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RELATIONSHIPS BETWEEN MORPHOLOGICAL AND PHYSIOLOGICAL
CHARACTERISTICS AND YIELD OF DRY BEAN
(PHASEOLUS VULGARIS L.) CULTIVARS
DIFFERING IN THEIR PLANT ARCHITECTURE

By

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ABSTRACT

RELATIONSHIPS BETWEEN MORPHOLOGICAL AND PHYSIOLOGICAL CHARACTERISTICS AND YIELD OF DRY BEAN (PHASEOLUS VULGARIS L.) CULTIVARS DIFFERING IN THEIR PLANT ARCHITECTURE

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The relationships between morphological and physiological characteristics and yield were investigated in seven sets of F_6 lines near-isogenic for plant architectural traits and five parental cultivars of dry bean (Phaseolus vulgaris L.). The genotypes were classified as type I bush bean, type II architype beans, type II single sten beans and Type III beans.

The twenty-two genotypes were tested for yield and morphological traits. A principal factor analysis and a modified principal component distance were performed on the morphological traits. Dry seed weight from the central three nodes on the main stem were collected on a four to seven days basis. Seed filling duration and rate were calculated for each genotype by fitting a cubic polynomial for the change in dry seed weight with time. A remobilization factor was calculated between mid-seed-filling and physiological maturity.

Four of the architype genotypes were the highest yielding genotypes and outyielded the conventional bush bean cultivar by almost 30%. The architype F_6 lines outyielded their respective near-isogenic type I and type III lines. The factor analysis suggested that two different sets of associations exist for the determinate and the architype genotypes. It is inferred that the existing genic balance in the conventional cultivars has been replaced in the architype genotypes by a more efficient one.

The genotypes had different remobilization factors for the period between mid-seed-filling and physiological maturity. The architype genotypes flowered later than the type I genotypes and had a longer seed filling duration when compared to their respective near-isogenic F_6 lines. The seed filling rate was positively correlated with seed size and negatively correlated with seeds per pod and days to maturity. The seed filling duration was correlated with yield and days to maturity suggesting that a short reproducyive period might result in a reduction in yield.

To Lina and Riad

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INTRODUCTION

The manipulation of morphological traits has resulted in major yield gains in cereals (wheat and rice), and in legumes (bean and soybean). Plant breeders have improved yield by modifying plant architecture. The morphological traits manipulated are usually associated with important physiological processes. Such a strategy requires that breeders, using their knowledge of the physiology of a crop, and with the aid of statistical and mathematical modeling, define the ideal architectural plant for a specific environment. The concept of breeding for plant architecture involves the identification of morphological traits known to influence yield, and their combination into one genotype.

In dry bean (Phaseolus vulgaris L.), an ideotype strategy has been proposed to improve yield of small seeded beans (Adams 1973). The proposed plant model involved the restructuring of the bean plant using several architectural traits. Recent development of morphologically modified small seeded bean cultivars have incearsed yield potential by almost 30%. The new cultivars, similar to the model proposed

by Adams, differ drastically from the conventional bush bean plant grown in Michigan under monoculture cropping system. These cultivars were classified as "architypes", a term coined by Adams (1982) to reflect their distinct architectural characteristics. As a group, the architypes are characterized by an indeterminate type II growth habit, a reduced number of branches, a narrow, erect profile, large number of seeds per pod, numerous pods and a long seed filling period.

Existing variability and mutation of several architectural have been used to obtain the architypes. The genetic of some of these traits have been studied. However, little is known about the degree to which some of these traits may be associated and their relationships with yield. Physiological quantification for the differences in yield between the conventional and the architype cultivars is also lacking. Genetic differences has been observed for the remobilization of stem reserves. Under short period of stress, such remobilization would be of great importance for seed filling and yield. The study of the relationships between seed filling parameters and yield of the architypes has just begun. Some evidence has been accumulating recently suggesting that the length of the seed filling period is correlated with yield.

The relationships between architectural traits, seed filling parameters and yield are investigated in this study.

Six parental genotypes differing in their plant architecture were used to generate near-isogenic lines for morphological traits. Seven sets of near-isogenic F_6 lines for plant architectural traits were obtained and tested for yield. The association of the morphological traits is examined by principal component analysis. Dry matters remobilization factors between mid-seed-filling and physiological maturity were calculated. Cubic polynomial equations is used to fit the data of seed dry weight change with time. The curves were then used to obtain seed filling parameters (duration and rate).

The main objectives of this study was to investigate the relationships between morphological traits and yield, and to identify associations among these traits and to offer a physiological quantification for yield by examining remobilization of stem reserves, seed filling period and rate of seven sets of near-isogenic lines for plant architecture and five cultivars of bean.

CHAPTER 1

FACTOR ANALYSIS OF SEVEN FAMILIES OF NEAR-ISOGENIC F₆ LINES AND FIVE CULTIVARS OF DRY BEANS DIFFERING IN THEIR PLANT ARCHITECTURE

ABSTRACT

Six accessions of dry bean (Phaseolus vulgaris L.) exhibiting differences in their growth habits were crossed to generate near-isogenic lines for plant architectural traits. The parental genotypes included two determinate type I bush beans, two indeterminate type II single stem beans and two indeterminate type II architype beans. Seven sets of near-isogenic F₅ lines were obtained from F₄ families segregating for stem termination and architectural traits and were selfed to obtain seventeen F₆ lines of small white seeded beans.

Five parental genotypes and the seventeen F₆ lines were tested for yield, primary yield components and fourteen various morphological traits. A principal factor and a principal component distance analysis were performed on the seventeen traits for the overall data, the determinate and the architype genotypes.

Evidence is presented to show that the seed yield of the F_6 lines and the parental navy genotypes was associated with their modified architecture habits. All the high yielding genotypes were type II architypes. The F_6 architype lines outyielded their respective near-isogenic type I or type III lines.

The principal factor and the principal component distance analyses suggested that two sets of different associations exist for the determinate and the architype genotypes. Several yield promoting traits and primary yield components were associated in the first factor for the architype but not for the determinate genotypes. The architype genotypes represented an optimum genic balance more efficient under Michigan conditions than the one existing in the traditional determinate genotypes.

INTRODUCTION

Productivity of a crop results from the proper combination of genotype, environment and cultural practices. The complexity of the plant characters involved has been a major challenge and an uneasy task for plant breeders in search for higher yield. Yield depends, to a certain extent, on the functioning of numerous physiological and biochemical processes and their interaction with the environment. Many of such processes can be modified through the science of plant breeding and genetics.

IDEOTYPE BREEDING

According to Donald (1968), most plant breeding has been based on "defect elimination" and "selection for yield". He suggested that a third approach would be the breeding of crop ideotypes, plants with model characteristics known to influence photosynthesis, growth and grain production. Ideotypes could be seen as an intellectual and conceptual construction of a variety before any attempt was made at plant breeding. Such a breeding strategy required that the breeder define the environment for the model, identify morphological and physiological traits known to influence yield performance in that

environment, formulate the ideal architectural plant, combine the traits into one plant type, and finally modify it upon testing (Adams, 1982).

Since Donald's paper, there has been much interest and some skepticism among plant breeders concerning the potential of such a concept for yield improvement. Frey (1971) proposed the development of optimum plant types through the modification of yield components, morphological and/or, physiological traits. A limited number of plant breeders have endorsed and applied the concept, and from these several ideotypes have been defined for a limited number of crops; wheat (Donald, 1968), barley (Donald, 1979), rice (Jenning, 1964), corn (Mock and Pearce, 1975), peas (Davies, 1981), and dry beans (Adams, 1973).

Conventional plant breeders have been reluctant to emphasize individual characters or several characters that might constitute an ideotype (Rasmusson and Gengenbach, 1983). Since primary yield components are correlated with yield, many attempts have been made to utilize primary yield components as selection criteria in improving grain yields often, however, with little success (Nickel and Grafius, 1969; Coyne, 1968). This failure to obtain satisfactory progress from selection based on yield components has been attributed to yield component compensation, an almost universal phenomenon expressed in the negative correlations

between component characters which develop in a sequential pattern (Adams, 1967). The primary yield components in beans, (number of pods, number of seeds per pod and seed size), are to some extent interdependent in their development. Since the interdependence is generally negative, the effects of any increase in one yield component are offset by decreases in one or more of the other components.

BREEDING FOR PHYSIOLOGICAL TRAITS

The value of morphological, physiological or biochemical traits depends on several criteria, among them the existence of genetic variability for trait expression, the knowledge of its genetic control, and its relationship to agronomic benefit (Mahon, 1983). Less progress has been made in selecting for specific physiological and biochemical traits associated with yield. In general, the results of research directed towards improved photosynthesis have been disappointing as avenues to production of improved varieties. Sufficient information has been lacking as to which physiological or biochemical characters influence yield and the optimum phenotype for these characters. Wallace et al. (1972) reviewed the work of many scientists and concluded that genotypes within species do indeed exhibit variation for most physiological components of yield. Furthermore, they proposed the breeding of beans for higher photosynthetic rate. But later studies failed to

show any association between high assimilation rate and yield (Kueneman et al. 1979). Direct selection for photosynthesis or related characters has not established the existence of any consistent effect on growth or dry matter yield (Wilson, 1981).

The growing understanding of crop physiology as attested by several studies (Wallace et al., 1972, Evans and Wardlaw, 1976, Wilson, 1981, Evans, 1983) should eventually permit the design of crop plants with potentially greater yield than existing cultivars. However, until the physiological and biochemical basis of yield are better understood, identification and development of physiological and biochemical selection tools useful to plant breeders will be delayed.

BREEDING FOR MORPHOLOGICAL TRAITS

Another current strategy shared by some breeders interested in yield improvement lies in the exploitation and the modification of the plant architectural traits associated with physiological function. Frey (1971) expressed more optimism about improving yield capacity of crop plants through selection for certain morphological types as compared to selection of physiological traits. Assisted by a better understanding of the factors involved, plant breeders have made significant advances in yield

breeding by their manipulating of plant habit of soybeans (Cooper, 1974), beans (Kelly et al., 1984), wheat and rice (Davies, 1983).

It is apparent that morphological traits have been modified considerably through selection. Most of these traits are readily observable and quantifiable, and can therefore easily be selected in plant breeding programs. As plants were domesticated, selection for or against certain features took place, and plant architecture was modified. The more common problem is determining the best combination of traits, which may be inter-correlated, and the feasibility of combining them into single cultivars for a specific cropping system. Reddy and Sinha (1971) cited several architectural features as having a pronounced effect on crop growth. Among these traits were: plant type as influenced by the canopy and thickness of leaf, leaf area, and light penetration as affected by the display of leaves. Other architectural features include the number and arrangement of branches or tillers (Donald, 1968).

When dealing with morphological traits, the variability and genetics of the trait are of prime importance to the plant breeder. Ghaderi and Adams (1981) found quite high broad sense heritability for such traits as plant height, nodes above 15 cm., hypocotyl diameter, number of pods, number of seeds per pod and seeds per plant in dry beans.

BREEDING FOR MORPHOLOGICAL TRAITS IN GRAIN LEGUMES

In grain legumes, Adams (1982) has formulated the basic principles and fundamental architectural objectives for achieving maximum yield potential. The plant architecture should maximize light interception, while the canopy profile should consist of as many source-sink units as possible. The adjustment of the source-sink ratio should maximize the sink size relative to the source.

In soybeans, Cooper (1974) demonstrated that lodging may be the most important single limitation to exploitation of yield potential in higher yielding environments. Through the modification of soybean plant architecture by genes for stem growth habit and maturity, several semi-determinate high yielding varieties have been developed (Cooper, 1985). In peas, the so-called semi-leafless peas retain improved standing ability without causing a serious growth reduction due to insufficient photosynthetic area. As a result, several semi-leafless varieties are being grown commercially in the United Kingdom (1977). In both cases, as in the case of the semi-dwarf wheat, the plant habit has been changed dramatically by simple manipulation of traits controlled by a few genes. However, such an impact on yield improvement is usually associated with an important effect on physiological processes.

BREEDING FOR MORPHOLOGICAL TRAITS IN DRY BEANS

In beans (Phaseolus vulgaris L.), considerable genetic variation exists for plant architectural traits. Singh (1982) classified the growth habit of beans into four major plant types (type I, II, III, and IV), with sub-division for types II, III and IV. The type I exhibited a determinate growth habit, while type II, III and IV exhibit an indeterminate growth habit. These three indeterminate types differed in the length of the vine growth, branch angle, and the canopy structure with types II being more upright than types III and IV. In general, the growth habit is affected by the environment, temperature and photoperiod. In addition to the natural variability in the bean germplasm, several architectural traits such as determinate type I, type II and single stem types have been obtained through mutation plant breeding (Adams 1982).

Factor analysis has been used in biological sciences to study the relationship between several traits (Walton, 1971, Denis and Adams, 1978). Principal factor analysis is a mathematical technique for reducing a large number of correlated variables into a smaller number of patterns of variables called factors. The derived factors are independent of each other with the first factor accounting for the largest proportion of the variation. It allows one

to observe some underlying patterns of relationships that might exist among several variables by reducing the number of factors accounting for the variance. Each factor is a hypothetical variable that contributes to the variance of at least two of the observed variables.

Denis and Adams (1978), using factor analysis on 22 traits of 16 pure line bean cultivars at two locations, identified patterns of morphological characteristics. Factor I was identified with the number of reproductive structures while factor II was identified with the size of the reproductive structures.

Based on several morphological and physiological studies, Adams (1973, 1983) has specified a new architectural plant type drastically different from the conventional navy bean plant grown under a monocultural cropping system. The new plant would be a tall, narrow profile indeterminate bean plant with a dominant main stem and two to four basal but erect branches. The stem must be a dominant central axis and must have as many nodes as possible. The upper internodes must be longer and more numerous than the basal internodes. Leaf size should also be small and capable of orientation to allow optimal light penetration through the canopy. The pods should be long with many present at each node and with six to seven seeds per pod.

Evans (1973) questioned the value of the bean ideotype on the grounds that it is "dogmatic and unrealistic" to breed for too strict a morphological ideotype for any particular defined environment. Instead, she favored giving great priority to, and breeding for, plant adaptability rather than designing a model suited only to a particular environment. Coyne (1980) evaluated plant architectural modification and stated that insufficient information on the contribution and the relative merits of many of the morphological and physiological yield components is available to develop a model which is likely to produce a high yielding plant. Instead, he advocated conventional breeding methods such as selecting parents with superior level of morphological and physiological traits associated with yield and using the parents in breeding programs with other high yielding germplasm.

In an attempt to study the effect of plant architecture on beans, Singh and Gutierrez (1979) developed several lines with enhanced or suppressed morphological traits. Their lines had one of the following architectural traits: plant with less than 10 nodes on the main stem, erect branching, suppressed branching, short foliage and internodes, lanceolate leaves, small pods and long pods. Some of these lines were compared with four conventional cultivars at 16 plant density-environment combinations (Nienhuis and Singh, 1985). None of the newly constructed

architectural lines yielded more than their respective check varieties in any environment or at any plant density.

Despite the initial skepticism (Evans, 1973), several navy bean lines, conforming to the initial principles stated in Adams's paper (1973), have been constructed and several varieties have been released in Michigan since 1981. These varieties, called "architypes", have been tested and proven to be superior in yield to the existing conventional varieties over locations and seasons (Kelly et al., 1984).

The main objectives of this study were to develop navy bean lines near-isogenic for plant architectural traits, with similar genetic background, using various parental lines differing in their plant architecture. These lines and the parental genotypes were compared for architectural traits and yield, to identify important patterns of traits and to determine whether there is a different association among the patterns identified for the determinate and architype genotypes.

MATERIALS AND METHODS

Six dry bean accessions were used to generate sets of near-isogenic lines with the same genetic background but differing in plant architectural traits. The parents, listed in table 1, were chosen to represent a wide range of variability in terms of plant architectural characteristics such as growth habit, number of branches, number of nodes, leaf area, number of seeds per pod and seed size.

Parental and Near-Isogenic Materials

The accessions described according to CIAT classification under Michigan environmental conditions and cultural practice consisted of: 1) Seafarer, a determinate navy type I bush bean which has been the earlier maturing standard cultivar, 2) Swedish Brown, a large yellow seeded type I, 3) Swan Valley, a narrow profile, high yielding type II navy bean, 4) MSU experimental line 790458, a narrow profile type II navy bean, 5) MSU experimental line 61319 a single stem type II navy bean and 6) MSU experimental line 791515, a single stem type II white seeded bean.

Seafarer and Swedish Brown were selected for their

different origin of determinancy. Swan Valley and 790458 were chosen as representatives of the architype lines, characterized by a narrow profile with a central dominant stem; plants are tall, erect, non-lodging high yielding navy bean cultivars. MSU experimental lines 61319 and 791515 were chosen for their main and dominant single stem. The crosses made are listed in table 2.

The F_1 seeds were planted in the field in East Lansing, Michigan during the summer of 1982. Around 250 F_2 seeds from each cross were sent to Isabela, Puerto Rico, where selections were made in February, 1983. Only F_2 plants showing intermediate growth habit were selected, thus establishing around 25 F_3 families from each of the crosses. The F_3 plants were planted in the field at East Lansing during the summer of 1983 and additional selections were made between and within families for indeterminate heterozygous lines. Around 10 heterozygous lines from different F_3 families were sent to Isabela, Puerto Rico, during the winter of 1983-1984. Selections were made within the F_4 families for plants differing in their architecture. The characters used in the selection procedure were determinate versus indeterminate and/or architype versus viny or single stem plants. The F_5 seeds were increased at Fortuna, Puerto Rico, to produce F_6 lines for the study. Although not all desired combinations for the architectural traits were found, several different near-isogenic lines

were obtained and are listed in table 3. Lines selected from the same F_4 family will be referred to as lines having the same genetic background.

Planting and Harvesting Procedures

Five parents and the seventeen F_6 lines were planted in June 12, 1984 at East Lansing, Michigan, using a precision drill mounted air planter. Due to the lack of seed, the parental accession 61319 was not planted, from past record its performance should be similar to line 791515. Each experimental unit consisted of 8 rows 5 m long, spaced 50 cm. apart. Within-row spacing was 7-8 cm giving 13-15 plants per meter of row. The experimental units were arranged in a randomized block design with four replications of twenty-two plots each. Standard practices of herbicide and fertilizer application were used. Irrigation was applied two weeks after planting to compensate for the deficiency in natural rainfall during that period.

Uniformly spaced plants were harvested at 50% flowering and at the normal physiological maturity for each line. Data were recorded for individual plants and all the architectural characters measured and calculated are listed in Table 4. Yield data were obtained by harvesting the middle two rows and seed weight was reported at 14% seed moisture content.

Principal Factor Analysis

A principal factor analysis from the Statistical Analysis System (SAS) package was performed on the means of the variables listed in table 4 for the overall data set, the determinate sub-set and the architype genotypes. Factor analysis established a set of derived factors which are independent of each other and fewer in number than the original variables. If two correlated variables with a number of measured scores are plotted, the contour of the scatter diagram will form an ellipse. The two axes or vectors defining the ellipse are the principal factors. The long axis is the first factor, accounting for as much of the total variance as possible and the other axis is the second factor accounting for the remainder of the total variance. Mathematically, the concept can be extended for any number of variables in a multi-dimensional space. The projection of the variable vector onto the factor is called the factor loading coefficient and constitutes the correlation between that variable and the factor.

The steps involved in the analysis included the use of the correlation matrix for all 17 variables. The prior communality for each variable was set to its maximum absolute correlation with any other variable. The factor loadings were extracted from the eigenvalues and eigenvector matrices. To make the interpretation less subjective the

factors were rotated using an orthogonal Varimax rotation, that is, by applying a nonsingular linear transformation. The transformation was used in order to establish orthogonality among the factors.

The interpretation was accomplished by examining the loading coefficients of variables in each factor, with particular attention to coefficients in the range of 0.5 to 0.9. A conceptual name was then assigned to each factor that reflects the importance and the biological meaning of the factor. In order to illustrate the relationships among the various genotypes, the scores of the genotypes for the first three factors were plotted in two dimensional graphs with factor I, II and III as axes.

A principal component distance program for the SAS package was used to calculate distances between the genotypes based upon the morphological traits listed in table 4. The program was designed to calculate distances among a set of bean cultivars by Adams and Wiersma (1977). Rather than using the D^2 statistic of Mahalanobis, the distances are calculated from the normalized principal component scores using the equation:

$$d_{ij} = [(X_{i1} - X_{j1})^2 + \dots + (X_{ik} - X_{jk})^2]^{1/2}$$

where d_{ij} equals the distance between varieties i and j on principal axes I through k , and X_{i1} is the normalized score of variety i on axis 1.

RESULTS

The various F_6 lines, with the exception of line 16, expressed the architectural traits for which they were selected (Table 4). Although line 16 was selected for the single stem trait, at the planting density used, it showed a reduced number of branches instead. The F_6 archetype lines were very close to the architectural structure of the released archetypes, but perhaps not as refined. All the F_6 lines were white-seeded and, based on their seed size, could be considered to belong to the navy bean class.

The means for seed yield and for various architectural traits are presented in tables 5 and 6. Significant differences among the genotypes (cultivars and the F_6 near-isogenic lines) were observed for seed yield and the architectural traits both within and between genetic backgrounds. Genotypes with type I growth habit were earlier maturing, shorter, with more branches and fewer nodes on both the main stem and the branches than either the type II or type III progenies. Seafarer and Swedish Brown, on the average, matured several days earlier than the F_6 lines. The F_6 lines classified as archetypes matured two to four days earlier than the archetype parents. Seafarer and Swedish Brown were the shortest stature genotypes and had the most

numerous branches, whereas line 790458 was the tallest genotype and had the lowest number of branches.

YIELD OF THE PARENTAL GENOTYPES AND THE F_6 LINES.

The yield of the genotypes ranged from 1961 to 3318 kg/ha., where Swan Valley was the highest yielding genotype and the single stem 791515 as the lowest yielding genotype. The already established architypes (Swan Valley and 790458) and the F_6 architype lines 2 and 13 significantly outyielded the conventional navy bean cultivar Seafarer. The increase in yield over Seafarer was 29%, 23%, 29% and 27% for Swan Valley, 790458, and F_6 lines 2 and 13, respectively. The four architype lines also outyielded the single stem cultivars by around 40%. The increase in yield for these genotypes over Seafarer and 791515 was significantly different at the 1% level (Table 5). Swedish Brown, a large seeded bean (40.1 g/100 seed) was higher yielding than Seafarer. Its yield, though numerically less, was not significantly different from the top four yielding architypes (LSD .01 = 482 kg/ha).

In the genetic background of families 1, 2 and 6, the F_6 type II architypes outyielded their respective near-isogenic type I or type III lines by 23%, 19% and 29%, respectively. The increase in yield was statistically significant at the 1% level. In the genetic backgrounds of

families 3, 4, and 5, the architype F_6 lines were higher yielding than their near-isogenic lines by at least 10%, although this difference was not statistically significant. In the genetic background of family 7, consisting of type I, a bush type II, and a reduced branching type II, no significant differences in yield were observed.

The type III F_6 lines were similar in yield both to their near-isogenic type I lines and to the type I lines in different genetic backgrounds. Between the different genetic backgrounds, F_6 lines 2 and 7 were higher in yield than any other F_6 line. No type I F_6 line produced a higher yield than the traditional navy bean Seafarer. The F_6 line 5, a determinate architype, had a lower yield than its near-isogenic type II architype, although the difference was not statistically significant.

GENETIC DISTANCE AMONG THE GENOTYPES AND FACTOR ANALYSIS OF ALL GENOTYPES, THE TYPE I AND THE ARCHITYPE GENOTYPES.

The factor loadings for the complete data set (cultivars and F_6 lines), and for the determinate and the architype genotypes, are listed in tables 7, 8 and 9, respectively. The loading coefficient represents the correlation between a trait and a particular factor. Only the traits with the underscored high values of the loading coefficients were used in defining the factors. Major

emphasis will be put on the factor interpretation of the determinate and architype analysis, whereas the factor for the overall data set will be used to extract the factor scores of each line.

For the complete data set (twenty-two genotypes), four main factors, accounting for 78% of the total variance, can be recognized. The four factors account for 31.5%, 23.0%, 13.8% and 10.0% for the factors I, II, III and IV, respectively. The first factor included the number of branches, branch length at 50% flowering and maturity, number of nodes on the branches, branch internode length and average long internode length on the main stem. Negative loading consisted of plant height, number of nodes on the main stem and number of nodes above 10 cm., all being main stem traits. The second factor included plant height, number of nodes on the main stem, number of nodes below 10 cm, number of pods and total number of nodes. The negative loading coefficients were for seed size and short internode length, indicating negative compensation between the primary yield components. The third factor included only seed size; its negative loading coefficient for number of seeds per pod and average long internode length also indicate a compensatory relationship.

The number of factors and the loading coefficients for the various traits were quite different for the determinate

and the architype genotypes (Tables 8 and 9). For the determinate type, three factors emerged (Table 8), accounting for 83% of the total variation, with two factors almost equivalent in respect to the variance for which they accounted. The first factor included plant height, total branch length, total number of nodes and nodes on branches. The negative loading coefficient for seed size indicated yield component compensation. The second factor included number of branches and branch internode length. A strong negative loading coefficient for number of seeds per pod also indicated a strong component compensation among primary yield components. The third factor included number of pods and number of nodes on main stem.

The factors in the architype genotypes (Table 9) were dissimilar to the factors for the determinate genotypes. The first five factors, accounting for 91% of the total variance, will be examined. The first factor was dominated by number of pods, seeds per pod, number of nodes on branches and number of nodes on main stem. Negative loading included branch length, branch internode length and average long internode length on the main stem. The second factor included number of nodes below 10 cm., and number of nodes on branches. The third factor included mainly seed size with a weak negative loading coefficient for number of pods. The fourth factor included number of nodes on branches, and plant height at 50% flowering. The fifth factor was

dominated by the number of branches.

The graph of the first two factors for the overall analysis (Figure 1) indicated that the parental genotypes were quite divergent from each other, with the notable exception of Swan Valley and 790458. This observation is supported by the calculated genetic distances among the parental genotypes (Table 10). Seafarer and 791515, the single stem genotype, were the farthest apart (Distance = 1.3063), whereas Swan Valley and 790458 were the closest (Distance = 0.3663).

Further examination of the various graphs (Figures 1-6), and the calculated distances among the genotypes (Table 11) indicated that the determinate genotypes were also divergent from the type II parents, but even more from the determinate parents. Line 5, the archetype determinate genotype, was the most divergent from the other type I F_6 lines. While all the F_6 archetypes were quite divergent from either one of the determinate parental genotypes, most of them were quite close to either one of the archetype parental genotypes (Figure 7-9 and Table 12). Surprisingly, line 2 was closer to 790458 than to its parental archetype Swan Valley. The determinate line 5 was quite divergent from its F_6 archetype near-isoline and its parental genotypes.

DISCUSSION

The morphological data collected were used in the factor analysis for the determinate and the archetype genotypes and will be discussed in this context. It should be stressed that the results and interpretation that emerge are completely dependent upon the data used and no physiological interpretation will be made. The choice of the data set was a deliberate one, in order to identify the morphological differences between the conventional type I and the type II archetype beans.

The first factor in the type I genotypes (Table 8) is a composite factor that includes both vegetative vigor, in the traits of plant height and branch length, but also potential reproductive structures in the form of number of nodes and nodes on branches. There is a certain logic in their being loaded in the same factor, since the number of nodes and number of nodes on branches should be greater when the branch number and length are greater. The second factor completes the vegetative aspect of the first factor with the number of branches and branch internode length. The factor also possesses a negative dimension due to the compensatory relationship between plant height, branch and hypocotyl diameter. The third factor is mainly a reproductive factor

with the number of pods being heavily loaded. Also heavily loaded is node number on the main stem and number of nodes above 10 cm.

The first factor for the architype genotypes (Table 9) is a major reproductive structure factor, an architectural factor in which number of reproductive structures is of the predominant importance. The negative loading for branch length is a consequence of the expression of negative vegetative component compensation. Such compensation is in agreement with findings of Harmsen (1984) who showed that any increase in the main stem will result in a decrease in the branches. The second factor completes the yield promoting factor, and can be identified as a vegetative vigor and reproductive potential factor. The factor promotes long branches with numerous nodes on branches. The third factor is a seed size or weight factor. The branch internode length is not important to the identity of the factor. The loading is only fortuitous for the traits and it should not be thought to characterize or identify the factor. The negative loading for number of pods is a consequence of the expression of a weak yield component compensation. The remaining two factors are basically vegetative vigor factors with the number of branches being loaded heavily on the fifth factor. The last factor suggests that the number of branches is not as important as the branch length.

Based on the overall factor analysis (Table 7 and Fig. 1) and the calculated genetic distances among the genotypes (Table 10-12), the genotypes used in this study could be defined in terms of several gene pools, where each gene pool represents a sample of genes interacting to produce a genic balance and thus an acceptable array of genotypes for the Michigan environment. The determinate navy genotypes consisted of two gene pools represented by the F_6 lines and Seafarer, respectively, whereas the indeterminate archetype consisted of one gene pool. The determinate F_6 lines were quite different from the traditional cultivar Seafarer and from the archetype parents which confirms visual observation that the attempt to recover the parental type I was not fully successful. The difference among the determinate lines and Seafarer is not surprising. It is the direct result of the method of enforced heterozygosity used to generate the near isogenic F_6 lines. The indeterminate F_6 archetypes were more similar to either one of the archetype parents, than to each other.

Further examination of the main loading coefficients of the various factors and of the calculated distances suggests that two different sets or associations of genes exist for the determinate and the archetype genotypes. Each association of genes, relatively independent of the other, regulates a pattern of related growth or development of a number of traits. In the archetype genotype several yield

promoting traits and primary yield components are associated in the first factor, whereas in the determinate genotypes the association exists only for potential reproductive traits.

Such associations have broad implication in breeding for plant morphological architecture. The existing genic balance among the various traits in the traditional determinate genotypes has been replaced by a more efficient or potentially higher yielding one. While the various architectural traits individually can have an influence on yield, it is their integration into a particular genic balance that will eventually result in an increase in yield. The parental architypes are a representative of such an optimum genic balance. The bean breeders at Michigan State University have been able to transfer several important morphological traits and combine them into one genotype. The first factor in the architype analysis (Table 9) indicates that the various traits promoting yield have been associated together in contrast with the determinate genotypes. It also appears from the number of determinate architype lines obtained during the selection procedure that it is more difficult to obtain a determinate architype line by a simple cross followed by selection.

Dry bean yield increases in Michigan have been relatively low for several years when compared to

increases in other field crops. Advances have been made in disease resistance, and in cultural practices. It was not until recently that increased grain yield per se has been achieved mainly by restructuring the bean plant and by combining several physiological and morphological characteristics into one genotype.

The use of near-isogenic lines offered an opportunity to further test the relationship between yield and plant morphological modification in the navy bean plant, grown under Michigan conditions. The near-isogenic lines developed did not include all possible combinations in one genetic background nor did they attain the refined morphological canopy of some of the released lines. However, the lines obtained allowed comparison among several different architectural plants within the same genetic background and among several genetic backgrounds. The seed yields of the various F_6 lines and the archetype parents were associated with their modified architectural growth habit (Table 5). Line 2 and 13 outyielded significantly the conventional variety Seafarer and their respective near-isogenic lines. All the superior lines were type II archetypes, with a longer growing season and seed filling period. They outyielded significantly the conventional navy bean Seafarer and their near isogenic type I and III lines.

These results do not agree with the finding reported by

Nienhuis and Singh (1985), who did not find any morphologically modified genotypes of any growth habit capable of outyielding the commercial cultivars. Furthermore, indeterminate prostrate type III and type II cultivars in that order were among the highest yielding, regardless of environment and plant density. It should be noted that the various lines used in their study each had a pronounced expression of one of the various architectural traits rather than a combination of several traits. The developmental interdependency among the various architectural traits is well documented (Adams 1982). It would be difficult in the bean plant to achieve an increase in yield by simply manipulating one or few architectural traits.

The high yielding F_6 lines obtained in this study were closely similar to the conceptual model offered by Adams (1982). The archetype cultivars released in navy and black beans have been consistently superior in yield to the conventional small-seeded type I genotypes across locations and years. The archetypes are also able to capitalize on a longer seed filling period associated with a larger sink (Izquierdo and Hosfield 1983).

The breeding of archetypes has required simultaneous selection for several traits at once and a willingness to compromise in the expression of a specific trait. The new

architypes arose by bringing together genetic variability from the Central American small seeded black beans with domestic navy types, thus permitting a remodeling of architectural growth habit through selection. Such a remodeling happened by using an ideotype strategy. The bean ideotype defined by Adams was, however, never intended to be a universal one. The bean architypes were designed specifically for the Michigan environment and a high density planting arrangement.

Rarely are two cultivars identical. They may share the same gene pool and follow a similar strategy to maximize yield, but the development of the sequential traits of seed yield is usually different. The present study pointed to the advantage of the morphologically modified genotype over the traditional bush navy bean type. As a group, the F_6 architype lines obtained share the same gene pool as their parental type II architypes. They are characterized by an indeterminate growth habit with a longer growing season, a narrow tall profile, with reduced branching and numerous nodes and seeds per pod. As a group, their morphological traits important to yield are associated together in contrast to the case of the type I bush navy beans. It should be noted that the type II architypes represent in no way a model to be used under an environment markedly different from the Michigan agro-ecological environment, without extensive testing.

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Table 1. List of parents used to generate the near-isogenic lines.

Lines	MSU Accession #	Plant type	Architecture
Seafarer	N67001	I	Standard Bush
Swedish Brown	I81099	I	Bush
Swan Valley	N76004	II	Architype
790458	N79021	II	Architype
61319	N76010	II	Single Stem
791515	X80004	II	Single Stem

Table 2. List of crosses made to generate the near-isogenic lines.

Cross #	Cross		
1	Seafarer	x	Swan Valley
2	Seafarer	x	790458
3	Seafarer	x	61319
4	Swan Valley	x	791515
5	Swan Valley	x	Swedish Brown
6	790458	x	791515
7	791515	x	Swedish Brown

Table 3. List of the F₆ near-isogenic lines used in the study.

F ₆	Line #	F ₄ Family	Cross	Plant Type	Plant Characteristics
	1	1	Seafarer x Swan Valley	I	Determinate
	2	1	Seafarer x Swan Valley	II	Indet. Architype
	3	2	Seafarer x 790458	II	Architype
	4	2	Seafarer x 790458	III	Indet. Viny
	5	3	Seafarer x 790458	I	Det. Architype
	6	3	Seafarer x 790458	II	Indet. Architype
	7	4	Seafarer x 61319	I	Det. Bush
	8	4	Seafarer x 61319	II	Indet. Architype
	9	4	Seafarer x 61319	III	Indet. Viny
	10	5	Swan Valley x Swedish Brown	I	Det. Bush
	11	5	Swan Valley x Swedish Brown	II	Indet. Architype
	12	5	Swan Valley x Swedish Brown	III	Indet. Viny
	13	6	790458 x 791515	II	Indet. Architype
	14	6	790458 x 791515	III	Indet. Viny
	15	7	791515 x Swedish Brown	I	Determinate Bush
	16	7	791515 x Swedish Brown	II	Indet. Red. Br.
	17	7	791515 x Swedish Brown	II	Indet. Bush

Table 4. List of traits measured and estimated.

	CODE	TRAITS
1.	PLTHT	Plant height
2.	PLTHT50	Plant height at 50% flowering
3.	NUMNODE	Total number of nodes
4.	NODEMS	Number of nodes on the main stem
5.	NODEBR	Number of nodes on branches
6.	NUMBER	Number of branches
7.	BRLGTH50	Branches length at 50% flowering
8.	BRLGTH	Branches length
9.	HYPDIAM	Hypocotyl diameter
10.	NUMPOD	Number of pods
11.	SEEDPOD	Number of seeds per pod
12.	SEEDSIZE	Seed size
13.	NODEA10	Number of nodes above 10 cm.
14.	NODEB10	Number of nodes below 10 cm.
15.	AINTLER	Average internode length on branches
16.	ALINIMS	Average long internode on the main stem
17.	ASINIMS	Average short internode on the main stem

Table 5. Mean yield of five dry bean cultivars and seven sets of near-isogenic F₆ lines.

F ₄ Family	F ₆ Lines number and Genotypes	Growth Habit	Plant Architecture	Yield @ (Kg/ha)
1	1 Seafarer x Swan Valley	I	Determinate	2523 bode
1	2 Seafarer x Swan Valley	II	Indet. Architype	3295 a
2	3 Seafarer x 790458	II	Architype	2860 abc
2	4 Seafarer x 790458	III	Indet. Viny	2304 de
3	5 Seafarer x 790458	I	Det. Architype	2208 e
3	6 Seafarer x 790458	II	Indet. Architype	2508 bode
4	7 Seafarer x 61319	I	Det. Bush	2257 de
4	8 Seafarer x 61319	II	Indet. Architype	2781 abcd
4	9 Seafarer x 61319	III	Indet. Viny	2229 de
5	10 Swan Valley x Swedish Brown	I	Det. Bush	2479 bode
5	11 Swan Valley x Swedish Brown	II	Indet. Architype	2993 ab
5	12 Swan Valley x Swedish Brown	III	Indet. Viny	2528 bode
6	13 790458 x 791515	II	Indet. Architype	3205 a
6	14 790458 x 791515	III	Indet. Viny	2273 de
7	15 791515 x Swedish Brown	I	Determinate Bush	2113 e
7	16 791515 x Swedish Brown	II	Indet. Single Stem	1968 e
7	17 791515 x Swedish Brown	II	Indet. Bush	2275 de
Cultivar	SEAFARER	I	Det. Bush	2326 cde
Cultivar	SWEDISH BROWN	I	Det. Bush	2883 ab
Cultivar	SWAN VALLEY	II	Architype	3318 a
Exp. Line	790458	II	Architype	3030 ab
Exp. Line	791515	II	Single Stem	1961 e
LSD (0.01)				481.8
CV (%)				10.0

@ Mean followed by the same letter or letters are not significantly different according to Duncan's Multiple Range Test at 1% level.

Table 6. Means of various architectural traits of five dry bean cultivars and seven sets of near isogenic F6 lines.

F4 Family	Genotypes	Growth Habit	Days to Flowering	Days to Maturity	Plant Height (cm.)	Average Nodes on Main Stem	Average Number of Branches	Branch Length (cm.)	Number of Pods / Plant	Seeds / Pod	Seed Size (gr.)	Number of Nodes / Plant
1	Seafarer x Swan Valley	1	42	86	46.63	9.0	4.3	22.5	20.2	6.3	17.1	25
1	Seafarer x Swan Valley	11	47	94	62.60	13.3	4.9	16.7	26.2	7.2	16.9	36
2	Seafarer x 790458	11	44	85	56.07	14.0	4.5	31.2	21.3	6.5	23.3	32
2	Seafarer x 790458	111	46	95	76.60	16.0	5.6	25.7	24.4	4.7	24.4	35
3	Seafarer x 790458	1	47	87	51.73	9.7	4.7	22.5	23.0	5.1	17.2	31
3	Seafarer x 790458	11	47	92	58.63	13.3	5.3	23.0	26.2	6.3	18.0	36
4	Seafarer x 61319	1	40	86	44.93	8.7	4.8	13.8	19.2	6.8	21.8	27
4	Seafarer x 61319	11	43	94	58.53	12.7	4.7	17.1	23.2	6.9	20.8	29
4	Seafarer x 61319	111	49	94	60.50	13.3	4.0	17.4	21.7	6.4	22.2	25
5	Swan Valley x Swedish Brown	1	40	82	46.83	11.0	6.0	17.9	23.2	6.4	22.1	32
5	Swan Valley x Swedish Brown	11	49	96	54.63	12.3	5.1	24.7	20.0	7.0	21.5	38
5	Swan Valley x Swedish Brown	111	50	97	71.03	15.0	4.8	24.7	21.0	5.9	21.6	37

Table 6 (contd). Means of various architectural traits of five dry bean cultivars and seven sets of near isogenic F6 lines.

F4 Family	Genotypes	Growth Habit	Days to Flowering	Days to Maturity	Plant Height (cm.)	Average Nodes on Main Stem	Average Number of Branches	Branch Length (cm.)	Number of Pods / Plant	Seeds / Pod	Seed Size (gr.)	Number of Nodes / Plant
6	790458 x 791515	11	50	100	55.93	13.3	5.5	23.2	28.2	7.0	20.8	37
6	790458 x 791515	111	50	97	77.10	15.7	4.0	15.4	19.2	6.8	20.8	34
7	791515 x Swedish Brown	1	38	82	45.30	8.0	4.5	20.5	18.1	5.7	20.5	24
7	791515 x Swedish Brown	11	50	99	57.87	11.3	4.2	19.5	19.2	5.8	20.2	38
7	791515 x Swedish Brown	11	47	89	53.27	10.3	3.7	18.6	18.2	6.8	19.1	29
Cultivar SEAFARER		1	38	81	43.67	9.0	8.5	23.8	20.1	5.4	17.0	41
Cultivar SWEDISH BROWN		1	37	79	38.07	8.0	6.5	17.9	22.0	4.2	40.1	26
Cultivar SWAN VALLEY		11	49	97	58.97	16.3	4.3	15.5	30.0	7.2	17.4	36
Exp. Line 790458		11	50	99	62.73	15.3	4.1	19.8	27.1	7.3	19.3	39
Exp. Line 791515		11	47	98	79.37	18.3	2.2	10.9	12.8	4.2	28.6	24

Table 7. Factor loadings of the four most important factors for all the genotypes.

TRAITS	FACTOR1	FACTOR2	FACTOR3	FACTOR4
PLTHT	-0.66035	<u>0.50764</u>	0.27624	-0.28480
PLTHT50	-0.16889	0.31087	-0.43927	-0.29536
NUMNODE	0.33751	<u>0.74472</u>	0.21859	0.30542
NODEMS	-0.64240	<u>0.62883</u>	0.40322	-0.13643
NODEER	<u>0.69294</u>	0.40585	-0.00088	0.28287
NUMBER	<u>0.78618</u>	-0.12583	0.41315	0.34694
ERLGH50	<u>0.77601</u>	0.09522	-0.13107	-0.13586
ERLGH	<u>0.75235</u>	0.22482	0.34085	-0.30344
HYPDIAM	-0.62669	0.18238	-0.44166	0.06423
NUMPOD	0.26787	<u>0.57828</u>	0.13547	0.46773
SEEDPOD	-0.00559	<u>0.54872</u>	-0.45496	0.46424
SEEDSIZE	-0.29179	-0.61490	<u>0.55201</u>	0.06255
NODEA10	-0.74107	0.49648	0.41241	-0.07828
NODEB10	0.41961	<u>0.66235</u>	-0.07324	-0.43642
AINTLER	<u>0.59778</u>	-0.19437	0.58329	-0.35878
ASINIMS	-0.43153	-0.68608	0.11927	<u>0.52444</u>
ALINIMS	<u>0.53930</u>	-0.35572	-0.55783	-0.32349
PROPORTION	0.3157	0.2301	0.1382	0.1006
CUMULATIVE	0.3157	0.5458	0.6840	0.7846

Table 8. Factor loadings of the three most important factors for all the determinate genotypes.

TRAITS	FACTOR1	FACTOR2	FACTOR3
PLTHT	<u>0.67768</u>	-0.71430	0.08936
PLTHT50	0.21975	-0.61542	-0.49883
NUMNODE	<u>0.75999</u>	0.59382	0.08310
NODEMS	0.53183	-0.12928	<u>0.82682</u>
NODEER	<u>0.71125</u>	0.65356	-0.06025
NUMBER	0.27895	<u>0.94381</u>	0.06110
BRLGTH50	<u>0.82443</u>	-0.19709	-0.01994
BRLGTH	<u>0.68518</u>	0.53670	-0.39381
HYPDIAM	-0.48171	-0.73883	0.15307
NUMPOD	0.28588	0.12505	<u>0.80959</u>
SEEDPOD	0.12759	-0.55184	0.10527
SEEDSIZE	-0.76223	0.46518	0.26372
NODEA10	0.09811	-0.03691	0.87796
NODEB10	<u>0.87111</u>	-0.38057	0.11477
AINTLER	0.35155	<u>0.78364</u>	-0.32234
ASINIMS	-0.90398	0.39889	-0.09838
ALINIMS	0.45674	-0.53210	-0.59901
PROPORTION	0.3488	0.3052	0.1839
CUMULATIVE	0.3488	0.6540	0.8379

Table 9. Factor loadings of the five most important factors for all the archetypes.

TRAITS	FACTOR1	FACTOR2	FACTOR3	FACTOR4	FACTOR 5
PLTHT	<u>0.78010</u>	0.21720	-0.15021	-0.27210	-0.03310
PLTHT50	0.01129	0.38919	-0.07668	<u>0.53643</u>	-0.70639
NUMNODE	<u>0.63090</u>	<u>0.63569</u>	-0.21765	0.34488	-0.00372
NODEMS	<u>0.80552</u>	0.40012	0.19001	-0.36681	-0.07211
NODEBR	0.24405	<u>0.52270</u>	-0.39890	<u>0.67630</u>	0.04387
NUMBER	0.02083	0.34557	-0.00055	0.44010	<u>0.73550</u>
ERLGTH50	-0.83650	0.19651	-0.16238	-0.39160	0.10565
ERLGTH	-0.47950	<u>0.59707</u>	<u>0.62540</u>	0.10344	0.01265
HYPDIAM	0.33027	-0.27997	0.00168	0.46314	0.40095
NUMPOD	<u>0.64145</u>	0.31853	-0.34634	-0.39426	0.41119
SEEDPOD	<u>0.89440</u>	-0.14829	0.24011	0.16988	-0.13525
SEEDSIZE	-0.06560	0.08703	<u>0.94745</u>	0.22803	-0.00693
NODEA10	<u>0.88143</u>	0.22896	0.20092	-0.33716	-0.07720
NODEB10	-0.50757	<u>0.76055</u>	-0.23366	-0.21789	-0.04868
AINTLER	-0.48718	0.41355	<u>0.72711</u>	-0.08904	0.20374
ASINIMS	0.46123	-0.77975	0.27009	0.17255	0.07500
ALINIMS	-0.84630	-0.22515	-0.43332	0.16720	0.00594
PROPORTION	0.3630	0.1894	0.1558	0.1240	0.0861
CUMULATIVE	0.3630	0.5524	0.7082	0.8322	0.9183

Table 10. Distances between the parentals genotypes based on seventeen morphological traits.

	S. Brown	S. Valley	790458	791515
Seafarer	1.0727	1.1062	0.9502	1.3063
S. Brown		1.1112	1.0737	1.1592
S. Valley			0.3663	1.1040
790458				0.9706

Table 11. Distances between the determinate genotypes based on seventeen morphological traits.

	Line 5	Line 7	Line 10	Line 15	Seaf.	S.B.	S.V.	790458	791515
Line 1	0.6054	0.4174	0.5089	0.4788	0.9780	0.9794	0.7890	0.7034	0.9932
Line 5		0.7910	0.7930	0.9177	1.0472	1.1766	0.9813	0.8465	1.1321
Line 7			0.4434	0.5018	0.9448	0.8538	0.9980	0.6684	1.0079
Line 10				0.6922	0.8341	0.6950	0.5467	0.5401	0.9945
Line 15					0.9060	1.0761	0.9487	0.8384	0.9044

Table 12. Distances between the archetype genotypes based on seventeen morphological traits.

	Line 3	Line 5	Line 6	Line 8	Line 11	Line 13	S.V.	790458
Line 2	0.9326	0.7204	0.2956	0.4513	0.6020	0.3921	0.5013	0.2225
Line 3		1.1600	0.7508	0.8668	0.8167	0.8041	1.0398	0.8733
line 5			0.5924	0.8618	1.0501	0.9830	0.9813	0.8465
Line 6				0.5190	0.6395	0.4591	0.6134	0.3417
Line 8					0.6372	0.4175	0.4304	0.4293
Line 11						0.5544	0.8248	0.5955
Line 13							0.5592	0.3469

Figure 1. Distribution of the genotypes on the basis of their scores on the first three principal factors, (a-c) plots for all the genotypes, (d-f) plots for the determinate genotypes, (g-h) plots for the architype genotypes. (SF=Seafarer, SB=Swedish Brown, SV=Swan Valley, A2=790458, SS=791515).

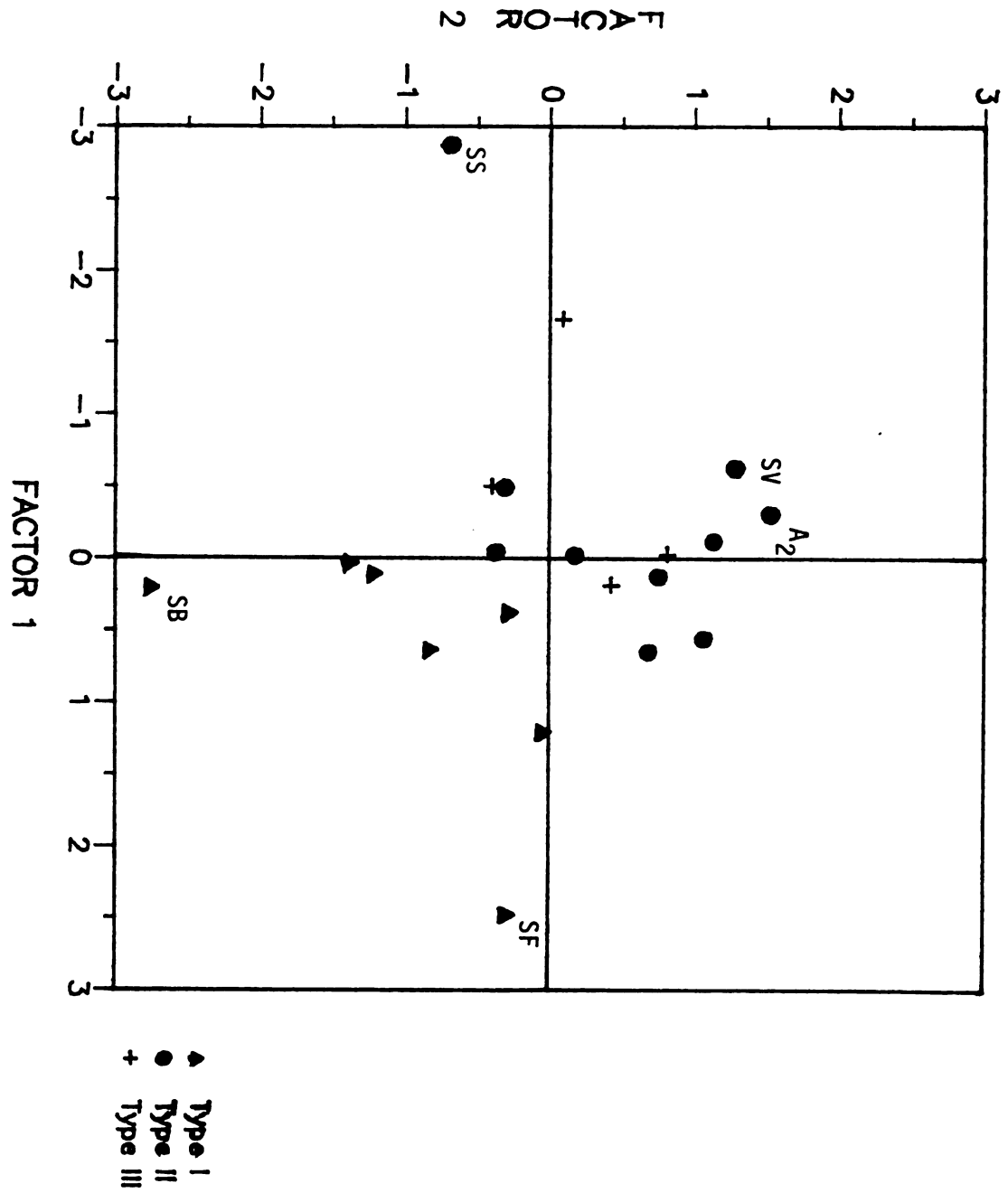


Figure 1a.

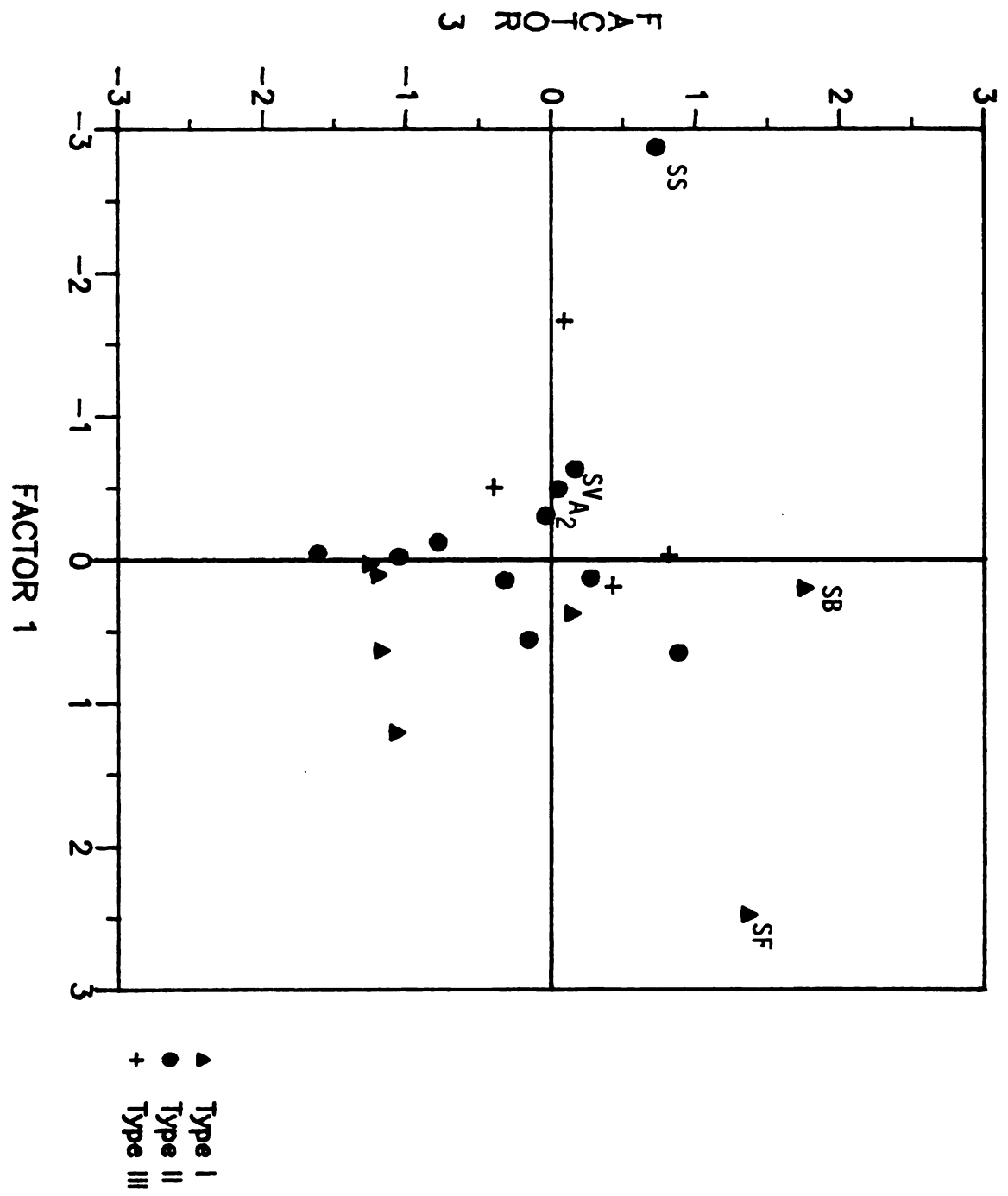
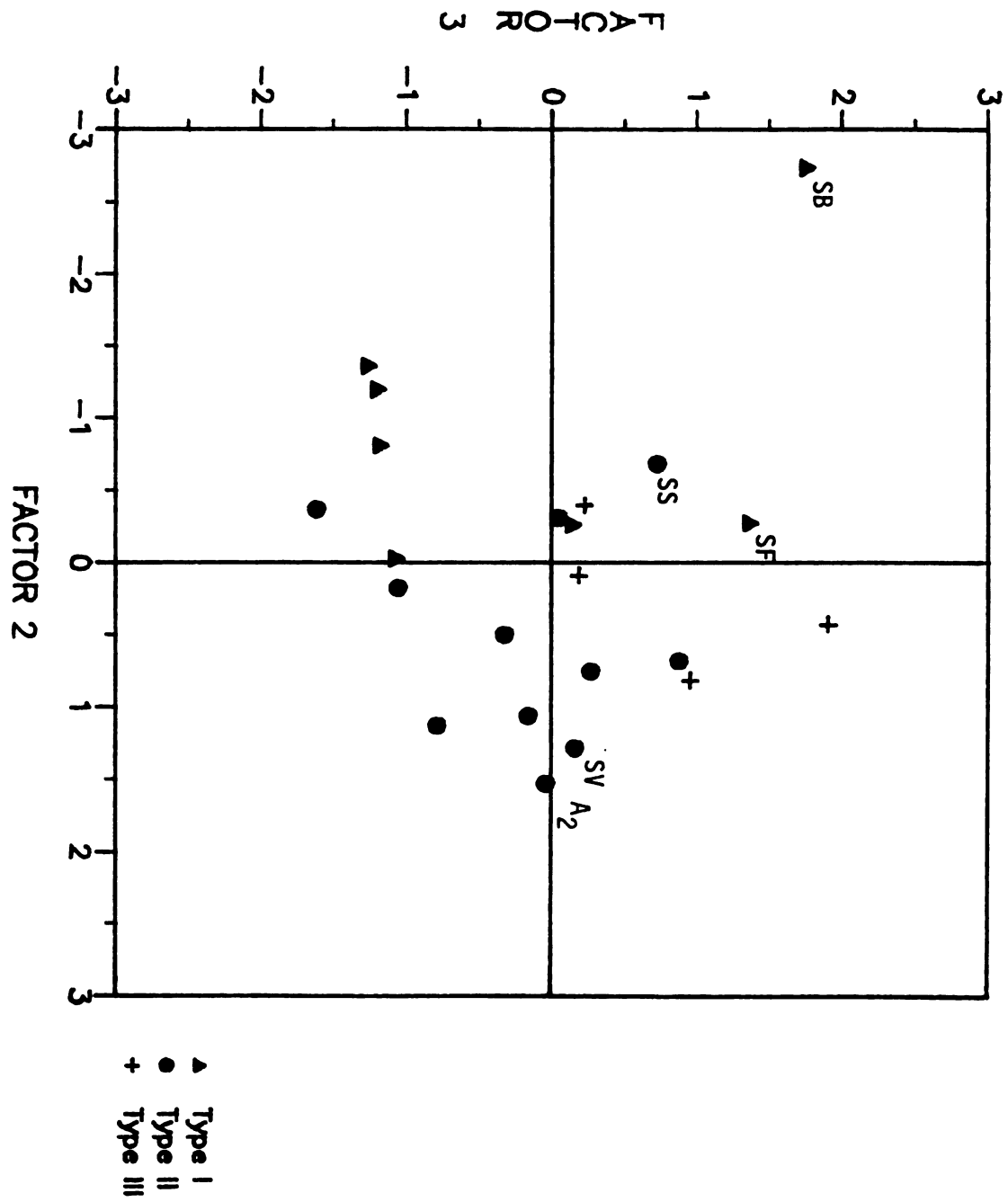


Figure 1b.



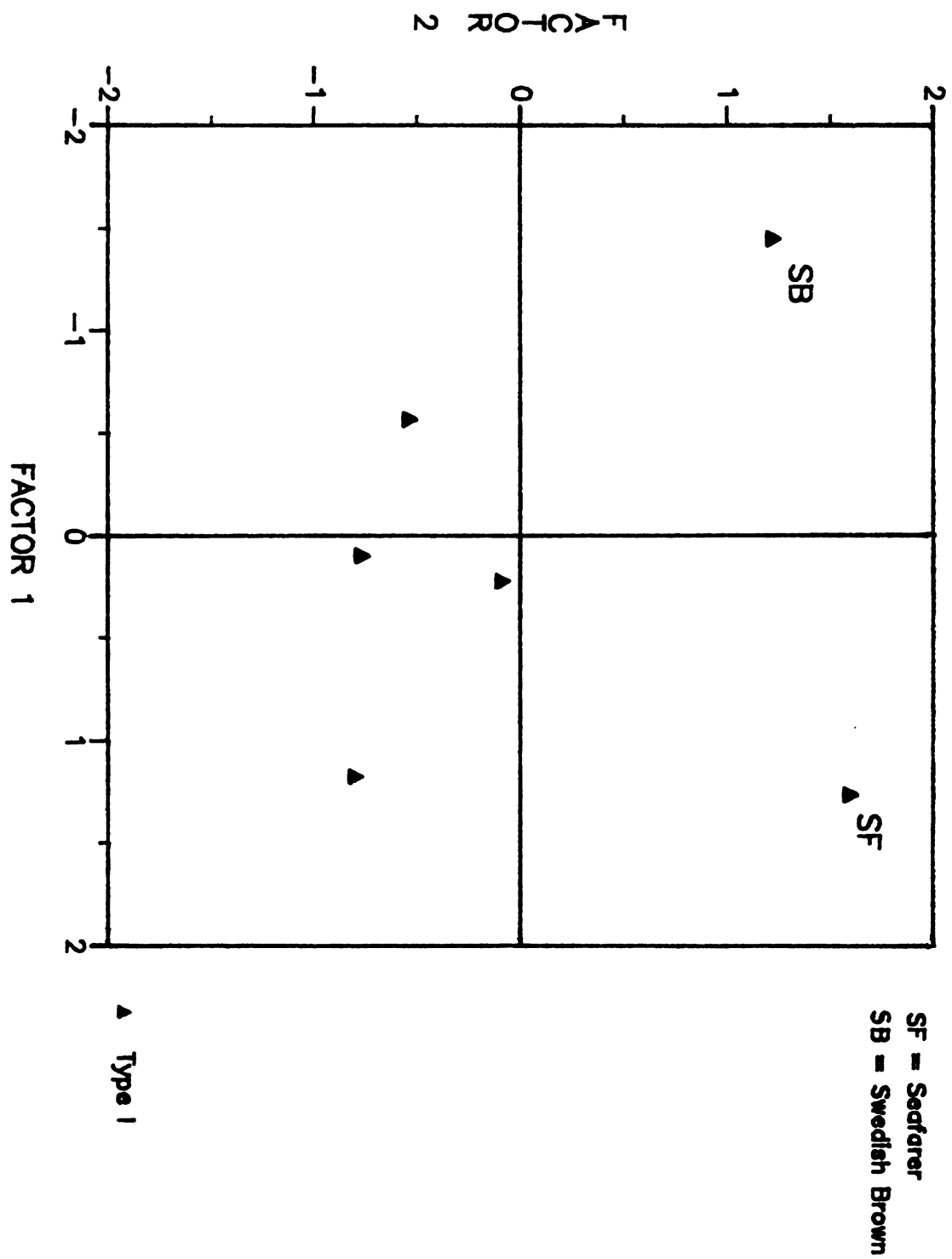


Figure 1d.

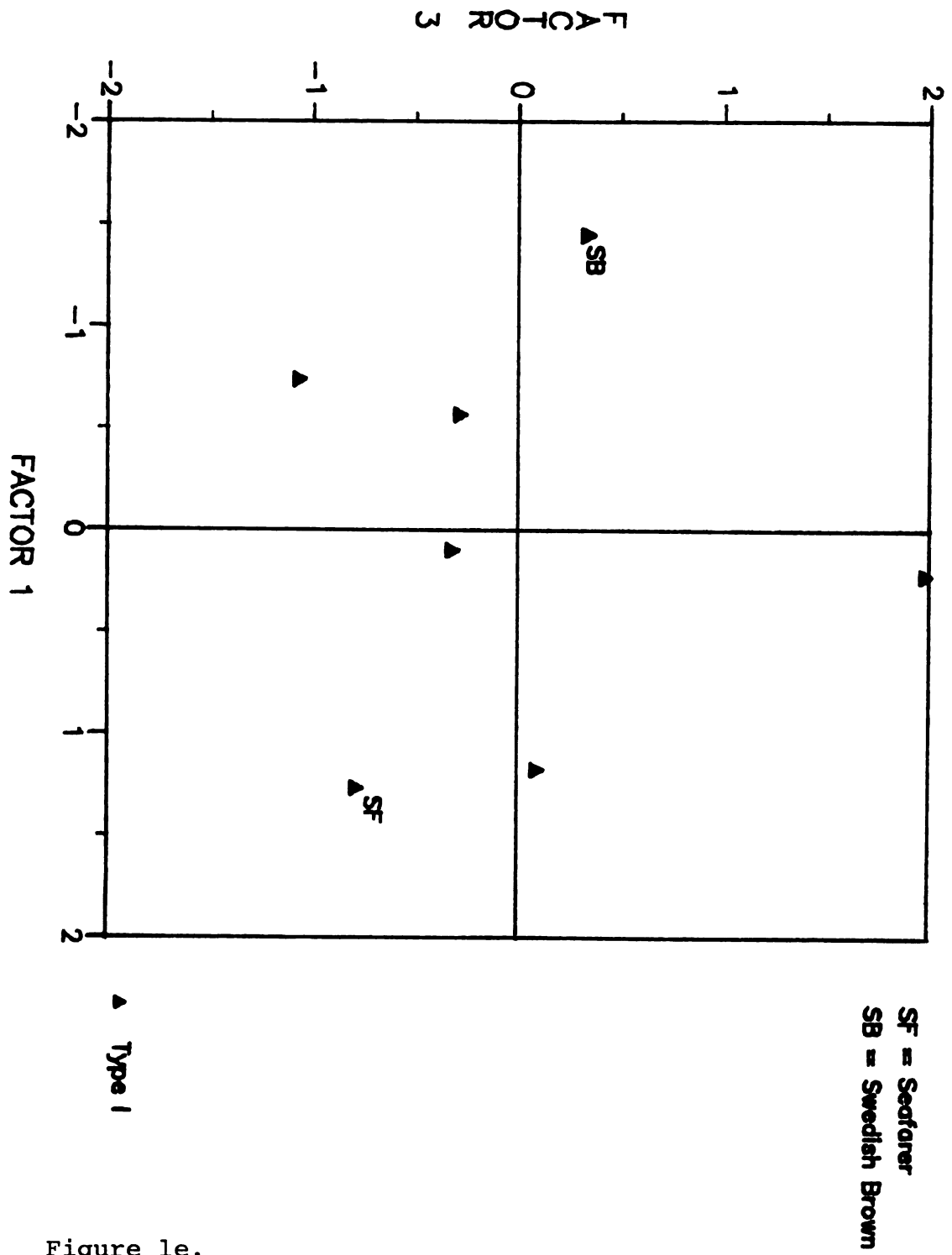


Figure 1e.

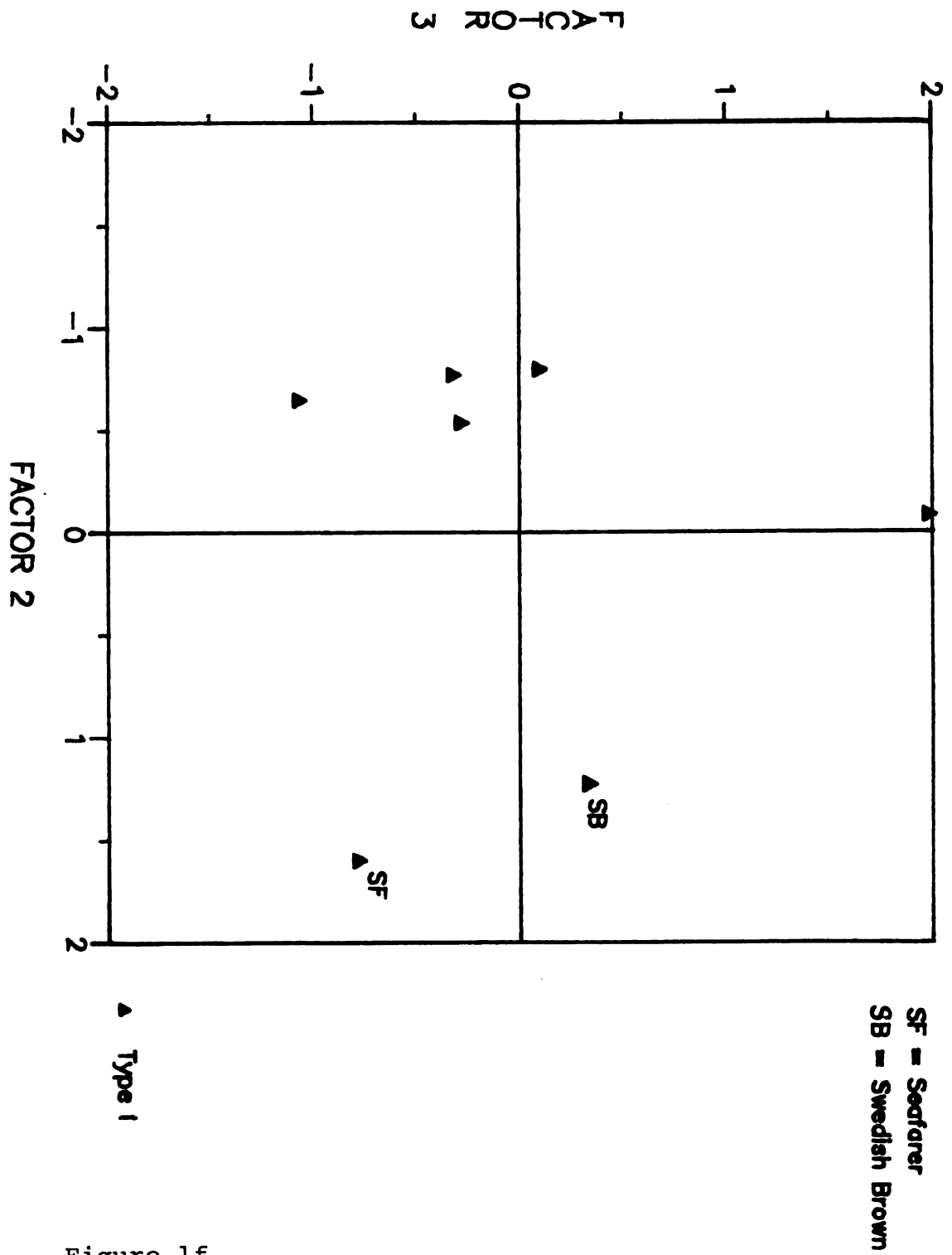


Figure 1f.

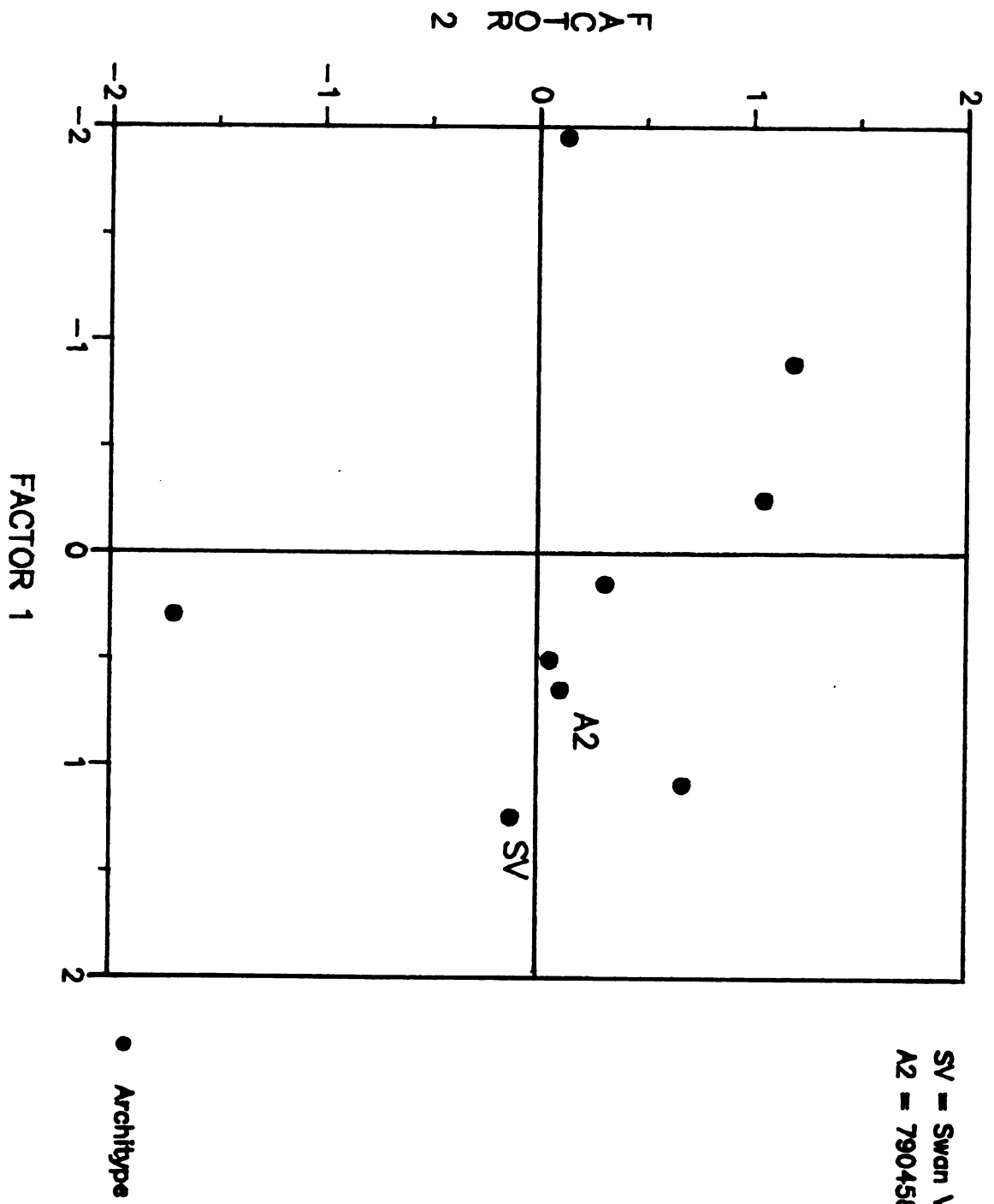
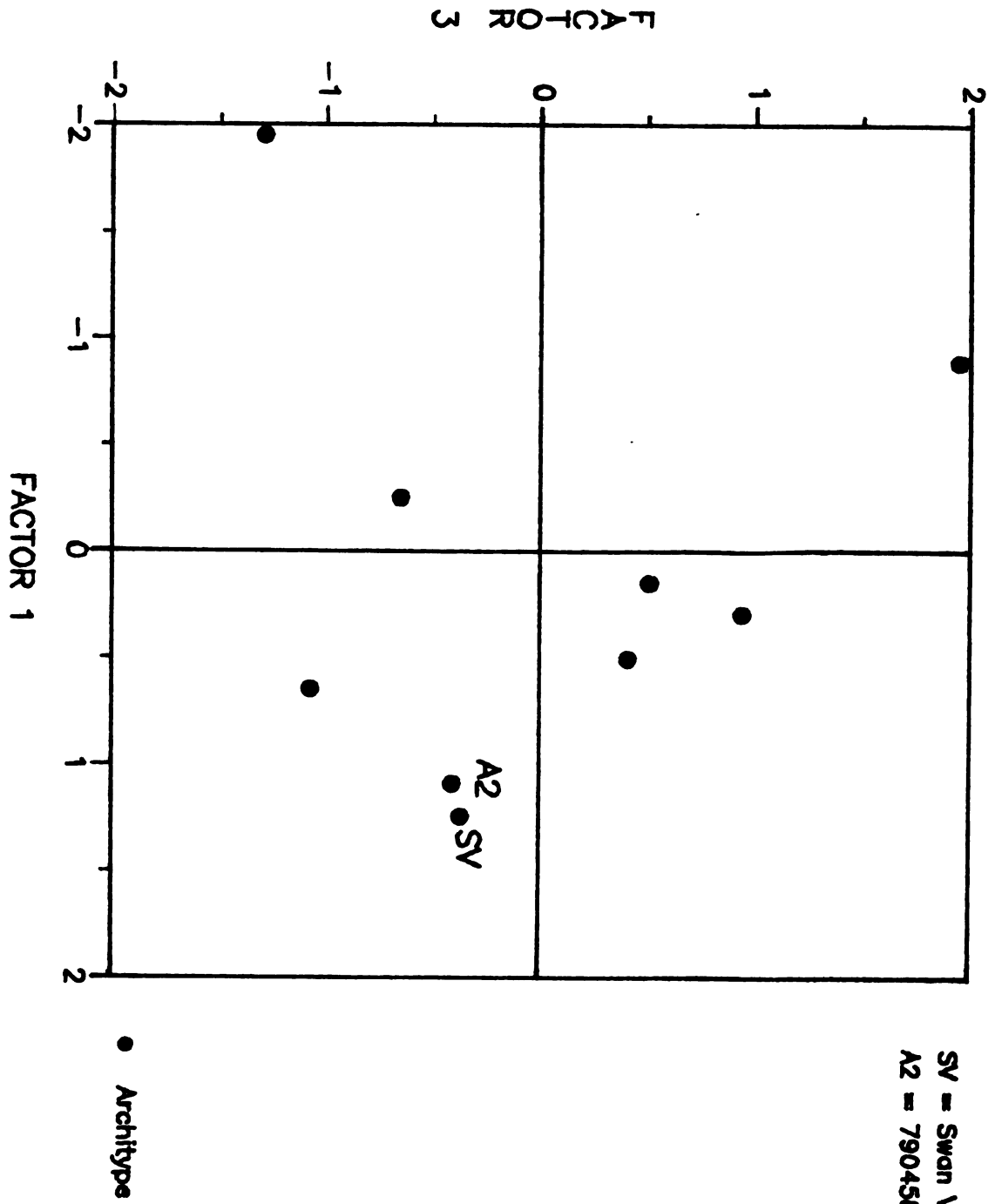


Figure 1g.



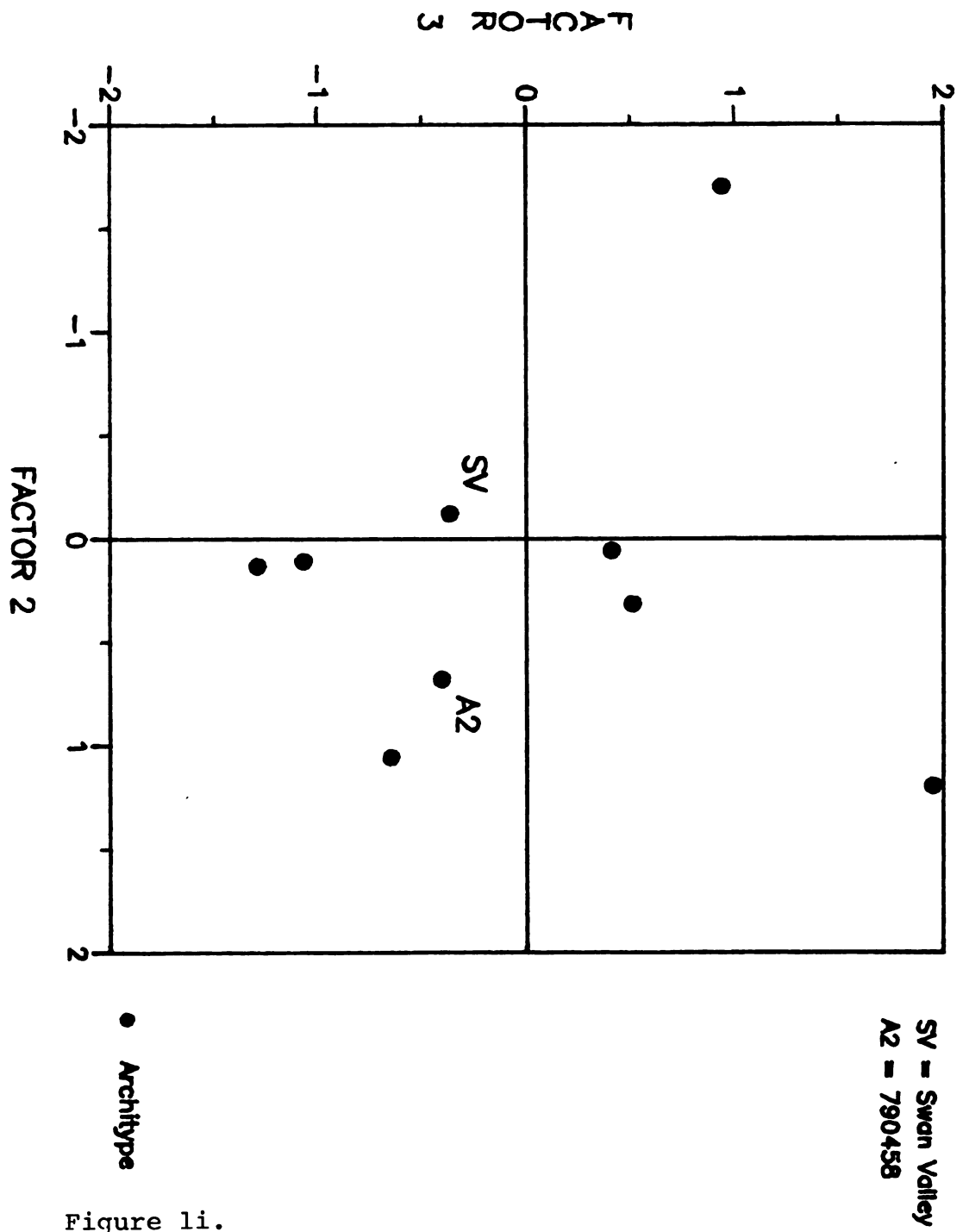


Figure 1i.

CHAPTER 2

DRY MATTER REMOBILIZATION AND SEED FILLING PARAMETERS AMONG SEVENTEEN F_6 LINES AND FIVE CULTIVARS OF DRY BEANS DIFFERING IN THEIR ARCHITECTURAL TRAITS.

ABSTRACT

The purpose of this experiment was to examine the inter-relationships between dry matter remobilization, seed filling parameters and plant architecture in seventeen F_6 lines and five cultivars of dry bean.

The genotypes used represented a wide range of variability with respect to days to flowering, days to maturity and plant architectural characteristics. Thirty days after flowering, dry weight of stems, leaves, pods and seeds were measured for each genotype. From these data, the change in stem, grain dry weight and a remobilization factor were determined between mid-seed-filling and physiological maturity. After 50% flowering, dry seed weights from the central three nodes on the main stem were collected on a four to seven days basis. The data were fitted for each genotype using a cubic polynomial model. The linear seed filling period (LFP), effective filling period (EFP) and linear filling rate (LFR) were calculated.

The genotypes differed in their accumulation and remobilization of stem reserves. No consistent trend was found between the different genetic backgrounds, suggesting a different sink demand or a lesser ability of some genotype to re-allocate reserves.

All the high yielding lines had a long seed filling period. On the average the type II archetypes had a relatively longer linear filling period than type I or type III genotypes. The two seed filling parameters were highly correlated with each other which would indicate that the linear filling period alone could be used to evaluate the length of the seed filling period. The linear filling rate was negatively correlated with days to maturity. The seed filling period parameters were correlated with yield and days to maturity suggesting that a reduction in the reproductive period might result in a reduction in yield.

INTRODUCTION

The adoption of an ideotype strategy for improvement of a grain legume requires careful selection of useful morphological traits. These morphological traits must be associated with physiological processes related to sink development. High yield is only achieved through the proper combination of numerous physiological and morphological components in each genotype. However, each cultivar attains yield through its own combination of these components and its interaction with environmental factors. Thus, stable yield promoting traits must be identified and combined into one genotype.

The efforts in achieving high yield in beans (Phaseolus vulgaris) under Michigan conditions have been concentrated on development of archetype cultivars. These archetypes are characterized by an indeterminate growth habit, a narrow profile, small leaves capable of orientation under strong light, a large number of potential reproductive sites, a high remobilization of dry matter, a long seed filling period and a high rate of seed filling (Adams, 1983).

Partitioning Among Plant Parts

Plant breeders have devised various indirect selection

criteria in developing strategies for increasing yield. Direct selection for photosynthesis or related characters has not established the existence of any consistent relationship with growth or yield of dry matter (Wilson, 1981). In wheat, modern high yielding varieties produce no more biomass than older varieties of comparable growing period (Austin et al., 1980). In bean, Tanaka and Fujita (1979) found no significant cultivar effect upon photosynthetic rate in leaves of comparable age.

Harvest index has been widely used to express the relationship of partitioning of dry matter between the biological and economical yield of plants. Due to the difficulties of obtaining an accurate measurement of root dry weight, only shoot dry weight is usually considered. Thus the harvest index has been defined as the ratio of economic product, such as grain, to the above ground biomass at harvest. Donald and Hamblin (1976) have reviewed the use of the concept of harvest index. They pointed out that when harvest index is used as the sole parameter for selection, it may fail to predict the yield of a crop. It does not take into consideration differences in total biomass.

In both barley and wheat, increase in grain weight often exceeds the dry weight of the vegetative portion of the plant, sometimes by 50% or more (Gallagher et al., 1975). In these instances, some portion of grain growth is

apparently sustained by translocation of assimilates produced before anthesis and stored temporarily in the stem.

Grain legumes in general and beans in particular have been described as a series of phytomeric or source-sink units (Adams and Pipoly, 1980). Each unit consists of a raceme associated with a leaf, node and internode. Normally, a major fraction of the assimilate in the seed unit will have been produced in the leaf associated with the same phytomeric unit (Dure, 1975). Such association is, however, never complete and movement from adjacent phytomeric units may occur, depending on the ratio of source to sink.

Some evidence suggests that yields in grain legumes are source limited (Sinclair and de Wit, 1975). In peas, Meadley and Milbourn (1971) concluded from a series of shading experiments that the limitation to yield in peas lies less in the ability of the plant to produce pods than in the capacity of the crop to produce dry matter. In beans, Burga-Mendoza (1978), studying the trends of dry weight distribution over time, suggested a movement of assimilates from leaves to stems to pods. Tanaka and Fujita (1979) reported that during the most active period of flowering and pod wall growth the carbohydrate content of stems is low. Such situations indicate that the sink capacity exceeds the source capacity during this period. In this sense the source

may be the limiting factor during the blooming and pod wall growth period.

Seed Filling Period

Bunting (1975) observed much of the improvement in yield that has been achieved so far has come from research directed at components which influence the rate rather than the duration of yield accumulation. Recent evidence has suggested that length of seed filling period and seed yield are positively correlated in beans (Izquierdo, 1983) and in soybeans (Gay et al., 1980, Dunphey et al., 1979, Kaplan et al., 1974 and Jones et al., 1979). The finding suggests that increases in yield may be achieved by selecting for a long seed-filling period. The evaluation of some one hundred strains from the soybean germplasm collection, (Reicosky, et al. 1981) indicated that the length of the reproductive period and duration of seed filling period were highly correlated and were under genetic control. Furthermore, the data suggested that the length of the reproductive period can be used as an indirect estimate of seed filling period. The adoption of such selection criteria would cut down on the amount of work needed to estimate seed filling period.

To accomplish an increase in yield, the greater duration of photosynthetic activity must be matched by the potential for greater duration of grain growth (Evans, 1978). Grain

growth in wheat may cease even though conditions are favorable and ample assimilate is still available (Sofield, et al., 1977).

The purpose of this study was to evaluate the dry matter production of seventeen F_6 lines of navy beans from seven different genetic backgrounds and five parental cultivars differing in their plant architecture. Specifically, the relationship between stem dry matter and seed dry matter was studied between mid seed-filling period and physiological maturity; the seed filling parameters such as rate and duration of seed filling were compared for the various architectural groups.

MATERIALS AND METHODS

Seventeen F_6 lines of dry beans belonging to seven different genetic backgrounds and five parental cultivars were used in this study. The parents represented a range of variability in terms of plant architectural characteristics such as growth habit, number of branches, number of nodes, leaf area, number of seeds per pod, seed size and days to flowering and maturity. Each genetic background included several near-isogenic lines with contrasting architectural traits. The F_6 lines differed their plant architecture and in their growth habits; they are described briefly in table 1 and in more detail elsewhere (Chapter one).

Planting and Sampling Procedures

The five parental lines and the seventeen F_6 lines were planted on June 12, 1984, at East Lansing, Michigan, using a precision drill air planter. Due to the lack of sufficient seed, the parental line 61319 was not planted. Each experimental unit consisted of 8 row plots, 5 m long spaced 50 cm apart. Within-row spacing was 7-8 cm giving 13-15 plants per meter of row. The experimental units were arranged in a randomized block design with four replications of twenty two plots each. Standard practices of herbicide

and fertilizer application were used. Irrigation was applied two weeks after planting to compensate for the deficiency in natural rainfall during that period.

To insure full competition among the plants harvested for sampling purposes, the second and seventh rows of each experimental unit were used for periodic collection of data. Each row was divided into four sections, each one meter long. Sampling began thirty days after planting and was performed early in the morning. Five uniformly spaced plants from each experimental unit were harvested at weekly intervals, with the last sample taken at physiological maturity. No attempt was made to collect abscised plant parts such as leaves or petioles. The sampling frequency increased during the seed filling period. Each sample was divided into stems (main stems and branches), flowers, petioles, leaves and reproductive materials (pods and seed). The samples were then dried at a constant temperature of approximately 70° C in a forced air dryer for two days.

After 50% flowering, all the pods from the central three nodes on the main stem were removed and opened with a razor. The seeds and pods were then dried at a constant temperature for two days. After drying, the weight of all the plant parts was obtained. At maturity, two 4 meter segments from the middle two rows were harvested and threshed to obtain an estimate of grain yield. Apparent

harvest index was calculated by dividing grain seed dry weight by total dry weight of five uniformly spaced plants.

Statistical Analysis

Multiple regression techniques were used to derive functions relating the change in dry weight of the stem and the seed with time (number of days). The polynomial model $Y = b_0 + b_1t^1 + b_2t^2 + b_3t^3$, where Y is the stem dry weight (g/m²) or the seed dry weight (mg/seed) and where t is the number of days after planting or after 50% flowering at which time samples were taken, was fitted to the data using least squares regression techniques of the PLOTIT package.

The changes in stem dry weight and seed dry weight were calculated for the period between mid seed-filling and physiological maturity. A remobilization factor was obtained by dividing the change in stem dry weight by the change in seed dry weight. Grain dry weights were plotted against the number of days after 50% flowering. The data points were then fitted using the model described. The effective filling period (EFP) was calculated as the period for the linear phase of grain growth. The linear filling period (LFP) was calculated using the methods described by Sofield, et al. (1977) and utilized in beans by Izquierdo (1981). The method consisted of selecting several data points in the middle of the range of the filling period. The middle region was then

progressively extended by the inclusion of data points first at one end then at the other end. At each step the least squares fit and the coefficient of determination (R^2) were calculated. This procedure was continued until inclusion of a data point no longer gave as good a least squares fit as the ones pre calculated. The length of the linear filling period was then obtained by projecting the limit of the selected linear phase on the X axis (days after 50% flowering). The seed filling rate (SFR) was considered as the linear regression of the linear phase.

RESULTS

The determinate F_6 lines flowered and matured earlier than their respective indeterminate near-isogenic lines, with the exception of line 5 in genetic background 3 (Table 2). The determinate archetype line 5 had the same days to 50% flowering as its near-isogenic line 6, but nevertheless had reached maturity five days earlier. The difference between type I, type II and type III plants in days to 50% flowering ranged from zero to twelve days, whereas for the days to maturity it ranged from five to seventeen days. All the F_6 determinate lines except line 15 flowered later than the determinate parents Seafarer and Swedish Brown. Time to maturity ranged from seventy-nine (Swedish Brown) to one hundred days after planting (Line 13). The reproductive period ranged from forty (line 5) to fifty one days (line 8).

The yields of the genotypes are presented elsewhere (chapter one). In summary, the archetypes Swan Valley, line 2, line 13 and 790458 yielded significantly more than all other genotypes. All the F_6 archetypes were superior in yield to their respective type I and type III near-isogenic lines. The harvest indexes (HI) and the yield efficiencies (YE) of all the genotypes are presented in table 2. The

harvest index was highly correlated with yield ($r=0.76$) and ranged from 0.32 (791515) to 0.58 (Swedish Brown). The type III F_6 lines had consistently lower harvest indices in comparison with their respective near-isogenic lines. The architype genotypes had a high harvest index and a high yield efficiency, but so had Swedish Brown (HI = 0.58, YE = 36.5). The lowest harvest index and yield efficiency was obtained for the single stem experimental line 791515 (HI = 0.32, YE = 20.0). These low values result from several factors including the heavy weight of a strong green stem, an observed high seed abortion within each pod and a low number of seeds per pod.

Little increase in stem length occurred for the determinate genotypes between period from 50% flowering to physiological maturity, but stem dry weight increased considerably. The change in stem dry weight and seed dry weight was calculated between mid-seed filling and physiological maturity stages. The average period between the two stages was two weeks for the determinate genotypes and three weeks for the indeterminate genotypes. The results are presented in table 3.

All the genotypes decreased in their stem dry weight between the stages of mid-seed-filling and physiological maturity (Table 3). The type III F_6 lines were the lowest remobilizers, with lines 4, 9, 12 and 14 reallocating 7.8,

2.7, 6.0 and 9.1 (g/m²), respectively, of dry matter from the stem between mid-seed-filling and physiological maturity. The change in stem dry weight for the type I's was high and reallocation values ranged from 12.2 to 33.5 g/m². However, no consistent trend was detected among the remobilization factors of the type I lines. While Seafarer, Swedish Brown and line 15 displayed high remobilization, determinate lines 1, 5, 7 and 10 were lower in this regard. A similar lack of consistency also prevailed among the type II architypes. The parental type II lines displayed a lower remobilization than the F₆ lines. The single stem cultivar 791515 had an extremely low remobilization factor of 0.04 g/m².

The seed filling parameters (linear filling period, effective filling period and linear filling rate) are presented in table 4. The curves for Swedish Brown, Seafarer and Swan Valley are presented in figure 1. With the exception of Swedish Brown, the type I lines had a shorter seed filling duration as compared to the type II lines. The estimate of regression parameters and coefficient of determination (R²) for the cubic polynomial used to describe the seed growth are presented in table 6. The high coefficient of determination indicated a good fit to the data. The sampling procedure of four to seven days between harvest dates appeared adequate. The mean number of days for the linear filling period and the effective filling

period were 6.5 and 10.5 days, respectively. The mean duration for the type II architypes were 10.5 and 14.6 days for linear filling period (LFP) and effective filling period (EFP), respectively.

The correlations between the seed filling parameters and yield, its primary components and days to maturity are presented in table 5. The relationships between the EFP, LFP and yield were highly significant ($r = 0.62$ and 0.77 , respectively) (Table 5). Such results agreed with several findings previously reported for beans and soybeans. The EFP was also positively correlated with number of pods, seeds per pod and maturity. Interestingly, the LFP was not correlated with seeds per pod. The linear filling rate was highly negatively correlated with seeds per pod but positively correlated with seed size. The LFP and EFP were highly correlated among each other. The EFP could then be used alone to indicate the length of the seed filling period, avoiding tedious calculation to obtain the LFP.

DISCUSSION

The development of the near-isogenic genotypes, from seven genetic backgrounds differing in their growth habits, coupled with their respective parental lines, allowed the comparisons of dry matter partitioning and seed filling parameters in the navy bean plant. The results presented above provided some physiological quantification for the differences in yield between the conventional and the archetype navy bean genotypes. In the previous chapter, it was shown that the highest yielding navy bean genotypes all belonged to the archetype group. Furthermore, the type II archetypes outyielded either their respective type I or type III near-isogenic lines.

Genetic differences observed in the accumulation, depletion and remobilization of stem reserves agreed with previous findings in beans (Adams, 1978, Burga-Mendoza, 1978). All the genotypes reallocated different amounts of dry matter, suggesting different levels of sink demand. The same data may also indicate that some genotypes simply do not re-allocate, or do so poorly, thus having nothing to do with sink demand per se. The contribution of previously stored material in the stem to the final seed dry weight for

the period from mid-seed-filling to physiological maturity was, however, not consistent nor uniform between the different genetic backgrounds or within the type I or type II growth habits. The type I genotypes which required roughly the same length of time from mid-seed-filling to physiological maturity (14-16 days) had different patterns of remobilization. Although the cultivars Seafarer, Swedish Brown and line 15 had a high remobilization factor, other F_6 type I lines had a lower remobilization factor. The same patterns occurred in the type II genotypes. The parental lines, Swan Valley, 790458 and 791515, had the lowest remobilization factors, while line 2 had the highest one.

In most cases changes in the remobilization factor did not result in any change in grain yield. The lack of any clear trend, coupled with the low non-significant correlation between yield and the remobilization factor suggested that the genotypes studied have different source-sink relationships independent of their architecture or their growth habit. The genotypes included in the study varied quantitatively with respect to their sink (number of pods, seeds per pod, seed size) and their source (leaf area, stem weight). As distinct groups, the type I, type III and the archetype genotypes have consistent trends with respect to yield. The F_6 archetypes were superior to their respective near-isogenic lines. However, their tendencies to

remobilize available reserves differed. From past observation, it was noted that several lines retained a green stem and green leaves that are presumably still photosynthetically active late in the growing season. Such traits, characterizing the parental lines (Swan Valley, 790458 and 791515) were also transmitted to some of the F_6 lines, such as lines 1 and 13. Waters et al. (1980) suggested that starch stored in the stem may later move to the pods during the period of rapid pod growth.

The performance of the archetypes Swan Valley, 790458 and line 2 were similar with respect to yield, days to flowering, maturity, seed size and other yield components. The differences in their remobilization factors suggested that the reserves in the stem were not remobilized. Adams et al. (1978) postulated that certain bean genotypes will not remobilize all their reserves in the stems or roots. Remobilization may depend on differences in sink demands. The reserve associated with low yield levels may be an indication of lack of reproductive demand, whereas at higher yield levels, reserves may indicate a lesser ability to remobilize. One could speculate that the inability to remobilize, as in the high yielding archetypes (Swan Valley, 790458 and line 13), would indicate that reserves could be available for pod growth over a short period of stress. This feature would contribute to tolerance among genotypes to some levels of environmental stress and overall greater

yield stability.

Seed yield is determined not only by the rate of seed growth but also by the duration of growth. Evidence has been accumulating concerning the contribution of the seed filling parameters to final grain yield. The positive significant relationship between seed filling duration (LFP and EFP) and yield reinforces results already reported in beans and soybeans. The positive relationship with days to maturity suggests that long seed filling duration not only was associated with later maturity but may actually require it. All the high yielding genotypes had a long seed filling duration (LFP and EFP), whereas all the F_6 type I navy bean genotypes had short EFP and LFP values but a relatively high rate of filling. The selection of the various F_4 parental lines was performed in Puerto Rico a few days after maturity, without any monitoring or knowledge of the plants prior to that time. No deliberate attempt was made to select the F_4 lines for early or late flowering. Rather the most promising, non-border plants were selected and one must assume that some earlier type II lines if they occurred were overlooked due to complications relating to rust disease infection or lodging.

The bean plant has been viewed as a series of nutritional or source-sink units, which are composed of a leaf, an internode, a raceme and/or a branch (Tanaka and

Fujita, 1979). Within each source-sink unit, pods, seeds per pod and seed size constitute a system of sinks which might be competing in a delicate balance with each other for nutrients derived from the leaf component of the unit. In an environmental system where resources are limiting, two alternatives may occur; either the beginning of seed growth will cause the reallocation of nutrients to the developing seed and the number of seeds per pod will cease to increase; or when the number of seeds per pod has reached its maximum, it no longer behaves competitively as a sink. The order of events in the pods indicates that the first possibility is more likely (Adams, 1967).

The high negative correlation between seed filling rate with seeds per pod and days to maturity is in accordance with the concept of yield component compensation. It represents a sequential and serial adjustment of plant investment to limited resources during fruit growth. Once seed filling begins, the relationship between the primary yield components will respond in an oscillatory fashion. Should maturity be delayed, the rate of seed filling will decrease in the pod in the same nutritional unit resulting in more seeds per pod being retained but with smaller seed size.

The high yield was, however, not associated with a single pattern of interaction. Swan Valley, 790458 and line

2 are morphologically similar and share a common gene pool. The first two genotypes had a greater seed set plus a lower rate of filling over a longer time period which resulted in high seed yield. Line 2, on the other hand, achieved a similar yield with a greater seed set (pod number) but with a higher rate of filling over a shorter period of time than Swan Valley and 790458. Data for Swedish Brown, although not in the navy bean group, are also revealing. The high rate of filling is associated with a larger seed size, but a low number of pods and seeds per pod.

Such diverse source-sink systems suggest that the plant is a richly interconnected, self-regulatory system in which the various components of growth and yield are strongly coupled and controlled at some level of operation below their potential. A developmental plasticity allows the plant to maintain a certain equilibrium. An increase in yield can be obtained provided that constraints to development are removed during critical stages of growth. The determinate navy genotypes with their excessive demands of assimilate over a short period of time seem to have little potential for developmental plasticity, or higher grain yield.

The architypes used in this study have achieved high yield by an increase in vegetative growth, a high harvest index, a high yield efficiency, longer effective and longer linear seed filling periods. The indeterminate type II

growth habit allows a greater accumulation of assimilates during vegetative growth and hence a larger supply of nitrogen and carbon assimilates for redistribution. A long seed-filling period is clearly beneficial to an increase in yield, nevertheless, practical considerations dictate early or no later than mid-season harvest maturities. Furthermore, little is known about bean root storage tissues and their ability or inability to redistribute their stored assimilates. Field observations indicated that some of the archetypes have a very strong deep tap root which might utilize assimilate before the shoot is fully established thus delaying the onset of the linear phase of vegetative growth. The results provide some encouragement in the breeding for higher yield in beans using the archetype strategy. The morphological traits selected appear to be associated with physiological processes important to improved yield potential.

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Table 1. List of the twenty two genotypes of dry beans used and means of their primary yield components.

F4 Family	F6 Line Number and Parentage	Growth Habit	Number of Pods /Plant	Seeds /Pod	Seed Size (gr.)
1	1 Seafarer x Swan Valley	I	20.2	6.3	17.1
1	2 Seafarer x Swan Valley	II	26.2	7.2	16.9
2	3 Seafarer x 790458	II	21.3	6.5	23.3
2	4 Seafarer x 790458	III	24.4	4.7	24.4
3	5 Seafarer x 790458	I	23.0	5.1	17.2
3	6 Seafarer x 790458	II	26.2	6.3	18.0
4	7 Seafarer x 61319	I	19.2	6.8	21.8
4	8 Seafarer x 61319	II	23.2	6.9	20.8
4	9 Seafarer x 61319	III	21.7	6.4	22.2
5	10 Swan Valley x Swedish Brown	I	23.2	6.4	22.1
5	11 Swan Valley x Swedish Brown	II	20.0	7.0	21.5
5	12 Swan Valley x Swedish Brown	III	21.0	5.9	21.6
6	13 790458 x 791515	II	28.2	7.0	20.8
6	14 790458 x 791515	III	19.2	6.8	20.8
7	15 791515 x Swedish Brown	I	18.1	5.7	20.5
7	16 791515 x Swedish Brown	II	19.2	5.8	20.2
7	17 791515 x Swedish Brown	II	18.2	6.8	19.1
Cultivar	SEAFARER	I	20.1	5.4	17.0
Cultivar	SWEDISH BROWN	I	22.0	4.2	40.1
Cultivar	SWAN VALLEY	II	30.0	7.2	17.4
Exp. Line	790458	II	27.1	7.3	19.3
Exp. Line	791515	II	12.8	4.2	28.6

Table 2. Days to 50% flowering, days to maturity, harvest index and yield efficiency of twenty-two genotypes of beans

F4 Family	F6 Line & Cultivars	Growth Habit	Days to 50% Flowering	Days to Maturity	Harvest Index	Yield Efficiency (g/m ² /day)
1	1	I	42	86	0.52	29.30
1	2	II	47	94	0.53	35.05
2	3	II	44	85	0.50	33.60
2	4	III	46	95	0.47	24.25
3	5	I	47	87	0.43	25.0
3	6	II	47	92	0.48	27.2
4	7	I	40	86	0.52	26.20
4	8	II	43	94	0.53	29.57
4	9	III	49	94	0.41	23.72
5	10	I	40	82	0.48	30.20
5	11	II	49	96	0.50	31.20
5	12	III	50	97	0.43	26.06
6	13	II	50	100	0.54	32.05
6	14	III	50	97	0.44	23.43
7	15	I	38	82	0.46	25.76
7	16	II	50	99	0.39	19.87
7	17	II	47	89	0.42	25.50
SEAFARER		I	38	81	0.52	28.70
SWEDISH BROWN		I	37	79	0.58	36.50
SWAN VALLEY		II	49	97	0.54	34.22
90458		II	50	99	0.56	30.60
791515		II	47	98	0.32	20.81

Table 3. Stem dry weight at mid seed-filling (S1), at physiological maturity (S2), seed dry weight at mid seed-filling (G1), at physiological maturity (G2), and remobilization factor (RF) of twenty-two genotypes of dry beans between mid-seed-filling and physiological maturity (g/m^2).

Genotype	S1	S2	S2-S1	G1	G2	G2-G1	RF
Line 1	198	179	-18.5	138	232	109	-0.168
Line 2	258	231	-26.7	182	301	118	-0.224
Line 3	263	242	-21.3	159	272	113	-0.188
Line 4	218	210	- 7.8	122	246	123	-0.069
Line 5	242	230	-12.2	141	233	92	-0.132
Line 6	247	226	-21.0	135	243	108	-0.193
Line 7	170	157	-13.1	123	212	89	-0.146
Line 8	210	194	-16.2	165	256	91	-0.177
Line 9	255	252	- 2.7	146	202	55	-0.048
Line 10	219	198	-20.3	127	232	105	-0.192
Line 11	272	250	-22.5	164	283	118	-0.190
Line 12	216	210	- 6.0	120	233	113	-0.052
Line 13	256	236	-14.0	194	332	148	-0.094
Line 14	246	236	- 9.1	118	204	86	-0.105
Line 15	212	178	-33.5	142	230	162	-0.206
Line 16	203	199	- 4.1	154	132	27	-0.148
Line 17	200	185	-14.8	102	189	86	-0.161
Seafarer	171	158	-13.0	155	210	55	-0.236
Swedish Brown	154	178	-24.4	178	272	94	-0.259
Swan Valley	223	207	-16.5	240	341	100	-0.164
790458	204	196	-8.1	231	325	93	-0.086
791515	309	306	-3.3	96	176	79	-0.042

Table 4. Seed filling period (linear and effective) and seed filling rates of twenty-two genotypes of dry beans.

F4 Family	F6 Lines	Growth Plant		Filling Period (Days)		Filling Rate (mg seed/day)
		Habit	Architecture	Effective (EFP)	Linear (LFP)	(LFR)
1	1	I	Determinate	11	7	7.85
1	2	II	Indet. Architype	13	9	7.75
2	3	II	Architype	14	9	9.92
2	4	III	Indet. Viny	12	6	10.95
3	5	I	Det. Architype	11	5	12.25
3	6	II	Indet. Architype	11	9	9.11
4	7	I	Det. Bush	11	7	9.09
4	8	II	Indet. Architype	14	9	9.93
4	9	III	Indet. Viny	14	8	10.05
5	10	I	Det. Bush	10	7	11.74
5	11	II	Indet. Architype	12	9	10.80
5	12	III	Indet. Viny	12	7	9.60
6	13	II	Indet. Architype	17	12	11.38
6	14	III	Indet. Viny	13	8	9.16
7	15	I	Determinate Bush	9	6	12.19
7	16	II	Indet. Reduced br.	10	6	8.02
7	17	II	Indet. Bush	11	7	10.80
SEAFARER		I	Det. Bush	11	5	9.80
SWEDISH BROWN		I	Det. Bush	15	10	17.50
SWAN VALLEY		II	Architype	17	12	6.10
790458		II	Architype	19	14	6.30
791515		II	Single Stem	15	8	13.35

Table 5. Correlation between length of seed filling, rates of seed fill and primary yield components and days to maturity for twenty-two genotypes of dry beans.

SeedFillingParameters	Yield	Number of Pods	Seed/ pod	Seed Size	Days to Maturity
Effective Filling Period (EFP)	0.77**	0.59**	0.48**	0.12	0.43*
Linear Filling Period (LFP)	0.62**	0.47*	0.22	0.22	0.47*
Linear Filling Rate (SFR)	-0.24	-0.37*	-0.70**	0.77**	-0.45*

*,** Significant at the 5% (*) and the 1% (**) level of probability, respectively.

Table 6. Regression parameter estimates and coefficients of determination of twenty two genotypes of dry beans for the cubic polynomial regression equation for the seed dry weight upon times in days after 50 % flowering.

Genotype	b0	b1	b2	b3	R2
LINE 1	58.0206	-13.19104	0.790312	-.983E-02	0.989
LINE 2	67.6127	-14.65121	0.825031	-.998E-02	0.974
LINE 3	101.9411	-19.79607	1.121449	-.139E-01	0.984
LINE 4	207.9713	-32.29854	1.522700	-.177E-01	0.959
LINE 5	296.6726	-45.47385	2.160021	-.277E-01	0.960
LINE 6	157.3682	-26.37311	1.333790	-.165E-01	0.990
LINE 7	268.4436	-40.78507	1.846639	-.217E-01	0.939
LINE 8	271.2762	-37.42336	1.556519	-.169E-01	0.944
LINE 9	198.2983	-30.47627	1.394067	-.158E-01	0.948
LINE 10	306.8010	-44.56079	1.966518	-.227E-01	0.920
LINE 11	301.7623	-42.29321	1.784645	-.198E-01	0.980
LINE 12	114.0519	-21.37206	1.021938	-.111E-01	0.939
LINE 13	85.6262	-16.83900	0.887219	-.102E-01	0.987
LINE 14	233.0621	-32.15430	1.339983	-.143E-01	0.975
LINE 15	111.8580	-24.33368	1.352827	-.173E-01	0.976
LINE 16	77.0366	-14.64596	0.788903	-.910E-02	0.912
LINE 17	201.7863	-34.98758	1.760988	-.223E-01	0.986
SEAFARER	190.3416	-32.78090	1.675480	-.217E-01	0.987
SWEDISH BROWN	201.1694	-39.80769	2.300455	-.298E-01	0.988
SWAN VALLEY	11.0127	- 5.28011	0.418699	-.504E-02	0.981
790458	27.1524	- 6.45112	0.403704	-.418E-02	0.985
791515	-4.4603	- 8.55952	0.807771	-.107E-01	0.968

**Figure 1. Seed filling curves of the cultivars Swedish Brown,
Seafarer and Swan Valley.**

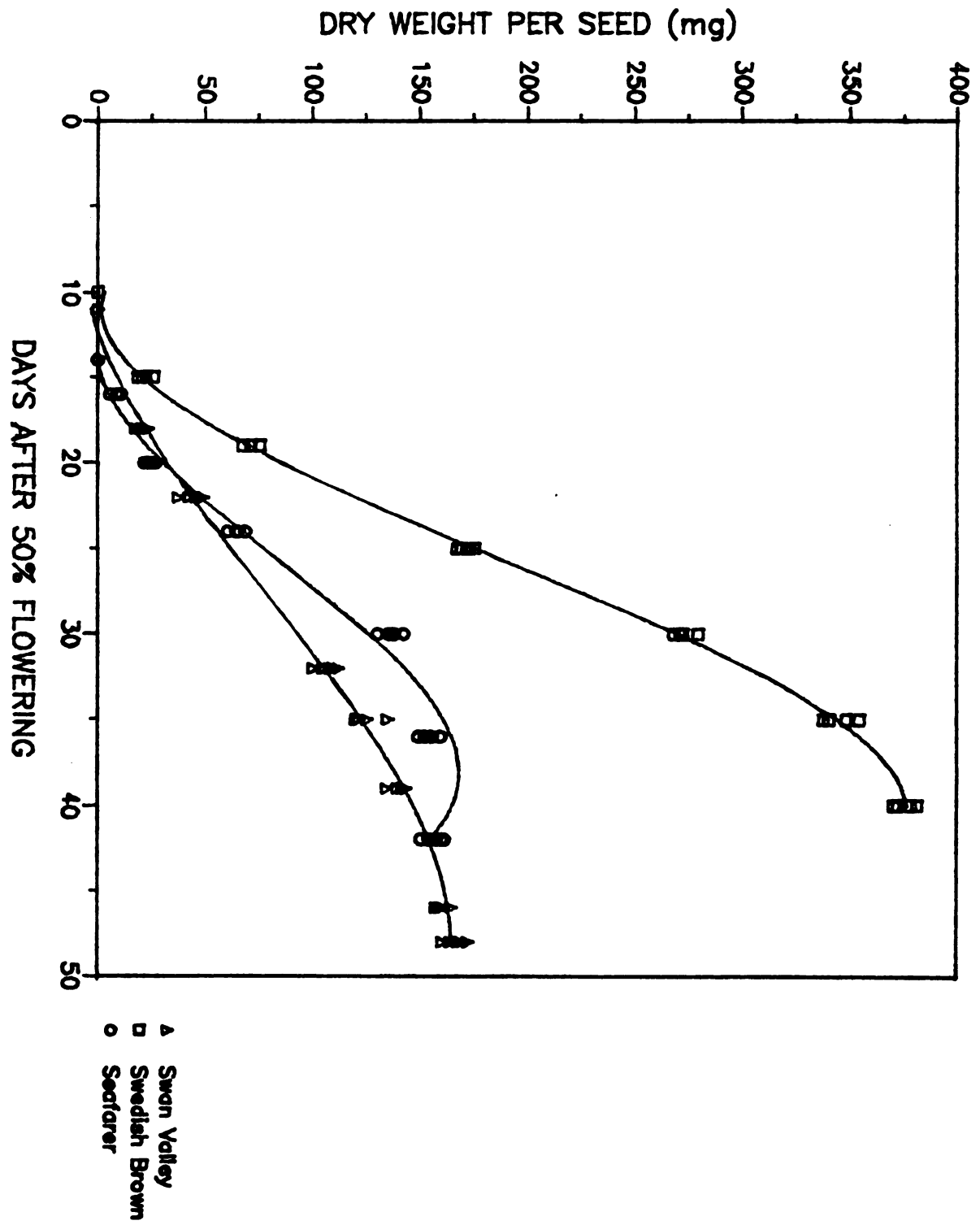


Figure 1.

SUMMARY AND CONCLUSIONS

Breeding for morphological traits has resulted in major yield improvement in several crops. In dry bean (Phaseolus vulgaris L.), the breeders at Michigan State University have restructured the small seeded navy bean plant based on an ideotype concept. The ideotype was formulated for a monoculture cropping system at high plant density for the Michigan environment. The new released cultivars are characterized by their unique architectural structure. As a distinct group they are referred to as "architypes". In contrast to the conventional navy bean cultivars, the architypes are tall, upright type II plant with a reduced number of branches, numerous pods and seeds per pod. Their yield has proven to exceed the conventional varieties by as much as 30% across years and locations.

To gain a better understanding of the relationships between yield and the architype genotypes, this study was undertaken with the following objectives; 1) Generate near-isogenic lines for architectural traits in different genetic backgrounds, 2) Identify patterns of association among morphological traits and their relationships with yield for determinate and architype genotypes, 3) Study the dry matter

remobilization, linear and effective seed filling period and seed filling rate among determinate and architype genotypes.

The study was conducted on seven sets of near-isogenic lines and five of the six parental cultivars. The near-isogenic lines were obtained by selecting F_5 seeds selected from within F_4 families. The seventeen F_6 lines differed in their growth habits (type I, II and III). The twenty-two genotypes were tested for yield and various morphological traits. A principal factor analysis was performed to detect patterns of association among the various traits. A modified principal component distance was calculated to measure the genetic distances among the various genotypes. In addition, the dry matter remobilization was calculated for the period between mid-seed-filling and physiological maturity. Seed filling parameters were obtained from a fitted curve of seed dry weight and days after flowering for each genotypes.

The following conclusions were made:

1. Significant differences among the genotypes were found for seed yield and the various architectural traits. The architype genotypes outyielded the conventional type I bush bean and the type III genotypes. The yield of some of the architype genotypes increased by as much as 29% when compared to the conventional bush cultivars.

2. The calculated genetic distance indicated that the parental genotypes with the exception of the architypes were quite distant based on their morphological traits. The determinate F_6 lines were distant from the determinate parental genotypes, whereas the indeterminate ones were closer to the parental architypes.

3. Two gene pools were defined for the determinate type and one gene pool was defined for the architype genotypes.

4. Two different patterns of association was obtained for the determinate and the architype genotypes. The first two factors of the determinate genotypes were characterized mainly by vegetative vigor and potential reproductive traits. The first factor in the architype genotypes included the major reproductive structures.

5. The existing genic balance among the conventional cultivars has been replaced by a more efficient one and potentially higher yielding one.

6. No consistent patterns were detected for the remobilization between the period from mid-seed-filling and physiological maturity.

7. The architype genotypes flowered and matured later

than the type I genotypes or than the respective type I near-isogenic lines.

8. The architypes had a longer linear and effective seed filling period when compared to the type I genotypes with the notable exception of Swedish Brown, the large yellow seeded cultivars.

9. The effective and linear filling periods were positively correlated with yield and negatively correlated with days to maturity. The linear filling rate was negatively correlated with seeds per pod and positively correlated with days to maturity.

APPENDICES

APPENDIX A

Table 1. Scores of twenty-two genotypes from the factor analysis of the morphological traits

Genotype	Factor 1	Factor 2	Factor 3
line 1	0.6332	-0.8112	-1.1706
line 2	-0.1190	1.1306	-0.7866
line 3	0.6506	0.6823	0.8791
line 4	0.1860	0.4236	1.9037
line 5	1.2027	-0.0289	-1.0619
line 6	0.5592	1.0623	-0.1578
line 7	0.1026	-1.1981	-1.1883
line 8	-0.4910	-0.3102	0.0469
line 9	-0.5033	-0.3991	0.2227
line 10	0.3738	-0.2643	0.1517
Line 11	0.1445	0.5002	-0.3218
Line 12	-0.0321	0.8143	0.9553
Line 13	0.1271	0.7528	0.2713
Line 14	-1.6627	0.0859	0.1855
Line 15	0.0255	-1.3614	-1.2493
Line 16	-0.0208	0.1761	-1.0555
Line 17	-0.0429	-0.3692	-1.6162
Seafarer	2.4762	-0.2771	1.3756
Swedish Brown	0.1987	-2.7375	1.7651
Swan Valley	-0.6281	1.2839	0.1637
790458	-0.3062	1.5281	-0.0389
791515	-2.8738	-0.6830	0.7262

Table 2. Scores of the determinate genotypes from the factor analysis of the morphological traits

Genotype	Factor 1	Factor 2	Factor 3
Line 1	0.0981	-0.7665	0.3149
Line 5	1.1730	-0.7958	0.1016
Line 7	-0.5671	-0.5349	0.2772
Line 10	0.2225	-0.0837	1.9910
Line 15	-0.7402	-0.6466	1.0625
SEAFARER	1.2629	1.6013	0.7780
SWEDISH BROWN	-1.4492	1.2261	0.3398

Table 3. Scores of the archetype genotypes from the factor analysis of the morphological traits

Genotype	Factor 1	Factor 2	Factor 3
Line 2	0.6472	0.1080	-1.0690
Line 3	-0.8879	1.1928	1.9500
Line 5	-1.9500	0.1327	-1.2918
Line 6	-0.2502	1.0557	-0.6500
Line 11	0.2940	-1.7008	0.9400
Line 8	0.1475	0.3155	0.5080
Line 13	0.5048	0.0580	0.4090
SWAN VALLEY	1.2435	- 0.1212	-0.3650
790458	1.0906	0.6799	-0.4046

APPENDIX B

Figure 1. Seed filling curves of the twenty-two genotypes

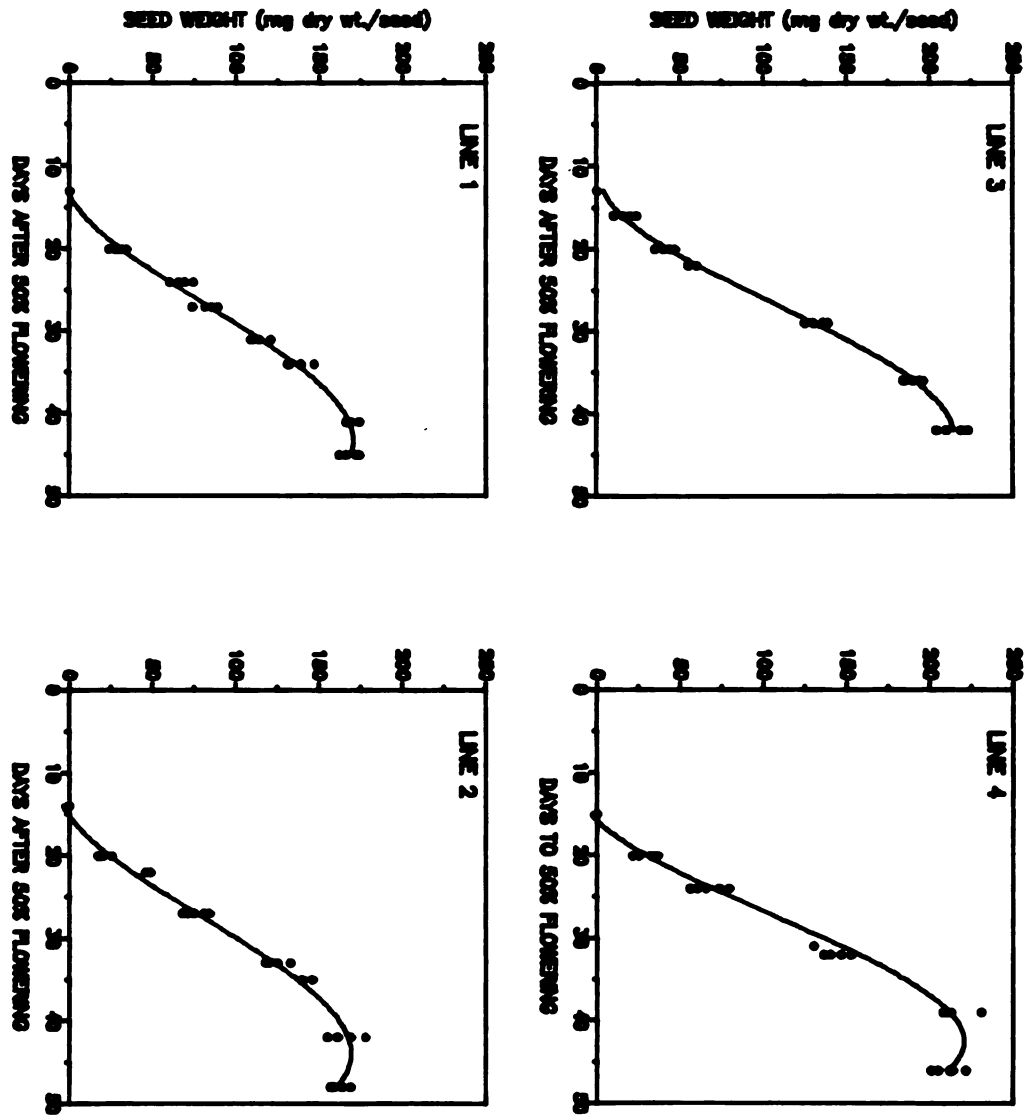


Figure 1.

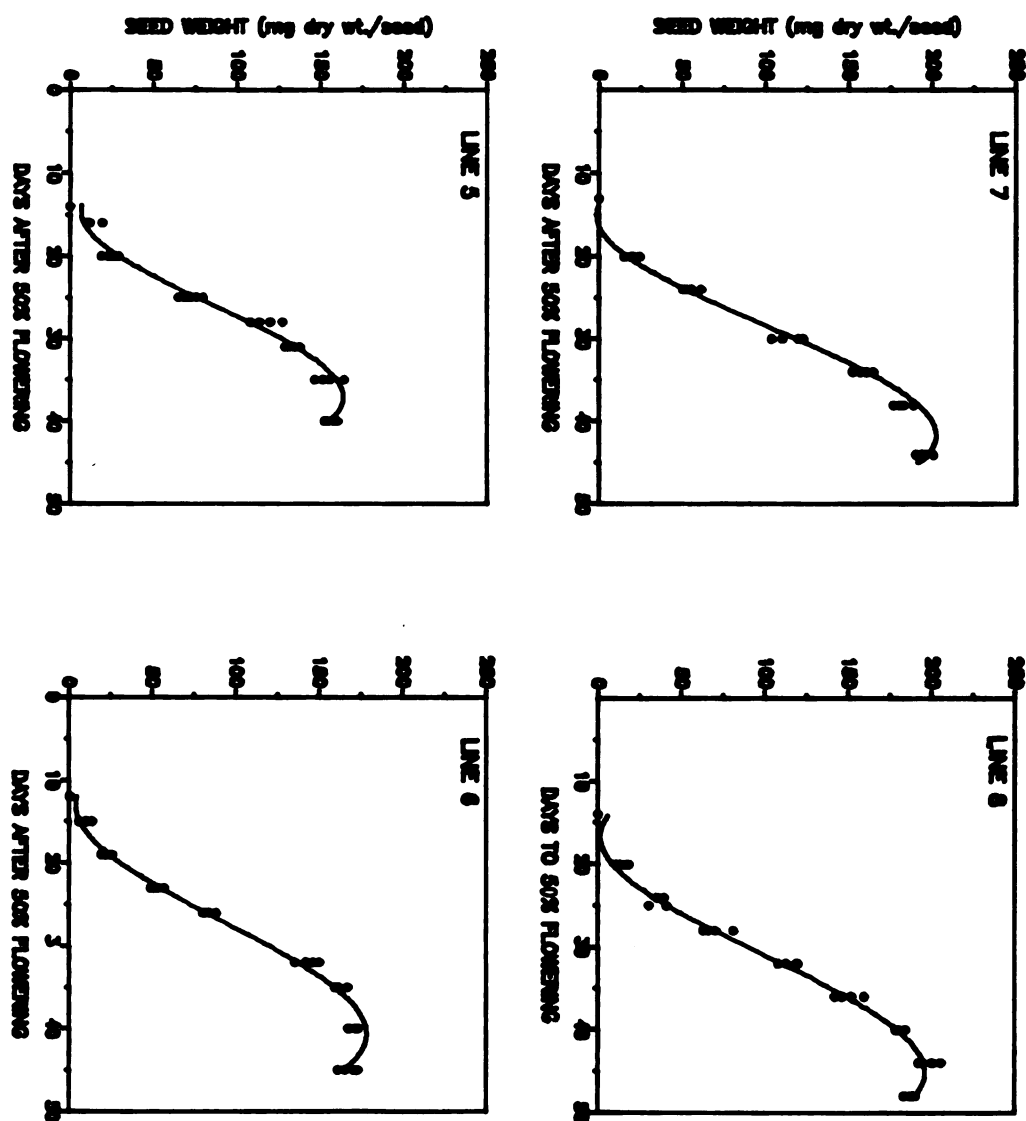


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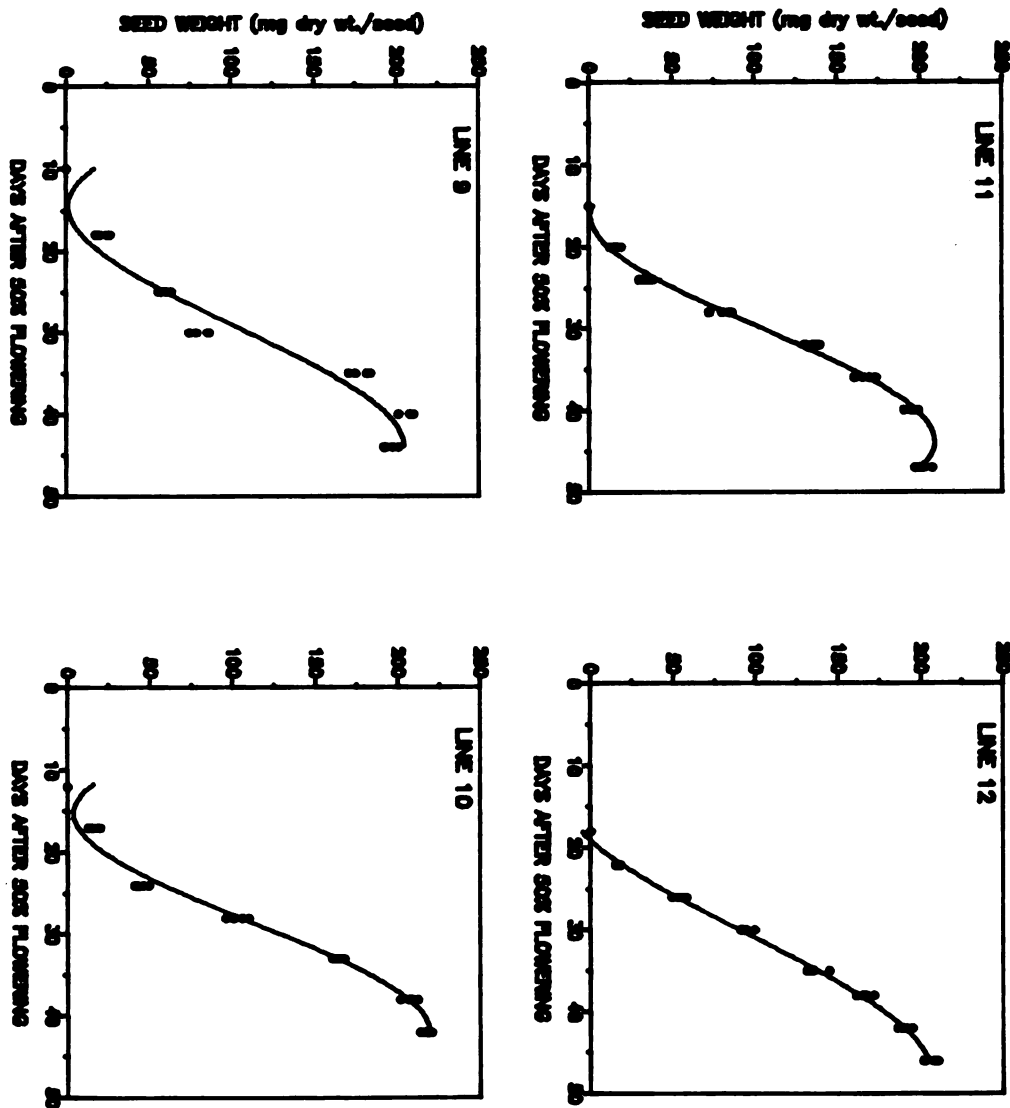


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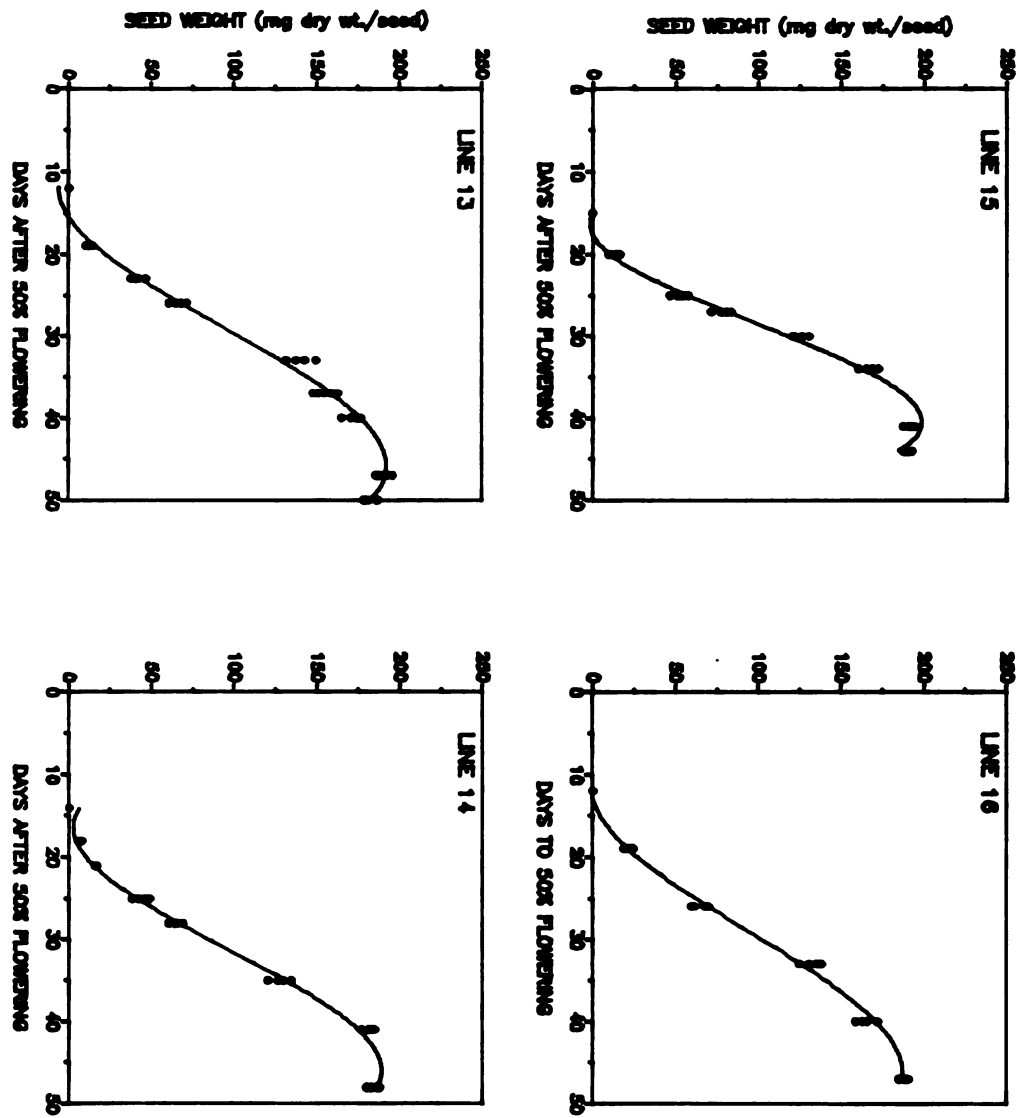


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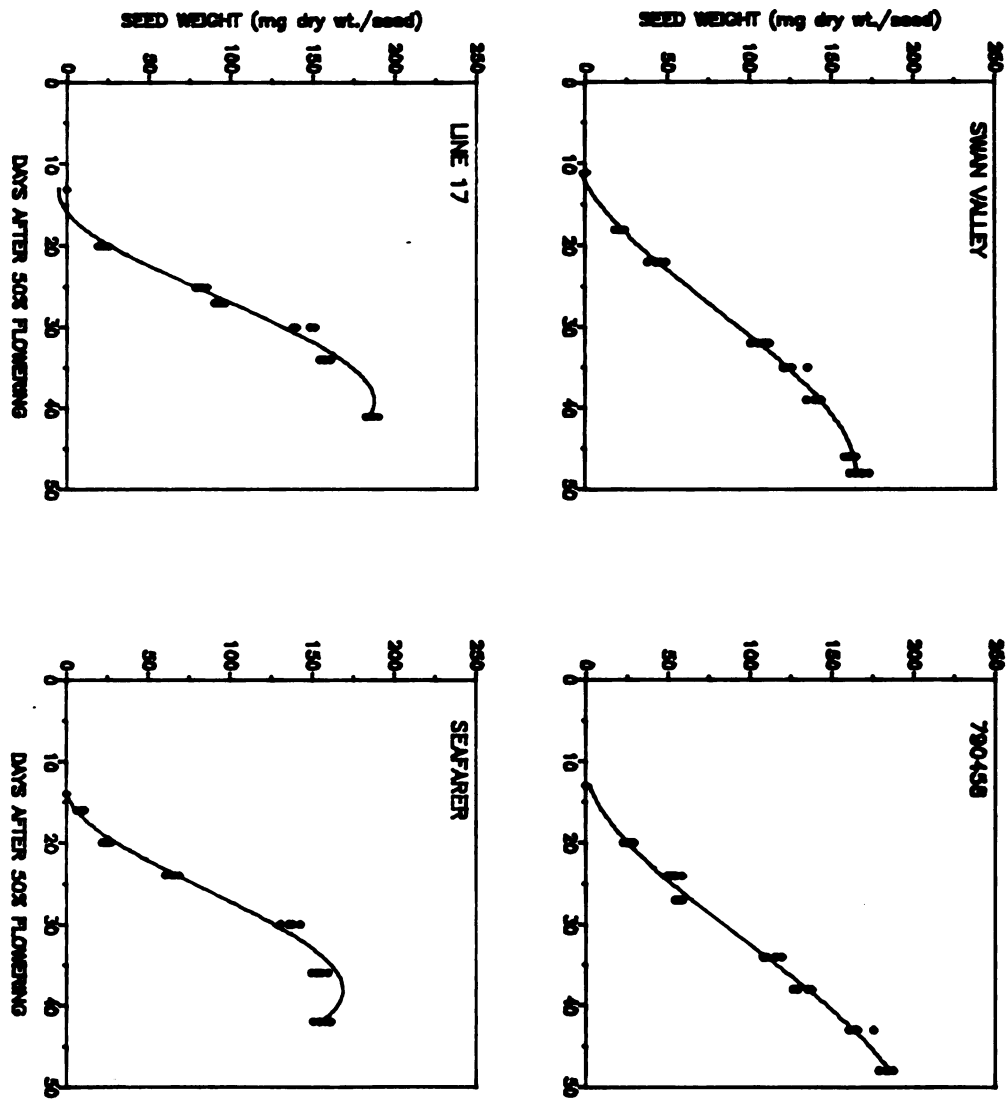


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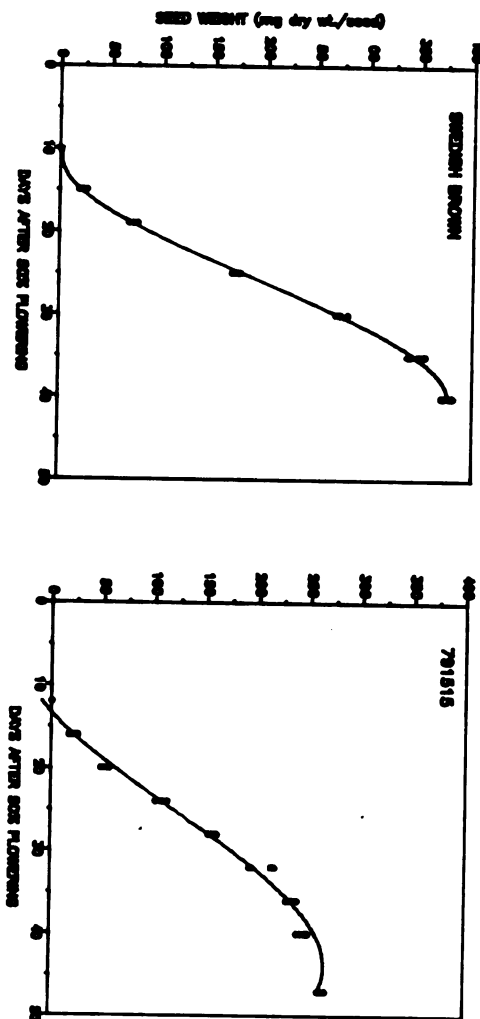


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