variation in crude protein content of field beans (Vicia faba) in relation to the possible improvement of the protein content in the crop. Euphytica 27: 487-495.

Hamblin, J. and C.M. Donald 1974. The relationships between plant form, competitive ability and grain yield in a barley cross. Euphytica 23: 535-542.

Hamblin, J. and A.M. Evans 1976. The estimation of cross yield using early generation and parental yields in dry beans (Phaseolus vulgaris L.). Euphytica 25: 515-520.

Hamblin, J., R. Knight and M.J. Atkinson 1978. The influence of systematic micro-environmental variation of individual plant yield within selection plots. Euphytica 27: 497-503.

Hanelt, P., H. Schafer and J. Schultze-Motel 1972. Die Stellung von Vicia faba L. und Betrachtungen zur Entstehung dieser Kulturart. Kulturpfl. 20: 263-275.

Hanson, P.R., G. Jenkins and B. Westcott 1979. Early generation selection in a cross of spring barley. Zeitschrift f. Pflanzenzuchtg. 83: 64-80.

Harlan, H.V. and M.L. Martini 1938. The effect of natural selection in a mixture of barley varieties. J.agric.Res. 57: 189-199.

Hawtin, G.C. 1981. An overview of breeding methods for the genetic improvement of faba beans. In: International Conference on Faba Beans, Cairo, 7.-11.March, 28pp..

Hawtin, G.C. and P.D. Hebblethwaite 1983. Background and history of faba bean production. In: The Faba Bean (Vicia faba L.). Ed. P.D. Hebblethwaite, Butterworths, London, pp. 3-22.

Helwig, J.T. and K.A. Council (editors) 1979. SAS User's Guide. SAS Institute Inc., Cary, N.C., 494 pp..

Hodgson, G.L. and G.E. Blackman 1956. An analysis of the influence of plant density on the growth of Vicia faba. I. The influence of density on the pattern of development. J. Experimental Botany 7 (20): 147-165.

Hodgson, G.L. and G.E. Blackman 1957. An analysis of the influence of plant density on the growth of Vicia faba. II. The significance of competition for light in relation to plant development at different densities. J.Experimental Botany 8 (23): 195-219.

Igwilo, N. 1982. Nodulation and nitrogen accumulation in field beans (Vicia faba L.).J.agric.Sci.Camb. 98: 269-288.

Ishag, H.M. 1973. Physiology of seed yield in field beans (Vicia faba L.). I. Yield and yield components. J.agr.Sci. Camb. 80: 181-189.

Jennings, P.R. and R.C. Aquino 1968. Studies on competition in rice. III.The mechanism of competition among phenotypes. Evolution 22: 529-542.

Jennings, P.R. and J. de Jesus 1968. Studies on competition in rice. I. Competition in mixtures of varieties. Evolution 22: 119-124.

Jensen, N.F. and W.T. Federer 1965. Competing ability in wheat. Crop Sci. 5: 449-452.

Kao, H.M. 1984. Inheritance of yield and agronomic characters in diallel crosses of spring fababeans (Vicia faba L.). MSC Thesis, University of Manitoba.

Keatinge, J.D.H. and C.F. Shaykewich 1977. Effects of the physical environment on the growth and yield of field beans (Vicia faba minor) in the Canadian prairie. J. agric. Sci., Camb. 89: 349-353.

Kelker, H.A. and K.G. Briggs 1979. The effects of intergenotypic competition and interplant spacing in simulated segregating rows of wheat. Proc. 5th Int. Wheat Genetics Symp. 2: 778-786.

Keller, E.R. and J. Burkhard 1981. Relationship between plant density and structure of yield in different growth types of Vicia faba L.. In: Vicia faba: Physiology and Breeding. Ed. R. Thompson. Martinus Nijhoff, Netherlands, pp. 244-255.

Khalifa, M.A. and C.O. Qualset 1974. Intergenotypic competition between tall and dwarf wheats. I. In mechanical mixtures. Crop Sci. 14: 795-799.

Knight, R. 1983. Some factors causing variation in the yield of individual plants of wheat. Aust.J.Agric.Res. 34: 219-228.

Knott, D.R. 1972. Effects of selection for F2 plant yield on subsequent generations in wheat. Can.J.Plant Sci. 52: 721-726.

Knott, D.R. 1979. Selection for yield in wheat breeding. Euphytica 28: 37-40.

Knott, D.R. and J. Kumar 1975. Comparison of early generation yield testing and a single seed descent procedure in wheat breeding. Crop Sci. 15: 295-299.

Ladizinski, G. 1975a. On the origin of the broad bean, Vicia faba L.. Israel.J.Bot. 24:80-88.

Ladizinski, G. 1975b. Seed protein electrophoresis of the wild and cultivated species of section faba of Vicia. Euphytica 24: 785-788.

Lafiandra, D.,G.B. Polignano and G. Colaprico 1979. Protein content and amino acid composition of seed in varieties of Vicia faba L.. Zeitschrift f. Pflanzenzuchtg. 83: 308-314.

Lawes, D.A. 1980. Recent developments in understanding, improvement, and use of Vicia faba.In: Advances in Legume Science. Eds. R.J. Summerfield and A.H. Bunting. Richmond, U.K., Kew, pp. 625-636.

Lawes, D.A., D.A. Bond and M.H. Poulsen 1983. Classification, origin, breeding methods and objectives. In: The Faba Bean (Vicia faba L.). Ed. P.D. Hebblethwaite, Butterworths, London, pp. 23-76.

LeClerg, E.L. 1966. Significance of experimental design in plant breeding. In: K.J. Frey (ed.), Plant Breeding Symp. held at Iowa State Univ., Univ. Press,Ames,Iowa, pp 243-313.

Lee, J.A. 1960. A study of plant competition in relation to development . Evolution 14: 18-28.

Leffel, R.C. and W.D. Hanson 1961. Early generation testing of diallel crosses of soybeans. Crop Sci. 1: 169-174.

Luedders, V.D., L.A. Duclos and A.L. Matson 1973. Bulk, Pedigree, and early generation testing breeding methods compared in soybeans. Crop Sci. 13: 363-364.

Lungu, D.M. 1984. Effectiveness of the honeycomb design in early generation yield evaluation in spring wheat. PhD Thesis, Univ. of Manitoba, 142 pp.

Magyarosi, T. and J. Sjodin 1976. Investigations of yield and yield components in field beans (Vicia faba L.) varieties with different ripening time. Zeitschrift f. Pflanzenzuchtg. 77: 133-144.

McGinnis, R.C. and L.H. Shebeski 1968. The reliability of single plant selection for yield in F2. In: Proc. 3rd Int. Wheat Genetics Symp., Canberra, Australia, pp. 410-415.

McKenzie, R.I.H. and J.W. Lambert 1961. A comparison of F3 lines and their related F6 lines in two barley crosses. Crop Sci. 1: 246-249.

McVetty, P.B.E. and L.E. Evans 1980a. Breeding Methodology in wheat. I.Determination of characters measured on F2 spaced plants for yield selection in spring wheat. Crop Sci. 20: 583-586.

McVetty, P.B.E. and L.E. Evans 1980b. Breeding Methodology in wheat. II. Productivity, harvest index, and height measured in spring wheat. Crop Sci. 20: 587-589.

McVetty, P.B.E. and J. Nugent-Rigby 1984. Natural cross pollination of faba beans (Vicia faba L.) grown in Manitoba. Can. J. Plant Sci. 64: 43-46.

Mitchell, J.W., R.J. Baker and D.R. Knott 1982. Evaluation of honeycomb selection for single plant yield in durum wheat. Crop Sci. 22: 840-843.

Monde, S.S. 1981. Nearest neighbor procedure and density dependent yield prediction in barley (Hordeum vulgare L.). Diss. Abstracts Int. B 42, No. 811664.

Muratova, V.S. 1931. Common beans (Vicia faba L.). Supplement 50, Bull.app.Bot.Genet.Pl.Breed. pp. 1-298.

Nass, H.G.1983. Effectiveness of several selection methods for grain yield in two F2 populations of spring wheat. Can.J.Plant Sci. 63: 61-66.

Neal, J.R. and P.B.E. McVetty 1984. Yield structure of faba beans (Vicia faba L.) grown in Manitoba. Field Crop Res. 8: 349-360.

Niehaus, W.S. 1980. Effectiveness of harvest index and the honeycomb design in early generation yield evaluation in durum wheat. PhD Thesis, North Dakota State Univ., 38pp.

O'Brien, L., R.J. Baker and L.E. Evans 1978. Response to selection for yield in F3 of four wheat crosses. Crop Sci. 18: 1029-1033.

O'Brien, L., R.J. Baker and L.E. Evans 1979a. Evaluation of F3 selection for yield. In: Proc 5th Int. Wheat Genetics Symp. 2: 787-793.

O'Brien, L., R.J. Baker and L.E. Evans 1979b. Comparison of hill and row plots for F3 yield testing. Can.J.Plant Sci. 59: 1013-1017.

Okolo, E.G. 1977. Harvest index of F2 single plants as a yield potential estimator in common wheat. MSC Thesis, Univ. of Manitoba.

Pernas, A. 1974. Growth characteristics of six wheat cultivars under normal and spaced planting. MSC Thesis, Univ. of Manitoba, 89 pp.

Platford, G., J.R. Rogalsky, D. Small, J.F. Furgal, L.D. Campbell, T.J. Devlin, J.R. Ingalls, S.C. Stothes and M.E. Seale 1981. Fababean production and use in Manitoba. Manitoba Agric. Publ. 20pp.

Poulsen, M.H. 1975. Pollination, seed setting, cross-fertilization and inbreeding in Vicia faba L. Zeitschrift f. Pflanzenzuchtg. 74: 97-118.

Poulsen, M.H. 1977, Genetic relationships between seed yield components and earliness in Vicia faba L. and the breeding implications. J.agric.Sci.Camb. 89 643-654.

Presber, A.A.W. 1972. An inquiry into the origin, cultivation and utilization of the small faba bean (horsebean) in Austria, The Federal Republic of Germany and England. Report of Canada Grains Council, Winnipeg, Manitoba, October 31st, 97pp.

Pritchard, F.J. 1916. The use of checks and repeated plantings in varietal tests. J.American Soc. Agronomy 8 (2): 65-81.

Richey, F.D. 1924. Adjusting yields to their regression on a moving average, as a means of correcting for soil heterogeneity. J. Agric. Res. 27: 79-90.

Richey, F.D. 1926. The moving average as a basis for measuring correlated variation in agronomic experiments. J.Agric.Res. 32: 1161-1175.

Sakai, K.J. 1955. Competition in plants and its relation to selection. Cold Spring Harbor Symp. quant. Biol. 20: 137-157.

Sakai, K.J. 1961. Competitive ability in plants: its inheritance and some related problems. Symp. Soc. exp. Biol. 15: 245-263.

Saxena, M.C. 1982. Physiological aspects of adaption. In: Faba Bean Improvement. Eds. G. Hawtin and C. Webb. ICARDA, Netherlands, pp. 145-160.

Schultze-Motel, J.von, 1972. Die archaologischen Reste der Ackerbohne Vicia faba und die Genase der Art. Kulturpfl. 19: 321-358.

Seitzer, J.F. 1973. An evaluation of seed yield, protein content and other agronomic characters of fababeans (Vicia faba L.). MSC Thesis, Univ. of Manitoba, 130 pp.

Shebeski, L.H. 1967. Wheat and Breeding. In: Canadian Centennial Wheat Symp. Ed. K.F. Nielson, Modern Press, Saskatoon, pp. 249-272.

Shebeski, L.H. and L.E. Evans 1973. Early generation selection for wide range adaptability in the breeding program. In: Proc. 4th Int. Wheat Genetics Symp., Columbia, Missouri, pp. 587-593.

Simmonds, N.W. 1981. Principles of Crop Improvement. Longman, London and New York, 408 pp.

Skorda, E.A. 1973. Increasing the efficiency of selection for F2 plant yield by reducing environmental variability. Proc. Fourth Int. Wheat Genetics Symp., Columbia, Missouri, pp. 595-600.

Smith, H.F. 1938. An empirical law describing heterogeneity in the yields of agricultural crops. J. agric. Science 28: 1-23.

Sneep, J. 1977. Selection for yield in early generations of self-fertilizing crops. Euphytica 26: 27-30.

Soetono and C.M. Donald 1980. Emergence, growth and dominance in drilled and square-planted barley crops. Aust. J. Agric. Res. 31: 455-470.

Soetono and D.W. Puckridge 1982. The effect of density and plant arrangement on the performance of individual plants in barley and wheat crops. Aust. J. Agric. Res. 33: 171-177.

Spitters, C.J.T. 1979. Competition and its consequences for selection in barley breeding. Agr. Res. Reports 893, Wageningen, Netherlands, 268 pp.

Sprent, J.I., A.M. Bradford and C. Norton 1977. Seasonal growth patterns in field beans (Vicia faba L.) as affected by population density, shading and its relationship with soil moisture. J.agric.Sci.Camb. 88: 293-301.

Steel, R.G.D. and J.H. Torrie 1980. Principles and Procedures of Statistics. A biometrical approach. 2nd edition, McGraw-Hill Book Company. New York, 633 pp.

Thompson, R. and H. Taylor 1981. Factors limiting growth and yield of Vicia faba. In: Vicia faba: Physiology and Breeding. Ed. R. Thompson, Martinus Nijhoff, Netherlands, pp. 34-45.

Townley-Smith, T.F. and E.A. Hurd 1973. Use of moving means in wheat yield trials. Can. J. Plant Sci. 53:447-450.

Utz, H.F., K.D. Alber, F.W. Schnell and M.L. Snoy 1973. Selektion in fruhen Generationen des Winterweizens. Zeitschrift f. Pflanzenzuchtg. 70: 38-50.

Vries, A.P. de, 1979. In search of characters to be used for indirect selection on grain and protein yield in Vicia faba L. In: Some current research on Vicia faba in Western Europe. Eds. D.A. Bond, G.T. Scarascia-Mugnozza and M.H. Poulsen. Commission of the European Communities, Luxemburg, pp. 324-341.

Valentine, J. 1982. Variation in monoculture and in mixture for grain yield and other characters in spring barley. Ann. appl. Biol. 101: 127-141.

Whan, B.R., R. Knight and A.J. Rathjen 1982. Response to selection for grain yield and harvest index in F2, F3 and F4 derived lines of two wheat crosses. Euphytica 31: 139-150.

Yassin, T.E. 1973. Genotypic and phenotypic variances and correlations in field beans (Vicia faba L.). J. agric. Sci. Camb. 81: 445-448.

Appendix A

APPENDIX TABLES

Table 1 . Soil analysis of the field experiment in 1983.

Sample	Depth cm	pH	Salinity mmhos/cm	Nitrate-N		Phosphorous		Potassium		Sulphate-S	
				ppm	kg/ha	ppm	kg/ha	ppm	kg/ha	ppm	kg/ha
1	0-15	7.6	0.3	19.0	34.2	24.6	44.3	268	482	8.2	14.8
	15-30		0.2	23.2	41.8					8.6	15.5
2	0-15	7.9	0.1	17.2	31.0	33.4	60.1	375	675	7.2	13.0
	15-30		0.3	25.8	46.4					8.4	15.1
3	0-15	7.5	0.3	35.6	64.1	48.4	87.1	502	904	20+	36+
	15-30		0.2	31.2	56.2					20+	36+
4	0-15	7.7	0.1	26.8	48.2	46.4	83.5	449	808	9.0	16.2
	15-30		0.3	32.6	58.7					7.8	14.0
5	0-15	7.7	0.1	10.6	19.1	25.0	45.0	352	634	5.4	9.7
	15-30		0.2	15.0	27.0					4.8	8.6
6	0-15	7.7	0.1	3.0	5.4	19.2	34.6	395	711	2.4	4.3
	15-30		0.1	7.8	14.0					4.8	8.6

Table 2. Soil analysis of the field experiment in 1984.

Sample	Depth cm	pH	Salinity mmhos/cm	Nitrate-N ppm	Nitrate-N kg/ha	Phosphorous ppm	Phosphorous kg/ha	Potassium ppm	Potassium kg/ha	Suphate-S ppm	Suphate-S kg/ha
1	0-15	7.0	0.2	3.0	5.4	14.4	25.9	374	673	2.4	4.3
	15-30		0.3	5.2	32.8					3.8	23.9
2	0-15	6.9	0.2	3.6	6.3	12.4	22.3	375	675	3.0	5.4
	15-30		0.3	6.8	42.8					4.6	29.0
3	0-15	6.9	0.4	9.8	17.6	32.8	59.0	488	878	5.8	11.5
	15-30		0.5	12.4	78.1					6.4	40.3
4	0-15	6.9	0.2	6.8	12.2	32.4	58.3	500	900	4.2	7.6
	15-30		0.3	14.4	90.7					5.4	34.0
5	0-15	7.6	0.2	5.8	10.4	14.2	25.6	405	729	3.4	6.1
	15-30		0.3	14.0	88.2					5.6	35.3
6	0-15	7.0	0.4	5.6	10.1	16.2	29.2	410	738	3.0	5.4
	15-30		0.4	12.6	79.4					4.8	30.2

Appendix Table 3. Means and ranges of characters measured on single plants of the entire honeycomb populations for each cross and generation.

		ASH2			HSH2	
Variable	Mean	S.D. N=210	Range	Mean	S.D. N=203	Range
EMER	135.82	4.56	130-154	134.33	5.91	130-156
FLOW	173.83	5.49	160-188	166.05	6.27	160-187
MAT	216.01	4.03	200-221	212.45	5.22	200-221
HT	90.52	9.92	60-128	83.00	9.66	61-111
YIELD	45.71	18.35	10- 95	47.27	21.96	10-105
TDM	112.78	36.69	20-211	116.16	39.18	20-238
HI	41.01	11.30	6- 59	41.99	15.60	6- 63

		ASH4			HSH4	
Variable	Mean	S.D. N=130	Range	Mean	S.D. N=176	Range
EMER	140.40	10.25	130-164	136.85	8.77	130-160
FLOW	177.52	8.77	160-198	168.86	8.37	160-190
MAT	221.16	6.84	204-230	218.85	7.01	200-230
HT	87.94	11.63	55-114	88.22	11.39	60-122
YIELD	37.43	23.75	10-118	43.22	23.04	10-133
TDM	116.33	48.07	23-280	120.77	44.64	23-268
HI	32.84	14.50	6- 62	36.39	14.58	6- 64

Appendix Table 4. Means and ranges of characters measured on single plants of the entire index populations for each cross and generation.

	ASI2			HSI2		
Variable	Mean	S.D. N=164	Range	Mean	S.D. N=134	Range
EMER	137.73	6.56	130-165	133.49	5.72	130-156
FLOW	176.46	5.30	164-200	167.11	5.84	160-189
MAT	216.10	4.49	200-221	211.66	5.09	200-221
HT	87.48	10.55	55-117	77.85	11.70	53-105
YIELD	43.71	20.75	10-122	33.06	15.42	10- 70
TDM	104.04	42.32	18-254	89.46	36.96	30-242
HI	42.68	12.14	10- 66	40.12	16.27	7- 74

	ASI4			HSI4		
Variable	Mean	S.D. N=73	Range	Mean	S.D. N=102	Range
EMER	141.03	10.71	130-166	136.04	7.60	130-160
FLOW	178.65	8.21	160-198	168.78	7.13	160-190
MAT	220.23	7.81	210-230	214.17	6.35	200-230
HT	83.23	12.92	43-110	79.92	13.22	50-113
YIELD	40.42	26.71	10-117	30.51	17.21	10- 93
TDM	124.91	56.16	21-253	92.92	43.20	24-261
HI	32.39	14.20	7- 62	35.20	14.73	4- 63

Appendix Table 5. Analysis of Covariance for yield versus stand for each derived cross and generation.

Source of Var.	DF	MS	F	b
AS284:				
Treatment	80	4,625.23	4.00***	
Group	2	131,362.36	113.74***	
Stand	1	67,777.10	58.69***	6.93***
Error	159	1,154.92		
AS484:				
Treatment	80	5,007.76	3.78***	
Group	2	22,501.52	16.96***	
Stand	1	1,498.59	1.13	1.90
Error	159	1,326.51		
HS284:				
Treatment	80	6,420.20	4.77***	
Group	2	46,578.90	34.62***	
Stand	1	16,439.14	12.22***	6.82***
Error	159	1,345.50		
HS484:				
Treatment	80	6,308.03	4.75***	
Group	2	198,266.94	149.37***	
Stand	1	20,806.44	15.68***	5.74***
Error	159	1,327.35		

*** Significant at the 0.001 level of probability.

Appendix Table 6. Adjusted means for entries of AS284 for each selection method.

Honeycomb		Index		Random	
Entry No.	Yield (g)	Entry No.	Yield (g)	Entry No.	Yield (g)
2	248	3	246	1	238
4	240	5	260	7	255
6	265	8	324	10	200
11	296	9	257	18	221
14	270	12	258	19	259
16	232	13	319	21	319
20	380	15	299	23	212
24	250	17	259	26	263
29	265	22	268	28	287
30	250	25	216	32	279
34	208	27	248	36	295
35	209	31	308	39	238
37	239	33	268	40	239
41	272	38	230	43	265
42	240	44	225	47	226
48	278	45	217	51	227
49	251	46	201	53	227
52	191	50	244	54	211
56	290	55	176	58	284
62	197	57	148	60	241
64	227	59	290	63	294
71	247	61	204	66	171
72	238	65	260	67	229
74	242	70	274	68	180
76	220	73	291	69	272
78	264	75	243	79	265
81	284	77	354	80	267

Mean = 251.23
S.E. = 26.92
L.S.D. 5% = 50.84

Appendix Table 7. Adjusted means for entries of AS484 for each selection method.

Honeycomb		Index		Random	
Entry No.	Yield (g)	Entry No.	Yield (g)	Entry No.	Yield (g)
4	308	1	248	3	337
6	355	2	282	5	242
8	306	12	199	7	208
10	288	14	313	9	298
11	320	19	207	13	294
16	283	20	233	15	264
17	263	23	293	18	260
21	244	26	300	22	340
24	322	27	282	25	250
33	305	28	315	30	238
39	310	29	254	32	209
40	246	31	258	35	306
44	317	34	239	36	269
45	307	37	213	38	203
47	303	41	306	42	299
49	331	48	273	43	300
50	298	54	312	46	284
51	248	56	365	52	306
57	334	59	284	53	289
58	208	62	249	55	254
60	328	64	272	61	264
67	259	66	323	63	236
68	293	69	295	65	266
72	316	70	347	71	297
74	237	73	300	77	322
75	250	79	204	78	322
76	320	81	297	80	292

Mean = 281.66
S.E. = 25.89
L.S.D. 5% = 48.12

Appendix Table 8. Adjusted means for entries of HS284 for each selection method.

Honeycomb		Index		Random	
Entry No.	Yield (g)	Entry No.	Yield (g)	Entry No.	Yield (g)
4	357	1	353	2	208
7	270	3	354	5	306
9	308	11	276	6	275
10	325	14	336	8	383
12	283	20	286	15	283
13	261	24	325	16	290
17	299	25	217	18	332
21	303	27	400	19	248
23	295	28	293	22	286
30	359	33	349	26	308
32	256	36	383	29	307
34	361	39	327	31	320
35	196	44	383	38	315
37	212	50	224	41	318
40	332	52	358	43	286
42	356	55	325	45	228
46	233	58	340	47	332
53	263	60	323	48	251
56	281	61	274	49	299
59	296	62	273	51	313
64	292	66	253	54	345
67	331	68	352	57	302
69	234	70	340	63	233
72	365	71	317	65	256
74	324	73	273	76	321
75	322	77	315	78	296
81	365	79	381	80	273

Mean = 303.89
S.E. = 26.32
L.S.D. 5% = 48.95

Appendix Table 9. Adjusted means for entries of HS484 for each selection method.

Honeycomb		Index		Random	
Entry No.	Yield (g)	Entry No.	Yield (g)	Entry No.	Yield (g)
3	241	1	243	2	249
4	197	7	252	6	323
5	238	13	215	9	281
8	218	14	174	10	192
11	237	19	217	15	209
12	315	26	229	16	202
17	244	33	169	18	231
21	212	36	216	20	274
23	351	39	280	22	359
25	221	41	257	24	237
28	159	42	222	27	251
34	251	43	213	29	279
35	273	48	262	30	270
37	222	49	238	31	220
38	179	52	230	32	235
45	223	53	261	40	253
47	303	56	214	44	211
50	178	58	336	46	150
51	219	60	304	55	243
54	303	63	244	61	290
57	277	64	273	62	273
59	198	65	309	68	221
67	200	66	316	74	195
70	206	69	228	75	233
72	199	71	291	77	234
73	258	76	237	78	233
79	296	80	262	81	328

Mean = 244.28
S.E. = 30.60
L.S.D. 5% = 57.17