CHARACTERISATION OF THE IDEAL BEAN (*Phaseolus vulgaris* L.) GENOTYPE FOR INTERCROPPING

BY

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DECLARATION BY THE CANDIDATE

This thesis is my original work and has not been presented for a degree in any other University.

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DECLARATION BY THE UNIVERSITY SUPERVISORS

This thesis bas been submitted for examination with our approval as University Supervisors.

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FOR THOSE WHO WITHOUT PREJUDICE, ATTEMPT TO HELP THE TROPICAL SUBSISTENCE FARMER IMPROVE HIS ON-FARM PRODUCTIVITY.

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ABSTRACT

Some 73 hybrid populations of beans (*Phaseolus vulgaris* L.) were raised at Thika.

Commencing at F_2, F_3 or BC1, the seed from each population was divided into two portions. In subsequent segregating generations, each portion of seed was advanced and selection repeatedly done in either monoculture beans or beans intercropped with maize at two locations in Kenya.

In order to characterise the ideal bean genotype for intercropping, studies were conducted on the resultant bean genotype groups having selection histories either in monoculture or under intercropping with maize. The performances of genotype groups were compared with respect to yield, yield components and developmental plant characteristics. Genotype by cropping system interactions for these characters and yield correlations between monoculture and intercropped beans were addressed.

When intercropped with maize, bean genotypes selected under intercropping gave higher grain yield than those selected in monoculture. Low correlation coefficients between monoculture and beans intercropped with maize were obtained.

The study indicated the early enhancement of the reproductive phase and short maturity duration as adaptive features of the bean to the intercropping environment.

Adaptive architectural characteristics of an ideal intercropping bean genotype include a short plant stature with high amount of branching.

CHAPTER I

INTRODUCTION

Dry bean (*Phaseolus vulgaris* L.) is a New World species of very ancient cultivation in Central and South America (Leakey, 1970). Having reached Europe by the sixteenth century, it was spread to coastal parts of Africa just after the Portuguese. Introduction of beans in Kenya most likely took place early during the seventeenth century (Njugunah *et. al*., 1979). It is estimated that beans have been grown in East Africa for the last three centuries. Existing records however date back to only late nineteenth century (Mukunya and Keya, 1975). In Kenya, beans have since assumed the status of the most important pulse and second only to maize in importance as a food crop (Thairu, 1979).

In the tropics, beans are produced in different cropping systems (Voysest, 1980). In Kenya, beans are grown either in pure stands or intercropped with maize. Intercropped maize and beans is by far the predominant of the two systems (Schonherr and Mbugua, 1976) and is considered the traditional production system. Intercropping refers to the inter-planting of a number of different crops on the same piece of land at the same time.

For a considerable length of time, agricultural research scientists generally tended to neglect the complicated intercropping systems. Research efforts were concentrated on one crop at a time, an approach inherited from the temperate regions. In the meantime, intercropping was being variously labelled as primitive, uneconomic and unscientific (Monyo et. al., 1976). Notwithstanding the grim picture painted by agricultural extentionists, the peasant farmer persistently practised mixed cropping for his subsistence and sustenance (van Rheenen et. al., 1980). This persistent clinging by farmers to the mixed cropping system had by mid 1960's provoked research work to try and understand this complex system. Most of the reported work so far concerns the agronomy of the crop associations and very limited literature presenting empirical data on special characteristics of genotypes for intercropping exists.

The need for separate genotypes for intercropping has been advocated (Finlay, 1976; Hamblin, et al., 1976). These recommendations have been made mainly on the basis of the known contrasting environmental differences between monoculture and an intercrop situation other than on factual data.

Landraces of crop species used in traditional mixed cropping systems have been selected by the farmer in his specific microclimate and system. Plant breeders on the other hand have been selecting and evaluating genotypes in monoculture. Superior genotypes from such breeding programmes have been assumed to perform as well in mixed cropping. Conscious selection of genotypes specifically adapted to complex cropping systems has received low priority in plant breeding programs. Dry bean has been no exception.

The need to verify the presupposition that superior genotypes of beans selected in monoculture will also be optimum in associated cropping system is of paramount importance. Of equal importance, is to empirically show that specific bean genotypes are required for specific cropping systems if the former is not true.

The author of this thesis compared groups of bean genotypes having different selection histories, in an attempt to identify any special plant features of the intercropping genotype.

CHAPTER II

L I T E R A T U R E   R E V I E W

Intercropping, or associated cropping, is a form of multiple cropping that involves some degree of temporal overlap in the life cycles of the component crops and has been traditionally associated with low-input small farm operation (Clark and Shibles, 1979). Although the low productivity of intercropped systems has often been cited (Fisher, 1977 b; Jennings and Cock, 1977), Boserup (1965) states that agricultural development has been marked by an intensification of cropping of which intercropping could be one aspect in the continuum of crop intensification. Applying the commonly used land-based productivity index, land equivalent ratio (LER), Willey and Osiru (1972) and Osiru and Willey (1972) working under high levels of crop management have reported higher productivity of intercropping than either of the mono-culture of the component crops. Willey (1979 a) attributed the observed higher productivity to the possibility that optimum population pressure in a mixture may be higher than in mono-culture.

The intercropping of maize (Zea mays L.) and field beans (Phaseolus sp) seems to have been practised for a long time. American Indians used to raise beans with corn for centuries may be thousands of years before the birth of Christ (Mian, 1977). Santa-Cecilia and Vieira (1978) reported that 70% of the bean (Phaseolus vulgaris L.) crop in Brazil is produced in associated systems, primarily with maize. Francis et. al. (1975) and Pinchinat (1976) put the figure at 90%. Beans reached Africa about three hundred years ago and Schonherr and Mbugua (1976), indicate the intercropping of beans with maize dominate bean production in Kenya. The majority of bean production in other African countries is no less dominated by intercropping (Osiru, 1980). For example, 75-90% of bean production in Uganda is under intercropping. Adams (1973) contends that, having been under such system of production for such a length of time, no doubt that there has occurred both natural and intentional selection in both maize and beans for traits tending towards greater compatibility of the two species.

It is likely that the most successful compatible types of maize and beans represent co-adapted systems of either of the two species.

With the advent of agricultural technologies of the temperate regions to the tropics, the complexities of this traditional cropping system were largely ignored (Janzen, 1973; Danlberg, 1979). Research has been carried out on sole crops and assumed fitting to complex crop mixtures. Though so lightly taken, the traditional cropping system no doubt had seen many centuries of gradual development and rightfully needed understanding through research work. About mid-sixties of this century, work on mixed cropping research is said to have started (van Rheenen et. al., 1981). Most reports, however, so far as maize - bean intercrops are concerned,dwell on the agronomy of the association. Huxley and Maingu (1978) noted that although the social advantage of intercropping are generally accepted, agronomic issues still were the subject of some controversy. Willey (1979 a) observed that, until recently intercropping was considered a vestigial system which would inevitably be replaced when more modern and productive methods were made available.

Security or risk-minimisation is generally regarded as a goal served by the use of intercropping (Andrews and Kassam, 1976; Crookston, 1976). Hardwood and Price (1976) contended that the yield stabilizing effect of compensatory growth by one component in an intercrop in response to a growth reduction in another, could only occur if the potential for vegetative growth still existed at that time in the undamaged crop. On this basis, the authors expressed doubt on the concept of crop insurance or yield stability from intercropping. Working with climbing beans, Francis and Sanders (1978) have demonstrated the superiority of profits accruing to the association, to that of either maize or bean in monoculture. Hall (1974 a) refers to a situation where components of a mixture exert resource demands at different times as noncompetitive. Complementary resource use or annidation were terms coined to describe the same relationship by Trenbath (1976). Such relationship can give higher total yields than each component grown singly on a unit of land.

Intercropping has been seen to possess the potential to absorb, retain and profitably employ more labour due to its labour intensive nature thereby reducing unemployment and urban migration (Dickinson, 1972; Cleave, 1974; Turner, 1976).

Hirst as reported by Leakey (1970), working in Uganda takes the credit for the earliest effort in improving beans in East Africa. However, the same author contends that any effort at organized application of conventional breeding techniques to bean improvement was initiated in 1959 by World Health Organization (W.H.O.) of the United Nations Food and Nutrition Conference at Kawanda Research Station, Uganda. Since then, bean improvement activities have started in other E. African countries, Kenya included. As is normal with most crop improvement programmes, the first tasks were to collect together land races, evaluate them, select and recommend superior landraces genotypes to farmers and then hybridization procedures followed. In order to understand the nature and magnitude of the problems that bean breeders need to solve and which the work being reported was addressed to, it is worthwhile to mention the characteristics of the land races so collected and the method by which they were handled.

The local land races can be separated into their component pure lines by planting progeny rows from single plants. Differences in growth habit, seed coat colour, disease resistance and yield potential are readily observed in the progeny rows emanating from a single land race. Leakey (1970) records that the differences are so pronounced that it is even difficult to understand why some have survived as they are so obviously inferior to others. He postulates, and understandably so, that the land races must have some advantages over pure lines and at least under traditional husbandry.

Allard and Bradshaw (1964) suggested that in mono-culture crops, stability (performance of a genotype with respect to changing environmental factors over time within a given location) is dependent on genotypic adaptation expressed at individual plant level while in mixtures or heterogenous populations e.g. multilines, individual plant adaptation can be supplemented by populational buffering reflected in the different ranges of adaptation of the component genotypes.

Mixed cropping of beans with a cereal is a primary characteristic of the traditional bean production system. However, it is observed that after collection, the material was handled and selected under mono-culture as opposed to their main source i.e. mixed crop. Superior genotypes selected and evaluated in monoculture were assumed to be optimum for mixed cropping also. This was so, despite the fact that farmers refused to adapt pure cropping.

With more research work on intercropping systems, significant cultivar by cropping system interactions have been interpretted to indicate a re-examination of the earlier assumption with empirical and conclusive data. Semu and Jana (1975) working with 12 soybean varieties grown under monoculture and intercropped with maize failed to detect significant cultivar by cropping system interaction. From this work they submitted that, where the interaction is minor or nonexistent, the question of cultivar specificity becomes unimportant. Finlay (1976) reported highly significant cultivar by cropping system interaction when 12 soybean varieties were evaluated over four cropping system i.e. monoculture and in association with either maize, millet and sorghum. Makena and Doto (1980) contend that although the two studies may appear to have conflicting results, in both studies the cultivar ranking order varied from one cropping system to another. Their contention is that a limited number of test cropping systems may conceal the presence of cultivar by cropping system interaction in an analysis of variance. Makena and Doto (1980) studied soybean developmental characteristics i.e. days to 50% flowering, days to 50% maturity; height to first pod and also yield components i.e. productive pods per plant; 200 seed weight and grain yield under four cropping systems. They reported significant cultivar by cropping system interaction for all characters examined. They stated that this observation was evidence for having different varieties being recommended for different cropping systems. They also submitted that although information on the magnitude and nature of cultivar by cropping system interaction is scanty, it is vital in the formulation of breeding programs. There has been some doubt that the best varieties for mono-cropping are also the best for intercropping (Finlay, 1974 a). It has been suggested by Francis, et. al.,

(1975) that cultivars to be recommended for intercropping must be screened separately from those for mono-cropping. Finlay (1976 a) and Francis et al. (1976) based their recommendation of developing specific varieties of crops for intercropping on the basis of the observed cultivar by cropping system interaction. Gomez and Zandstra (1976), agreed with these contentions and started selecting among their best cultivars of soybeans and mungbeans those that would do well under shade. Shading effects produced differential reduction of yield in the test cultivars.

The authors also reported significant cultivar by planting condition interaction. These observations further convinced them that the best varieties for monocrop culture may not be the best for intercropping. Finlay (1975) has stated that cultivars selected and tested in normal monoculture breeding programs may not perform well in mixtures. Working with genotypes of sesame and sunflower grown in four cropping systems (monoculture and intercropped with maize, bulrush millet and sorghum), May and Misangu (1980) were of the contention that genotypes developed under monoculture do not give significant differential response in different environments. The genotypes they tested were either cultivars or advanced selections from mono-culture plant breeding programs. These workers further state that their finding need not exclude the possibility that such genotypes exist. Dart and Krantz (1976) observed that where the intercrop shaded the pigeon pea, some pigeon pea cultivars developed differently in intercropping situations. In their opinion, this observation suggested that cultivars should be screened in the appropriate intercrop situations if they are to be used as an intercrop.

Francis et. al.(1978 c) reviewed bean work which compared cultural systems in addressing the genotype by environment interaction. The data are conflicting, often reflecting positive but inconsistent correlations between cultivar yield in mixture and in mono-culture. In three seasons at C.I.A.T. (Centro Internacional de Agricultural Tropical) with bush beans, significant positive correlations were observed (r = 0.91**, 0.88** and 0.51* with 9, 19, and 20 cultivars respectively). As reported by Francis et. al. (1978 b), climbing bean yield correlation between mono-culture and maize associated systems were positive and significant in two out of three seasons (r = 0.90**, 0.31** and 0.41 with 9, 20 and 20 cultivars respectively).

Muigai and van Rheenen (1982) reported significant cultivar by cropping system interactions for bean-maize intercrops. They contended that the phenomenon pointed to the need for specific genotypes for different cropping systems. The same authors also reported a 0.26 average correlation coefficient of mono-culture yield and beans grown in association with maize for a number of experiments. Monteiro et. al. (1981) had reported correlation coefficients of 0.71 and 0.29 for two trials at two different sites respectively. C.I.A.T. (Anonymous, 1978) reported an average correlation coefficient value of 0.8 over a series of different experiments. Though the reported correlation coefficients are usually high and statistically significant, Muigai and van Rheenen (1982) cautioned that high positive and significant correlations between mono-culture and intercrop yields need not render screening for mixed cropping superflous.

Osiru (1980) worked with three bean cultivars each representing early, medium or late maturity and reported that bean yields were affected in a similar manner by intercropping with maize. He however reported that early maturing beans maintained better yields in mixture than the medium or late cultivars. Important characteristics that may be useful for identifying suitable genotypes for intercropping were early maturity, fairly erect and determinate in growth habit, the author contended. His argument was that a bean type that matures early, maximises resources early, while the growth type proposed would ensure maximum competition with maize during the early part of the season.

Hamblin et. al. (1976) records that reported work on the intercropping of maize and beans have used genotypes of beans developed under monoculture. In view of this then it would seem that research workers initially "put the cart before the horse". It could well be that, the landrace genotype found in a mixed crop is a product of simultaneous natural selection in both the cereal and the legume so that they nick very well (Finlay, 1976). In modern plant breeding however, it is important to differentiate between the major and minor components of the intercrop. Ckigbo (1976) noted that in the humid tropics, most of the herbaceous grain legumes are grown as minor crops usually as intercrops with major staples. This relationship between maize and beans may be reversed in the marginal areas during adverse seasons when, the bean, requiring a shorter period to mature, assumes the status of a major crop (Fisher, et. al., 1976). 1976). In the Kenyan situation, the growing of hybrid maize has been so well accepted and adapted by farmers that, the breeder is left to breed bean genotypes that will nick well with recommended maize. To do this effectively, the critical question is: What did the bean genotypes become as a result of co-adaptation with maize and can this be improved upon? (Adams, 1973).

Interspecific studies are indicated in order to understand this basic intercropping phenomenon. Little work in this field has been done (Thompson, et. al., 1976). Available literature only relates to crop cultivars developed under mono-culture and tested under intercropping conditions. However, findings from studies done on other interplanted plant species could also be extrapolated in an attempt to understand the situation existing in a legume-cereal intercrop such as maize and beans.

A maize-bean mixture is characterized by stiffer competition for environmental factors than that existing in mono-culture system, maize being the major competitor (Hamblin and Rowell, 1975). The area then of greatest relevance is considered to be competition studies and their findings in inter-genotypic (characterising segregating populations) as well as inter-specific mixtures, the character of which is a maize-bean intercrop.

The work reported by Gibson et. al. (1963) showed that performance of white clover (Trifolium sp) grown in spaced mono-culture was a poor predictor of performance in a sod. Thus it was concluded that superiority of a clone in pure stand may not show where growing conditions are radically different. It would seem that the most critical measure of the value of a forage legume is realised by studying it in association with the crop with which it will be used.

Competitive ability is critical in successful clover clones (Dijkstra and De Vos, 1972). Dijkstra and her colleagues selected white clover under mono-culture and at the same time in association with grass. They concluded that when sufficient seed is available, it becomes possible and desirable for a breeder to include a mixed clover-grass cultivation in his selection scheme.

When studying plant interactions, indices of competitive ability have become a central feature (Willey, 1979 a). Hamblin and Rowell (1975) had concern with the loss of weakly competitive but potentially high yielding genotypes in segregating populations. Competitive ability was defined simply as the yield in genotype mixture less that in monoculture. The regression coefficient of the relationship between competitive ability and pure culture yield was used as an index denoting the propensity for genotype loss. Where the index was less than -1, the probability of loss was high and pedigree selection was indicated, whereas if the index was greater than -1, bulk breeding was safe enough. Selection efforts for yield primarily were said to be of no consequence when the regression coefficient was equal to -1 regardless of the selection technique adapted.

The plant height and leaf length of F_3 and F_5 barley lines were positively correlated (Hamblin and Donald, 1974), although the yield performance of F_3 single plant selections was shown to be unrelated to the yield potential expressed in F_5 barley lines. Furthermore, plant height and leaf length were positively correlated with yield at the F_3 generation while the same parameters were negatively correlated at F_5. Thus it was observed that the competitive characters which enabled the F_3 plants to surpass their weaker neighbours were a liability to yield when all of their neighbours were strong in the F_5 generation. Remison and Snaydon (1978) demonstrated that rooting aggresivity in a mixture of genotypes was unrelated to yield performance in mono-culture.

The negative relationship between competitiveness and yield is of fundamental interest to both geneticists and plant breeders (Hamblin, 1975). Donald (1968) proposed that weakly competitive genotypes are the most suitable for high yielding crop communities. These however are prone to rapid elimination from segregating populations. Jennings and Aquino (1968) proposed hand-roguing of all tall, leafy and vegetatively vigorous rice (*Oryza sativa* L.) plants at several times during the growth cycle to minimise interference and to enhance both the survival of weakly competitive individuals and subsequent genetic advance in rice breeding. Characters conferring competitive advantage in early growth of rice could not be statistically related to competitiveness when measured in later growth stages and on this basis Jennings and Aquino (1968) advocated an early identification of characters most associated with competitive ability.

Work with barley has shown competitive ability of a variety grown in mixture with others to be in good agreement with yield in single variety culture (Blijenburg and Sneep, 1975). On theoretical grounds, it has been suggested that low competitive ability of a genotype in pure culture is a pre-requisite for maximum seed yield (Donald, 1968). The breeding of crop ideotypes would be based on this contention. Donald (1968) stated that competition between genotypes is influenced by the environment. By implication, it would appear that genotype selection in mono-culture might result in genotypes of different performance potential from genotypes selected in association.

Single seed descent (SSD) method of breeding has been used in studying intergenotypic competition (Roy, 1976). Some wheat genotypes showed increased yield per plant and per ear in intergenotypic competition as compared to pure culture. Seed weight was also affected by the competition. If environment can give such an effect to yield and yield components, then by selecting for the bean component of ecological combining ability as well as for high yield, there could be a chance of picking out favourable interactions.

Trenbath and Harper (1973) as cited by Clark and Shibles (1979) observed a gain of 20% in average seed weight in a species of Avena when it was grown in a mixture of taller species of the same genus. This advantage was attributed to increased light interception through a 10 cm stem extension as a response to shading.

Meadley and Milbourn (1971) observed that when shading was applied to vining peas (Pisum sativum L.) up until flowering time, floral abortion was minimised and yields approached those of peas grown without shading. When shading was applied only from flowering onward, floral abortion was enhanced and yields were reduced to about the level of peas shaded throughout growth. Thus in the two cases, a new balance was attained between reproductive demands and the vegetative capacity as a consequence to a change in the environment which can be viewed as a change in competition for the photosynthetic energy resource. The timing of interplant competition can determine the partitioning of plant resources among vegetative and generative functions (Murneek, 1926).

Clark and Shibles (1979) reported work with two groups of bean cultivars each representing low or high yield potential. When measured at early pod filling stage, pod number per plant was higher in maize-bean association and with significant differences expressed in the high yield group. At mid-pod filling however, pod numbers were significantly lower in most cultivars and in both the high and low yield groups. It was inferred that the maize effect on bean growth in association, differed only in magnitude from that exerted by neighbouring bean plants in mono-culture. By studying sink; source relationships, they observed that at 47 days, this ratio was highest within the high yielding, associated cultivars and hence suggested that, the early enhancement of reproductive growth may be a useful selection criterion representing an appropriate adaptation in the growth limits imposed by the presence of maize.

It is important to design and implement a selection and testing procedure which takes into account the magnitude of genotype by cropping system interaction (Francis et. al., 1978). These authors tested non-climbing bean genotypes (C.I.A.T. types I, II and III) under mono-culture and in association with maize for three seasons. They obtained significant correlation of bean seed yields for cultivars grown in mono-culture and in association with maize. However, some cultivars did not have as large a yield reduction as others. Seed size as well as plant height were not influenced by cropping system. Maize yields were not differenially affected by bean cultivars. Genotype by season interaction in each crop could complicate the procedure of selection. On the basis of more yield, low coefficient of variation in mono-culture, higher efficiency in selection and the resultant faster genetic advance, they advocated early generation testing in mono-culture. When testing genotypes, the milder competition of a mono-culture is desirable as cultivar differences are more easily measured because error means tend to be larger (Finlay, 1976).

Osiru (1980) has stated that selection of genotypes to be grown in intercrops on the basis of sole crop performance seems to offer very little success. This is especially so if the crop in question is dominated in an intercrop and grows essentially in an environment which is modified by the dominant crop e.g. beans in maize-bean intercropping system. This underscores the need to determine whether or not the best bean cultivars selected under sole crop systems are also likely to be the best cultivars when grown in association with maize. Osiru and Willey (1976) tried to characterize desirable plant type for intercropping as the one that minimises intercrop competition and maximises complimentary effects. Within the non-climbing growth habits (C.I.A.T. types I, II and III), it was observed that growth habit had a neutral role in the determination of the suitability of a bean genotype for association cropping with maize (Anonymous, 1976). In an intercrop, higher yield reductions was observed and attributed to a longer growing cycle of the climbing beans (Francis et. al., 1978; Edje and Laing, 1980).

May and Misangu (1980) working at Morogoro, Tanzania with cereals and legumes have reported non-significant genotype by cropping system interaction as well as variable correlations of grain yields of sole crop legumes and intercrops with cereals. These findings, according to the authors downplay the recommendations for separate genotypes for intercropping on the basis of interspecific competition being quite different from intravarietal competition. However, although they didn't get significant differential response under different environments, they still express the need for specific genotypes for intercrop systems.

Error means were said to be larger in mono-culture (Finlay, 1976). However, Clark and Shibles (1979) observed that this index of random variation around the mean when calculated for each cropping system (standard error of the mean per system), the means were defined with nearly equal precision in mono-culture (0.086), and in association (0.096), suggesting that selection can be done under any system with equal efficiency. Clark and Shibles (1979), further observed that, the range between highest and lowest yielding beans in absolute terms was larger in mono-culture, however when they expressed this range as a percentage of the highest yielding cultivar in each system, the range among the associated beans was larger than that among the monoculture beans. In this latter context then, the authors contended that relatively more latitude for selection and bean improvement existed in the associated than in mono-culture cropping system.

Over and above the plant interactions based on resource use, the species diversity of an inter-crop appears to affect plant-pest relations as well (Farnworth and Golley, 1974). It is generally believed that intercropping is advantageous with respect to disease and insect pest control (Mukiibi, 1976; Mukiibi, 1980; Shoyinka, 1976; Keswani and Mreta, 1980). Observations in Kenya showed reduced incidence of halo blight, bean common mosaic virus, bollworm and to a lesser extent angular leafspot in beans grown in association with maize as compared to beans grown in mono-culture (van Rheenen _et_. _al_., 1981). The same authors however reported higher incidence of white mould and the black beetle _systates_ when beans were grown in association with maize. When bean cultivars are developed under intercropping environment, the disease and insect pest pressure are reduced by this apparent pest control or tolerance properties of the intercrop complex. Under such circumstances it is not unlikely that plant selections in mono-culture and in an intercrop might result in genotypes of differing potentialities.

Work with bean rust (Uromyces appendiculatus (Pers.) Ung.) has shown that induced resistance is conferred by maize rust (a mixture of Puccinia sorghi and Puccinia polysora). This phenomenon could retard the development of rust in a legume - cereal intercrop (Allen, 1976). Thus depending on the magnitude of such effects of the intercrop as compared to the mono-culture circumstances, it has been observed that the relative importance of some traits may certainly change (Finlay, 1976 b).

When Makena and Doto (1980) found significant cultivar by cropping system interactions for developmental characteristics of soybean i.e. days to 50% flowering, days to maturity, height at first pod and for yield and its components i.e. productive pods per plant and seed weight, they contended that the importance of such interactions depend on the magnitude of non-additive proportion of the interactions. Despite the resource constraints that such a policy could pose, it has been stated that, there could be a case for developing new soybean genotypes under the relevant cropping system.

It is evident that the occurrence and

magnitude of cultivar by cropping system interactions has been investigated in some intercrops. Whenever such interaction has been found, it has been used to speculate on the need for developing specific crop cultivars for specific cropping systems. These investigations have used genotypes developed under mono-culture conditions. It is noted that while genotype selection for mixed cropping includes the basic methodological problems of monocrop breeding, an additional complication is the need to select for compatibility in association with other genotypes and most often species of other genera. Moreover what the relationship between competitive ability and yield at intergenotypic level becomes at the combined intergenotypic and interspecific or intergeneric competition levels, remains largely un-addressed.

CHAPTER III

MATERIALS AND METHODS

Materials

Some 73 hybrid populations were made at the National Horticultural Research Station, Thika. The hybridization involved parents that were adapted popular local bean types and anthracnose or Bean Common Mosaic Virus resistant types. The populations were handled as family lines through either F_1, F_2 or backcross and self stages in preparation for pedigree selection breeding at three climatically different sites.

The sites represented the marginal and medium rainfall ecological zones, characterized by the National Dryland Farming Research Station - Machakos and Eastern Agricultural Research Station - Embu experimental sites respectively.

The material from each hybrid population (Table 1), was randomly divided into three portions, one portion for each site. At the selection site, seed from each population was again randomly divided into two halves. Each of the halves was to be grown and selection carried out either in beans monoculture or beans grown in association with maize. The recommended maize plant densities and cultivars were to be grown at each experimental site.

The first selection cycle was carried out during the long rains season of 1977. The aim was to perform two selection cycles per year i.e. during both the long and short rains cropping seasons. Occassionally however, two selection cycles each year could not be achieved at different sites due to operational difficulties.

During the first selection cycle, the families were grown in selection blocks with each family appearing in a block of monoculture beans and in the association cropping block. In subsequent generations, selected progenies or families were grown under the cropping system where they had been selected. Systematic, non-statistical design was used during the selection cycles.

Starting from the second generation of selection, disease spreader rows of unclean and disease susceptible seed was grown between rows of selection material. From the third and subsequent selection

TABLE 1: BACKGROUND OF THE SEGRAGATING POPULATIONS AT THE PLANTING OF THE FIRST SELECTION CYCLE.

Population	Background constitution*
1.	F_2 (GLP-1 x GLP-16)
2.	F_2 (GLP-2 x GLP-16)
3.	F_2 (GLP-12 x GLP-16)
4.	F_2 (GLP-13 x GLP-16)
5.	F_2 (GLP-17 x GLP-16)
6.	F_2 (GLP-20 x GLP-16)
7.	F_2 (GLP-22 x GLP-16)
8.	F_2 (GLP-431 x GLP-16)
9.	F_2 (GLP-343 x GLP-16)
10.	F_2 (GLP-344 x GLP-16)
11.	F_2 (GLP-12 x ((GLP-20 x GLP-1) x GLP-12))-S
12.	(GLP-12 x (GLP-12 x (GLP-20 x GLP-1)))-S
13.	(GLP-12 x(GLP-1 x GLP-20) x GLP-12)-S
14.	(GLP-12 x (GLP-12 x (GLP-12 x GLP-18)))-S
15.	((GLP-20 x GLP-10) x GLP-12)-S
16.	((GLP-20 x GLP-1) x GLP-12)-S^2
17.	(GLP-12 x (GLP-20 x GLP-1)) - S^2
18.	((GLP-1 x GLP-20) x GLP-12) - S^2
19.	((GLP-18 x GLP-1) x GLP-12) - S^2
20.	(GLP-12 x(GLP-18 x GLP-1)) - S^2
21.	(GLP-12 x (GLP-1 x GLP-18)) - S^2
22.	(GLP-20 x (GLP-1 x GLP-12)) - S^2
23.	(GLP-12 x (GLP-20 x GLP-1)) - S^2
24.	((GLP-1 x GLP-20) x GLP-12) - S^2
25.	(GLP-12 x (GLP-18 x GLP-1) - S^2
26.	(GLP-12 x (GLP-1 x GLP-18)) - S^2
27.	((GLP-11 x (GLP-20 x GLP-11)) x GLP-10)-S
28.	(GLP-11 x (GLP-18 x GLP-10)) - S
29.	(GLP-11 x (GLP-18 x GLP-11)) - S
30.	(GLP-11 x (GLP-11 x GLP-18)) - S
31.	((GLP-20 x GLP-11) x GLP-10) - S^2

TABLE 1 (CONTD..)

32.	((GLP-20 x GLP-11) x GLP-10) - S^2
33.	(GLP-18 x GLP-10) -S^2
34.	(GLP-18 x GLP-11) -S^2
35.	(GLP-11 x GLP-18) -S^2
36.	(GLP-11 x (GLP-18 x GLP-10)) - S^2 (a)
37.	(GLP-11 x (GLP-18 x GLP-10)) - S^2 (b)
38.	(GLP-11 x (GLP-18 x GLP-10)) - S^2 (c)
39.	(GLP-11 x (GLP-18 x GLP-10)) - S^2 (d)
40.	(GLP-11 x (GLP-18 x GLP-11)) - S^2 (a)
41.	(GLP-11 x (GLP-18 GLP-11)) - S^2 (b)
42.	(GLP-11 x (GLP-18 GLP-11)) - S^2 (c)
43.	(GLP-11 x (GLP-18 GLP-11)) - S^2 (d)
44.	(GLP-11 x (GLP-11 x GLP-18)) - S^2 (a)
45.	(GLP-11 x (GLP-11 GLP-18)) - S^2 (b)
46.	(GLP-11 x (GLP-11 GLP-18)) - S^2 (c)
47.	(GLP-11 x (GLP-11 GLP-18)) - S^2 (d)
48.	F_2 (GLP-4 x GLP-16) + F_2 (GLP-16 x GLP-4)
49.	F_2 (GLP-16 x GLP-5)
50.	F_2 (GLP-21 x GLP-16) + F_2 (GLP-16 x GLP-21
51.	F_2 (GLP-26 x GLP-16)
52.	F_2 (GLP-11 x GLP-16)
53.	F_2 (GLP-11 x GLP-3)
54.	F_2 (GLP-4 x GLP-8)
55.	F_2 (GLP-22 x GLP-8)
56.	F_2 (GLP-3 x GLP-8)
57.	((GLP-3 x GLP-16) x GLP-3) - S (a)
58.	((GLP-3 x GLP-16) x GLP-3) - S (b)
59.	((GLP-4 x GLP-16) x GLP-4) - S
60.	((GLP-12 x GLP-16) x GLP-12) - S
61.	((GLP-21 x GLP-16) x GLP-21) - S
62.	((GLP-26 x GLP-16) x GLP-26 - S
63.	F_3 (GLP-3 x GLP-16) (a)
64.	F_3 (GLP-3 x GLP-16) (b)

TABLE 1 (CONTD..)

65.	F_3 (GLP-4 x GLP-16)	
66.	F_3 (GLP-12 x GLP-16)	
67.	F_3 (GLP-11 x GLP-16)	(a)
68.	F_3 (GLP-11 x GLP-16)	(b)
69.	F_3 (GLP-21 x GLP-16)	
70.	F_3 (GLP-26 x GLP-16)	
71.	F_3 (GLP-1 x GLP-16)	
72.	F_3 (GLP-2 x GLP-16)	
73.	F_3 (GLP-12 x GLP-16)	

*S: = Open pollinated

a-d: = Different seed types.

cycles, a control plot of the recommended cultivar for each selection site was also planted after every five selected progeny rows. This arrangement was intended to enable preliminary performance comparisons.

As seed quantities increased over selection cycles, and the selected numbers decreased, it became possible and necessary to replicate each selection. Each selected entry was replicated twice during the fourth, and three times during each of the fifth and sixth selection cycles. The replication was under both monoculture and association cropping systems.

Single plant or progeny row selection was carried out on two occasions during each growing season. The first assessment and selection was done at podding stage and the second at about physiological maturity.

At podding stage, when plants are still green, criteria for selection were general plant vigour, freedom from halo-blight, bean common mosaic, common-blight, angular leaf-spot, scab and anthracnose symptoms on the foliage. Plant architecture and pod-ground clearance were also used in judging the superiority of the plants.

When at about physiological maturity, the apparent pod yield, clean pods i.e. freedom from halo-blight, scab, common-blight, angular leafspot and anthracnose were important criteria in judging the plants. Earliness to maturity was also emphasized at Machakos selection site. A selection intensity of approximately 10 per cent was envisaged. The selected fraction was estimated via consideration of the size of land planted with the material, plant density used and subsequently arriving at the number of plants to be selected per unit length of a row of bean plants.

The first selection cycle at Machakos and Embu, was of single plants. Families were then harvested individually and again depending on seed size, seed testa colour and yield per plant, some whole families were selected. The selected families were those with large seed size, testa colours within acceptable ranges and a relatively high seed yield per plant. At Machakos, this selection cycle resulted in 3521 selections in total. Of these, 2026 were selected under monoculture and 1495 under association cropping system. At Embu, 2508 selections were made, 1593 and 915 of which were made under monoculture and association cropping respectively.

At the second selection cycle, one progeny row of ten plants per single plant selected during the first selection cycle was grown. Additionally, a block of $16m^2$ per selected family was also grown. Selections were grown in the cropping system under which they had previously been selected. Disease spreader rows of a mixture of unclean, susceptible seeds were grown between selection bean rows. The spreader rows were intended to increase the pathogen pressure on the selections. Single plant selections was carried out in all the material. Again, a selection intensity of 10% was aimed at. This resulted in 584 single plants selected at Machakos, of which 316 and 268 were made under monoculture and association cropping respectively. The same selection generation at Embu resulted in a total of 397 single plants, 193 and 204 of which were selected under monoculture and association cropping respectively.

Selection procedure during the third selection cycle, was operationally similar to that of the second cycle except that progeny rows of 20 plants were grown and a control after every five entries. After harvesting, seed testa colour and as well, ratios of the selection yield to the mean yield of the two control plots grown nearest to it were used as indices of determining the suitability of the selected entry. Selection was on family or progeny rows. Testing for anthracnose resistance was done on seed of the selected families. Lambda race of the pathogen was used to test for resistance conferred by the dominant "Are" gene. The test was done by inoculating seedlings with a spore suspension of the fungus (Colletotrichum lindemuthianum). Homozygous resistant or susceptible as well as progenies that were segregating for the resistance were identified. During subsequent generations of selection, the anthracnose resistance status was among other criteria to be used in judging the plants. Third selection cycle resulted in 232 and 157 selections from monoculture and association cropping respectively at Katumani. At Embu the same cycle resulted in 449 selections from monoculture and 135 from association cropping system.

At Embu, the fourth selection cycle saw family selection but no further selection cycles were carried out at this site. Two replications of each entry were grown during the fourth cycle while the fifth and sixth cycles had each entry replicated three times. Control plots and disease spreader rows were also planted as previously described. Details on how the material was handled through the segregating generations are shown (Table 2).

Methods

General

In total, six experiments were conducted. Three of these were during the short rains 1981/82 cropping season while the other three were during the long rains 1982 season.

During each season, an experiment was carried out at the National Horticultural Research Station - Thika, Eastern Agricultural Research Station - Embu, and National Dryland Farming Research Station - Machakos. Information on the climate and location of the three trial sites are shown (Appendix 1). Except for the Thika site where crops were grown under partial irrigation, the other experiments were essentially rainfed.

In each experiment, sixteen bean populations were evaluated. Eight of these bean treatments emanated from the selection under monoculture beans while the other eight were from the selection under

TABLE 2: DETAILS ON THE HANDLING OF THE SEGREGATING POPULATIONS

Selection Site	Season	Selection Cycle	Generation(s) Grown	Selection Operation
Embu	L/R 1977	First	$F_2/F_3/F_4/B.C.F_1$	Single Plant Selection
Machakos	L/R 1977	First	$F_2/F_3/F_4/B.C.F_1$	Family and Single Plant Selection.
Embu	S/R 1977/78	Not Planted	-	-
Machakos	S/R	Second	$F_3/F_4/F_5/B.C.F._2$	Single Plant Selection
Embu	L/R 1978	Second	$F_3/F_4/F_5/B.C.F_2$	Single Plant Selection
Machakos	L/R 1978	Third	$F_4/F_5/F_6/B.C.F_3$	Family Selection
*Embu	S/R 1978/79	Third	$F_3/F_5/F_6/B.C.F_3$	Family Selection
*Machakos	S/R 1978/79	Fourth	$F_5/F_6/F_7/B.C.F_4$	Single Plant Selection
Embu	L/R 1979	Not Planted	-	-
Machakos	L/R	1979	$F_6/F_7/F_8/B.C.F_5$	Family Selection
Embu	S/R 1979/80	Fourth	$F_5/F_6/F_7/B.C.F_4$	Family Selection
Machakos	S/R 1979/80	Sixth	$F_7/F_8/F_9/B.C.F_6$	Family Selection

*All selections tested for Anthracnose resistance.

NB/During L/R 1980, all selections were planted at Thika and tested for resistance to B.C.M.V. Promising material was bulked during L/R 1981.

association cropping.

All the bean treatments were either of a determinate bush, indeterminate bush or indeter-mine semi-climbing with prostrate branching (CIAT types I, II or III) growth habit. The maize cultivar grown at Embu and Thika was the medium maturing Kitale H511, while the short maturing Katumani Composite 'B' was grown at Machakos.

Experiments of Short Rains 1981/82

The first three experiments carried out one at each of the experimental sites consisted of eight bean genotypes selected in monoculture. Four of these had been selected at Embu while the other four had been selected at Machakos site. The rest eight genotypes had been selected under association cropping. Five of these coming from the programme at Machakos while three were from the selection programme at Embu site. Details pertaining to these genotypes treatments are shown (Table 3).

Experiments of Long Rains 1982.

The second set of three experiments had a slightly different set of genotype treatments. All

TABLE 3: TREATMENTS OF SHORT RAINS 1981/82 SEASON AT ALL THE SITES:

Treatment Code	Source Population	Pedigree* Notation
A	65	KAP - $X.a.b.B.c.B^2$
B	65	KAP - $x.a.b.B.c.B^2$
C	70	KAP - $x.a.b.B.c.B^2$
D	66	KAP - $x.a.b.B.c.B^2$
E	33	MEP - $x.a.b.B^2$
H	48	MEP - $x.a.b.B^2$
I	57	MEP - $x.a.b.B^2$
K	70	MEP - $x.a.b.B^2$
L	65	KAM - $x.a.b.B.c.B^2$
M	66	KAM - $x.a.b.B.c.B^2$
N	70	KAM - $x.a.b.B.c.B^2$
O	48	KAM - $x.B.a.B.b.B^2$
P	70	KAM - $x.b.a.B^4$
R	46	MEM - $x.a.b.B^2$
S	48	MEM - $x.a.b.B^2$
T	49	MEM - $x.a.b.B^2$

*X - Population number
a,b,c - Single plant selection
B - Family selection
KAM, KAP - Selection at Machakos - Pure or Mixed
MEP, MEM - Selection at Embu - Pure or Mixed.

bean genotypes in the Embu and Thika trials had been selected at Embu while those included in the Machakos trial had all been selected at that selection site.

Eight genotypes in each case had been selected under monoculture while the other eight came from association cropping selection programme. Details to the genotypes tested at Embu and Thika (Table 4) and those at Machakos (Table 5) are shown.

Design and Layout of the Experiments

The experimental design used was a split-plot with the cropping systems i.e. monoculture and assocation cropping taking the main plot treatments. Bean genotype treatments were alloted randomly to the sixteen sub-plots in each main plot. This arrangement was replicated three times at each of the three experimental sites.

In monoculture beans, the sub-plot consisted of five bean rows each measuring 3.6m in length with an inter-row spacing of 0.5 m. This gave a gross plot size of 9.0 m^2. An intra-row spacing of 0.1 m was observed. This arrangement gives a plant population of 2.0×10^5 plants per hectare.

TABLE 4: TREATMENTS OF LONG RAINS 1982 SEASON AT EMBU AND THIKA SITES:

Treatment Code	Source Population	Pedigree Notation*
A	34	MEP - x.a.b.B^2
B	12	MEP - x.a.b.B^2
C	41	MEP - x.a.b.B^2
D	33	MEP - x.a.b.B^2
E	57	MEP - x.a.b.B^2
H	47	MEP - x.a.b.B^2
I	65	MEP - x.a.b.B^2
K	70	MEP - x.a.b.B^2
L	3	MEM - x.a.b.B^2
M	19	MEM - x.a.b.B^2
N	33	MEM - x.a.b.B^2
O	46	MEM - x.a.b.B^2
P	49	MEM - x.a.b.B^2
R	48	MEM - x.a.b.B^2
S	59	MEM - x.a.b.B^2
T	59	MEM - x.a.b.B^2

*x - Population number

a,b,c - Single plant selection

B - Family selection

MEP, MEM - Selected at Embu - Pure or Mixed

TABLE 5: TREATMENTS OF LONG RAINS 1982 SEASON AT KATUMANI SITE:

Treatment Code	Source Population	Pedigree* Notation
A	65	KAP - x.a.b.B.C.B^2
B	65	KAP - x.a.b.B.c.B^2
C	65	KAP - x.a.b.B.c.B^2
D	70	KAP - x.a.b.B.c.B^2
E	73	KAP - x.a.b.B.c.B^2
H	51	KAP - x.B.a.B.b.B^2
I	66	KAP - x.B.a.B.b.B^2
K	51	KAP - x.B.a.B.b.B^2
L	65	KAM - x.a.b.B.c.B^2
M	66	KAM - x.a.b.B.c.B^2
N	70	KAM - x.a.b.B.c.B^2
O	70	KAM - x.a.b.B.c.B^2
P	48	KAM - x.B.a.B.b.B^2
R	17	KAM - x.a.b.B^4
S	12	KAM - x.B.a.B^4
T	66	KAM - x.a.b.B^4

* X - Population number.

a,b,c - Single plant selection

B - Family selection

KAP, KAM - Selected at Machakos - <u>P</u>ure or <u>M</u>ixed

A furrow application of 200 kg/ha diammonium phosphate (DAP; 18: 46: 0), was done at planting. The fertilizer was well mixed with the soil before a single seed per hill was placed. All operations were manually done.

Observations were taken from the central portion of 3.6 m^2 i.e. three bean rows of 2.4 m length each.

A sub-plot in association cropping was a gross 13.5 m^2 in size. There were five maize rows spaced at 0.75 m and maize hills spaced at 0.3 m within the row. This would result in a maize population of 44,444 plants per hectare. Two maize seeds were sown but thinned out to one, two weeks after emergence. Double rows of beans were grown between maize rows at 0.25 m and 0.15 m inter-row and intra-row spacing respectively. This would result in a bean population of 178,778 plants per hectare.

The net plot was 3.6 m^2 in size, consisting of the central two double rows of beans measuring 2.4 m in length each. The harvested maize plot was the middle three rows of 2.4 m length each.

At planting, the beans had an application of diammoniam phosphate fertilizer at the rate of 100 kg/ha. This was applied in the furrow as previously described. Maize got triple superphosphate (46%; P_2O_5), at the rate of 150 kg/ha applied in the furrow. A side dress with calcium ammonium nitrate (26%; N) was done at knee height stage of growth of the maize.

Data Collection

Observations based on visual judgement were taken from the net plot. Developmental plant characteristics i.e. measurements involving height and branching, as well characters related to yield were all measured on a ten plant sample randomly selected from the net plot. This sample was taken at physiological maturity. Freshly opened flowers were counted on a sample of three plants randomly choosen at the start of flowering. This data was only collected for the short rains experiment at Thika. Freshly opened flowers were counted over a duration of 21 days. Seed harvested from the net plot was dried to a constant weight and this formed the plot yield. It was from such dried seed that a random one hundred seeds were taken for seed weight determinations.

Analysis of Data

The procedural ANOVA for a split - plot design was performed on the data of every character measured. This enabled the detection of overall genotype variation and genotype by cropping system interaction effects. The hypothesis H_0: the cropping system under which bean segregating generations are advanced and selection done has an influence on the adaptation to cropping system of the resultant genotypes was tested by partitioning the sums of squares due to a tested effect according to the genotype cultural system source. The respective degrees of freedom were likewise decomposed. This resulted in genotype groups that could be compared between and amongst each other. Correlation coefficients between monoculture yields (Ygn;Ru), and association crop yields (Xgn;Ru), where corresponding genotype gn:n = 1 ——————>n, within replication Ru:u = 1 ——————>u were computed. The per cent yield reduction due to association cropping was computed for each genotype and also for the mean yields of each genotype group.

Analysis of variance for maize yield data was done in the conventional randomised complete block system to test whether different bean genotypes showed differential effects on maize yields.

CHAPTER IV

RESULTS

GENERAL

The developmental and yield characteristics of two groups of bean genotypes having their selection history under either monoculture or in association with maize were measured in order to test the hypothesis that: specific genotypes are required for specific production systems. The objective was approached by: first testing for the occurrence of genotype by cropping system interaction, also by contrasting between the two groups for all characters measured.

The two groups of genotypes shall hereafter be referred to as monoculture selections and mixed crop selections.

Due to severe drought stress commencing just at about flowering time, both at Machakos and Embu, no data could be obtained for the 1981/82 season at the two sites as the bean plants did not pod or in some cases did not reach flowering stage before they permanently wilted. Some weather data during the span of the intended growth periods are presented in appendix 2. Therefore, out of the three experiments intended during the short rains 1981/82, only one materialised, and shall be reported upon.

Experiment at Thika - Short Rains: 1981/82

Genotype by cropping system interaction in the yield performance of the bean genotypes could not be detected in this experiment. However, significant genotype variation in yield was observed (Table 7).

On partitioning the sums of squares due to genotype effects, the difference between monoculture selections and mixed crop selections was significant. Mixed crop selections on average yielded more than monoculture selections (Table 6). Most of the yield superiority of the mixed crop selections was realised under association cropping where they yielded 13.3 per cent (101.7 kg/ha) higher. Under monoculture, the yield superiority was 6.4 per cent (87.5 kg/ha).

The difference between the two genotype groups was largely accounted for by the heterogeneity within the mixed crop selections. The monoculture selections did not show statistically significant differences amongst themselves.

TABLE 6: YIELD AND YIELD-RELATED CHARACTERISTICS FOR MONOCULTURE SELECTIONS AND MIXED CROP SELECTIONS TESTED IN MONOCULTURE AND IN ASSOCIATION WITH MAIZE AT THIKA: SHORT RAINS 1981/82.

CHARACTER	CULTURAL[a] SYSTEM	MONOCULTURE SELECTIONS								MONO		MIX[b]
		A	B	C	D	E	H	I	K	$\bar{X}$		$\bar{X}$
Yield	M	567.7	440.3	553.8	456.2	452.7	470.2	442.1	542.4	382.6	**	416.7
g/plot	A	342.0	201.0	309.3	243.9	281.9	318.1	274.9	224.6			
Productive	M	9.7	8.5	8.5	8.2	6.5	9.1	8.2	11.7	7.4	*	7.9
Pods/plant	A	5.7	4.9	6.0	6.3	5.3	6.6	5.9	6.2			
Seeds/	M	4.0	3.8	4.1	4.0	3.8	4.0	4.0	3.9	3.9	**	4.0
Pod	A	3.6	3.7	4.2	3.8	3.8	3.9	4.0	3.6			
Un-productive	M	2.6	2.1	2.9	2.6	2.8	4.0	3.4	3.7	3.2		3.2
Pods/plant	A	2.5	3.1	3.7	3.7	4.1	3.0	3.7	2.7			
Flowers/	M	29.8	24.3	33.8	39.6	23.2	26.2	22.5	26.8	25.3	*	27.9
Plant	A	21.5	18.9	25.6	27.5	27.6	19.2	20.2	18.0			
100 seed	M	33.3	31.9	28.3	30.3	33.9	28.2	28.1	25.3	30.1	*	31.3
Weight	A	33.9	32.6	28.4	30.3	33.8	29.6	28.6	24.9			

[a] Cultural systems are designated as M(Monoculture) and A (Association)
[b] Monoculture Selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% levels of probability).

TABLE 6 (CONTD..)

CHARACTER	CULTURAL SYSTEM[a]	MIXED CROP SELECTIONS								MONO	MIX[b]
		L	M	N	O	P	R	S	T	$\bar{X}$	$\bar{X}$
Yield	M	585.0	512.6	449.8	499.7	465.4	696.4	455.1	513.9	382.6 **	416.7
g/plot	A	339.4	298.9	266.3	291.5	333.8	343.2	280.2	335.6		
Productive	M	10.0	9.6	9.2	9.2	9.3	7.7	6.9	8.7	7.4 *	7.9
Pods/plant	A	6.9	6.9	6.3	7.5	6.8	5.8	7.3	8.1		
Seeds/	M	4.0	4.2	4.7	4.0	4.4	3.9	3.4	3.8	3.9 *	4.0
pod	A	3.8	4.3	4.2	3.6	4.1	3.5	3.1	4.0		
Un-productive	M	2.8	2.2	5.1	3.4	4.0	3.9	1.9	2.8	3.2	3.2
pods/plant	A	3.1	3.2	4.1	3.4	2.9	3.3	2.1	3.4		
Flowers/	M	44.3	24.2	32.9	36.2	25.3	34.1	20.7	29.8	25.3 *	27.9
plant	A	24.6	18.2	23.7	26.8	23.9	25.8	26.9	28.8		
100 seed	M	31.5	29.1	25.3	30.3	28.9	43.6	33.2	32.0	30.1 *	31.3
weight	A	31.5	28.7	23.8	28.5	27.3	41.0	35.6	30.5		

[a] Cultural systems are designated as M (Monoculture) and A (Association).

[b] Monoculture selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% levels of probability).

TABLE 7: VARIANCE RATIOS+ FOR YIELD AND YIELD RELATED CHARACTERISTICS - SHORT RAINS - THIKA: 1981/82:

Source of variation	df	Seed yield per plot (g)	Productive pods per plant	Seeds per pod	100 seed weight	Un-productive pods per plant
Blocks	2	47.72*	29.33*	3.32	0.43	0.38
Cropping Systems(c)	1	3247.98**	805.77**	24.39*	0.19	0.75
Error (a)	2					
Genotypes (G)	15	2.26*	2.54**	2.93**	19.53**	2.77**
G x C	15	0.77	1.82	0.85	0.46	1.47
Error (b)	60					
Mono vs Mix	1	4.19*	4.75*	2.36	6.47*	0.07
Within Mono	7	1.73	3.17**	1.48	10.09**	1.26
Within Mix	7	2.50*	1.59	4.47**	30.82**	4.64**
SE ($\bar{x}$;6)		33.33	0.51	0.95	0.95	0.35
CV (%)		20.4	16.3	10.4	7.6	26.9

+ * and ** indicate significance at the 5 and 1% levels respectively.

In general, the latitude between the yield levels of the test genotypes was more pronounced under mono-cropping than in association with maize. However, when the two genotype groups were considered separately, monoculture selections showed larger yield divergence under association cropping while for mixed crop selections, yield divergence was largest under monoculture cropping.

A low, positive but non-significant correlation coefficient (r = 0.243), between mono-crop yields and association crop yields was observed (Appendix 3).

None of the measured yield related characteristics gave significant genotype by cropping system interaction (Table 7).

Comparisons between the two groups of genotypes gave significant differences for the number of productive pods per plant, seeds per productive pod and hundred seed weight. In all characters, except the number of un-productive pods per plant, the mixed crop selections had significantly higher value, than monoculture selection group (Table 6).

Differences within the mixed crop selections were significant for all characters except the number of productive pods per plant. Monoculture selections differed amongst themselves for the number of pods per plant and the seed weight.

Association cropping led to a significant reduction in the number of productive pods and seeds per pod. The number of un-productive pods per plant and the seed weight, remained stable over the test cropping systems.

The interaction: genotype by cropping system was observed for the duration of flowering and the number of flowers per plant (Table 9).

Mixed crop selections, exhibited a longer duration of flowering (Table 8) and a higher number of flowers per plant. Association cropping did not affect any of the developmental characteristics except the number of flowers per plant. However, genotype differences were significant in all cases.

Monoculture and mixed crop selections differed significantly for all developmental characteristics except the height to attachment of the lowest pod (Table 9). Mixed crop selection group showed both fewer days to reach 50% flowering and a shorter maturity duration. Both the height to attachment of the highest pod and total plant height were shorter for mixed crop selections.

TABLE 8: BEAN DEVELOPMENTAL CHARACTERISTICS FOR GENOTYPES GROWN IN MONOCULTURE AND IN ASSOCIATION WITH MAIZE: THIKA - SHORT RAINS 1981/82:

Character	Cultural[a] system	MONOCULTURE SELECTIONS								Mono		Mix[b]
		A	B	C	D	E	H	I	K	$\bar{X}$		$\bar{X}$
Days to 50% flowering	M	45.7	46.3	46.0	46.0	37.3	45.3	45.7	45.3	45.2	**	31.3
	A	47.3	46.3	46.7	47.7	37.0	45.0	48.7	46.7			
Duration of flowering	M	18.0	17.7	17.3	19.7	14.9	20.0	20.3	19.3	17.5	**	18.7
	A	18.0	15.3	16.7	17.3	16.3	20.3	12.7	15.7			
Flowers per plant	M	29.3	24.3	33.8	39.6	23.2	26.2	22.5	26.8	25.3	*	27.9
	A	21.5	18.9	25.6	27.5	27.6	19.2	20.2	18.0			
Days to maturity	M	93.7	92.3	90.7	92.3	87.3	92.3	91.0	89.3	89.7	*	87.3
	A	90.7	87.3	87.3	88.3	84.3	89.3	91.0	88.0			
Branches per plant	M	3.8	3.9	4.0	3.6	3.8	3.6	4.0	4.0	3.6	**	4.2
	A	3.3	3.2	3.3	3.6	3.4	3.3	3.5	3.1			
Lowest pod[c] attachment	M	19.8	20.0	19.9	20.7	22.7	19.2	20.1	16.9	20.6		20.2
	A	19.9	28.6	21.8	19.8	23.7	21.5	16.5	17.7			
Highest pod[c] attachment	M	49.5	45.9	51.4	43.4	35.8	47.9	44.1	45.2	45.4	**	41.6
	A	49.3	54.7	50.8	39.8	37.8	49.9	41.6	40.0			
Plant[c] height	M	94.4	76.7	89.7	77.7	48.2	77.9	69.9	77.9	80.1	**	70.3
	A	96.1	104.1	96.9	80.1	50.2	84.7	81.5	75.9			

[a] Cultural systems are designated as M (Monoculture) and A (Association).

[b] Monoculture selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% level of probability).

[c] Heights in centimetre.

TABLE 8 (CONTD..)

Character	Cultural system[a]	L	M	N	O	P	R	S	T	Mono $\bar{X}$		Mix[b] $\bar{X}$
		MIXED CROP SELECTIONS										
Days to 50% flowering	M	45.7	46.0	46.0	37.3	46.0	33.0	37.3	37.3	45.2	**	41.3
	A	46.3	47.3	46.7	37.0	47.3	33.7	37.0	37.3			
Duration of flowering	M	19.3	20.7	17.0	17.7	25.0	20.3	17.0	16.7	17.5	**	18.7
	A	17.0	18.3	15.7	18.0	24.3	16.3	19.3	16.7			
Flowers per plant	M	44.3	24.2	32.9	36.2	25.3	34.1	20.7	29.8	25.3	*	27.9
	A	24.6	18.2	23.7	26.8	23.9	25.8	26.9	28.8			
Days to maturity	M	90.0	93.3	89.3	84.7	92.3	82.0	85.3	89.0	89.7	*	87.3
	A	87.0	90.3	88.0	82.0	82.0	89.3	82.0	87.5			
Branches per plant	M	3.8	3.8	3.9	5.5	3.9	4.3	4.4	4.2	3.6	**	4.2
	A	3.7	3.7	3.3	4.5	3.6	3.6	5.1	4.5			
Lowest pod[c] attachment	M	21.5	18.3	21.7	19.5	18.3	21.5	22.5	18.3	20.6		20.2
	A	20.2	20.2	21.5	19.6	16.5	21.2	23.7	18.1			
Highest pod[c] attachment	M	49.2	51.1	49.4	34.6	43.8	36.2	32.7	37.8	45.4	**	41.6
	A	46.0	54.8	47.6	32.2	33.8	32.5	34.1	38.7			
Plant[c] height	M	95.4	88.5	88.4	48.6	81.2	47.2	45.2	57.9	80.1	**	70.3
	A	96.8	105.1	85.4	44.5	87.3	45.4	47.4	60.7			

[a] Cultural systems are designated as M (Monoculture) and A (Association).

[b] Monoculture selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% level of probability).

[c] Heights in centimetre.

TABLE 9: VARIANCE RATIOS+ FOR BEAN DEVELOPMENTAL CHARACTERISTICS SHORT RAINS - THIKA: 1981/82

Source of variation	df	Days to 50% flowering	Duration of flowering	Flowers per plant	Days to maturity	Branches per plant	Height of lowest pod(cm)	Height of highest pod(cm)	Plant height (cm)
Blocks	2	1.29	16.09	7.24	2.72	17.62	1.65	1.99	1.70
Cropping systems(C)	1	2.19	10.83	135.06**	16.63	11.73	0.70	0.02	2.04
Error (a)	2								
Genotypes(G)	15	157.23**	5.81**	3.77**	13.65**	5.96**	3.38**	7.66**	19.51**
G x C	15	1.51	1.89*	1.89*	1.13	1.43	1.38	0.52	0.86
Error (b)	60								
Mono vs Mix	1	369.12**	7.98**	5.34*	35.03**	31.22**	0.49	10.07**	20.21**
Within Mono	7	72.35**	2.66*	3.62**	5.87**	0.25	4.29**	4.58**	11.27**
Within Mix	7	207.99**	8.66**	3.71**	18.39**	8.05**	2.89*	10.19**	27.66**
SE ($\bar{x}$;6)		0.39	0.89	2.28	0.80	0.19	1.12	2.42	4.36
CV(%)		2.2	12.0	21.0	2.3	11.7	13.4	13.6	14.2

+ * and ** indicate significance at the 5 and 1% levels respectively.

Experiment at Embu - Long Rains: 1982

The test genotypes in this experiment showed neither significant genotype variation nor the interaction: genotype by cropping system for yield performance (Table 11). Although the monoculture selections on average yielded more than mix crop selections, (Table 10), the magnitude of the difference was insignificant.

Very low and non-significant yield correlation (r = 0.170), between monoculture and association cropping system yield was realized (Appendix 3). Absolute genotype mean yield differences were more divergent when beans were grown under monoculture than when under association cropping.

Yield differences among monoculture selections were significant (P = 5%). This was not the case for mixed crop selections.

All the yield related characteristics measured showed genotypic differences (Table 11). None of them however, showed genotype by cropping system interaction.

A general decrease in the measurement of all yield related characteristics was recorded under association cropping. The only exception was the hundred seed weight which was higher under association cropping. This difference between the two cropping

TABLE 10: YIELD AND YIELD-RELATED CHARACTERISTICS FOR MONOCULTURE SELECTIONS AND MIXED CROP SELECTIONS TESTED IN MONOCULTURE AND IN ASSOCIATION WITH MAIZE AT EMBU DURING LONG RAINS, 1982.

CHARACTER	CULTURAL[a] SYSTEM	MONOCULTURE SELECTIONS								MONO		MIX[b]
		A	B	C	D	E	H	I	K	$\bar{X}$		$\bar{X}$
Yield	M	447.0	720.5	635.2	819.6	531.4	660.0	774.7	692.2	531.9		511.8
g/plot	A	364.9	579.8	397.5	372.6	353.9	470.7	434.3	345.3			
Productive	M	7.6	9.4	9.5	10.8	9.6	8.0	10.6	13.9	8.6		8.6
pods/plant	A	5.6	7.4	6.8	5.8	7.6	5.6	8.4	10.7			
Seeds/	M	3.5	3.9	3.3	4.3	4.1	3.9	4.5	4.1	3.8	**	3.7
productive pod	A	3.4	3.0	3.1	4.3	4.0	3.5	4.2	3.8			
Un-productive	M	3.5	3.6	3.7	3.3	3.9	4.3	2.5	3.1	3.3	**	3.7
pods/plant	A	2.9	4.9	3.2	2.3	2.8	3.3	2.4	3.5			
100 seed	M	42.8	50.0	42.7	35.0	33.4	47.8	33.9	28.4	40.4		40.1
weight	A	47.8	53.2	47.1	34.9	34.0	50.6	35.1	29.3			

[a]Cultural systems are designated as M (Monoculture) and A (Association)

[b]Monoculture Selections (Mono) and Mixed crop selections (Mix) compared and significant diferences between them are denoted as * and ** (5 and 1% levels of probability).

TABLE 10 (CONTD....)

CHARACTER	CULTURAL SYSTEM[a]	MIXED CROP SELECTIONS								MONO	MIX[b]
		L	M	N	O	P	R	S	T	$\bar{X}$	$\bar{X}$
Yield	M	556.8	678.8	691.7	647.2	666.2	631.3	510.2	629.9	531.9	511.8
g/plot	A	447.5	409.8	358.4	422.4	427.9	421.1	349.1	339.7		
Productive	M	9.8	11.1	9.1	8.7	10.6	10.8	7.8	9.6	8.6	8.6
pods/plant	A	8.4	8.4	5.6	7.6	7.0	8.1	6.7			
Seeds/	M	3.9	4.1	4.5	3.5	4.4	3.6	3.4	3.4	3.8 **	3.7
productive pod	A	3.6	3.6	4.1	3.0	4.1	3.1	3.3	2.9		
Un-productive	M	4.0	4.4	3.5	2.7	4.5	4.5	4.1	5.4	3.3 **	3.7
pods/plant	A	3.7	3.0	2.1	3.2	3.0	2.3	4.2	4.9		
100 seed	M	33.3	39.3	37.1	44.5	35.2	36.1	40.9	42.7	40.4	40.1
weight	A	35.8	41.2	41.0	48.1	37.1	37.8	44.7	46.6		

[a]Cultural systems are designated as M (Monoculture) and A (Association).

[b]Monoculture Selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% levels of probability).

TABLE 11: VARIANCE RATIOS+ FOR YIELD AND YIELD RELATED CHARACTERISTICS LONG RAINS - EMBU: 1982.

Source of variation	df	Seed yield per plot (g)	Productive pods per plant	Seeds per pod	100 seed weight	Un-productive pods per plant
Blocks	2	5.81	7.67	743.87**	0.79	29.67*
Cropping systems (C)	1	38.97**	11.87	2916.00**	13.24	60.77**
Error (a)	2					
Genotypes (G)	15	1.57	4.62**	10.23**	74.17**	3.84**
G x C	15	1.23	0.46	0.59	1.01	1.67
Error (b)	60					
Mono vs Mix	1	1.03	0.01	5.03**	0.63	5.13*
Within Mono	7	2.22*	7.84**	10.21**	126.85**	2.67*
Within Mix	7	0.99	2.07	10.99**	31.99**	4.82**
SE ($\bar{x}$; 6)		39.50	0.64	0.13	0.74	0.34
CV (%)		18.5	18.1	8.7	4.5	23.8

+* and ** indicate significance at the 5 and 1% levels respectively.

systems was however insignificant.

Differences between the two groups of genotypes were significant for the number of seeds per productive pod and the number of un-productive pods per plant. The two genotype groups did not differ significantly for the number of productive pods. This trait was also not significantly affected by association cropping, however the reduction in the number was relatively smaller for mixed crop selections. This relatively lower reduction in pods, may partly account for the relatively higher yield for mixed crop selections under association cropping. Monoculture selections, showed a higher number of seeds per pod both under monoculture and in association cropping with a larger margin appearing under the latter cropping system.

Mixed crop selections showed a significantly higher number of un-productive pods than monoculture selections. The intra-group variation was also significant for this character. Association cropping gave a relatively larger reduction of un-productive pods for mixed crop selections.

Genotypic differences were significant for all bean developmental characteristics, that were measured (Table 13). Genotype by cropping system interaction was detected for days to maturity, the number of branches per plant and the height to attachment of the highest pod.

The group of mixed crop selections showed a shorter duration to reach 50% flowering and to mature (Table 12). The comparisons between the two genotype groups also revealed significantly lower attachments of both the lowest and highest pod for mixed crop selections. Total plant height was likewise shorter for this group of genotypes and they also showed significantly more branching.

Association cropping significantly delayed maturity and reduced the amount of branching. Plant height and the height to attachment of the highest pod increased but not significantly so under association cropping. The lowest pod attachment was also elevated. The magnitude of this change was statistically significant (P = 5%).

For height related characteristics, the magnitude of change was relatively smaller for mixed crop selections.

TABLE 12: BEAN DEVELOPMENT CHARACTERISTICS FOR GENOTYPES GROWN IN MONOCULTURE AND IN ASSOCIATION WITH MAIZE: EMBU - LONG RAINS 1982:

Character	Cultural system[a]	MONOCULTURE SELECTIONS								Mono	Mix[b]
		A	B	C	D	E	H	I	K	$\bar{X}$	$\bar{X}$
Days to 50% Emergence	M	7.0	6.3	6.3	6.3	7.3	6.3	6.3	6.7	6.7	6.8
	A	7.3	6.7	6.7	6.7	7.7	6.7	6.3	6.7		
Days to 50% flowering	M	36.7	34.7	36.7	37.3	43.7	36.0	39.7	43.0	38.6**	37.1
	A	37.0	35.7	36.3	38.0	43.3	36.3	40.3	43.0		
Days to maturity	M	83.0	86.3	83.7	87.7	88.3	84.7	86.3	89.7	88.0**	86.9
	A	86.0	88.3	86.7	88.0	97.0	87.0	91.7	93.7		
Branches per plant	M	1.7	1.7	2.0	2.2	1.7	1.5	1.7	1.9	1.7 **	1.9
	A	1.7	1.8	1.9	1.8	1.4	1.6	1.7	1.6		
Lowest pod[c] attachment	M	27.6	26.3	28.1	25.4	22.0	27.8	23.2	20.8	26.9**	25.7
	A	30.0	28.6	30.3	31.9	25.8	32.9	24.8	25.5		
Highest pod[c] attachment	M	44.1	43.7	48.2	44.9	48.3	44.5	45.0	51.5	49.8**	45.9
	A	47.2	43.7	51.4	48.3	68.8	49.5	45.8	71.3		
Plant[c] height	M	54.5	53.1	59.0	55.1	84.5	53.3	60.0	85.2	68.5**	58.2
	A	61.1	55.8	64.7	65.6	117.8	61.3	56.1	109.1		

[a]Cultural systems are designated as M (Monoculture) and A (Association).

[b]Monoculture selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% level of probability).

[c]Heights in centimetre.

TABLE 12 (CONTD..)

Character	Cultural system[a]	MIXED CROP SELECTIONS								Mono		Mix[b]
		L	M	N	O	P	R	S	T	$\bar{X}$		$\bar{X}$
Days to 50% Emergence	M	6.7	7.0	7.3	6.3	6.3	6.3	7.0	6.3	6.7		6.8
	A	6.7	7.0	7.3	6.7	6.7	6.7	7.7	6.7			
Days to 50% flowering	M	37.0	37.0	36.7	35.3	36.7	38.3	36.7	26.0	38.6	**	37.1
	A	38.3	38.0	36.7	36.3	38.3	39.3	36.3	36.7			
Days to maturity	M	87.7	90.0	85.7	83.0	88.0	85.7	83.0	83.0	88.0	**	86.9
	A	87.3	92.0	89.3	85.3	90.0	89.3	85.3	85.3			
Branches per plant	M	1.7	2.3	1.9	1.6	2.0	2.2	1.9	2.0	1.7	**	1.9
	A	1.8	1.8	1.6	1.9	1.6	1.7	2.0	2.1			
Lowest pod[c] attachment	M	21.3	23.3	30.4	24.1	24.4	24.7	22.2	23.2	26.9	**	25.7
	A	24.8	27.5	33.9	26.4	26.4	27.5	26.4	24.4			
Highest pod[c] attachment	M	42.4	46.2	49.7	45.2	46.5	44.4	38.6	39.7	49.8	**	45.9
	A	43.8	50.9	51.5	46.6	53.9	48.1	42.0	44.6			
Plant[c] height	M	50.2	60.8	56.5	53.9	68.3	53.8	49.2	49.3	68.5	**	58.2
	A	55.4	66.2	63.5	58.8	77.0	59.3	52.5	56.3			

[A] Cultural systems are designated as M (Monoculture) and A (Association).

[b] Monoculture selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% level of probability).

[c] Heights in centimetre.

TABLE 13: VARIANCE RATIOS[+] FOR BEAN DEVELOPMENTAL CHARACTERISTICS LONG RAINS - EMBU: 1982.

Source of variation	df	Days to 50% flowering	Days to maturity	Branches per plant	Height of lowest pod (cm)	Height of highest pod (cm)	Plant height (cm)
Blocks	2	2.43	1.71	1.88	11.83	0.14	0.57
Cropping systems (C)	1	4.92	49.00*	0.40	23.71*	9.49	6.96
Error (a)	2						
Genotypes (G)	15	42.78**	20.77**	3.35**	6.49**	6.80**	20.12**
G x C	15	0.74	2.91**	2.06*	0.45	2.04*	1.70
Error (b)	60						
Mono vs Mix	1	64.41**	14.16**	8.37**	5.50*	12.98**	38.61**
Within Mono	7	75.75**	24.63**	3.41**	6.59**	9.34**	32.95**
Within Mix	7	6.71**	17.86**	2.55*	6.54**	3.17**	4.65**
SE ($\bar{x}$; 6)		0.37	0.60	0.09	1.10	2.13	3.32
CV (%)		2.4	1.7	12.0	10.2	10.9	12.8

+ * and ** indicate significance at the 5 and 1% levels respectively.

Experiment at Thika - Long Rains: 1982

Yield performance of test genotypes of this experiment showed non-significant differences (Table 15). Homogeneity was also observed both between and within the monoculture and mixed selection groups. Differences in yield performance across the two cropping systems likewise fell short of statistical significance.

Although the yield difference between the two genotype groups was non-significant, the monoculture selections yielded more than the mixed crop selections (Table 14). The association cropping effects were also slightly smaller for monoculture selections. No correlation was shown between monoculture and association cropping yields ($r = 0.074$) (Appendix 3 refers).

Genotype differences were detected for all the yield related characteristics that were measured. The interaction: genotype by cropping system was observed for the number of seeds per productive pod and unproductive pods per plant. For these two characters, mixed crop selections showed larger measurements under monoculture. The magnitude of reduction in these two characters due to association cropping was larger for mixed crop selections.

TABLE 14: YIELD AND YIELD RELATED CHARACTERISTICS FOR MONOCULTURE SELECTIONS AND MIXED CROP SELECTIONS TESTED IN MONOCULTURE AND IN ASSOCIATION WITH MAIZE AT THIKA DURING LONG RAINS 1982.

CHARACTER	CULTURAL SYSTEM[a]	MONOCULTURE SELECTIONS								MONO	MIX[b]
		A	B	C	D	E	H	I	K	$\bar{X}$	$\bar{X}$
Yield	M	600.5	699.9	657.3	711.1	645.1	663.6	665.2	597.2	510.8	473.4
g/plot	A	338.7	311.0	309.3	313.0	307.8	448.8	479.1	425.6		
Productive	M	6.1	7.6	8.6	8.3	10.0	7.1	9.2	12.1	7.5	7.5
pods/plant	A	5.3	6.0	5.7	5.0	5.7	5.5	7.6	10.4		
Seeds per	M	3.1	3.3	3.2	4.1	4.2	3.6	4.6	3.7	3.6	3.7
productive pod	A	3.1	3.2	3.0	3.7	3.2	3.5	4.4	3.9		
Un-productive	M	3.1	3.3	2.5	3.4	2.8	2.3	4.2	3.1	2.7	2.9
pods/plant	A	2.5	2.6	1.8	2.4	2.0	1.8	3.0	2.2		
100 seed	M	51.8	49.7	46.5	37.3	30.5	46.6	30.4	25.4	37.9	** 35.1
weight	A	45.6	43.3	40.2	33.7	27.8	43.4	28.2	26.0		

[a] Cultural systems are designated as M (Monoculture) and A (Association).

[b] Monoculture selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% levels of probability).

TABLE 14 (CONTD...)

CHARACTER	CULTURAL[a] SYSTEM	MIXED CROP SELECTIONS								MONO	MIX[b]
		L	M	N	O	P	R	S	T	$\bar{X}$	$\bar{X}$
Yield	M	726.3	578.1	700.4	558.0	648.7	488.6	617.0	737.0	510.8	473.4
g/plot	A	238.1	403.4	324.0	245.9	283.8	423.1	202.2	399.5		
Productive	M	10.3	7.9	7.8	6.5	10.0	9.7	7.4	8.3	7.5	7.5
pods/plant	A	5.2	5.9	5.2	5.0	7.7	9.3	5.0	8.0		
Seeds per	M	4.1	3.9	4.7	3.5	4.3	3.0	3.7	3.7	3.6	3.7
productive	A	3.6	3.8	3.5	3.0	3.8	3.3	3.2	3.9		
Un-productive	M	4.9	2.9	2.7	3.6	4.6	2.1	3.9	3.8	2.7	2.9
pods/plant	A	2.0	2.0	2.0	2.0	2.2	2.3	2.2	2.6		
100 seed	M	32.1	38.6	37.9	43.8	33.0	34.5	38.2	40.9	37.9 **	35.1
Weight	A	25.8	36.8	33.8	36.7	28.3	33.5	32.9	34.2		

[a]Cultural systems are designated as M (Monoculture) and A (Association).

[b]Monoculture selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% levels of probability).

TABLE 15: VARIANCE RATIOS[+] FOR YIELD AND YIELD RELATED CHARACTERISTICS - LONG RAINS - THIKA 1982.

Source of variation	df	Seed yield per plot (g)	Productive pods per plant	Seeds per pod	100 seed weight	Un-productive pods per plant
Blocks	2	25.28*	0.99	0.73	0.47	2.46
Cropping systems(c)	1	1100.64**	29.62*	29.19*	53.28*	21.54*
Error (a)	2					
Genotypes (G)	15	0.67	4.96**	9.95**	37.60**	4.93**
G x C	15	0.90	0.95	2.78**	1.07	2.79**
Error (b)	60					
Mono vs Mix	1	1.59	0.06	1.47	25.60***	2.83
Within Mono	7	0.38	6.66**	13.42**	65.58***	5.06***
Within Mix	7	0.83	3.96***	7.71***	11.28***	5.11***
SE ($\bar{x}$; 6)		39.50	0.64	0.13	0.74	0.34
CV (%)		19.7	20.8	9.0	5.0	29.8

[+]* and ** indicate significance at the 5 and 1% levels respectively.

TABLE 16: BEAN DEVELOPMENTAL CHARACTERISTICS FOR GENOTYPES GROWN IN MONOCULTURE AND IN ASSOCIATION WITH MAIZE AT THIKA DURING LONG RAINS 1982:

Character	Cultural system[a]	MONOCULTURE SELECTIONS									MONO		MIX[b]
		A	B	C	D	E	H	I	K		$\bar{X}$		$\bar{X}$
Days to 50% flowering	M	37.7	41.3	38.3	40.7	45.3	38.7	43.7	45.7		41.4	**	40.2
	A	39.0	39.7	38.3	41.0	46.7	33.7	43.7	44.3				
Days to maturity	M	81.7	85.0	82.3	87.0	86.7	83.3	84.7	89.0		86.7	*	86.1
	A	84.3	87.3	85.3	86.7	94.3	86.0	90.0	92.7				
Branches per plant	M	2.1	2.6	2.7	2.6	2.4	2.4	2.7	2.6		2.3		2.4
	A	2.0	2.1	2.2	1.8	1.7	2.0	2.2	2.3				
Lowest pod[c] attachment	M	29.1	27.3	28.3	29.9	22.9	28.5	24.7	21.9		23.7	*	22.7
	A	20.9	21.3	22.9	22.8	15.8	24.7	19.0	18.4				
Highest pod[c] attachment	M	44.7	44.4	50.3	46.2	54.0	44.2	45.7	53.8		40.0	*	37.7
	A	32.4	29.4	34.1	29.0	25.8	34.7	30.6	40.2				
Plant[c] height	M	54.5	51.2	60.6	59.6	88.1	52.2	55.0	93.7		53.2	**	46.5
	A	41.0	34.6	42.5	37.9	32.0	40.6	39.4	67.7				

[a]Cultural systems are designated as M (Monoculture) and A (Association).

[b]Monoculture selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1 level of probability).

[c]Heights in centimetre.

TABLE 16 (CONTD..)

Character	Cultural[a] system	MIXED CROP SELECTIONS L	M	N	O	P	R	S	T	MONO $\bar{X}$		MIX[b] $\bar{X}$
Days to 50% flowering	M	41.0	42.0	39.0	40.7	41.7	41.3	38.7	39.3	41.4	**	40.2
	A	39.0	41.7	38.0	38.7	41.0	41.0	38.3	41.7			
Days to maturity	M	86.7	90.0	86.0	81.7	87.0	85.0	81.7	81.7	86.7	*	86.1
	A	86.3	91.3	88.7	84.3	89.3	88.3	84.3	84.3			
Branches per plant	M	3.0	2.6	2.6	2.4	2.8	2.6	2.5	2.5	2.3		2.4
	A	1.8	2.1	2.0	2.0	2.3	2.7	1.9	2.4			
Lowest pod[c] attachment	M	21.7	23.9	32.6	25.4	25.5	23.1	24.9	25.7	23.7	*	22.7
	A	16.6	19.2	24.8	18.9	19.2	22.6	18.2	20.0			
Highest pod[c] attachment	M	44.7	43.4	47.7	40.3	52.0	43.3	38.8	45.1	40.0	*	37.7
	A	24.0	29.3	34.1	29.4	34.0	37.3	26.0	33.9			
Plant[c] height	M	51.0	54.9	55.4	49.7	73.7	49.4	46.2	53.0	53.2	**	46.5
	A	28.3	39.5	39.4	36.4	46.8	42.8	31.3	46.0			

[A] Cultural systems are designated as M (Monoculture) and A(Association).

[b] Monoculture selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% level of probability).

[c] [illegible]

The number of productive pods per plant was about equal for the two genotype groups under both cropping systems. Variation within each genotype group was highly significant for this character ($P \geq 1\%$).

Under both cropping systems, monoculture selections had heavier seed weight. Association cropping led to a decrease in seed weight for both genotype groups, however, mixed crop selections were affected to a larger extent with respect to this character.

Significant genotypic variation was detected for all developmental characteristics measured with an exception of the amount of branching (Table 17). Genotype by cropping system interaction was significant for the number of days to 50% flowering, maturity and plant height. Mixed crop selections flowered and matured significantly earlier and showed lower height measurements. Although the amount of branching was higher for mixed crop selections, the difference between the two genotype groups was not significant(Table 16).

TABLE 17: VARIANCE RATIOS+ FOR BEAN DEVELOPMENTAL CHARACTERISTICS LONG RAINS - THIKA: 1982

Source of variation	df	Days to 50% flowering	Days to maturity	Branches per plant	Height of lowest pod (cm)	Hight of highest pod (cm)	Plant height (cm)
Blocks	2	0.43	1.45	21.50*	1.71	1.52	2.67
Cropping systems (C)	1	2.32	127.26**	22.17*	193.00**	119.26**	72.96**
Error (a)	2						
Genotypes (G)	15	132.59**	21.64**	1.35	8.06**	3.02**	7.88**
G x C	15	8.81**	2.50**	0.90	0.97	1.49	2.53**
Error (b)	60						
Mono vs Mix	1	143.44**	4.10*	2.30	4.36*	4.82*	13.64**
Within Mono	7	226.04**	23.36**	1.38	8.65**	2.52*	11.44**
Within Mix	7	35.57**	22.43**	1.19	7.98**	3.26**	3.50**
SE ($\bar{x}$; 6)		0.37	0.60	0.09	1.10	2.13	3.32
CV (%)		2.2	1.7	9.2	11.6	13.5	16.3

+ * and ** indicate significance at the 5 and 1 % levels respectively.

Experiment at Machakos - Long Rains: 1982

Generally. low yield levels were realised in this experiment. Damage by wild animals in one replication was very severe resulting to data from only two replicates being available for purposes of statistical analyses.

Despite the foregoing statements, the available data revealed statistically significant genotype differences for yield (Table 19). The genotype by cropping system interaction was also significant (P = 5%). Association cropping gave significant reduction on the yield levels.

The correlation between monoculture and association crop yields (Appendix 3) was low (r = 0.329) and non-significant.

Mean yield differences between the two genotype groups failed to reach significance. However, under both cropping systems, mixed crop selections yielded more than monoculture selections. Mixed crop selections showed detectable heterogeneity while the converse was true for monoculture selections.

Association cropping led to a significant reduction in the number of productive pods while the number of seeds per pod were unaffected and so were the number of unproductive pods.

Genotype differences were shown for the number of seeds per pod and the number of unproductive pods per plant. Genotypes did not differ significantly for the number of productive pods. Variation between and within genotype groups was also non-significant for the number of productive pods.

Seed number per pod differed within both groups of genotypes although differences between the two genotype groups was non-significant. Mixed crop selections had higher number of seeds per pod under association cropping and they were affected to a lesser extent for the number of productive pods (Table 18). These differences were however ineffective in significantly separating the two genotype groups in yield performance.

Among the yield related characteristics, statistically significant difference between the two genotype groups was observed only for the number of unproductive pods per plant. Mixed crop selections showed less numbers of these under both cropping systems with the margin getting larger under association cropping.

In general, association cropping resulted in an increased number of unproductive pods per plant.

Seed weight was not determined in this

TABLE 18: YIELD AND YIELD RELATED CHARACTERISTICS FOR MONOCULTURE SELECTIONS AND MIXED CROP SELECTIONS TESTED IN MONOCULTURE AND IN ASSOCIATION WITH MAIZE AT MACHAKOS DURING LONG RAINS, 1982.

CHARACTER	CULTURAL[a] SYSTEM	MONOCULTURE SELECTIONS								MONO		MIX[b]
		A	B	C	D	E	H	I	K	$\bar{X}$		$\bar{X}$
Yield g/plot	M	108.8	114.4	112.8	82.7	74.4	105.6	90.9	57.3	89.6		96.7
	A	73.2	86.6	119.7	93.0	79.7	82.5	64.6	89.1			
Productive Pods/plant	M	3.4	3.5	3.2	2.9	2.1	3.9	3.1	3.6	3.0		3.1
	A	2.3	2.9	3.0	2.9	2.9	3.0	2.2	3.5			
Seeds/ Productive pod	M	2.6	3.2	3.4	3.3	3.0	3.3	3.1	3.6	3.2		3.2
	A	2.8	3.0	2.9	3.4	3.5	3.2	2.7	3.9			
Un-productive pods/plant	M	1.4	2.2	1.5	1.3	2.7	4.0	1.1	4.0	2.7	**	2.0
	A	2.6	3.6	2.0	2.7	3.4	3.6	2.2	4.2			

[a]Cultural systems are designated as M (Monoculture) and A (Association).

[b]Monoculture selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% levels of probability).

TABLE 18 (CONTD...)

CHARACTER	CULTURAL[a] SYSTEM	MIXED CROP SELECTIONS								MONO	MIX[b]
		L	M	N	O	P	R	S	T	$\bar{X}$	$\bar{X}$
Yield g/plot	M	94.9	133.4	90.3	96.7	132.2	54.3	105.8	102.7	89.6	96.7
	A	113.4	149.4	63.3	85.9	68.7	90.7	87.2	78.5		
Productive pods/plant	M	2.7	3.5	3.2	3.7	3.6	2.2	3.4	2.9	3.0	3.1
	A	3.4	2.5	2.4	2.9	2.4	3.6	2.6	3.9		
Seeds/ productive pod	M	2.8	3.5	3.4	3.2	2.7	2.7	3.2	3.1	3.2	3.2
	A	2.9	3.3	3.9	3.1	3.5	2.9	3.4	3.2		
Un-productive pods/plant	M	1.1	1.0	1.6	1.8	0.6	2.2	2.7	1.9	2.7 **	2.0
	A	1.2	1.8	2.1	1.4	3.8	3.2	3.4	2.4		

[a]Cultural systems are designated as M (Monoculture) and A (Association).

[b]Monoculture selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% levels of probability).

TABLE 19: VARIANCE RATIOS[+] FOR YIELD AND YIELD RELATED CHARACTERISTICS-LONG RAINS - MACHAKOS: 1982.

Source of variation	df	Seed yield per plot (g)	Productive pods per plant	Seeds per pod	Un-productive pods per plant
Blocks	1	11211.61**	1426.00*	0.37	59.18
Cropping system (C)	1	3586.06*	1936.00*	0.50	121.00
Error (a)	1				
Genotypes (G)	15	3.54**	0.83	2.44**	3.54**
G x C	15	2.07*	1.67	0.94	0.94
Error (b)	30				
Mono vs Mix	1	2.34	0.01	0.03	8.11**
Within Mono	7	2.24	1.36	2.85*	3.34**
Within Mix	7	5.01**	0.42	2.38*	2.09
SE ($\bar{x}$; 4)		9.42	0.32	0.18	0.45
CV(%)		20.2	20.8	11.3	38.7

[+] * and ** indicate significance at the 5 and 1% levels respectively.

experiment as a large number of plots yielded less than hundred seeds. Due to the heterogeneity of seed sizes observed in these plot yields, it was considered unwise to even estimate seed weight through a smaller number of seeds.

Genotypes tested in this experiment differed significantly for all developmental characteristics except for the height to the attachment of the highest pod (Table 21). Overall, the amount of branching ranged from meagre to no branching at all and genotype differences were explicitly nonexistent. Cropping system effects were likewise nonexistent. Subsequently, analysis of variance for this character was not performed.

Association cropping significantly hastened the period to 50% flowering but the reduction in the maturity duration, was not large enough to reach significance level.

The effect of association cropping was a general increase in all measurements involving height but these increases too failed to be significant.

Significant genotype by cropping system interaction effects were shown for maturity duration (P = 5%).

Comparisons between the two groups of genotypes gave significant differences for days to 50% flowering and maturity (Table 20). Mixed crop selections both flowered and matured earlier. Variation for these characters existed to about the same extent in each of the genotype groups (Table 21).

Differences in height measurements between the two groups of genotypes were nonsignificant although mixed crop selections on average tended to grow a bit taller and bore their lowest pod slightly lower on the plant. The mixed crop selections showed heterogeneity for the total plant height.

Maize Performance

Due to weather or other circumstances discussed earlier, maize yields could not be obtained in half of the experiments. The results of analysis of variance for the data obtained is shown in Appendix 4.

Different bean genotypes did not affect maize yields differently.

TABLE 20: BEAN DEVELOPMENTAL CHARACTERISTICS FOR MONOCULTURE SELECTIONS AND MIXED CROP SELECTIONS TESTED IN MONOCULTURE AND IN ASSOCIATION WITH MAIZE AT MACHAKOS DURING LONG RAINS, 1982

CHARACTER	CULTURAL SYSTEM[a]	MONOCULTURE SELECTIONS								MONO	MIX[b]
		A	B	C	D	E	H	I	K	$\bar{X}$	$\bar{X}$
Days to 50% flowering	M	46.0	46.5	46.0	47.0	42.0	43.5	46.0	45.0	44.6 **	42.6
	A	45.0	46.0	44.5	45.5	39.5	44.0	44.0	43.0		
Days to mature	M	89.0	89.0	95.0	95.0	88.0	88.0	95.0	88.0	88.9 **	86.2
	A	85.0	88.0	88.0	88.0	88.0	85.0	88.0	85.0		
Lowest pod[c] attachment	M	20.0	19.2	20.0	18.8	19.6	17.8	17.3	16.6	20.3	19.5
	A	22.8	23.2	21.3	22.4	24.1	19.6	22.4	19.2		
Highest pod[c] attachment	M	30.2	24.8	26.8	25.5	23.0	24.1	24.6	23.4	28.3	28.5
	A	32.2	31.6	33.2	31.4	32.2	28.1	30.3	30.3		
Plant[c] height	M	47.8	33.0	38.6	34.9	29.1	31.6	31.0	34.2	40.5	43.7
	A	52.2	46.3	53.6	55.7	39.9	37.6	43.2	39.6		

[a] Cultural systems are designated as M (Monoculture) and A (Association).

[b] Monoculture selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% level of probability).

[c] Heights in centimetre.

TABLE 21: VARIANCE RATIOS[+] FOR BEAN DEVELOPMENTAL CHARACTERISTICS - LONG RAINS - MACHAKOS: 1982

Source of variation	df	Days to 50% flowering	Days to maturity	Height of lowest pod (cm)	Height of highest pod (cm)	Plant height (cm)
Blocks	1	25.00	0.25	5.52	0.12	0.02
Cropping systems(C)	1	625.00*	156.25	50.46	144.14	30.50
Error (a)	1					
Genotype (G)	15	75.61*	9.82**	1.90*	0.94	2.18*
G x C	15	1.80	2.38*	0.75	0.38	0.68
Error (b)	30					
Mono vs Mix	1	133.56**	35.68**	3.25	0.10	1.78
Within Mono	7	27.12**	6.13**	2.29	0.77	1.58
Within Mix	7	115.81**	9.81**	1.31	1.23	2.85*
SE ($\bar{x}$; 4)		0.35	0.92	0.91	1.91	4.68
CV (%)		1.6	2.1	9.1	13.5	22.2

[+]* and ** indicate significance at the 5 and 1% levels respectively.

TABLE 20 (CONTD..)

Character	Cultural system[a]	L	M	N	O	P	R	S	T	Mono $\bar{X}$		Mix[b] $\bar{X}$
		MIXED CROP SELECTIONS										
Days to 50% flowering	M	44.5	47.0	47.0	46.0	41.5	38.5	39.0	44.5	44.6	**	42.6
	A	43.5	45.0	46.0	44.0	40.0	36.0	35.5	43.5			
Days to mature	M	85.5	94.5	89.0	88.0	88.0	82.0	83.0	88.0	88.9	**	86.2
	A	86.0	87.0	86.0	88.0	83.0	82.0	82.0	86.0			
Lowest pod[c] attachment	M	20.2	16.9	17.9	18.4	17.6	17.6	19.8	16.0	20.3		19.5
	A	20.2	20.3	19.5	19.4	22.4	21.3	23.0	20.8			
Highest pod[c] attachment	M	26.4	27.2	25.9	26.3	22.3	21.0	26.4	25.4	28.3		28.5
	A	35.3	32.0	30.0	32.6	30.0	29.2	29.9	36.5			
Plant[c] height	M	49.4	37.4	40.2	38.9	28.4	27.2	35.1	32.4	40.5		43.7
	A	63.2	54.8	46.0	58.1	46.9	37.2	37.8	65.2			

[a]Cultural systems are designated as M (Monoculture) and A (Association).

[b]Monoculture selections (Mono) and Mixed crop selections (Mix) compared and significant differences between them are denoted as * and ** (5 and 1% level of probability).

[c]Heights in centimetre.

CHAPTER V

D I S C U S S I O N S

Thika - Short Rains: 1981/82

The group of bean genotypes selected under association cropping showed higher yields both under monoculture and when intercropped with maize. The mean yield reduction due to intercropping was smaller for the mixed crop selections (Table 22).

Correlation coefficient between monoculture and intercropped bean yields (Appendix 3) was low (r = 0.243). Similarly low correlation values have been reported elsewhere by Monteiro et. al. (1981) and Muigai and van Rheenen (1982).

Clark and Shibles (1979), observed that a group of high yielding bean cultivars under monoculture maintained their yield superiority also under association cropping. They also reported a lower yield reduction for their high yielders a result of intercropping. These workers did not record any genotype by cropping system interaction for yield.

In the experiment being reported on, higher pod numbers per plant together with heavier hundred seed weight (Table 6), may account for the higher

TABLE 22: RELATIVE ASSOCIATION CROPPING EFFECTS EXPRESSED AS PER CENT BEAN SEED YIELD REDUCTION.[+]

Site	MONOCULTURE SELECTIONS								Mono	Mix[b]
	A	B	C	D	E	H	I	K	$\bar{X}$	$\bar{X}$
Thika 1981/82	39.8	54.4	44.2	46.5	37.7	32.4	37.8	58.6	43.9	39.8
Embu 1982	34.5	47.3	37.4	54.5	33.4	28.7	43.9	50.1	41.2	36.1
Thika 1982	43.6	55.6	52.9	56.0	52.3	32.4	28.0	28.7	43.7	48.7
Machakos* 1982	32.7	24.3	(6.1)	(12.5)	(7.1)	21.9	28.9	(55.5)	3.3	4.0

[+]Yield reduction (M-A/M) per cent

[b]Mono; Mix - Monoculture and Mixed crop selections respectively.

*Figures in parenthesis denote per cent yield increase.

TABLE 22 (CONTD...)

Site	MIXED CROP SELECTIONS								Mono	Mix[b]
	L	M	N	O	P	R	S	T	$\bar{X}$	$\bar{X}$
Thika 1981/82	42.0	41.7	40.8	41.7	28.3	50.7	38.4	34.7	43.9	39.8
Embu 1982	19.6	39.6	48.2	34.7	35.8	33.3	31.6	46.1	41.2	36.1
Thika 1982	67.2	30.2	53.7	55.9	56.3	13.4	67.2	45.8	43.7	48.7
Machakos* 1982	(19.5)	(12.0)	29.9	11.2	48.0	(67.0)	17.6	23.6	3.3	4.0

+ Yield reduction (M-A/M) per cent

[b] Mono; Mix - Monoculture and Mixed crop selections respectively

* Figures in parenthesis denote per cent yield increase.

yield of the mixed crop selections. Clark and Shibles (1979), had observed a smaller number of pods for their high yield cultivar group under monoculture while intercropping reduced the pod numbers to equality for their two cultivar groups. They had observed a higher number of pods at mid pod filling (47 days) for intercropped beans.

Although pod numbers in the experiment under report were not determined at a similar stage of growth, it seems unlikely that having given a smaller flower count (Table 8), intercropped beans would have given a higher number of pods than beans grown in monoculture at any time during development. Similar to the findings of Clark and Shibles (1979) is that their higher yield cultivar group also showed heavier hundred seed weight.

The observation that intercropping did not affect hundred seed weight is shared with the above cited authors. Francis et. al. (1978), reported similar findings.

Intercropping led to reduced prolificacy of flowering. The magnitude of reduction was about equal for both groups of genotypes: 20.9 and 19.7% for monoculture and mixed crop selections respectively.

In this experiment, the higher flower count for the mixed crop selections (Table 8), resulted in both significantly higher number of unproductive and productive pods. The mean rates of flower abortion and/or pod abscission were about similar: 58:1 and 60.2% for monoculture and mixed crop selections respectively. The mode by which the significantly longer duration of flowering manifested by the mixed crop selections, affected this outcome, is not easily discernible.

Mixed crop selections reached 50% flowering faster than monoculture selections. Maturity period was significantly shorter for mixed crop selections. Meadley and Milbourn (1971), working with peas (Pisum sativum L.), reported that shading was critical in floral abortion and yield reduction when it occurred from the time of flowering onwards but not when it occurred at pre-flowering stage. Mixed crop selection genotypes, considered in this light, may have escaped a larger amount of shading effects by being able to flower earlier, than the monoculture selections.

Mixed crop genotypes were significantly shorter in height and bore their highest pod significantly lower than monoculture selections. Osiru (1980), had characterised an ideal genotype for association cropping as one that matures early and was fairly erect and determinate in growth habit. Genotypes of my experiment were non-climbing although not necessarily determinate (Table 3). The mixed crop selections manifested shorter maturity and more branching.

Under association cropping, higher yield reduction has been attributed to long growing cycles by various authors: Francis et. al. (1978), Edge and Laing (1980). The results of this experiment similarly point to a short maturity duration as a positive attribute for an association cropping genotype. The higher number of branches may be a positive architectural quality. Their generally shorter total plant height and lower pod placement along the plant height may point to a unique plant stature for the ideal intercropping bean genotype.

Embu - Long Rains: 1982

Bean genotypes in this trial did not differ in yield performance. However, the per cent yield reduction (Table 22) as a result of intercropping with maize, was relatively smaller for mixed crop selections: 41.2 and 36.1% for monoculture and mixed crop selections respectively.

Heavier hundred seed weight was realised under association cropping. The relative increase in seed weight was higher for mixed crop selections and may have contributed to the relatively lower yield reduction for this group of genotypes as a result of intercropping with maize.

A mean stem extension of 10.8 cm and 5.8 cm was recorded for monoculture and mixed crop selections respectively (Table 12), as a result of association cropping. In a species of Avena, Trenbath and Harper (1973), observed a 20% mean seed weight increase and credited it to an increased light interception, through a 10 cm stem extension in response to shading.

The correlation coefficient between monoculture and association crop yields was low (r = 0.170) and non-significant (Appendix 3). This kind of result is frequently regarded as evidence for differential genotypic response to different cropping systems. Notwithstanding this, the interaction: genotype by cropping system interaction was not shown to occur in this experiment. It is proposed that, the failure to detect the interaction lay in the range represented in the composition of test genotypes. As the global variance ratio test indicated (Table 11), the test genotypes were similar in yield. Subsequently, differences large enough to significantly shift a genotype or a genotype group from the yield range of one another or from the mean yield of one cropping system into another, might have been difficult to achieve. Hence the philosophy of genotype specificity for cropping systems did not seem to be strongly supported by this outcome. May and Misangu (1980), expressed similar sentiments when they failed to register significant interaction effects under four test cropping systems.

Mixed crop selections showed significantly shorter duration to 50% flowering and to maturity (Table 12). This group of genotypes also showed significantly shorter plant height and more branching. Genotype by cropping system interaction was observed for maturity duration and the number of branches per plant. These differences and interactions were however not effective in an interaction for yield. Dart and Krantz (1976) had observed that, where an intercropping situation resulted in differential cultivar development, screening was required in the approriate cropping system. The differential cultivar development and the relatively smaller reduction in yield for the mixed crop selection group as a result of intercropping, seem to underscore this contention.

Thika - Long Rains: 1982

The yields of genotypes in this trial were statistically similar. This was in agreement with the results of the Embu - Long rains trial. These two trials had the same genotype treatments (Table 4). However, in the Thika trial, the heterogeneity recorded among the monoculture selections at Embu was not realised (Table 15).

Unlike the Embu trial, under association cropping, mixed crop selections at Thika exhibited a relatively larger yield reduction (Table 22), than monoculture selections. This could have resulted in part, from a relatively larger reduction for this genotype group in 100 seed weight under intercropping.

Genotype by cropping system interaction for yield did not occur. A casual examination of the yield data (Table 22), reveals that the relative yield reduction under association cropping differed amongst the genotypes. This phenomenon was however not limited to a single genotype group. Francis et. al. (1978c) made similar observations when working with bean cultivars of C.I.A.T. growth types I, II and III. They however, reported significant positive correlation between monoculture and association cropping yields. This was not the case for the trial of this report as an insignificant and negative correlation (r = -0.074) was realised (Appendix 3).

Association cropping significantly delayed maturity and reduced the height of the lowest and highest pods and total plant height. In the work of Makena and Doto (1980), association cropping had hastened maturity of soybean and increased height to the first pod. As indicated in the chapter of results, the maize crop in my experiment was not successful enough to give the normal maize canopy and most likely the right magnitude of above ground competition. Despite this, my work and the cited one bare a similarity in that, both recorded significant genotype by cropping system interaction for maturity duration.

A statement on the specificity of bean genotypes for cropping systems would seem more strongly consolidated if differential reactions to cropping systems for various characters culminated in an interaction in yield. This was not the case in this trial. Yield determination may be a more complicated process than to fit such an obvious trend. However, going by the relative magnitudes of yield reductions for the various genotypes (Table 22) it seems that chances of a genotype with higher adaptation to intercropping exists. It also seems that such chances can most likely be enhanced when bean genotypes are tested under association cropping.

Machakos - Long Rains: 1982

This was the only trial in which the interaction: genotype by cropping system was significant for seed yield (P = 5%). The interaction in yield was not accompanied by interaction(s) in any of the yield related characteristics measured (Table 19).

When Makena and Doto (1980) reported work on soybean, significant cultivar by cropping system interaction in yield was accompanied by interactions in the number of productive pods and seed weight. Their work involved four cropping systems.

Seed yields were generally low (Table 18) and the yield change due to intercropping (Table 22) was on average similarly very low. This was an adverse season. As previously indicated in the chapter on results, maize failed to give seed yield. Fisher et. al. (1976), stated that: although a cereal in an intercrop is considered as the major crop, adverse seasons may see the legume assume the status of a major crop. The maize cultivar grown in this trial (Katumani Composite"B"), has a short maturity duration. Short maturity here is of the order of ninety to a hundred days. Looking at the average maturity period recorded for the beans (Table 20), it becomes apparent that the difference in maturity of the maize and the beans is rather marginal. In this case it could well be, that the separation of resource demands for the two crops was marginal in time and hence competition for available moisture critically stiff. The wisdom of Fisher and his colleagues becomes even more strongly supported by such circumstances. Subsequently, the beans now having assumed the status of the major crop in terms of yield may not perform so well in the intercrop but approach the performance of monoculture.

Genotype differences were significant for the number of seeds per pod and unproductive pods per plant. The variation in the number of pods per plant failed to reach significance but pods showed significant reduction under association cropping (Table 19). This cropping system effect on the number of pods may explain the cropping system effect on the yield. However, genotype yield differences could not be explained by pod number differences. It is suggested that, differences in the number of seeds and possibly the seed weight, might have accounted for the yield differences. However, seed weight was not determined (see results).

Both monoculture and mixed crop selections did not differ in the number of productive pods overall, but mixed crop selections had significantly fewer unproductive pods. More interesting was that monoculture selections showed a higher number of unproductive than productive pods under association cropping. The converse was true for mixed crop selections (Table 18). Severe water stress has been reported to affect the number of seeded pods (Anonymous, 1981).

Genotype by cropping system interaction for developmental characteristics was shown for maturity duration (Table 21). An interaction in the maturity duration was accompanied by an interaction in yield. This could imply that, under the resource status prevailing during the trial, maturity length was a most important developmental characteristic in yield determination. Earliness to maturity has severally been regarded as a desirable trait in an ideal inter-cropping genotype: Osiru and Willey (1976); Anonymous (1976); Francis et. al. (1978 c); Edje and Laing (1980). This could be supported by the observation that mixed crop selections showed significantly shorter maturity duration.

Association cropping led to a tendency of bean plants growing taller. However, the magnitude of this change fell short of statistical significance. Francis et. al. (1978 c), found no influence of cropping system on plant height. In the resource circumstances prevailing during this growth period, it is not easy to account for this apparent change in plant stature. Murneek (1926), had observed that the timing of interplant competition may determine the partioning of plant resources among vegetative and generative functions.

CHAPTER VI

SUMMARY

Genotype by cropping system interactions occurred in three out of four trials for maturity duration, while grain yield, days to 50 per cent flowering, height to attachment of highest pod, plant height and the number of branches showed the interaction in one out of four trials. The duration of flowering and number of flowers per plant were determined in one trial and both characters gave significant genotype by cropping system interaction effects.

Correlation between monoculture and association crop yields were in all cases low and insignificant (Appendix 3).

Among other genotypic features pertinent to the ideal association cropping bean genotype, the study revealed most clearly that this genotype is one that flowers early and has a short maturity duration. In all cases, the genotypes that had been selected under mixed cropping exhibited significantly shorter duration for the two characters. The early enhancement and completion of the reproductive phase would

ensure that the critical yield related characteristics of the bean e.g. pods per plant and seeds per pod will have, to a large extent, been determined before competitive effects of the maize have set in.

The yield superiority of mixed crop selections when it occurred was apparent in both systems of cropping. Should this always be the case, then the bean breeder needing to satisfy both monoculture and association cropping within the range of non-climbing bean growth types could opt to select under association cropping only as superior genotypes then would satisfy either of the two cropping systems. The advantages of such an approach are explicit in research institutions where personnel and budgetary constraints are vehement. Under such a proposal, the breeding material need not be tested under two cropping systems simultaneously. Subsequently, there would theoretically be double the amount of genetic variation represented in a single programme. This should enhance the chances of finding a superior genotype in which case the occurrence of faster genetic advance may not be disregarded.

Architectural characteristics of an ideal association cropping system genotype were shown to be a short plant stature with high amount of branching.

The suggested stature could ensure low degree of aggresiveness thereby curtailing above ground intra-specific competition. The higher number of branches should contribute towards a better display of the photosynthetic surface area.

The absolute indicator of the degree of bean adaptation to association cropping is the bean grain yield. Moreover, the yield performance of maize should be minimally affected by the presence of beans. To ensure high bean yield, total dry matter production has primarily to be guaranteed as this is the basis of high grain yield. The stature of the bean genotype indicated by the results of my experiments appear to be antagonistic to this requirement. However, as significant variation apparently exists for extent of branching, it should be possible to compensate for leaf area index and subsequent dry matter production foregone by selecting a short statured plant type via selection of highly branched type. Although the series of experiments of this thesis did not address the character of stem strength, a strong stem may be required if a high number of branches have to be supported and in the proper display. Within such a plant framework, yield could be maximised through a high number of nodes, racemes and pods per plant.

Selecting in a maize-bean association is physically inconvenient compared to selecting in monoculture. In order to ease the operational shortcomings associated with the intercrop, the breeding lines could be advanced as bulks during the first two generations. At F_3, early generation selection and testing may start. The breeder then has enough quantities of his breeding material to be able to plant sufficient number of replication. This is desirable as random variation is diminished thereby enabling the breeder to confidently eliminate inferior whole lines or families at this stage. This will be based on the expectation that the best lines will always be found in the best families.

Disease and pest incidences did not occur at any practical degree in the series of my experiments. However it has been reported that association cropping naturally partially shields the bean component from pests and diseases. On this basis, it could well be that when selecting in association, some potentially high hielding progenies of otherwise moderate disease tolerance, might not be sacrificed for high degrees of resistance.

As human population continues to grow, one of the consequences shall be increased pressure on agriculturally productive land thereby requiring intensification of production. For maize and beans, it has repeatedly been empirically shown that intercropping is, per unit area of land, more productive than sole crops of either of the two components. Naturally, these circumstances are not reminiscent of the disappearance of the system of intercropping maize and beans in the humid tropics. Furthermore, the marrying of this popular traditional cropping system with present day crop production technology e.g. the use of herbicides, insecticides and fungicides is no longer a major bottleneck amongst agricultural scientists. Moreover, should mechanisation of crop mixtures become a reality, planting in alternate rows or strips easily affords scope for implementation. On the basis of the foregoing, it is imminent that maize in conjunction with bean breeders might have to design nubile genotypes of the two component crops as this should be subservient to increased total system productivity.

CHAPTER VII

CONCLUSIONS

The results of this study supported the hypothesis that specific bean genotypes are required for intercropping with maize.

Among the genotypic features pertinent to the ideal intercropping bean genotype, early flowering and short maturity duration were most clearly indicated from the study.

High amount of branching within a short plant stature was indicated as a positive architectural characteristic of an ideal intercropping bean genotype.

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APPENDICES

APPENDIX 1: CLIMATE AND LOCATION OF TRIAL SITES

Site +	Province	Climatic + zone	Soil + Classi-fication	Mean Annual Rainfall (mm)	Et + (mm)	Tempe-rature mean (°C)	Centre Co-ordinates
N.H.R.S.	Central	III	Rhodic Ferralsol	1020	1214	19.4	0°59'S - 37°04'E
E.A.R.S.	Eastern	III	Dystric Nitosol	1238	1207	20.7	0°30'S - 37°27'E
N.F.R.S.	Eastern	IV	Chronic Luvisol	718	1193	19.5	0°35'S - 37°14'E

+ N.H.R.S. - National Horticultural Research Station -Thika
E.A.R.S. - Eastern Agricultural Research Station - Embu
N.D.F.R.S. - National Dryland Farming Research Station - Machakos
E_t - Mean Potential Evapotranspiration (mm)
Climatic Zones: III - Dry Sub-humid to Semi-arid
IV - Semi-arid
Source: - Siderius and Muchena (1977)

APPENDIX 2a: RAINFALL DATA (MM) AT EXPERIMENTAL SITES DURING SHORT RAINS (1981/82) CROPPING SEASON AND MEAN PAN EVAPORATION (MM)

Month	Thika	Embu	Machakos
November	69.0	89.9	55.3
December	69.8	0.0	63.3
January	0.7	6.0	0.1
February	0.0	0.0	1.6
March	118.8	147.1	68.0
April	153.9	330.6	93.1
Mean	68.7	95.6	46.9
Mean P.E.*	-	-	-

* P.E. = PAN EVAPORATION
\- = DATA NOT AVAILABLE

APPENDIX 2b: RAINFALL DATA (mm) AT EXPERIMENTAL SITES DURING LONG RAINS (1982) CROPPING SEASON AND MEAN PAN EVAPORATION (MM).

Month	Thika	Embu	Machakos
April	153.9	330.6	93.1
May	36.9	264.1	99.4
June	7.5	29.6	3.6
July	24.9	14.6	8.5
August	7.7	57.8	4.0
September	7.1	53.8	9.5
Mean	39.7	125.1	26.4
Mean P.E.*	-	-	117.1

*P.E. = PAN EVAPORATION
\- - DATA NOT AVAILABLE

APPENDIX 3: CORRELATION COEFFICIENTS BETWEEN BEAN GRAIN YIELDS FOR GENOTYPES GROWN IN MONOCULTURE AND IN ASSOCIATION WITH MAIZE.

TRIAL SITE	CROPPING SEASON	r-VALUE
Thika	1981/82	0.243
Thika	1982	-0.148
Embu	1982	0.170
Katumani	1982	0.263

APPENDIX 4: STATISTICS+ AND MEAN YIELDS (g/plot) FOR MAIZE WHEN GROWN IN ASSOCIATION WITH VARIOUS BEAN GENOTYPE TREATMENTS:

Treatment	Thika Short Rains 1981/82	Embu Long Rains 1982
A	1685	2830
B	1802	2681
C	1702	2071
D	1797	2837
E	1997	1943
H	1818	2411
I	2211	2729
K	1703	2019
L	1563	2226
M	1597	1979
N	902	3005
O	1210	2825
P	1496	2277
R	1422	2135
S	1891	2612
T	1428	2556
Mean	1639	2884
$F^{Blocks}_{(2;\ 30\ d.f.)}$	17.2**	4.4*
$F^{Genotype}_{(15;30\ d.f.)}$	1.6NS	1.1NS
S.E. ($\bar{x}$)	244	331
C.V. (%)	25.8	23.1

+* and ** indicate significance at 5 and 1% levels respectively.