# SELECTION AND DEVELOPMENT OF SYNTHETIC MAIZE (*Zea mays* L.) FOR INTERCROPPING WITH COMMON BEAN (*Phaseolus vulgaris* L.)

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BY

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A Thesis Submitted to the graduate school in partial fulfillment of the requirement for the degree of Master of Science in Plant Breeding of Egerton University.

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## Declaration and Recommendation

This thesis is my original work and has not been presented in part or as a whole for any academic award in any other university.

Muraya Moses mahugu — Signature: ..... Date: 6/8/2004

K15/0269/00

This thesis has been submitted for examination with our approval as university supervisors.

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## Abstract

Maize was bred specifically for monoculture, unfortunately, Kenyan small scale farmers dominating food production pratice intercropping. The main objective of this study was to develop synthetic maize varieties adapted for intercropping. The plant types suited for intercropping were identified from KSTP and Embu lines using $S_1$ selection method. Based on GCA test of the $S_1$ lines, seven lines with good GCA were used for developing synthetic maize varieties. For most traits the ratio of GCA:SCA was greater than one, indicating preponderance of additive gene effects for inheritance of these traits. Narrow-sense heritability estimates were highest for leaf angle (0.54) and lowest for LAI (0.14). The performance of three best parental Syn-1 varieties, KSTP Synthetic 1, KSTP Synthetic 2 and KSTP Synthetic 3, were evaluated as monoculture or intercropped with beans. KSTP Synthetic 1 gave the highest grain yield (5686 kg/ha) which was 41% above that of base population (KSTP). KSTP Synthetic 2/bean intercrop resulted in the highest bean yield with 23% reduction over bean monocrop. KSTP/bean intercrop resulted on 46% bean grain reduction over bean monocrop. KSTP Synthetic 1 and KSTP Synthetic 2 had similar LER indicating that both are suitable for intercropping. Predicted yield and leaf angle of Syn-2 maize varieties also indicated KSTP Synthetic 1 having the highest grain yield (2590 g/plot) while KSTP Synthetic 2 had the smallest leaf angle (23.70°). The decline in predicted yield of KSTP Synthetic 1 and KSTP Synthetic 2 from those of Syn-1 is 10.0% and 10.5%, respectively. Both synthetics should be tested under National Performance Variety Trials (NPVT) in medium maturing agro-ecological zones before releasing for commercial use.

## Dedication

This work is dedicated to my parents, Mr. and Mrs Solomon Muraya

**Aknowledgement**

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## List of Abbreviations

ANOVA Analysis of variance

ARF Agricultural research fund

CAN Calcium ammonium nitrate

CIMMYT International maize and wheat improvement centre

CV Coefficient of variation

DAP Diammonium phosphate

df Degree of freedom

DMRT Duncan multiple range test

EMS Estimated means squire

EU European union

FAO Food and agriculture organisation

$F_1$ Filial one generation

$F_2$ Filial two generation

GCA General combining ability

$h^2$ Heritability in narrow sense

H Heritability in broad sense

KARI Kenya Agricultural Research Institute

KSM Kitale station maize

KSTP Kakamega striga tolerance population

KSTP-Syn Kakamega striga tolerance population synthetic variety

LAI Leaf area index

LH1 Lower highland zone one

LH2 Lower highland zone two

LER Land equivalent ratio

LSD Least significance difference

ME Mean squire error

MS Mean squire

NPVT National Performance Variety Trials

PAR Photosynthetic active radiation

RCBD Randomised complete block design

$S_1$ First generation self line

SCA Specific combining ability

Syn Synthetic variety

Syn-1 First generation synthetic variety

Syn-2 Second generation synthetic variety

UNESCO United nations educational scientific and cultural organisation

# CHAPTER ONE

## Introduction

### 1.1 Background Information

Maize *(Zea mays L.)* is believed to have originated in Mexico. Archeological evidence show that maize has been cultivated over the last 4,500 years (Weatherwax and Randolph, 1955). At the discovery of the new world maize (*Zea mays L.)* was already cultivated in many parts of the Americas, and it formed the staple diet of the indigenous population. From there maize is believed to have spread to the rest of the world.

Maize is one of the most widely cultivated cereal crops in the world. With regard to cultivated area, maize is ranked third after wheat and rice in the world (CIMMYT,1990). It is ranked first in Kenya (Kimurto, 2000). The crop is planted in wide range of climatic conditions than either wheat or rice due to its great adaptability. It is an important crop in the warm-temperate regions as well as in the humid sub-tropical zones; it is also grown successfully in the tropics (Poehlman, 1979).

Maize is used for three main purposes: first as a staple human food; second as feed for livestock and third as a raw material for many industrial products. In many parts of the world maize is the most important foodstuff and in particular acts as daily bread for indigenous poor rural population.

In Kenya, maize has been and continues to be the major staple food crop for most Kenyans with vast acreage being sown each year by the majority of small-scale farmers

throughout the country (Gichuhi, 1982). Production of the crop has expanded rapidly since the introduction of synthetic and hybrid maize varieties in the 1960's (Gichuhi, 1982). It is estimated that over 2.5 million acres of maize are grown annually (Acland, 1971) and the national average yield varies but may be approximately 1600 kg per hectare (Gichuhi, 1982).

In Kenya, maize breeding started in the 1930s and was mainly to serve the interests of the European farmers. Early maize breeding programmes were geared towards development of varieties for monoculture. Maize genotypes were selected and bred mainly for monoculture which was commonly practised by large scale farmers. However, when large scale farms were sub-divided to small-scale farmers, the agronomic practices changed from monocropping to intercropping, but the varieties remained the same. In addition, as the land becomes limited small holders are compelled to exploit more fragile marginal lands that cannot support a large plantation,thus practising subsistence agriculture (Kang, *et al.*, 1986).

Intercropping is the growing of two or more crops simultaneously on the same field or crop intensification in both time and space (Andrew and Kassam, 1975). It is one way of maximizing production per unit land. The system has advantages in that there is efficient land use, efficient use of limited resources and spread of risks inherent in monoculture. The most appropriate intercrop, however, depends on its economic value.

Intercropping was for a long-time regarded as primitive agriculture (Acland, 1971). However, majority of farmers in the tropical and sub-tropical regions are economically less endowed and as such they practise intercropping as a means of survival. Indeed, inclusion of legumes in intercropping system apart from boasting food security results in provision of a balanced diet. Legumes have a substantial contribution to the nutritional balance of the diets of millions of Kenyans, whose low purchasing power does not allow sufficient consumption of animal proteins. In addition, legumes have Rhizobia in the roots nodules, which contribute to the nitrogen nutrition of legume crop and other crops in the intercrop system. This is of a special importance to small scale farmers, who are often unable to meet the high costs of inorganic nitrogeneous (N) fertilizers.

## 1.2 Statement of Problem

An important aspect of crop production that escapes attention of agronomists and plant breeders is identification of genotypes for the intercropping system. Kenya was among the first countries in Africa to develop high yielding maize varieties in the early 1960s. The maize varieties were specifically bred for monoculture, which was a cropping system commonly practised by the large-scale farmers, who were mostly of European origin. With sub-division of the large-scale farms, when large-scale farms ownership changed hands to small-scale farms, the cropping system changed to intercropping. Unfortunately, the African farmers who are now the majority food producers in the country, are still using the same maize varieties, which were developed for sole cropping, in intercropping, a system the varieties were not bred for because maize adapted for intercropping has not

been developed. The most common intercropping regime in Kenya is that of maize and bean. It is against this background that this study is planned.

### 1.3 General Objective of the Study

In order to resolve the above stated problem, the study was guided by the following broad objective:

To make a contribution towards resource poor farmers food security at household level and thereby improve their livelihood.

#### 1.3.1 Specific Objectives

1. To characterize ten maize genotypes
2. To identify maize genotypes which offer less shading to the common bean.
3. To test combining ability of seven $S_1$ lines
4. To estimate heritability and estimate heterosis of seven $S_1$ lines
5. To develop synthetic maize varieties adapted to intercropping with common bean.

### 1.4 Hypothesis

To meet the objectives of the study, the following hypotheses was postulated:

1. There was no difference among the ten maize genotypes
2. There is no difference in shading effect on bean intercropped with improved potential KSTP Synthetic varieties and unimproved KSTP.

3. There was no difference between general combining ability and specific combining ability effects of the seven $S_1$ lines
4. The difference between heterosis over the mid-parent of the 21 $S_1$ hybrids were similar
5. There was no difference in terms of yield reduction of bean intercropped with the three potential KSTP synthetic varieties and unimproved KSTP

## 1.5 Justification

Maize *(Zea mays L.)* and common bean *(Phaseolus vulgaris L.)* are commonly grown in association, in other words, intercropped in Kenya. Therefore, intercropping as a practice has been with us for a long time. Despite the fact that for a long time it was regarded as primitive practice that would inevitably give way to monoculture, interestingly, the system has not only persisted but increased and there is now a great interest in intercropping as a means of improving food and livelihold of the resource poor farmers at household level.

Breeders have always been concerned with selections and development of new varieties for sole cropping. In view of the great interest in the intercropping systems within the tropics, there is need to select and develop varieties adapted to intercropping system.

# CHAPTER TWO

## Literature Review

### 2.1 Botany of Maize

Maize (*Zea mays L*) belongs to the family *Gramineae* and the *Tripsaceae* tribe. The *Zea* genus has only one species which is variable in grain colour and spindle, cob size, plant height, amount of yield and growth period. Maize has 10 pairs of chromosomes. Staminate flowers are produced in the tassel and the pistillate flowers on the cob (Poehlman, 1979).

Pollination is by means of wind and gravity. About 95% of the ovules on a shoot are cross-pollinated and about 5% are self-pollinated. Most of pollen that pollinates an ear of maize usually comes from the plants in immediate vicinity, but may be also carried by wind from long distances (Poehlman, 1979). For this reason, in production of synthetics or any varieties where pollination is to be controlled, isolation distance of about 600 m between crop of the same species should be observed.

### 2.2 Selection of Breeding Material

When initiating a breeding program, the first consideration is selection of material to be used in compositing the breeding populations. The success of selection in a breeding programme is partly dependent on the penetrance and expressivity of the gene(s) controlling the character under selection. The character under selection may be controlled by a major or few number of genes (qualitative characters) or polygenes (quantitative characters). The qualitative characters show discontinous variation and are easily

recognized. On the other hand, the quantitative characters show continuous variation and are strongly influenced by the environment (Agwanda, 1988). Therefore, selection for quantitative characters not only depend on the presence and magnitude of genetic variation, but also on the degree to which the environmental factors render the genetic variations unrecognizable. Yield is a typical quantitative character.

Progress from selection depends on a source of genetic variation. Sources of breeding material can and should initially be sought in local land races or cultivars to provide materials of immediate and practical use, being well adapted to the existing production constraints. In some cases the materials required may not be identified in local germplasm and must be sought from introduced material. However, such sources rarely have the required agronomic and consumer characteristics and yield potential needed for release in a given production zone, and more usually can only be deployed by incorporating it into an adapted background.

### 2.2.1 Selection Method

From a heterogeneous population promising plants for the character(s) of interest are selected. The selected plants all of superior character(s) of interest, are usually self pollinated to fix the desired traits and seeds harvested from each plant, giving $S_1$ progenies which are then grown in progeny rows. Progeny rows can be crossed in diallel plan and their combining ability determined before the seeds are composited to form a bulk population of Synthetic cycle one (Syn $C_1$) or specific progeny line to form hybrid seeds.

### 2.2.2 Production of Synthetic Varieties

Hayes and Garber (1919) were the first to suggest the possibility of the commercial utilisation of synthetics varieties in maize improvement. The suggestion grew out of some results they obtained with maize, from which they concluded: "The production of improved varieties through the recombination of several selfed strains has one advantage over either the single- or double- cross plan in that the farmer can save his own seed from yearly crop and that yearly crosses need not be made".

Synthetic varieties are advanced generation of open-pollinated seed mixtures of a group of strains, clones, inbred or hybrids which have been synthesized from genotypes which have been tested for combining ability. A synthetic variety is obtained by randomly mating lines in all possible crosses among n lines of high combining ability (Allard, 1960). The first generation (Syn-1) of a synthetic variety is obtained by making the possible crosses among the components or parental lines. The second generation (Syn-2) is the result of randomly mating Syn-1. A decline of 8 – 10% is expected when Syn-1 is advanced to Syn-2. Production of synthetics involves the following steps:

1. the selection of $S_1$ lines suitable for trait(s) of interest from a heterogeneous population;
2. testing of the $S_1$ lines for their general combining ability for the character(s) of interest. Before recombining selfed lines for the purpose of producing synthetic varieties, it is necessary to determine the yielding ability of all $F_1$ combinations. Selfed lines which combine favourably with all others that are to be used should then be used for the recombination;

3. Intercrossing the better $S_1$ lines to produce a synthetic variety. Seeds from these crosses are harvested, which can be bulked or increased to form synthetic variety.

Once synthesized, it is maintained by open-pollinating in isolation or by random-mating. The residual seeds are maintained so that the same synthetic may be reconstituted at any time. Sythetics have wider genetic basis than hybrids.

### 2.2.2.1 Combining Ability and its Evaluation

Combining ability has two components which Sprague and Tatum (1942) have described as general combining ability (GCA) and specific combining ability (SCA). GCA is given by the average performance of a line in several hybrid combinations. This implies that the GCA of a plant is measured as the difference in the average performance of all crosses with that plant and the mean performance of all crosses in some population either random or selected. Estimate of GCA can provide an empirical estimate on the inheritance of a trait and also suggest a basis for forecasting the value of a plant in untested crosses.

$$H = V_G/V_p \quad \text{..... (1)}$$

$$V_G = 2V_{GCA} + V_{SCA} \quad \text{..... (2)}$$

Where H is heritability in broad sence, $V_G$ is the estimated genotypic variance and $V_p$ is the phenotypic variance.

SCA refers to those cases in which certain combinations do relatively better or worse than would be expected on the basis of average performance of the lines involved. Both types of combining ability are important in the identification of performance of selected

lines. The significance of a trait with high GCA is that that trait can be improved through recurrent selection method.

The GCA and SCA effects can be evaluated by various analyses, but the diallel cross techniques are the commonly used methods. Griffing (1956b) provided detailed methodology for the estimation of effects and variances in diallel cross analysis.

In terms of genetic variances, GCA represents additive genetics and additive X additive type of epistatic interaction. SCA is made up of non-additive types of variances, comprising of dominance and epistasis (Griffing, 1956a). several studies have shown that relatively selected maize inbred lines, non-additive genetic variances are of greater importance in the inheritance of yield and other quantitative traits of economic importance (Rojas and Sprague, 1952; Gamble, 1962; Darrah and Hallauer, 1972). However, for relatively unselected materials the additive genetics variance assume greater role. However, Sprague (1966) concluded that the relative importance of additive and non-additive variance will depend upon the past selection history of lines entering into the diallel. Hayman (1954) and Jinks (1954) extended it for heterozygous populations.

The evaluation of the selected lines for their combining ability is expensive and time consuming. Several methods can be used for evaluation of general combining ability of the selected lines. Test crossing, top-crosses and diallel crosses have been used for screening of lines for GCA. In case of related lines derived from same heterozygous

source, even performance *per se* has been suggested by some workers for rapid sceening of lines for GCA.

### 2.2.2.2 Predicting Synthetic Performance

The performance of a synthetic variety can be estimated by using the following formulae:

$$\overline{F}_2 = \overline{F}_1 - (\overline{F}_1 - \overline{P})/n \quad \ldots\ldots (3)$$

Where, $\overline{F}_2$ = the estimated performance of the synthetic.

$\overline{F}_1$ = the average performance of all possible single crosses among the parental lines involved.

$\overline{P}$ = the average performance of all parental lines involved.

n = the number of parental lines involved.

The performance of synthetic varieties in theory thus depends on (1) the number of parental lines included, (2) the mean performance of these parental lines, and (3) the mean performance of all possible combinations among the n lines.

### 2.2.2.3 Heritability

Heritability of a character is one of its most important properties. It expresses the proportion of the total variability for a given trait in a progeny that is attributed to genetic basis and this is what determines the degree of resemblance between relatives (Falconer, 1989). The most important function of heritability in the genetic study of a character is its predictability role, expressing the reliability of the phenotypic value as a guide to the breeding value. Only the phenotypic values of individuals can be directly measured, but it

is the breeding value that determines their influence on the next generation. Therefore, if the breeder chooses individuals to be parents according to their phenotypic values, his success in changing the characteristics of the population can be predicted only from a knowledge of the degree of correspondence between phenotypic values and breeding values. This degree of correspondences is measured by the heritability.

Heritability is important in plant breeding because (i) it determines to a greater extent the type of breeding method to be applied in selection for a given trait, (ii) it tells the breeder the extent to which a trait is affected by the environment and (iii) if heritability is known it is possible to predict the expected response to be gained due to selection during improvement of a given trait

Heritability values ranges from 0 – 1, 0 indicating low/no heritability while 1 indicates high heritability. As a general rule, if heritability is high, selection will be effective since most of variation will be due to genetic factors which are heritable. Heritability value of 1 indicates that offsprings look exactly like their parents. Alternatively, if heritability is low, selection will not be effective since most of the variation observed would be due to environmental factors which are not heritable. Therefore, they cannot be passed to the subsequent generations. Heritability value of 0 indicates no resemblance of offsprings to their parents ( variation is entirely due to environment).

There are basically two types of heritabilty:

1. Heritability in broad sense (H): This is the ratio of genetic variance to the total phenotypic variance. It is also called the degree of genetic determination.

$$H = \sigma_g^2/\sigma_p^2 = \sigma_g^2/(\sigma_g^2 + \sigma_e^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where: $\sigma_g^2$ is the genetic variance.

$\sigma_p^2$ is the phenotypic variance.

$\sigma_e^2$ is the environmental variance

2. Heritability in narrow sense ($h^2$): This is the ratio of additive variance to the total phenotypic variance.

$$h^2 = \sigma_A^2/\sigma_p^2 = \sigma_A^2/(\sigma_g^2 + \sigma_e^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where: $\sigma_A^2$ is the additive genetic variance.

$\sigma_p^2$ is the phenotypic variance.

$\sigma_e^2$ is the environmental variance

**2.2.2.4 Heterosis**

Heterosis is expressed in the increase in size, yield or vigour after crossing. Heterosis is achieved by crossing inbred lines and to a lesser extent by crossing other varieties. It can be estimated by:

1. $H = \overline{((F_1 - \overline{M}_p)/\overline{M}_p)} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$

Where: H is heterosis.

$\overline{F_1}$ is the mean performance of the $F_1$ hybrid.

$\overline{M}_p$ is the mean performance of mid-parent.

## 2.3 Maize Improvement in Kenya

Maize is a crop that was introduced in Kenya about 16th century. However, the crop has successfully taken a significant place in Kenyan agriculture; having become an important staple food compared to other East African cereals such as finger millet, sorghum and bulrush millet. Maize breeding started in Kenya in early 1930's and was mainly an inbreeding and hybridization programmes (Leakey, 1970). This was mainly to serve the interests of European farmers.

The programme was based at Njoro station. By 1939, few single and double crosses hybrids were developed. In 1953 all the germplasm and the records at Njoro programme was destroyed by fire. Later an East Africa specialist committee for Agricultural botany chaired by Hutchison was set up. The committee discussed an elaborate breeding technique that could be used for maize improvement rather than inbreeding and hybridization.

The work was transferred to Kitale in 1955 and started by breeding for resistance to *Puccinia sorghi* and *Helminthorsporium turcicum* which were then very important (Leakey, 1970). The Kitale station programme was initiated with the objective of breeding for corn blight and rust resistance, high yield and vigour. The methods used incorporated mass selection, half-sib selection and selfed lines evaluation. These methods were used for population improvement to enhance development of synthetics and hybrid varieties. The lines were subjected to recurrent selection to develop improved populations from which inbred lines were extracted. In 1959, breeders introduced germplasm from

South America, which included Ecuador 573 which has been incorpolated in most of the 600 series of the hybrids.

The programme led to production of Kitale Synthetic I and II. The latter was released in 1961 and became a popular variety. The synthetic varieties were favourable to small-scale farmers because of low cost of seeds. Farmers could also produce seeds from their crops unlike hybrids. Hybrid program was also initiated and by 1964 the first hybrid 611 was released to farmers.

A number of inbred lines (A, D, E, F and G) were developed from the Kitale Station maize (KSM). Synthetics, commercial double and three-way cross hybrids were formed. Since then, different hybrids derived from these inbred lines were released to the farming community. These include H621, H631, H622, H632. The breeders also made varietal crosses. The varietal crosses and other crosses involving Ecuador 573 were high yielding in high altitude. Among these were H611, H612, H613, H614, H625 and H628. Composite varieties namely Kitale Composite B, E and F were developed and utilized in later programmes.

In 1957 a breeding programme was started at Katumani for short duration maturing maize. The methods he used incorporated recurrent selection methods. The programme led to release of Katumani composite A and B in 1966 and 1968 respectively. In addition, a number of synthetics have been developed.These includes Katumani synthetic I–VIII.

The composites have been under continuous selection using Lonnquist ear-row method. Breeders have developed C78 which is a cross between Katumani synthetic VII and VIII.

Katumani programme contributed significantly in development of Embu programme whose mandate was to develop medium maturing maize for medium rainfall. Crosses between early maturing Katumani maize with late maturing Kitale maize gave medium maturing maize, such as H511. A breeding programme at Kikambala (Mtwapa) had come up with coast composite. In addition, there is a breeding programme at Muguga with objective of development of streak virus resistance. Other problems being investigated includes disease, insect pests and striga, with a view to develop cultivars with their resistance.

**2.4 Genotypes Performance under Intercropping**

Crops react differently to competition when grown in mixtures. Evans (1960), observed that over a wide range of populations, intercropping maize or sorghum with groundnuts (*Arachis hypogea L.)* led to greater overall yield per acre than growing these crops in pure stands. Dalal (1974), showed that intercropping maize with pigeon peas significantly reduced grain yields of maize. Keith (1983) showed that physical yields per acre of individual crops are lower in mixtures compared to pure stands. The reason being that competition for light, space and nutrients occurs among lower crops in mixtures. Keith (1983) demonstrated that the height of maize affect light availability to bean in a maize-bean intercrop.

Intercropping of maize with bean is more common practice than sole cropping in the tropics and subtropics where small-scale farmers predominate. While on one hand intercropping undoubtedly is a major contributing factor to low bean yields, on the other hand, there are reasons for the persistence of this system which is particularly well suited to the needs of small-scale farmers. The challenge therefore is to discover how to raise productivity of the various maize-bean intercropping systems, while maintaining the inherent stability and risk avoidance needed by small-scale farmers.

## 2.5 Evaluation and Implication of Genotype Suitable for Intercroping

Finlay (1976) and Zimmerman (1995), stated that varieties selected and tested under monoculture may not perform well in mixtures. Additional data presented by Finlay (1976) supported this statement with highly significant interaction when twelve soybean genotypes were tested in four different cropping systems. Elsewhere, Santalla et al. (1995) suggested that sole cropping may provide sufficient information required to select bean populations efficiently for bean-maize intercropping system, although advanced generations should be tested for quantitative traits for compatibility with cropping system.

The need for developing specific varieties of crops for intercropping has frequently been discussed (Finlay, 1976). However, data on the need for separate varieties for intercropping is limited. Francis *et al.* (1976) have a lengthy discussion on this topic from which variety by cropping system interactions can be calculated. Results presented by Finlay (1976), Semu and Janu (1975) and other workers show evidence that varieties may

have to be recommended for different cropping systems. Such conclusions follow from the fact that variety performance changes from one cropping system to the other.

Average leaf angle of a normal maize ranges between 30-40°. However, others have a mean leaf angle of 5-11°, which can allow intercropping. Modification of crop geometry can give way to intercrop and more so for the understory crop (Francis *et al.* 1976).

**2.6 Benefits of Intercropping**

In Kenya the majority of bean are grown in mixed stand with maize. Many of the factors which are considered to benefit the farmer using intercropping can be readily and intuitively understood. Risk is minimized by having more than one crop in the field at one time in the same season or year. Longer periods of ground cover improve soil conservation. Mixtures of legumes and non-legumes may help to maintain soil fertility. Competition from crops is the cheapest method of weed control. Use of resources (light, water, nutrients) is maximized in the intercropping systems and output per unit area is usually higher.

Mixed cropping provides species diversity. The diversification promote yield stability because all the crops are not likely to be equally affected by weather variations. Moreover, intercropping of legumes may enrich the soil with symbiotically fixed nitrogen. Ssebuliba and Itulya (1994) and Itulya (1996) have demonstrated that maize-bean intercrop have greater potential for increased food output per unit area in Kenya.

### 2.6.1 Limitations of Intercropping

It may be difficult to interpret the response of various crops under intercropping since two varieties of the same crop often give different results even though the treatment may be the same (Wahua and Miller, 1978). Close spacing may result in serious competition when nutrients are in short supply. Some crops, for example, sorghum may cause allelopathic effects on other crops. Wahua and Miller (1978)reported allelopathic effects or roots effects of sorghum and soybean. Mechanization of intercrop is also difficult due to lack of uniformity of crop used (Okigbo and Greenland, 1976).

## 2.7 Yield Interpretation under Intercropping

Mixed effects are difficult to interpret and the few quantitative analyses available are not satisfactory (Willey and Osiru, 1972). The International Rice Research Institute (IRRI, 1974) developed the concept of Land Equivalent Ratio (LER) to enable comparison in productivity of a unit land under intercropping to that under monoculture.

LER is the ratio of land under intercropping at same level of management to give equal yields of respective crops under pure stand. LER can be calculated as follows: For a two-crop intercropping system;

$$LER = YC_1I/YC_1M + YC_2I/YC_2M \quad \text{.....(7)}$$

Where, $YC_1I$ = yield of crop one (kg/ha) under intercropping

$YC_1M$ = yield of crop one (kg/ha) under purestand or monoculture

$YC_2I$ = yield of second crop (kg/ha) under intercropping

$YC_2M$ = Yield of second crop (kg/ha) under monoculture

LER value of 1 or more indicate advantages of intercropping over pure stand while less than 1 indicates that there is no obvious advantage of intercropping over monocropping.

# CHAPTER THREE

## Materials and Methods

### 3.1 Climate and Soil Characters of the Site

The experimental site was located at Egerton University, Njoro, Department of Agronomy, Field 7 Station ($0^0$ 23' S and $35^0$ 35' E; elevation 2225 m a.s.l.). The agroecological zone is lower highland zone 2 to 3 (LH2 - LH3). The site has a sub-humid modified tropical climate with a mean daily temperature range of 13.7°C in July to 16.1° in March. The maximum temperature is approximately 22.4°C while the minimum temperature is approximately 7.8°C. The area receives an average amount of rainfall of 908 mm per annum, with 60% reliability. The site experiences two growing seasons, the main cropping season ( March – August) and short rain season (September – February).

The soil types are predominantly *Mollic andosols* (friable and smeary, silty clay to clay) according to FAO/UNESCO classification. The soil is deep and well drained.

### 3.2 Materials

Kakamega Striga Tolerant Population (KSTP) an open pollinated population that was developed by Kenya Agricultural Research Institute (KARI-Kakamega) from local landraces which had been in Western Kenya in striga (*Striga hermonthica*) infested fields long enough to acquire good level of striga tolerance was used. It is a medium maturing variety which comprises a wide diversity of Western Kenya landraces, for example, Nyamula and Rachar. KSTP was selected for improvement in intercropping because of its genetic diversity and its striga tolerance. In addition, Embu lines (E11 and E12) which



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are also medium maturing like KSTP were also used. Other genotypes and hybrid included for general observation included inbred A, D, and F; single cross hydrids A x F, SR52; hybrids FS650, H628 and H614. Common bean (*Phaseolus vulgaris* L.) variety canadian wonder (GLP24) was used for intercropping.

### 3.3 Methods

#### 3.3.1 Planting Patterns

In the intercropping treatments maize was intercropped with bean (*Phaseolus vulgaris L.)*. Maize and bean were planted in a 4.5 m x 7 m plot size. Maize was planted at spacing of 75 cm between the rows and 30 cm between plants within the rows. The intercropped bean was planted between rows of maize plants at 37.5 cm, such that from one row of bean to the next is 75 cm and spacing between bean plants within rows was 15 cm. Both bean and maize were planted simultaneously. Maize for monoculture (pure stand) was planted at spacing of 75 cm between rows and 30 cm between plants within the rows. Bean for monoculture were planted at spacing of 45 cm between bean rows and 15 cm between plants within the rows.

At planting two seeds were placed per hill and 10 days after emergence, the stands were thinned to one plant per hill. For the intercropping, there were seven rows of maize and bean per plot. The rows of maize and bean on both sides of the plot acted as guard rows while the middle three rows of maize and four rows of bean were experimental. For pure stand, there were seven rows of maize and 10 rows of bean. Two rows of both maize and

bean on both sides of plot acted as guard rows while the middle three rows of maize and 4 rows of bean were experimental.

### 3.3.2 Parameters Observed

The parameters observed/ measured on these study were: (i) plant height (ii) ear height (iii) mean leaf angle at 50% flowering (iv) number of leaves per plant (v) leaf area index (vi) 50% maturity (vii) shelling percentage (viii)cob length (ix) cob diameter (x) number of grains per line (xi) number of lines per cob (xii) 100 seed weight and (xiii) grain weight.

### 3.3.3 Experimental Design, Statistical Model and Analysis

The following experimental designs, statistical models and analysis were used:

#### 3.3.3.1 Experimental Design for Selection Trials

The experimental design was randomized complete block design (RCBD) replicated three times. The treatments were individual selected $S_1$ plants. The model for RCBD was:

$$\mathbf{Y_{ij} = \mu + t_i + b_j + e_{ij}}$$

Where, $Y_{ij}$ = Observation on ith treatment and jth block

$\mu$ = Overall mean

$t_i$ = ith treatment effect

$b_j$ = jth block effect

$e_{ij}$ = Error in jth block on ith treatment

**GENERIC ANOVA TABLE**

| SOURCE | Df | Ems |
|---|---|---|
| Treatments | t – 1 | $\sigma^2 + \sigma^2_e + \sigma^2_t$ |
| Blocks | b – 1 | $\sigma^2 + \sigma^2_e$ |
| Error | (t - 1) (b-1) | $\sigma^2$ |
| **Total** | tb – 1 | |

i = 1, 2, …., t

j = 1, 2, 3

### 3.3.3.2 Diallel Evaluation Trial

Griffing (1956) model II was used. The statistical model:

$$\mathbf{Y_{ij} = \mu + g_i + g_j + s_{ij} + e_{ij}}$$

Where; $Y_{ij}$ = mean performance of the ith parental line mated to the jth parental line.

$\mu$= the population mean effect common to all observations.

$g_i$ and $g_j$ = the general combining ability effects of ith and jth parents.

$s_{ij}$ = the interaction of the ith and jth parents.

$e_{ij}$ = random error

**GENERIC ANOVA MODEL II**

| Source | Df | MS | E.M.S. |
|---|---|---|---|
| GCA | p-1 | Msgca | $\sigma_e^2 + \sigma^2_{sca} + (p + 2)\,\sigma^2_{gca}$ |
| SCA | $(p^2 - p)/2$ | Mssca | $\sigma_e^2 + \sigma^2_{sca}$ |
| Error | $(r-1)(p^2 + p - 2)/2$ | ME | $\sigma_e^2$ |

Where; p = number of parent used.
r = number of replications.

### 3.3.3.3: Estimation of Component Variances and their Genetic Interpretations

From the E(MS) given in the generic ANOVA model II:

$$\sigma^2_{gca} = (MS_{gca} - MS_{sca})/ p + 2 \quad \text{.....(8)}$$

$$\sigma^2_{sca} = MS_{sca} - ME \quad \text{.....(9)}$$

$$\sigma^2_{e} = ME \quad \text{.....(10)}$$

Where $\sigma^2_{gca}$, $\sigma^2_{sca}$, and $\sigma^2_{e}$ are the estimates. According to Griffing's (1956) method II, these components may be translated into genetic components using the following equations:

$$\sigma^2_{gca} = 1/2\ \sigma^2_{A} \quad \text{.....(11)}$$

$$\sigma^2_{sca} = \sigma^2_{D} \quad \text{.....(12)}$$

Accordingly,

$$\sigma^2_{A} = 2\ \sigma^2_{gca} \quad \text{.....(13)}$$

$$\sigma^2_{D} = \sigma^2_{sca} \quad \text{.....(14)}$$

### 3.3.3.4: Estimation of Heritability

Heritability was estimated as using equations 4 and 5.

### 3.3.3.5: Estimation of Heterosis

Heterosis was estimated according to Hallauer and Maranda (1988), using equation 6.

### 3.3.3.6: Estimation of Phenotypic Correlations

The phenotypic correlations (rp) between character X and Y was calculated as follows:

$$rp = Cov\,(P_x, P_y)/\sqrt{\sigma^2 P_x \times \sigma^2 P_y} \ldots \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(15)$$

### 3.3.3.7 The Experimental Design for Final Evaluation

The final evaluation for the identified genotype of the maize for intercropping was conducted in a simple split-plot experimental design in randomised complete block design (RCBD), replicated three times. The main plots were split into intercropping and monoculture and the subplots were split into improved and non-improved maize genotypes. The model was:

$$\mathbf{Y_{ijk} = \mu + Y_i + M_j + M_{ij} + S_k + (MS)_{jk} + E_{ijk}}$$

Where, $Y_{ijk}$ = estimates of performance of genotypes under the cropping patterns

$\mu$ = Overall mean

$Y_i$ = the effect of the $i^{th}$ block

$M_j$ = the effect of $j^{th}$ cropping pattern

$M_{ij}$ = the main plot error (error a)

$S_k$ = the effect of kth maize genotype

$(MS)_{jk}$ = the maize genotype x the cropping system interaction

$E_{ijk}$ = the random error component (subplot error or err b)

$e \sim N\,(o, \sigma^2)$

**GENERIC ANOVA TABLE**

| Source | Df | ems |
|---|---|---|
| Block | r-1 | $\sigma^2_e + b\sigma^2_m + ab\sigma^2_y$ |
| Cropping system (A) | a-1 | $\sigma^2_e + b\sigma^2_m + r\sigma^2_{ms} + rb\sigma^2_m$ |
| Error a | (r-1)(a-1) | $\sigma^2_e + b\sigma^2_m$ |
| Maize genotype (B) | b-1 | $\sigma^2_e + r\sigma^2_{ms} + ra\sigma^2_s$ |
| Interaction (AB) | (a-1)(b-1) | $\sigma^2_e + r\sigma^2_{ms}$ |
| Error b | a(b-1)(r-1) | $\sigma^2_e$ |
| Total | abr-1 | |

i = 1, 2, … , a

j = I, 2, …., r

k = 1, 2, …., b

### 3.3.4 Experiments

The study was carried out in five seasons. In the first season (Oct.,2000 – April, 2001), the treatments made up of 10 germplasm and varieties, that is, inbred A, D and F; single cross hybrid A x F, SR52; hydrids FS650, H628 and H614. These were sown in the field alongside the KSTP and E11 as well as E12 for general characterisation and observations. The genotypes were planted in an intercrop system with bean in the nursery block. Each plot had 4 rows of a particular genotype. The genotypes were randomly assigned into the plots within the nurserry.

Each genotype was planted in 2.25 m x 20 m plot size. Individual plants suitable for intercropping, based on plant architecture, viguor and prolificacy were selected from base population (KSTP), E11 and E12. Single plant selection method was used. The selected individual plants were selfed in the same season to form the $S_1$ plants. This constituted

the breeding population. Seventy plants were selected out of which 45 were from KSTP and 25 from E11 and E12. At harvest, only 49 $S_1$ plants survived, which included 30 and 19 selections from KSTP and Embu lines respectively. A number of lines were eliminated on the basis of plant health, leaf angle, while others did not reach maturity and a few failed to set seeds due to drought.

In the second season (April, 2001 – Oct., 2001), the selected 49 $S_1$ plants were tested for their suitability for intercropping system under intercropping to identify the suitable lines. The selected $S_1$ plant formed a progeny line. Each progeny line, which constituted a treatment, was planted under intercrop with bean. The trial was planted in a 7 x 7 lattice block design replicated 3 times. During the active growing period observations were made and based on their performance, 11 lines which were found to be suitable for intercropping system were selected. The 11 lines, which included 8 $S_1$ lines from KSTP (KSTP001, KSTP002, KSTP003, KSTP004, KSTP005, KSTP006, KSTP007 and KSTP008) and 3 lines from Embu lines (E1, E2 and E3), were selected on the basis of plant architecture and health. Visual selection was applied and lines with high shading effects on bean were eliminated. The 11 $S_1$ lines went into a diallel cross without reciprocal crossings, in the same season. Unfortunately, out of the possible combinations attempted only seven lines were successful.

Come the third season (November,2001 – April, 2002), the formed $S_1$ hydrids, from the diallel crosses were evaluated to determine the SCA and GCA of the selected $S_1$ lines, before synthetic population suitable for intercropping are formed. The diallel crosses of

the seven $S_1$ lines were tested in a replicated trial, using randomised complete block design replicated 3 times. The maize was planted in a 7.5 m x 6 m plot size each.

In the fourth season (April – October, 2002), based on their GCA test for grain yield, leaf angle, plant height and leaf area index, the remnant $S_1$ lines with good GCA were used as the parental lines for recombination of potential/parental KSTP Synthetic varieties, KSTP synthetic 1, KSTP Synthetic 2 and KSTP Synthetic 3. The $S_1$ lines KSTP001, KSTP003, KSTP004, E2 and E3 were mutually interpollinated to produce parental KSTP Synthetic 1. KSTP001, KSTP004, KSTP005, KSTP008 and E3 were mutually interpollinated to produce parental KSTP Synthetic 2. While KSTP001, KSTP004, KSTP005, E2 and E3 were mutually interpollinated to produce parental KSTP Synthetic 3. Each synthetic was isolated from one another either by distance or time. Inferior plants were eliminated through detasselling before shedding their pollen. Diseased plants were also rogued. At harvest KSTP Synthetic 1, KSTP Synthetic 2 and KSTP Synthetic 3 were formed from the selected $S_1$ lines to constitute the first generation (Syn-1) of the potential/parental synthetic maize varieties.

In the final season (Nov., 2002 - May, 2003), the potential synthetic maize varieietes were evaluated in replicated trials with KSTP under monoculture and intercrop system. In the evaluation trials, the potential synthetics and KSTP were compared in terms of yield and other related phenotypic traits. H614 was also used in the evaluation of effect of shading on understorey bean crop.

### 3.4 Crop Husbandry

Weeding was carried out mannual using a hoe. Maize and bean were planted with diammonium phosphate (DAP) at an equivalent rate of 70 kg $P_2O_5$ per hectare. The maize was topdressed using calcium ammonium nitrate (CAN) at an equivalent rate of 60 kg N/ha.

### 3.5 Data Collection

**Maize**: Plants were thinned 2 weeks after emergence and then stand count determined thereafter. Identification of genotypes compatible with intercropping was done by measuring plant height, mean leaf angle, and determination of number of leaves per plant and leaf area index. Generally, Plant height, ear height, leaf area index, leaf angle and number of leaves per plant was recorded from 10 randomly selected maize plants in each plot. Days to flowering and days to maturity were recorded when 50% of plants have flowered or cobs matured, respectively.

The height of plant was measured as the distance from soil surface to the horizontal-most section of the maize tassel. Leaf numbers per plant for the estimation of total photosynthesis apparatus was determined; this gave an estimate of total photosynthesis which will be reflected in grain as well as biomass yield. Leaf area index was determined during the active growth period of maize to assess the leaf cover on ground. The leaf area index was determined using the formula:

$$LA = ll * ld \quad \text{.............................................(16)}$$

$$LAI = \sum(0.75 * LA)/x \quad \text{.........................................(17)}$$

Where LA is the leaf area, ll is the leaf length, ld is the leaf diameter at the mid of the leaf, LAI is the leaf area index and x is the spacing of the plants

Mean leaf angle per plant was determined in order to identify maize genotypes with more erect leaves which can allow more light to the undercrop. This was done physically by carrying out measurements using a protractor. Leaf angle was taken as the vertical distance between the stalk and leaf. Measurements were carried out at 3 stages; just before flowering, 50% flowering, and at the end of flowering. Plants with $< 30^{o}$ mean leaf angle were selected.

Similarly, maturity based on flowering date (silking and tasseling) was determined. The flowering was determined at flower initiation, 50% flowering and when all the maize flowers. At harvest the cobs were harvested per plot, oven dried at 70°C, grains shelled and grain weight taken at 12-13% moisture content on plot basis. Grain yield was obtained by harvesting all the experimental plants in each plot.

**Bean**: Plant height, number of branches per plant, number of pods per plant and number of seeds per pod were recorded from 10 randomly selected bean plants in each plot and 10 randomly selected pods from the 10 randomly selected bean plants, respectively. Bean seed yield at 12% moisture and 100 seeds weight was recorded. 100 seeds weight was obtained by randomly getting 100 seeds from the bulk in each plot. Days to flowering were recorded when 50% of plants have one or more flower (R6). While days to maturity were recorded when 50% of plants have reached physiological maturity (R9). Grain yield

was obtained by harvesting all the experimental plants in each plot. Harvesting of bean was done by hand on plot basis at harvest maturity. They were oven dried at 70°C, pods threshed and grain weight obtained.

The yields of bean and maize were used to calculate Land Equivalent Ratios (LERs) using equation (6) (IRRI, 1974). Partial LER (individual crop's LER) and total LER (sum of individual crop's LER) were used as indices to evaluate the productivity of intercrop system. This enabled an assessment of improved synthetics and non-improved population.

**3.6 Data Analysis**

Data were analysed using analysis of variance. Fisher's LSD/DMRT at ($P< 0.05$) was calculated to compare treatment means (Steel and Torrie, 1980). MSTAT program was used to partition the total variance into genotypic, additive, dominance, and environmental effects. Genetic heritability of the maize genotypes was also determined. In addition to statistical analysis, land equivalent ratio (LER) was calculated to determine the comparative productivity of a unit area of land under intercroppping and monoculture.

# CHAPTER FOUR

## Results and Discussion

The results obtained in this study have been presented in four parts as follows:

1.) The phenotypic characteristics on which selection was based.

2.) The selection of lines adopted for intercropping with common bean (*Phaseolus vilgaris* L.).

3.) Combining ability of the selected lines and formation of the synthetic maize.

4.) Evaluation of synthetic maize under monoculture and intercropping systems.

### 4.1 The Phenotypic Characteristics that Formed the Basis of Selection.

The analysis of variance revealed that the differences between treatments were significant ($P<0.05$) for all characters under study (Table 1). This significance between treatments is an indication that there is marked genetic variation amongst the maize materials used and therefore selection for traits of interest would be effective.

#### Leaf Angle

Variation for leaf angle was evident (Table 2). Mean leaf angle at 50% flowering ranged from 12.23° for Inbred A to 46.73° for H614. Leaf angle in most of maize germplasm used in this study appeared relatively horizontal (planophile), but some are more erect, especially during early growth stages. In other words, erect-leaf habit was more evident in a short period and gradually tended to be more horizontal as the plant matures. But, some lines, for example, inbred A have a distinct erect-leaf appearance that is retained most of the season. Since maize populations have considerable genetic variability for leaf angle (Table 2), breeders can select for leaf angle of interest.

**Leaf Area Index**

Variation in leaf area index was evident (Table 2). The leaf area index ranged from 3.00 to 5.00 for inbred A and H614 respectively. Leaf area index (LAI) was associated with plant height and number of leaves per plant. Higher values of LAI were observed on taller plants than on shorter plants (Table 2). Moreover, plants with higher number of leaves gave higher LAI values than those with lower number of leaves per plant.

The term leaf area index (LAI) describes the sum of the area of all leaves (only one surface is counted) per unit area of ground. The LAI and arrangement of the foliage, i.e. canopy architecture, determine the interception of solar radiation by the crop and the distribution of irradiance among individual leaves (Loomis and Connor, 1992). Therefore, LAI is an important selection criterion when developing cultivars for intercropping system. This is because LAI will determine the amount of radiation reaching the understorey crop. Monsi and Saeki (1953), compared leaf area and light interception in various canopy architecture and found that light interception by canopy foliage diminished as LAI increased. In other words, mutual shading among leaves will lead to less light penetrating to the lower canopy and eventually to the bottom. Therefore, it was suggested that tall plants with large leaf area index, more leaves per plant, and more horizontal oriented leaves (large vertical angle) had a greater shading effect to the understorey crop than those with smaller ones. Based on this suggestion, it was recommended that H614 should be included in the final evaluation as one of the check in order to quantify our suggestion.

**Number of Leaves per Plant**

The number of leaves per plant ranged from 13.67 for inbred F to 17.91 for H614. There was a relationship between number of leaves per plant and plant height. Tall plants generally had more leaves than short plants (Table 2). Number of leaves per plant is important in crop improvement because leaves are the functional units of crop photosynthesis. Crop growth rate and ultimate grain yields depends on the photosynthetic activities of leaves (Loomis and Connor, 1992).

**Days to 50% Flowering**

Days to 50% flowering ranged from 101 days for H511 to 120 days for H614 (Table 2). Days to flowering are important in production of composites, synthetics and hybrids. This is because uniformity of flowering is important when making crosses. It also determines the end of asymptotic (vegetative) phase and signals the beginning of parabolic (reproductive) phase.

**Plant Height and Ear Height**

The plant height ranged from 110.66 cm to 233.01 cm in inbred A and FS650, respectively. While the ear height ranged from 44.98 cm to 128.86 cm in inbred A and H614, respectively (Table 2). There was a relationship between plant height and ear height. Generally, tall plants had higher values for ear height compared to short plants (Table 2).

Canopy structure is a central consideration in any description of plant-environment interaction, and especially of whole-plant photosynthesis, because it is related to the interception, scattering and emission of radiation in an intercrop system. Above ground competition is controlled by the density and spartial arrangement of the crops and by the plant of each species. For maize, the most important traits are plant height, internode length and leaf angle and width. Maize genotypes with short internodes, broad leaves and more horizontal oriented leaves shade bean relatively more than genotypes with long internodes, narrow leaves and more erect oriented leaves. Tall genotypes shade understorey crops more than short genotypes.

It was suggested that leaf angle, leaf area index, plant height and number of leaves per plant would form the basis for selection of lines suitable for intercroppig. In addition, selection for erect-leaf habit could result in transgressive yielding. For horizontal-leaf habit, only the upper leaves of the canopy receive full sunlight, with lesser amounts of sunlight penetrating to lower levels and thus decreasing the maximum potential photosynthesis because of self-shading. In the case of more erect, greater penetration of sunlight into the canopy should result, and this tend to increase total leaf area receiving the greater light intensity. This should result in more photosynthetic activity and, therefore, greater productions of dry matter per unit area of field space and ultimately grain yield. Besides, more light will be transmitted to the understorey crop which would result in an increased productivity of the understorey crop.

**Table 1:** Mean squares from analysis of variance of 10 different maize germplasm over one growing season (2000/2001) at Egerton University

| Source of variation | Df | DTF | Q1 | Q2 | Q3 | NL/P | LAI | PH | EH |
|---|---|---|---|---|---|---|---|---|---|
| Replication | 3 | $2.03^{ns}$ | $7.68^{ns}$ | $4.20^{ns}$ | $2.43^{ns}$ | $1.18^{ns}$ | 0.77* | 369.54* | 126.72* |
| Treatments | 9 | 160.96* | 436.67* | 473.71* | 465.91* | 10.11* | 1.79* | 6566.93* | 3484.00* |
| Error | 27 | 1.20 | 3.88 | 2.58 | 1.61 | 0.98 | 0.20 | 52.71 | 14.39 |
| c.v% | | 0.97 | 6.52 | 5.00 | 3.89 | 6.23 | 10.49 | 3.83 | 3.93 |
| S.E | | 0.55 | 0.62 | 0.51 | 0.40 | 0.31 | 0.14 | 2.30 | 1.20 |

*The mean difference is significant at the 0.05 level.

$^{ns}$The mean difference is not significant at the 0.05 level.

DTF = days to 50% flowering, Q1 = mean leaf angle at flower initiation (°), Q2 = mean leaf angle at 50% flowering (°), Q3 ==mean leaf angle after flowering (°), NL/P = number of leaves/plant, PH = plant height (cm), EH = ear height (cm) and LAI = leaf area index

**Table 2:** Performance of 10 different maize germplasm for different architectural and morphological traits at Egerton University in 2000/2001.

| Treatments | DTF | Q1 | Q2 | Q3 | NL/P | LAI | PH | EH | $S_d$ |
|---|---|---|---|---|---|---|---|---|---|
| Inbred A | 112.75$^{c}$ | 11.25$^{h}$ | 12.23$^{h}$ | 13.01$^{h}$ | 13.77$^{d}$ | 3.00$^{f}$ | 110.66$^{h}$ | 44.98$^{g}$ | 1.34 |
| Inbred F | 112.75$^{c}$ | 24.75$^{f}$ | 26.33$^{f}$ | 31.98$^{f}$ | 13.67$^{d}$ | 3.20d$^{f}$ | 135.33$^{g}$ | 48.33$^{g}$ | 1.53 |
| Inbred D | 116.50$^{b}$ | 28.22$^{de}$ | 31.42$^{d}$ | 36.96$^{e}$ | 13.97$^{d}$ | 3.91$^{e}$ | 199.39$^{d}$ | 79.87f | 1.81 |
| A x F | 116.50$^{b}$ | 19.67$^{g}$ | 20.31$^{g}$ | 26.01$^{g}$ | 16.53$^{d}$ | 4.40$^{cd}$ | 167.34$^{f}$ | 105.27d | 2.89 |
| FS650 | 117.00$^{b}$ | 26.93$^{e}$ | 27.94$^{e}$ | 33.12$^{f}$ | 17.03$^{ab}$ | 4.50$^{bcd}$ | 233.01$^{a}$ | 115.27c | 3.87 |
| H511 | 101.25$^{d}$ | 35.41$^{c}$ | 37.70$^{c}$ | 43.17$^{c}$ | 16.67$^{ab}$ | 4.90$^{ab}$ | 215.33$^{c}$ | 122.67b | 4.57 |
| KSTP | 102.75$^{d}$ | 40.13$^{b}$ | 42.67$^{b}$ | 48.03$^{b}$ | 15.15$^{c}$ | 4.10$^{de}$ | 220.47$^{bc}$ | 115.53$^{c}$ | 15.43 |
| H628 | 117.25$^{b}$ | 29.66$^{d}$ | 32.72$^{d}$ | 38.40$^{d}$ | 17.01$^{ab}$ | 4.60$^{abc}$ | 184.33$^{e}$ | 100.38$^{e}$ | 3.67 |
| SR52 | 117.00$^{b}$ | 41.73$^{d}$ | 43.21$^{b}$ | 48.93$^{b}$ | 16.83$^{b}$ | 4.50$^{bcd}$ | 201.60$^{d}$ | 104.25d | 2.78 |
| H614 | 119.75$^{a}$ | 44.67$^{a}$ | 46.73$^{a}$ | 52.07$^{a}$ | 17.91$^{a}$ | 5.00$^{a}$ | 226.16$^{ab}$ | 128.86a | 4.56 |
| $LSD_{0.05}$ | 1.59 | 1.91 | 1.55 | 1.23 | 0.96 | 0.43 | 7.023 | 3.67 | |
| SE | 0.55 | 0.66 | 0.53 | 0.42 | 0.33 | 0.1472 | 2.42 | 1.265 | |

[a]Means followed by the same letter are not significantly different at the 0.05 level.

$S_d$ is the sample standard deviation for leaf angle at 50% flowering

DTF = days to 50% flowering, Q1 = mean leaf angle at flower initiation (°), Q2 = mean leaf angle at 50% flowering (°), Q3 ==mean leaf angle after flowering (°), NL/P = number of leaves/plant, PH = plant height (cm), EH = ear height (cm) and LAI = leaf area index

**Phenotypic Correlations**

Among the phenotypic characters, days to 50% flowering was negatively correlated with leaf angle, plant height and ear height, but positively correlated with number of leaves per plant and leaf area index. Plant height was significantly ($P \leq 0.01$) correlated with leaf area index and ear height (Table 3). This implies that as plant height increases, there are high chances that leaf angle, leaf area index, number of leaves per plant and ear height will also increase. Number of leaves per plant was not significantly ($P \leq 0.05$) correlated with leaf angle but was significantly ($P \leq 0.01$) correlated with leaf area index and ear height. Similarly number of leaves per plant was significantly ($P \leq 0.01$) correlated with leaf area index and ear height, and significantly ($P \leq 0.05$) correlated with plant height (Table 3). Plant height is very closely associated with the number of leaves per plant, because they both depend on the number of nodes per plant. These findings are in agreement with the results of Stojsin and Kannenberg (1994), working with 5 maize populations.

Leaf angle was significantly correlated with plant height, leaf area index, and ear height (Table 3). The non-significant correlation between leaf angle and number of leaves is important in breeding for intercropping system, as one can select for small leaf angle while maintaining high number of leaves.

It is worthy noting that low yields in crop plants are attributed to sink limitation to accumulate photosynthates. This occurs when the ability of source is limited. There is close correlation between grain yield and activity of the leaves from which the photosynthate is predominantly drawn. With increasing number of leaves per plant, the

LAI also increases, thus the source capacity is also increased. Therefore, though smaller leaf angle is important in breeding for intercropping system, it is important to consider source capacity if yields of maize crop are to be maintained or increased.

**Table 3:** Phenotypic correlations among eight architectural and morphological characters measured on 10 different maize germplasm in 2000/2001 at Egerton University.

| | **Q1** | **Q2** | **Q3** | **NL** | **L.A.I** | **PH** | **EH** |
|---|---|---|---|---|---|---|---|
| Days to flowering | -0.100 | -0.111 | -0.110 | 0.269 | 0.091 | -0.060 | -0.074 |
| **DTF** | | | | | | | |
| **Q1** | | 0.997** | 0.997** | 0.554 | 0.685* | 0.781** | 0.719* |
| **Q2** | | | 1.000** | 0.528 | 0.676* | 0.779** | 0.705* |
| **Q3** | | | | 0.526 | 0.673* | 0.779** | 0.705* |
| **NL/P** | | | | | 0.925** | 0.665* | 0.859** |
| **L.A.I** | | | | | | 0.820** | 0.945** |
| **PH** | | | | | | | 0.897** |

*,**Significant at the 0.05 and 0.01 level of significance, respectively.
DTF = days to 50% flowering, Q1 = mean leaf angle at flower initiation (°), Q2 = mean leaf angle at 50% flowering (°), Q3 ==Mean leaf angle after flowering (°), NL/P = number of leaves/plant, PH = plant height (cm) and LAI = leaf area index

## 4.2 The Selection of Lines Adopted for Intercropping with Common Bean (*Phaseolus vulgaris* L.)

Significant difference ($P \leq 0.05$) was detected among the $S_1$ lines selected for their suitability to intercropping for all traits under study except days to 50% flowering (Table 4). This suggests that the selected $S_1$ lines were still diverse and non-significance for days to 50% flowering is also important in that the lines will flower uniformly in the subsequent breeding programmes. Uniformity is important in production of maize synthetic varieties because at the end of the day, lines will be allowed to interpollinate randomly in isolation.

Leaf angle at 50% flowering ranged from 14.41° to 25.43° for KSTP001 and E3, respectively (Table 5). But the leaf angle at 50% flowering of the parental source KSTP and H511 (varietal cross of Embu 11 x Embu 12) from which these lines were derived, were 42.67° and 37.70° respectively (Table 2), demonstrated that selection for leaf angle was effective. It was worthy to note that mean leaf angle was given a greater consideration compared to other traits, being the principal selection criteria in these study. This was primarily because the specific objective of this study was to select lines that would offer less shading to the understorey crop. Hence, the need to consider the plant with more erect-oriented leaves. Only plants with less than 30° were selected. Other selection criteria included plant height, number of leaves per plant, leaf area index and to a lesser extent cob length (plants with large cobs were selected), to which grain yield was an indirect response.

Number of leaves per plant ranged from 12.87 to 15.13 for KSTP008 and KSTP005, respectively, and leaf area index ranged from 3.53 to 4.67 for KSTP008 and KSTP005, respectively. The Plant height ranged from 199.47 cm to 217.70 cm for KSTP008 and KSTP005, respectively, and ear height ranged from 87.54 cm to 113.85 cm for E2 and E3, respectively (Table 5).

**Table 4**: Mean Squares from Analysis of Variance of Seven $S_1$ lines in 2001 at Egerton University

| Source of Variation | df | DTF | Q1 | Q2 | Q3 | NL/P | LAI | PH | EH |
|---|---|---|---|---|---|---|---|---|---|
| Replication | 2 | $0.83^{ns}$ | 0.92* | 0.12* | 0.33* | 0.24* | 0.02* | 12.18* | 0.08* |
| Treatment | 10 | $0.76^{ns}$ | 33.77* | 43.01* | 39.93* | 1.20* | 0.28* | 118.94* | 282.14 |
| Error | 20 | 0.72 | 0.99 | 1.08 | 1.00 | 0.26 | 0.08 | 15.41 | 8.84 |
| SE | | 0.26 | 0.30 | 0.31 | 0.30 | 0.15 | 0.09 | 1.18 | 0.90 |
| CV% | | 0.81 | 4.64 | 4.24 | 3.90 | 3.65 | 6.89 | 1.90 | 3.05 |

* The mean difference is significant at the 0.05 level

$^{ns}$ The mean difference is not significant at the 0.05 level

DTF = days to 50% flowering, Q1 = mean leaf angle at flower initiation (°), Q2 = mean leaf angle at 50% flowering (°), Q3 ==Mean leaf angle after flowering (°), NL/P = number of leaves/plant, PH = plant height (cm), EH = ear height (cm) and LAI = leaf area index

### 4.3 Combining Ability of the Lines and Formation of the Synthetic Maize

Estimates of 11 morphological and agronomic traits were used to evaluate general combining ability through a diallel scheme and significant genotypic effects ($P<0.05$) were observed in all traits under study (Table 6). The significant genotypic effect recorded among the $F_1$ hybrids and parents (Table 6) lead to the determination of the ability of the lines to combine using combining ability analysis (Griffing 1956). The combining ability analysis revealed that mean squares for both GCA and SCA effects for all traits under test were significant ($P<0.05$) as shown in Table 7. This suggested existence of both additive and non-additive gene effects for all traits under study. Indicating that the lines could be useful in the production of hybrids as well as synthetics, and that the traits could be improved through recurrent selection methods. However, comparing the relative magnitudes of GCA and SCA, all the ratios of GCA:SCA, except that of 100 seed weight and cob diameter (Table 7), were greater than unity indicating preponderance of additive gene effects for the inheritance of these traits. Additive type of gene action suggests involvement of minor genes and hence quantitative inheritance of these traits (Falconer, 1989). These are some of the reasons that influenced the study to development of synthetics rather than hybrids, besides lack of genetic diversity. The exact number and the identity of such genes were not established by the present study, and further study to this effect would be necessary. On the other hand, the lower than unity ratios of GCA:SCA indicated preponderance of non-additive, i.e., dominance genetic effect for the inheritance of these traits.

Significant GCA demonstrates that an evaluation of parental phenotype would be sufficient for determining their breeding potential. This is because the GCA effects of

parents are the measure of their 'breeding value' as an average of their performance in hybrids. The SCA effects indicate those combinations that differ for better or worse from the expectation based on the average performance of the parents involved in the hybrid formation.

The predominant component of genetic variation determines the choice of an efficient breeding method for incorporation of concerned genes into new materials (Dhabholkar *et al.*, 1989). Selection is likely to be more effective for traits with higher additive genetic variance than those with higher dominance genetic variance. Selection can be less effective in isolation and especially when fixing genotypes superior due to dominance and epistasis. This is because dominance is a result of intralocus gene interaction. In advance generations provided it is conducted under random mating, the interactions are interrupted and the next generations have reshuffling and recombination of genes. Therefore, superiority may not necessarily be transmitted into the next generation since these conditions are not heritable. In terms of selection, if genes with additive effect control a character, there is always a good chance of improving that character by accumulation of the favourable genes. This component of genetic variance is contributed by genes having a linear quantitative effect, provided environmental variation are controlled. These are some of the major factors that determine response to selection.

Several studies involving the inheritance of various quantitative traits in maize have revealed the predominance of additive gene action (Shewangizaw, 1983; Stangland *et al.*, 1983; Zambezi *et al.*, 1986). This has breeding implications, since additive genetic

variation can effectively be exploited by recurrent selection. The results of this study suggest that effective breeding methods applied in a recurrent selection scheme exploits additive genetic effects and becomes useful in incorporating traits with greater GCA:SCA ratio (assumed to be polygenic) (Dhabholkar *et al*, 1989). The performance of the parents could be used to predict the performance of the progenies. Thus parents with good GCA and performance *per se* can be crossed to develop high yielding synthetics that can be released as an open pollinated variety or as a population or gene pool for further breeding work.

Estimates of GCA effects associated with each of the 7 $S_1$ lines for all characters under study are shown in Table 8. They indicate that lines KSTP001, KSTP003 and KSTP008 showed negative GCA effects for some of the characters whereas parent E3 showed positive GCA effects for all its characters under study (Table 8). The negative estimates indicated a high gene frequency of similarity in some loci for the traits in the former parents while the positive ones indicated diversity in gene frequency for the traits (Gevers and Lake, 1994). Though lines such as KSTP001 and KSTP008 had a negative GCA values for grain yield they were combining very well for reduction of leaf angle. Embu composite was genetically different from KSTP; therefore lines derived from them are genetically unrelated making the former parents good sources. KSTP being a population made up of different local landraces, it was possible some of KSTP lines were different as shown by GCA estimate for KSTP004 was highest for grain yield while that of KSTP001 was highest for leaf angle (Table 8) and both lines combine best for the inheritance of the both traits.

The study identified KSTP001 as a good combiner for most of the traits, while E3 was poor combiner for most of the traits. Line KSTP005 significantly decreased the leaf angle and plant height. It also decreased grain yield, 100 seed weight and number of leaves per plant. The present results agree with the work of Hallauer and Maranda (1988).

SCA effect of each of the 21 individual crosses is presented in Table (9). The positive SCA effects suggested that those respective specific combinations would be useful to breeders in improvement of those traits in maize (Lal *et al*, 1975, Jatasra, 1980). For improvement on leaf angle, for intercropping suitability, the negative SCA combinations would also be useful – because negative values are indicative of decrease in leaf angle compared to the parents. Positive SCA are indicative of increase of a given trait compared to the parents (Jatasra, 1980, Kang *et al*., 1995). Hybrid KSTP005 x E2 gave the highest negative value (-2.02) for leaf angle, thus good source and best combiners for leaf angle suitable for intercropping in a hybridization programme.

Hybrid KSTP001 X KSTP005 gave the highest negative value (-517.73) for grain yield, indicating that this cross had reduced grain yield than the expected mean performance of its parents. This might be because both parental lines were selected from the same population. Meaning that it is highly likely that some of the loci in these lines might be identical by descent. Hybrid KSTP005 X E3 gave the highest positive value (402.68) indicating that these cross had increased grain yield than the expected mean performance of its parents and showed genetic diversity and hence heterosis. Most of the crosses had a positive SCA values for all traits under study except days to flowering and leaf angle,

indicating that these crosses combine well to give higher performance than mean performance of their respective parents.

**Table 6:** Mean squares from analysis of variance of 7 x 7 diallel cross without reciprocal in 2001/2002 at Egerton University

| Source of variation | df | GY | DTF | Q2 | PH | EH | NL/P | LAI | CL | CD | NL/C | NS/L | 100SW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Genotypes | 27 | 1330011.27* | 0.70* | 26.32* | 1272.67* | 423.51* | 7.87* | 0.89* | 94.33* | 0.80* | 4.80* | 65.05* | 25.65* |
| Blocks | 2 | 1352.44$^{ns}$ | 0.15$^{ns}$ | 0.15$^{ns}$ | 41.91$^{ns}$ | 1.93$^{ns}$ | 0.01$^{ns}$ | 0.01$^{ns}$ | 4.25$^{ns}$ | 0.05$^{ns}$ | 0.98$^{ns}$ | 0.37$^{ns}$ | 0.54$^{ns}$ |
| Error | 54 | 4037.35 | 0.43 | 2.33 | 40.70 | 18.55 | 0.16 | 0.06 | 3.18 | 0.10 | 0.37 | 4.81 | 3.00 |
| CV% | | 2.77 | 0.63 | 6.34 | 3.50 | 4.68 | 3.02 | 6.33 | 8.87 | 10.82 | 5.37 | 7.90 | 3.94 |

*The means difference is significant at the 0.05 level.
$^{ns}$The means difference is not significant at the 0.05 level.
GY = grain yield (kg/ha), DTF = days to 50% flowering, Q2 = Mean leaf angle at 50% flowering (°), PH = plant height (cm), EH = ear height (cm), NL/P = number of leaves/ plant, LAI = leaf area index, CL = cob length (cm), CD = cob diameter (cm), NL/C = number of lines/cob, NS/L = .number of seeds/lines and 100SW = 100 seeds weight (grams)

**Table 7**: Means squares for analysis of variance of Griffing's general combining ability, method II, fixed model (2001/2002)

| Source of variation | Df | GY | DTF | Q2 | PH | EH | NL/P | LAI | CL | CD | NL/C | NS/L | 100SW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G.C.A. | 6 | 1741078.43* | 365.47 | 64.88* | 1700.35* | 1454.66* | 20.66* | 1.71* | 216.44* | 0.80* | 22.50* | 365.47* | 26.55* |
| S.C.A. | 21 | 580638.93* | 1.76* | 10.30* | 1150.47* | 440.61* | 9.46* | 0.98* | 100.67* | 0.88* | 5.92* | 82.60* | 26.57* |
| Error | 54 | 4038.18 | $0.43^{ns}$ | 2.33 | 40.70 | 18.55 | 0.16 | 0.06 | 3.18 | 0.10 | 0.37 | 4.81 | 3.00 |
| GCA:SCA | | 3.00 | 4.09 | 6.30 | 2.96 | 3.30 | 2.18 | 1.74 | 2.15 | 0.99 | 3.80 | 4.43 | 1.00 |

*The means difference is significant at the 0.05 level.
$^{ns}$The means difference is not significant at the 0.05 level.
GY = grain yield (kg/ha), DTF = days to 50% flowering, Q2 = Mean leaf angle at 50% flowering (°), PH = plant height (cm), EH = ear height (cm), NL/P = number of leaves/ plant, LAI = leaf area index, CL = cob length (cm), CD = cob diameter (cm), NL/C = number of lines/cob, NS/L = .number of seeds/lines and 100SW = 100 seeds weight (grams)

**Table 9**: Estimates of specifc combining ability (SCA) effects of 21 hybrids formed from $S_1$ lines suitable for intercropping with common bean (2001/2002)

| | SCA effects | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cross | GY | Q2 | PH | EH | NL/P | LAI | CL | CD | NL/C | NS/L | 100SW | DTF |
| KSTP001x KSTP003 | 251.81 | 0.59 | 2.42 | 2.88 | 1.07 | 0.55 | 3.69 | 0.17 | 1.83 | 4.72 | 4.02 | 0.17 |
| KSTP001x KSTP004 | 367.79 | 1.59 | -0.95 | 5.72 | 0.85 | 0.67 | 5.20 | 0.55 | 0.72 | 0.70 | 4.07 | 0.13 |
| KSTP001x KSTP005 | -316.03 | -0.38 | 10.84 | 3.65 | 0.94 | -0.01 | 1.83 | 0.12 | 0.45 | 1.06 | 0.30 | 0.02 |
| KSTP001x KSTP008 | -517.73 | 0.02 | 2.89 | 6.11 | 0.98 | 0.17 | -1012 | 0.03 | -0.28 | 0.78 | 1.38 | -0.32 |
| KSTP001x E3 | 392.36 | -1.42 | -1.17 | 10.85 | 0.74 | -0.12 | -1.73 | 0.41 | 0.60 | 1.01 | -2.39 | -0.32 |
| KSTP001 x E3 | 398.43 | 3.04 | 18.91 | 10.49 | 1.27 | 0.20 | -0.55 | 0.18 | 0.58 | 2.21 | 0.32 | -0.02 |
| KSTP003x KSTP004 | 28.68 | 0.13 | 7.59 | 5.11 | 0.94 | -0.06 | 0.36 | 0.03 | -0.46 | 1.06 | -0.35 | -0.20 |
| KSTP003x KSTP005 | 278.78 | -1.95 | 9.38 | 10.10 | 0.74 | 0.53 | 3.62 | 0.68 | 0.78 | 3.96 | 2.30 | 0.02 |
| KSTP003x KSTP008 | -378.49 | 1.84 | 3.63 | 8.06 | 0.69 | 0.14 | -0.74 | -0.06 | 0.12 | 2.39 | -0.04 | 0.69 |
| KSTP003x E2 | 279.47 | -3.40 | 4.69 | 2.52 | 0.26 | -0.04 | -1.06 | 0.06 | -0.00 | 1.43 | -1.91 | -0.32 |
| KSTP003x E3 | 291.18 | 0.21 | 14.84 | 4.60 | 0.86 | 0.14 | -2.05 | -0.14 | 0.30 | 1.37 | -0.96 | -0.02 |
| KSTP004x KSTP005 | 376.18 | 0.49 | 18.82 | 6.03 | 0.95 | 0.44 | 3.35 | 0.56 | 1.31 | 4.54 | 1.01 | 0.65 |
| KSTP004x KSTP008 | 258.63 | -0.96 | 1.61 | 1.95 | 0.83 | -0.05 | -1.00 | 0.25 | 0.87 | 0.98 | -2.35 | 0.65 |
| KSTP004x E2 | 309.50 | -2.41 | 1.23 | 2.86 | 0.69 | 0.34 | 1.23 | -0.02 | 0.87 | 3.79 | 3.31 | -0.35 |
| KSTP004x E3 | 148.48 | 1.61 | 10.70 | 5.16 | 0.84 | 0.22 | 1.04 | -0.02 | 0.64 | 4.41 | 1.39 | -0.39 |
| KSTP005x KSTP008 | 316.35 | 0.54 | 19.74 | 5.30 | 1.29 | -0.02 | -1.77 | -0.29 | 0.66 | -2.53 | -2.28 | -0.46 |
| KSTP005x E2 | 183.05 | -2.02 | 15.94 | 9.63 | 0.64 | 0.09 | 0.08 | 0.33 | 0.82 | 4.14 | 1.67 | -0.13 |
| KSTP005x E3 | 402.68 | 2.04 | 11.71 | 1.11 | 0.71 | 0.18 | 1.09 | 0.53 | 0.60 | 1.98 | 0.81 | 0.17 |
| KSTP008x E2 | 357.38 | -1.37 | 1.34 | 9.44 | 0.72 | 0.80 | 10.98 | 0.41 | 1.01 | 6.48 | 5.27 | 0.54 |
| KSTP008x E3 | 235.65 | 1.58 | 12.69 | 8.42 | 0.84 | 0.65 | 8.98 | 0.80 | 1.48 | 4.87 | 4.26 | -0.17 |
| E2x E3 | -236.65 | 0.14 | 15.10 | 2.66 | 1.53 | 0.44 | 10.38 | 0.18 | 0.69 | 1.08 | 0.16 | 0.17 |
| SE | 2.62 | 0.06 | 0.26 | 0.34 | 0.28 | 0.09 | 0.05 | 0.01 | 0.03 | 0.09 | 0.07 | 0.03 |

GY = grain yield (kg/ha), DTF = days to 50% flowering, Q2 = Mean leaf angle at 50% flowering (°), PH = plant height (cm), EH = ear height (cm), NL/P = number of leaves/ plant, LAI = leaf area index, CL = cob length (cm), CD = cob diameter (cm), NL/C = number of lines/cob, NS/L = .number of seeds/lines and 100SW = 100 seeds weight (grams)

**Estimates of Heritability**

Estimates of variance components are presented on Table 10. Narrow-sense heritability of all characters studied showed that leaf angle at 50% flowering had the highest narrow sense heritability ($h^2$=0.54). Leaf area index had the lowest heritability ($h^2$=0.14). The high narrow-sense heritability for mean leaf angle suggested that the additive genetic variance was a high proportion of total genetic variance for this character, whereas non-additive gene action plays a major role in leaf area index.

Heritability estimates indicate the extent selection is likely to be effective (Robinson *et. al.*, 1949, 1951; Dudley and Moll, 1969; Akanuou and Doku, 1998). It is worth noting that selection is dependent on three factors (1) heritability, (2) the amount of genetic diversity and (3) the intensity of selection or selection pressure.

In this study, estimates of narrow – sense heritability were moderate (Table 10). This indicates that even with an early selection ($S_1$) and similarly an early cycle of recombination ($C_1$) the proportion of additive genetic variance, although present in the total genetic variance was moderate for most of the characters under study. Similar results were observed by Akanuou and Doku (1998) on heritability of traits associated with striga resistance in maize. Estimates of narrow-sense heritability were highest for mean leaf angle at 50% flowering ($h^2$=0.54). This value indicated that sufficient proportion of additive type of genetic action account for the improvement in the study. This is confirmed by the large additive variance estimates found for this character (Table 10).

estimates obtained for respective characters. Given the higher narrow – sense heritability estimates for some characters, the present study recommends recurrent selection to improve phenotypic traits such as leaf angle for the development of maize varieties suitable for intercropping system.

**Table 10**: Estimates of additive variance ($\sigma^2_A$), dominance variance ($\sigma^2_D$) and narrow sense heritability ($h^2$) (2001/2002)

| Character | $\sigma^2_A$ | $\sigma^2_D$ | $h^2$ |
|---|---|---|---|
| Grain yield | 257875.45 | 576600.75 | 0.31 |
| Leaf angle at 50% flowering | 12.13 | 7.97 | 0.54 |
| Plant height | 500.05 | 1109.77 | 0.30 |
| Ear height | 225.34 | 422.06 | 0.34 |
| Number of leaves/plant | 2.49 | 9.30 | 0.21 |
| Leaf area index | 0.16 | 0.92 | 0.14 |
| Cob length | 25.73 | 97.50 | 0.20 |
| Cob diameter | -0.00 | 0.78 | xx |
| Number of lines/cob | 3.68 | 5.55 | 0.38 |
| Number of seeds/line | 62.86 | 77.78 | 0.43 |
| 100 seed weight | -0.00 | 23.57 | xx |

xx $h^2$ not estimated because $\sigma^2_A$ was negative (zero)

**Estimates of Heterosis**

The values of heterosis over the mid-parent (MP) are presented in Table 11. Different hybrids showed significant ($P \leq 0.05$) heterosis for the trait studied (Table 11). Twelve of

the 21 crosses expressed positive and significant mid-parent heterosis for cob length and number of seeds per line. Eleven of the 21 crosses expressed positive and significant mid-parent heterosis for cob diameter, number of lines per cob, number of leaves per plant, leaf area index and plant height. Eight of 21 crosses expressed negative and non-significant heterosis over the mid-parent for days to 50% flowers. Vasal *et al.* (1992a) reported similar results. Negative and non-significant heterosis was also observed in one and two of the 21 crosses for grain yield and number of seed per line, respectively (Table 11). Crosses that exhibited negative heterosis had related genes and therefore shared similar genes in the combination that leads to inbreeding depression in that trait.

Six of the 21 crosses showed positive and significant heterosis above the mid-parent for 100 seed weight with the other 15 crosses showing positive but non-significant heterosis for the trait (Table 11). This is in agreement with earlier findings of Shewangizaw (1983), and Nigussie and Zelleke (2001), who found significant heterosis above mid-parent and better parent only in few cross for 100 seed weight.

Sixteeen of the 21 crosses showed significant and positive heterosis above the mid-parent for grain yield (Table 11). The expression of grain yield above the mid-parent and high-parent has been reported by several investigators (Beck *et al*; 1990, Vasal *et al*., 1992; Nigussie and Zelleke, 2001). The percent heterosis over the mid-parent for grain yield ranged from 14.49% to to 55.04%.

In general, heterosis or hybrid vigour was more frequent in grain yield, yield components, plant height, number of leaves per plant and leaf area index than other traits studied in this work. Crosses which exhibited high heterosis indicated genetic diversity between the two parents. Heterosis and heterotic pairings are the central interest to maize breeding, because the search for heterotic groups in this crop has been most rewarding (Garay *et al.*, 1996). Heterosis was fairly good for most of the traits. This indicates the existence of directional dominance and a difference in the frequencies of alleles affecting most of the traits.

The existence of useful heterosis above the mid-parent should be encouraging to plant breeders as it indicates that promising gene combinations exist, which can result in enhanced yield performance. The genetic cause of heterosis, i.e., whether overdominance, linkage betweeen partial to completely dominant genes, or epistasis, is important as it indicates not only if homozygotes or heterozoygotes represent the most ideal genotype, but also affects the choice of the most appropriate selection procedure (Moll and Stuber, 1974). Generally, it seems that directly selected traits changed in the way that would most efficiently contribute to the desirable changes of the indirectly selected traits.

**Table 11:** Percent $F_1$ heterosis above mid-parent for different traits of 21 hybrids formed from seven $S_1$ lines suitable for intercropping with common bean (2001/2002)

| Parents | GY | PH | EH | CL | CD | NL/C | NS/L | LAI | NL/P | 100SW | Q2 | DTF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KSTP001 x KSTP003 | 24.43 | 5.14 | 1.22 | 31.36* | 7.47 | 13.81 | 27.65* | 17.63* | 15.46* | 16.73* | 3.81 | 0.16 |
| KSTP001 x KSTP004 | 41.83* | 4.17 | 2.46 | 42.60** | 29.76* | 16.02* | 36.61* | 22.46* | 12.67 | 19.24** | 11.24* | 0.15 |
| KSTP001 x KSTP005 | 6.60 | 19.23* | 2.58 | 13.28 | 18.15 | 15.25 | 3.75 | 1.29 | 15.59* | 7.63 | 0.66 | 0.00 |
| KSTP001 x KSTP008 | -14.49 | 7.02 | 6.59 | 15.76 | 6.90 | 6.35 | -5.28 | 13.23* | 14.78* | 12.35* | 6.67 | -0.16 |
| KSTP001 x E2 | 42.50* | 3.87 | 11.62* | 23.86* | 26.45* | 14.94 | 16.37 | 0.27 | 10.68 | 2.67 | 3.75 | -0.48 |
| KSTP001 x E3 | 39.44* | 22.66* | 8.64* | 32.44* | 16.23 | 15.31* | 26.19* | 10.73* | 17.74* | 8.96 | 9.16* | -0.16 |
| KSTP003 x KSTP004 | 27.21* | 19.14* | 0.13 | 8.35 | 28.61* | 1.53 | 19.64 | 1.37 | 12.87 | 5.34 | -1.53 | 0.00 |
| KSTP003 x KSTP005 | 38.39* | 18.26* | 7.55* | 22.07* | 27.08* | 15.21 | 28.49 | 14.18* | 13.49* | 9.58 | -11.18 | 0.16 |
| KSTP003 x KSTP008 | 35.80* | 7.39 | 7.01 | 0.60 | 0.41 | 7.06 | 9.68 | 8.19 | 11.74 | 5.74 | 7.10 | 0.96* |
| KSTP003 x E2 | 55.04** | 7.36 | 0.36 | 24.76* | 21.85* | 6.06 | 32.28* | 1.34 | 6.41 | 0.95 | -12.06* | -0.32 |
| KSTP003 x E3 | 32.75* | 20.16* | 1.04 | 19.51 | 17.41 | 9.58 | 32.81* | 8.12 | 13.88* | 3.07 | -8.24* | 0.00 |
| KSTP004 x KSTP005 | 51.18* | 25.09** | 1.66 | 19.60 | 46.45** | 23.67* | 40.34* | 13.59* | 13.50* | 8.76 | 1.01 | 0.80* |
| KSTP004 x KSTP008 | 39.68* | 7.25 | 0.52 | 11.16 | 40.19* | 17.88* | 29.61* | 4.65 | 11.92 | 2.43 | -1.77 | 0.96* |
| KSTP004 x E2 | 51.18* | 6.33 | 0.05 | 39.48** | 38.59* | 17.73* | 39.80* | 13.10* | 8.89 | 16.30* | -4.11 | -0.33 |
| KSTP004 x E3 | 39.52* | 18.94 | 0.01 | 38.77** | 31.65* | 16.16* | 34.16* | 11.98* | 12.79 | 10.91 | -0.11 | -0.33 |
| KSTP005 x KSTP008 | 34.68* | 26.66** | 4.30 | 23.53* | 21.27 | 17.59* | 0.00 | 3.72 | 17.88* | 0.53 | 2.59 | -0.16 |
| KSTP005 x E2 | 44.54* | 23.78* | 8.60* | 24.82* | 46.37** | 19.10* | 24.61* | 4.03 | 10.59 | 9.96 | -4.28 | -0.16 |
| KSTP005 x E3 | 51.90* | 27.57** | 0.00 | 31.49* | 48.44** | 17.50* | 37.04* | 8.11 | 13.86* | 7.45 | -0.14 | 0.15 |
| KSTP008 x E2 | 36.61* | 7.00 | 10.26* | 49.55** | 21.12 | 19.35* | 21.76 | 28.57** | 9.95 | 21.28** | 1.57 | 0.64 |
| KSTP008 x E3 | 28.13* | 21.02* | 6.65* | 37.41** | 33.92* | 24.44* | 24.50 | 25.83** | 13.81* | 17.68** | 0.96 | 0.00 |
| E2 x E3 | 19.66 | 9.68 | 0.26 | 10.33 | 7.84 | 14.71 | 14.71 | 17.18* | 19.12* | 7.62 | -1.31 | 0.00 |

*,** Data is presented in percentage; however symbols represent significance of differences between $F_1$ and mid-parent means compared to $S_d$ at 0.01 and 0.05 levels, respectively.

GY = grain yield (kg/ha), DTF = days to 50% flowering, Q2 = Mean leaf angle at 50% flowering (°), PH = plant height (cm), EH = ear height (cm), NL/P = number of leaves/ plant, LAI = leaf area index, CL = cob length (cm), CD = cob diameter (cm), NL/C = number of lines/cob, NS/L = .number of seeds/lines and 100SW = 100 seeds weight (grams)

**Phenotypic Correlations**

Phenotypic correlations reflect observed relationships between traits arising from the combined effects of genotype and environment (Moll and Stuber, 1974; Pandley and Gritton, 1975). The phenotypic correlation coefficients for all possible comparisons are presented in Table 12. Grain yield was positively and significantly ($p \leq 0.01$) correlated to all other traits except mean leaf angle at 50% flowering and days to 50% flowering (Table 12). These results indicate that superior yielding ability in maize is associated with enhanced expression of yields components and most architerctural traits, and selection for them should result in a correlated response for increased yield.

100 seed weight was positively and significantly correlated to all architectural traits but significantly and negatively correlated to number of seeds per line. Therefore though selection for increased number of seeds per line would result in increased grain yield, seed weight would be reduced. Consequently, within this reference population of genotypes and environment, increases in number of seeds per line was apparently compensated for by reduction in seed size and not by grain yield.

Most of architectural traits had a significant positive correlation with grain yield. The desirable association between these architectural traits and yield is perhaps better understood if one further considers their large positive association with yield components.

The phenotypic correlations (Table 12) indicated that architectural traits are not independent, and that selection for increased levels of expression of one architectural trait will likely result in concurrent changes in the expression of others. Selection indices could be constructed to simultenously shift the levels of expression of desirable architectural traits to optimum value for maximum expression of yield. However, the time and resources necessary for development and implementation of such index may prove prohibitive. A simpler alternative might be to select simultenously for yield and yield components within morphologically heterogeneous populations, and to limit selection for architectural characteristics to those necessary for general adaptation to specific cropping systems or enviroments.

Based on how well the lines combine with each other for various traits, three Syn-1 maize varieties were reconstituted. Each of the synthetic was developed by recombining five parental lines. The predicted grain yield and leaf angle of Syn-2 of all possible combinations involving 3, 4, 5, 6 and 7 parents were calculated and the best 9 are presented in Table 13.

**Table 12**: phenotypic correlations among agronomic and architectural traits in $F_1$ progeny from a seven parent diallel (2001/2002)

| | 100SW | CL | CD | NL/C | NS/L | Q1 | PH | EH | NL/P | LAI | DTF |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GY | 0.510** | 0.501** | 0.633** | 0.745** | 0.888** | 0.165 | 0.534** | 0.557** | 0.594** | 0.672** | -0.101 |
| 100SW | | 0.347 | 0.336 | -0.460* | 0.367 | 0.398 | 0.511** | 0.698** | 0.626** | 0.871** | 0.053 |
| CL | | | 0.647** | 0.656** | 0.504** | 0.095 | 0.425* | 0.449** | 0.393* | 0.759** | -0.041 |
| CD | | | | 0.748** | 0.689** | -0.180 | 0.523** | 0.520** | 0.597** | 0.759** | 0.136 |
| NL/C | | | | | 0.397 | 0.144 | 0.646** | 0.694** | 0.782** | 0.871 | 0.093 |
| NS/L | | | | | | 0.169 | 0.578** | 0.648** | 0.680** | 0.778** | 0.123 |
| Q1 | | | | | | | 0.403** | 0.483** | 0.277 | 0.256 | -0.028 |
| PH | | | | | | | | 0.811** | 0.850** | 0.673** | 0.137 |
| EH | | | | | | | | | 0.842** | 0.779** | 0.137 |
| NL/P | | | | | | | | | | 0.835** | 0.133 |
| LAI | | | | | | | | | | | 0.077 |

*,** phenotypic correlations significant at the 0.05 and 0.01 level, respectively.

GY = grain yield (kg/ha), DTF = days to 50% flowering, Q2 = Mean leaf angle at 50% flowering (°), PH = plant height (cm), EH = ear height (cm), NL/P = number of leaves/ plant, LAI = leaf area index, CL = cob length (cm), CD = cob diameter (cm), NL/C = number of lines/cob, NS/L = .number of seeds/lines and 100SW = 100 seeds weight (grams)

**Predicted Performance of Potential Synthetic Maize Varieties**

Field evaluation of the potential parents is required to predict the yield of the synthetic varieties that are possible to be developed; a statistical comparison of the means must provide to the plant breeder an objective basis to decide about the relative genotypic values of the different synthetics under consideration. Success from a breeding program aiming at the development of synthetic varieties depends heavily upon the ability of accurately predicting the yield of each of the potential variety that can be formed with m out of n parental lines at a minimum cost. For example, with n = 7 and n = 10 ($3 \leq m \leq n$) the number of possible synthetic varieties that can be formed is 99 and 968 respectively which, from a practical point of view, cannot be assembled, not to say compared.

The predicted grain yield of Syn-2 of all possible combinations involving 3, 4, 5, 6 and 7 parents were calculated using equation 3. The predicted Syn-2 grains yield and leaf angles of the best nine synthetic maize varieties are presented in Table 13. KSTP Synthetic Maize 1 gave the highest predicted yield of 2590.48 g/plot while KSTP Synthetic 2 had the lowest predicted leaf angle (23.70°). All seven $S_1$ lines used to constitute the synthetics had similar flowering dates, which will allow random intermating between parental lines in isolation or by hand pollination. The Syn-1 formed in this study need to be randomly intermated to form Syn-2 for yield stabilisation, in accordance with Hardy-Weinberg equilibrium, for commercial use. It is expected that the grain yield of Syn-2 will decrease by 8 – 10% from the grain yield of Syn-1. In this study, the decline in predicted grain yield for the KSTP Synthetic Maize 1 and KSTP Synthetic Maize 2 from those of Syn-1 is 10.0% and 10.5%, respectively. After about three

generations synthetic varieties would stabilise before they begin to drop drastically and it is at this stage they are supposed to be replaced with newly reconstituted ones.

**Table 13**: Predicted yield and leaf angle of the potential synthetic maize varieties

| Synthetic name | Number of parents | $S_1$ lines constituting the synthetic | Predicted yield (g/plot) | Preidicted leaf angle (°) |
|---|---|---|---|---|
| KSTP Synthetic 1 | 5 | KSTP001, KSTP003, KSTP004, E2 and E3 | 2590.48 | 26.33 |
| KSTP Synthetic 2 | 5 | KSTP001, KSTP004, KSTP005, KSTP008 and E3 | 2456.12 | 23.70 |
| KSTP Synthetic 3 | 5 | KSTP001, KSTP004, KSTP005, E2 and E3 | 2535.98 | 25.86 |
| KSTP Synthetic 4 | 5 | KSTP001, KSTP003, KSTP004, KSTP005, and E3 | 2532.27 | 26.03 |
| KSTP Synthetic 5 | 5 | KSTP001, KSTP003, KSTP005, E2 and E3 | 2493.76 | 26.37 |
| KSTP Synthetic 6 | 5 | KSTP001, KSTP003, KSTP004, KSTP005, and E2 | 2440.91 | 25.96 |
| KSTP Synthetic 7 | 6 | KSTP001, KSTP003, E2, E3, KSTP004, and KSTP005 | 2575.32 | 26.56 |
| KSTP Synthetic 8 | 6 | KSTP001, KSTP003, E2, E3, KSTP004, and KSTP008 | 2524.23 | 24.96 |
| KSTP Synthetic 9 | 6 | KSTP001, KSTP003, E2, E3, KSTP005, and KSTP008 | 2449.55 | 25.00 |

Grain yield was taken from 20 randomly taken plants per plot

## 4.4 Evaluation of the Potential Synthetic Maize Vatieties under Monoculture and Intercropping Systems

### Maize Performance

There was no significant difference ($p< 0.05$) among the cropping system and maize genotype x cropping system interactions for all characters studied (Table 14). This indicated that maize performance in both monoculture and intercropping system did not differ markedly. One possible explanation was that maize is a dominant component in a maize-common bean (*Phaseolus vulgaris* L.) intercrop. Leaf display is the key to maize dominance in the intercrop with common bean (bush type). The restricted extension potential of the bush bean is ill-suited to competing with the vertically oriented maize growth. The initial phase of mutually negative interaction between the two components ended when the the vertical extension of the maize stalk resulted in an overtopping of the bean by maize canopy. Subsequent maize growth paralleled that of the monocrop maize. Therefore, the competitive balance was unequal and, thus, the performance from the increasingly dominant maize approached that achieved by the monocrop maize.

However, there was significant difference ($p< 0.05$) among the maize genotypes for all traits under study except days to maturity, number of seeds per line, number of lines per cob and 100 seed weight (Table 14). This suggested that different maize genotypes have inherently different potential. The leaf angle at 50% flowering ranged from 19.49° (KSTP Synthetic 2) to 34.94° (KSTP) (Table 15). Plant height and ear height ranged from 178.37 cm and 92.07 cm (KSTP Synthetic 2) to 225.37 cm and 111.22 cm (KSTP Synthetic 1), respectively. Grain yield ranged from 4059.98 kg/ha (KSTP) to 5654.57 kg/ha (KSTP Synthetic 1). The results of this study indicated that KSTP Synthetic 1 was superior to

others in terms of grain yield while KSTP Synthetic 2 had the smallest leaf angle. The results showed that KSTP was responsive to selection for improved grain yield and other traits.

The performance of Syn-2, which is a result of randomly mating Syn-1, is expected to be lower than that of Syn-1 formed and evaluated in this study. This is due to the production of new genotypes and a decrease in heterozygosity as a consequence of random mating. The magnitude of decline in heterozygosity in Syn-2 depends on the number of the lines involved in constituting a synthetic and on the proportion of lines having different alleles at a give locus. There was a decline of 10 – 10.5% after random mating Syn-1 consituted with five parents in this study. However, though yields of Syn-2 are lower than those of Syn-1, they are more stable in the further generation. Syn-2 is maintained by open pollinating in isolation or random mating and seeds distributed to the farmers. The predicted yield and leaf angle of Syn-2 are give in Table 13.

**Table 14:** Means squares from the analysis of variance of three potential KSTP synthetic varieties and KSTP under monoculture and intercropping with common bean in 2002/2003 at Egerton University

| Source of variation | Df | Q2 | DTF | PH | EH | NL/P | LAI | CL | CD | NL/C | NS/L | SW | GY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Replication | 2 | 3.18$^{ns}$ | 0.29$^{ns}$ | 14.72$^{ns}$ | 7.62* | 0.19$^{ns}$ | 0.05$^{ns}$ | 0.36$^{ns}$ | 0.16$^{ns}$ | 0.27$^{ns}$ | 26.50* | 7.0$^{ns}$ | 17675.33 |
| Cropping system (A) | 1 | 2.65$^{ns}$ | 0.04* | 7.42$^{ns}$ | 1.83$^{ns}$ | 0.02* | 0.01$^{ns}$ | 2.31$^{ns}$ | 0.06$^{ns}$ | 0.03$^{ns}$ | 19.97* | 4.8$^{ns}$ | 96624.11 |
| Error | 2 | 15.95 | 1.04 | 133.77 | 0.38 | 0.65 | 0.07 | 2.88 | 0.50 | 0.07 | 0.23 | 14.22 | 21429.14 |
| Maize genotypes (B) | 3 | 262.15* | 2.38* | 2397.4* | 431.8* | 4.64* | 1.14* | 262.4* | 0.50* | 0.04$^{ns}$ | 22.68$^{ns}$ | 7.3$^{ns}$ | 3019267 |
| Interaaction (AB) | 3 | 0.07$^{ns}$ | 0.15$^{ns}$ | 29.63$^{ns}$ | 19.6$^{ns}$ | 0.01* | 0.01$^{ns}$ | 0.47$^{ns}$ | 0.04$^{ns}$ | 0.01$^{ns}$ | 4.27$^{ns}$ | 1.3$^{ns}$ | 10757.44 |
| Error | 12 | 11.18 | 0.39 | 43.00 | 16.37 | 0.19 | 0.03 | 4.20 | 0.07 | 0.13 | 11.41 | 5.10 | 10138.07 |
| CV % | | 12.65 | 0.60 | 3.20 | 3.89 | 3.09 | 4.26 | 8.19 | 7.26 | 2.86 | 10.22 | 4.95 | 1.99 |

*Means are significant at 0.05 level.

$^{ns}$ Means are not significant at 0.05 level.

GY = grain yield (kg/ha), DTF = days to 50% flowering, Q2 = Mean leaf angle at 50% flowering (°), PH = plant height (cm), EH = ear height (cm), NL/P = number of leaves/ plant, LAI = leaf area index, CL = cob length (cm), CD = cob diameter (cm), NL/C = number of lines/cob, NS/L = .number of seeds/lines and 100SW = 100 seeds weight (grams)

**Table 15**: Effect of selection of KSTP to develop three potential KSTP synthetic varieties on several agronomic characters at Egerton University in 2002/2003.

| eatment | Q2 | DTF | PH | EH | NL/P | LAI | CL | CD | GY |
|---|---|---|---|---|---|---|---|---|---|
| STP-Syn1 | 23.49$^{bc}$ | 103.80$^{b}$ | 225.37$^{a}$ | 111.22$^{a}$ | 15.06$^{a}$ | 4.82$^{a}$ | 34.91$^{a}$ | 3.95$^{a}$ | 5686 |
| STP-Syn2 | 19.49$^{c}$ | 103.80$^{b}$ | 178.15$^{c}$ | 92.07$^{c}$ | 13.42$^{b}$ | 3.78$^{c}$ | 21.28$^{b}$ | 3.67$^{b}$ | 5175 |
| STP-Syn3 | 27.79$^{b}$ | 104.30$^{ab}$ | 204.83$^{b}$ | 103.99$^{b}$ | 14.39$^{a}$ | 4.37$^{b}$ | 22.51$^{b}$ | 3.46$^{b}$ | 5494 |
| STP | 34.94$^{a}$ | 105.20$^{a}$ | 212.62$^{b}$ | 108.63$^{ab}$ | 13.16$^{b}$ | 4.11$^{b}$ | 21.40$^{b}$ | 3.28$^{b}$ | 4085 |
| $D_{0.05}$ | 5.95 | 1.11 | 11.67 | 7.20 | 0.77 | 0.32 | 3.65 | 0.46 | 179.1 |

[a]means followed by the same letter are not significantly different at 0.05 level
KSTP-Syn1 = KSTP Synthetic 1, KSTP-Syn2 = KSTP Synthetic 2, KSTP-Syn3 = KSTP Synthetic 3, GY = grain yield (kg/ha), DTF = days to 50% flowering, Q2 = Mean leaf angle at 50% flowering (°), PH = plant height (cm), EH = ear height (cm), NL/P = number of leaves/ plant, LAI = leaf area index, CL = cob length (cm) and CD = cob diameter (cm)

**Maize Grain Yield**

Maize grain yield in monoculture and intercropping system did not differ significantly ($p<0.05$) (Table 14). However, maize yield was relatively higher in monoculture than in intercrop system (Table 16). Though non-significant, reduction in maize yield indicated that maize do not possess complete dominance over bean. There is still some degree of interspecific competition between the two crop component of the intercrop system for the available resources (PAR, nutrients space and water).

Maize grain yields were higher in all synthetic compared to the KSTP (original population from which they were derived). The highest grain yield was obtained from KSTP Synthetic 1 (both monoculture and intercrop) while the lowest was obtained from KSTP (both monoculture and intercrop) (Table 16). Average percentage increase in yield

for KSTP Synthetic 1, KSTP Synthetic 2 and KSTP Synthetic 3 (taking KSTP = 100%) were 141.05%, 127.76% and 135.96%, respectively. These results indicated that KSTP population was responsive to selection for improved yield. This increase in yield can be attributed partly due to heterotic group pairings and presumably partly due to increased light penetration since the developed synthetics have more erect-leaf orientation compared to KSTP. With more erect-leaf, penetration of sunlight into the canopy should result, thus increasing the total leaf area receiving the greater light intensity. In addition, it can be hypothesized that most of the leaves will intercept light due to increased light penetration and thus reducing number of parasitic leaves. This will lead to source-to-sink manipulation: increase source capacity. This would result in more photosynthetic activity and therefore, greater production of dry matter and eventually grain filling. Loomis and Connor (1992) suggested that canopies bred for increased light penetration to lower leaves in cotton give higher yields. If the penetration of light into canopy increases in proportion to the decrease of the leaf angle from the vertical, there should be an increase in photosynthesis. Greater photosynthesis means increase in production of dry matter, part of which should be converted to grain. Pendleton *et al.*, (1968) found a yield increase of 14% when leaves above the ear of pioneer 3306 were tied upright during pollination at about 10° from vertical and maintained in this position until harvest compared with the untreated check. Decreased leaf angle distribution was associated with concomitant increase in light penetration. The data from this research do not give conclusive evidence of the optimum leaf angle to be developed in maize for maximum grain production. Much more research is needed before we will learn the relationship between leaf angle and grain yield for maize. Meanwhile, the data generated from this particular study, suggest

that the maize breeder should not restrict his selection of plant types to only those that have a distinctly erect-leaf orientation as grain yield is a function of the total phenotype, and leaf angle is only one phenotypic trait that affects grain production.

The erective-leaf habit of the three potential synthetics was more evident in a short period before pollination, but gradually disappears as the plant matures. KSTP Synthetic 2 has a relatively short leaf that accentuates the erect appearance. Data on light measurements of the different maize genotypes is presented in Table 17. The highest light penetration to the ground was obtained in the KSTP Synthetic 2 while the lowest was obtained in H614. This proves our hypothesis that more erect-leaf results in more light penetration and thus less light interception.

**Table 16**: Effect of selection on grain yield in the three Syn-1 maize varieties at Egerton University in 2002/2003.

| Genotypes | Grain yield (kg/ha) | | Percentage increase | | Average |
|---|---|---|---|---|---|
| | Monocrop | Intercrop | Monocrop | Intercrop | |
| KSTP-Syn1 | 5686.49 | 5622.64 | 139.18 | 142.91 | 141.05 |
| KSTP-Syn2 | 5175.00 | 5069.72 | 126.66 | 128.86 | 127.76 |
| KSTP-Syn3 | 5494.41 | 5407.29 | 134.48 | 137.44 | 135.96 |
| KSTP | 4085.66 | 3934.30 | 100.00 | 100.00 | 100.00 |

KSTP-Syn1 = KSTP Synthetic 1, KSTP2 = KSTP Synthetic 2 and KSTP-Syn3 = KSTP Synthetic 3

**Leaf Orientation and Light Interception**

Light penetrance was higher in KSTP Synthetic 2 (1146.90 μmol $m^{-2}S^{-2}$) and was lowest in H614 (493.62 μmol $m^{-2}S^{-2}$) (Table 17). It was evident that leaf angle affect the amount of light transmitted in a maize crop. Radiation interception is influenced by several architectural attributes, including leaf orientation (Duncan, 1971; McCree and Kenner, 1974; McMillen and McClendon, 1979; Oker-blom and Kellondki, 1982; Werk and Enlerignger, 1984). One effect of leaf orientation is that it changes radiation quality and penetration depending on canopy direction. Light interception by canopy increases as the leaf orientation to horizontal increases and as the leaves of a plant develop, thus reducing the plant net photosynthesis. Horizontally oriented leaves and too many leaves will shade each other, decreasing the maximum potential photosynthesis by self shading. Therefore, breeding for more erect oriented leaves may increase the net photosynthesis and ultimately the yield of the plant. Furthermore, erect oriented leaves will allow more transmission of light to the understorey crop and thus can lead to transgressive yielding.

**Table 17**: Relationship between leaf angle and radiation transmission in maize canopy (2002/2003)

| | PH | Q2 | NL/P | Radiation (μmol $m^{-2}S^{-2}$) | | | |
|---|---|---|---|---|---|---|---|
| aize genotype | | | | Incident | Transmitted | Intercepted/reflected | LAI |
| STP-Syn1 | 178.15 | 19.49 | 13.42 | 1383.50 | 1146.90 | 236.60 | 1.25 |
| STP-Syn2 | 204.83 | 27.79 | 14.39 | 1301.80 | 982.20 | 319.60 | 1.80 |
| STP-Syn3 | 225.37 | 23.49 | 15.06 | 1436.17 | 1075.76 | 360.41 | 1.90 |
| STP | 212.62 | 34.49 | 13.16 | 1218.78 | 637.54 | 580.63 | 2.13 |
| 514 | 235.14 | 44.81 | 15.42 | 1406.87 | 493.62 | 913.25 | 2.75 |

KSTP-Syn1 = KSTP Synthetic 1, KSTP2 = KSTP Synthetic 2 and KSTP-Syn3 = KSTP Synthetic 3, Q2 = mean leaf angle (°), PH = Plant height (cm) during time of radiation measurement, NL/P = number of leaf per plant, LAI = leaf area index given by sunscan canopy analysis systems (hence the lower value compared to those done using the formula method).
All measurements were taken at 50% flowering.

**Bean Performance**

There was significant difference ($P<0.05$) among different bean treatment for all traits under study (Table 18). This can be attributed to difference in leaf angle for different maize genotypes used in the maize – bean intercrop. The different maize genotype had different canopy architecture and transmitted light differently to the understorey bean crop (Table 17). Therefore, light intensity at the undercrop level was different for different maize genotypes. Decreased leaf angle to vertical was associated with concomitant increase in light penetration. The difference in light intensity reaching the understorey crop would lead to the difference in growth and accumulation of dry matter and eventually grain yield.

The highest yield of 2134.36 kg/ha was obtained when bean was planted solely, while the lowest yield of 1031.37 kg/ha was obtained when bean were intercropped with H614. The bean height ranged from 44.70 cm (KSTP – bean intercrop) to 48.97 cm (H614 – bean intercrop). Number of branches per plant ranged from 2.72 (H614 – Bean intercrop) to 3.78 (bean sole crop). Days to 50% flowering ranged from 65.22 days (bean monocrop) to 71.18 day (H614 – bean intercrop). Number of pods per plant ranged from 8.17 (H614 - bean intercrop) to 16.18 (bean monocrop) while 100 seeds weight ranged from 31.23 g (H614 - bean intercrop) to 35.92 g (bean monocrop) (Table 19). Bean under H614 were taller, had few branches and mature late whereas sole bean matured early, had more branches and shorter. This indicates that shading leads to increased height, prolonged maturity, reduced branches and reduced yield, but more light penetration increases yield.

The performance of bean was clearly affected by the maize intercrop component. There was decrease in performance of all traits under study except days to 50% flowering (Table 19). This could be attributed to sink limitation to photosynthesis. This occurs when the ability of the source is limited by the competition for environmental resources. Though not measured in this study, there is close correlation between grain yield and activity of leaves from which the photosynthetic is predominantly drawn. One possible explanation for delayed flowering and bigger plants in H614 was that due to competition for light, bean plants remained vegetative for longer periods than those which encountered less competition and as such a great proportion of leaves not necessarily active in photosynthesis.

**Table 18**: Mean squares from analysis of variance of common bean in 2002/2003 at Egerton University

| Source of variation | df | DTF | PH | NB/P | NP/P | 100SW | GY |
|---|---|---|---|---|---|---|---|
| Replication | 2 | | $0.09^{ns}$ | 0.01ns | $0.10^{ns}$ | $0.15^{ns}$ | $1961.25^{ns}$ |
| Treatments | 5 | | 7.38* | 0.59* | 25.09* | 9.05* | 434650.35* |
| Error | 10 | | 0.36 | 0.00 | 0.14 | 0.38 | 7169.95 |
| CV % | | | 1.31 | 1.62 | 3.14 | 1.78 | 5.57 |

* The mean difference is significant at the 0.05 level
$^{ns}$ The mean difference is not significant at the 0.05 level
GY = grain yield (kg/ha), DTF = days to 50% flowering, PH = plant height (cm), NB/P = number of branches/plant, NP/P = number of pods/plant and 100SW = 100 seeds weight (grams)

**Table 19**: Effect of intercropping on bean plant performance in 2002/2003 at Egerton University

| Treatments | DTF | PH | NB/P | NP/P | 100SW | GY |
|---|---|---|---|---|---|---|
| Bean monocrop | 65.22 | $45.90^{b}$ | $3.78^{a}$ | $16.18^{a}$ | $35.92^{a}$ | $2134.36^{a}$ |
| KSTP-Syn1/bean | 67.99 | $45.21^{bc}$ | $3.72^{a}$ | $13.42^{b}$ | $35.10^{a}$ | $1538.44^{c}$ |
| KSTP-Syn2/bean | 67.33 | $44.92^{bc}$ | $3.69^{a}$ | $13.20^{b}$ | $35.74^{a}$ | $1648.42^{b}$ |
| KSTP-Syn3/bean | 68.12 | $45.81^{b}$ | $3.30^{b}$ | $11.49^{c}$ | $35.26^{a}$ | $1448.94^{c}$ |
| KSTP/bean | 68.98 | $44.70^{c}$ | $2.98^{c}$ | $9.56^{d}$ | $34.83^{a}$ | $1257.64^{d}$ |
| H614/bean | 71.18 | $48.97^{a}$ | $2.72^{d}$ | $8.17^{e}$ | $31.23^{b}$ | $1031.37^{e}$ |
| $LSD_{0.05}$ | | 1.09 | 0.01 | 0.69 | 1.12 | 154.00 |

[a]means followed by the same letter are not significantly different at 0.05 level
KSTP-Syn1 = KSTP Synthetic 1, KSTP2 = KSTP Synthetic 2 and KSTP-Syn3 = KSTP Synthetic 3, GY= grain yield (kg/ha), PH = plant height (cm), DTF = days to 50% flowering, NB/P = number of branches per plant, NP/P = number of pods per plant and 100SW = 100 seed weight (grams)

**Bean Grain Yield**

In all cases bean seed yield was reduced compared to sole cropping. Yield reduction ranged from 23.09% (KSTP Synthetic 2/bean intercrop) to 51.88% (H614 - bean intercrop) (Table 20). Clark (1980) found a yield decrease by 40% of bush bean in maize-bean intercrop while Fininsa (1997) found a reduction of 67%. Willey and Osiru (1972) and Dagnew (1981) have also reported` yield reduction for both maize and bean in a maize –bean intercrop system. Since bean yield tends to reduced with decrease in light transmission it can be inferred that the yield of bean were reduced because of shading. The greater reduction (51.78%) was obtained when intercropped with H614 (1031.37kg/ha). H614 had the least light transmission of 493.62 umol $m^{-2}s^{-2}$ (Table 17).

Competition for light has been considered one of the major factors contributing towards reduction in yield and growth of plants in polycultures. Using additive and substitutive designs, Trenbath and Harper (1973) found that shading affected the pattern of growth of *Avena* species used as indicators in interspecific mixtures. Lockhart (1961) showed that the slow growth of pinto bean at low light intensity was due to a deficiency of photosynthetic products.

The critical determinant of intercropped bean yield is lateral rather than the vertical leaf area distribution (Clark, 1980). The leaf area of the bush bean is restricted to almost entirely to the bottom one metre of canopy. The bush bean maximizes its yield under light limiting conditions by minimizing direct competition with maize for light energy. Therefore in maize bean intercrop, by breeding for decreased leaf angle to the vertical

may have the useful effect of increasing bean yield without concomitant risk of stimulating bean competition. This is because it will allow for more light transmission to the understorey bean which has limited extension thus minimizing its ability to compete effectively with maize for light energy.

In general, though not specifically determined, yield reduction could be due to interspecific competition for available resources such as nutrients, water, space and photosynthetic active radiation. In addition, yield reduction could also be associated with reduced number of pods per plant and seeds per plant.

Clearly, intercropping with bean can successfully exploit underutilized early season resources and contribute to transgressive yielding only if the bean does not directly compete with the maize during later growth. The critical point is the accessibility of the intercrop to resources which were available, but unutilized by seedling maize. These resources can support transgressive yielding, however, only if the bean yield contribution is not exceeded by a corresponding maize yield loss. The specific competition balance attained by the bean and the maize determines not only the individual yield of each component but total system yields as well. Shifting the balance of resources use between the bean and maize by means of modification in maize canopy structure clearly demonstrates that the highest yields of bean were attained when the dominant maize had the smallest leaf angle. Thus resulting in higher light transmission to the understorey bean.

**Table 20**: Effect of maize-bean intercrop on bean yield (2002/2003)

| Treatment | Bean yield (kg/ha) | Percentage decrease |
|---|---|---|
| Bean monocrop | 2143.36 | 00.00 |
| H614/bean | 1035.37 | 51.78 |
| KSTP/bean | 1157.62 | 45.99 |
| KSTP-Syn1/bean | 1538.44 | 28.22 |
| KSTP-Syn2/bean | 1648.42 | 23.09 |
| KSTP-Syn3/bean | 1446.94 | 32.49 |

KSTP-Syn1 = KSTP Synthetic 1, KSTP2 = KSTP Synthetic 2 and KSTP-Syn3 = KSTP Synthetic 3

**Productivity of Intercropping**

It will be recalled that the major objective of this study was to determine whether or not intercropping bean with maize increases food production per unit area and hence economic returns per unit land. Data presented in Table 21 indicate that intercropping bean with maize increases food production per unit area. Productivity of intercropping was evaluated using partial and total LERs as indices.

Partial and total LERs for maize and bean intercropping are shown in Table 21 and both LERs for associate crops under the intercropping varied significantly ($P<0.05$). Partial LERs for the crops in the intercropped system are less than one. In the intercropping KSTP Synthetic 2 with bean the total LER indicates about 75% (highest) relative yield advantage while that of H614 - bean indicated about 49% (lowest) relative advantage. The productivity of bean/maize intercropping as determined by total LER, in all

combinations, was superior in resource use efficiently compared to sole cropping. However, in H614, bean produced only the equivalent of 49% of its sole crop yield while 77% was attained in KSTP Synthetic 2. Similarly, the equivalent of 101 percent and 96%, maize sole crop yield was harvested when H614 and KSTP were grown in an intercrop system, respectively. While H614 and KSTP hurt the bean most through shading (Table 17 &18), the potential KSTP synthetic varieties hurt bean the least therefore achieving the objective of the study. On the other hand, maize was not quite hurt by the bean (Table 21), in fact the yield of H614 is improved as a result of intercropping. This could be attributed to compensatory yield.

The bean-maize intercropping system increased the overall productivity. This cereal/legume intercropping could benefit smallholder through generating sustainable income, minimizing risk of crop failure and providing a source of protein diet. The inclusion of a nitrogen fixing legume in the system may improve fertility of Kenyan farms soils in the long run, which are continuously depleted because of continuous maize and sorghum cultivation. Future study should investigate the performance of indeterminate bean. Moreover, the effects of intercropping system on the associate crops pathosystem and insects pests deserve research attention.

**Table 21**: productivity of intercropping (2002/2003)

| Treatment | Land equivalent ratio (LER) | | |
|---|---|---|---|
| Intercropped genotype | Productivity | | |
| | Partial LER | | Total LER |
| | Bean | Maize | |
| KSTP-Syn1 | 0.75 | 0.99 | 1.74 |
| KSTP-Syn2 | 0.77 | 0.98 | 1.75 |
| KSTP-Syn3 | 0.68 | 0.98 | 1.66 |
| KSTP | 0.59 | 0.96 | 1.55 |
| H614 | 0.48 | 1.01 | 1.49 |

KSTP-Syn1 = KSTP Synthetic 1, KSTP2 = KSTP Synthetic 2 and KSTP-Syn3 = KSTP Synthetic 3

# CHAPTER 5

## General Discussion, Summary, Conclusion and Recommendations

### 5.1 General Discussion

Results of this study have opened an avenue which crop scientists in general and plant breeders in particular can continue to explore ways of increasing food production per unit area of land. This study has shown that with proper selection of crops and breeding genotypes for specific niches, food production can be greatly increased. In addition, breeding for more erectophile leaves can result in high yielding varieties which can be grown either as monoculture or as intercrop depending on the choice of the farmer. Due to their compact growth (erectophile leaves) when grown in monoculture with a slight population increase, the yield would be even higher. The crops selected in this study have shown their promise as candidates for intercropping investigation. By virtue of their ability to fix nitrogen, common bean are good candidates for combinations with cereal crops. Intercropping become important as it allows efficient utilization of soil nutrients and moisture, and solar radiation resources during the early stages of crop growth. Both economic and biological yield increases could be attributed to the more efficient utilization of both nutrients in the soil and photosynthetic active radiation (PAR)

Plant diversification can improve utilization of solar energy greatly. The importance of plant architectural design in facilitating intercropping cannot be overlooked. A plant capable of allowing more light penetration in an intercropping regime is more adaptable to intercropping than others. It is believed that the differences noted between bean intercropped with different maize genotypes were due to difference in light transmission (Table 17). KSTP Synthetic 2 which had more erect leaf orientation (19.49°) tended to

cause less shading of understorey bean compared to H614 which has more horizontal leaf orientation (44.81°) hence the high bean yield (1648.42 kg/ha) in KSTP Synthetic 2/bean intercrop compared to that of H614 - bean intercrop (1031.37 kg/ha) (Table 20). Therefore, modification of canopy geometry is an important consideration when developing varieties for intercropping system as well as high yielding varieties. Canopy architecture determines the interception of solar radiation by the crop and the distribution of irradiance among individual leaves and component crop(s) (Loomis and Connor, 1992).

The amount of photosynthetic active radiation (PAR) absorbed by a canopy is an important driving variable for vegetative process such as photosynthesis. The photosynthetic rates of crops depend on the quality of radiation they intercept and on the efficiency achieved in utilization (Nouvello *et al.*, 2000), which is dependent on canopy structure. The description of plant canopies and their interception of radiation have been the subject of considerable scientific endeavour involving both experimental and modeling investigations. Interception of radiation by plant canopies, which is key process determining the growth and productivity of plants, is described in many physiological models using Beer's Law (Monteith and Unsworth, 1990; Jones, 1992; Van Gardingen *et al.*, 1999).

$I_i = I_o \exp(-kL_i)$ .....(17)

Where k is an extinction coefficient for instantaneous or daily integrated PAR, $I_i$ is the radiation flux at $i^{th}$ level within the canopy, $I_o$ is the flux incident above the canopy and $L_i$

is the leaf area index of the canopy above the $i^{th}$ level. Therefore, the photosynthesis of the entire canopy per unit ground area is the sum of the component layers.

The importance of canopy architecture and leaf response to photosynthesis has been described by Davidson and Phillip (1958). Canopies with planophile leaves (large k) receive high irradiance on the top leaves, which, with small vertical distribution of gross photosynthesis are increasingly light saturated. Canopies with erectophile displayed leaves (small k) have more even distribution of low irradiance over their leaf surfaces (cosine law) and hence have less light saturation and higher photosynthesis per unit of intercepted radiation at any value of vertical distribution of gross photosynthesis. This could partly explain why the developed potential/parental KSTP synthetic varieties, which had more erectophile leaves compared to KSTP, gave higher yields despite having lower LAI compared to that of KSTP (Table 17). The higher LAI and aggregated foliage distribution associated with KSTP would cause increased foliage overlap and foliage self shading, thus reducing light capture efficiency and quality of light intercepted by the crops. The upper canopy intercepted most of the light thus reducing light penetrating the lower canopy (Table 17). Canopy architecture influences light penetration by influencing light extinction (k) (Sampson and Smith, 1983). It should be noted that if the light response of the component leaves were linear, there would be no light saturation within the canopy and so at full cover, canopy structure would have no significance to crop net photosynthesis. Loomis and Connor (1992) noted that highly productive canopies have the characteristics of erective leaves, which is in agreement with the results of this study.

The author believes that, since maize bred for intercropping has also proved to be superior for monoculture, the choice of whether or not bean should be intercropped with maize should be left to grower and no attempt will be made here to influence growers choice. It is therefore concluded that intercropping bush bean with maize bred and selected for intercropping can support transgressive yielding and thus contribute to food security.

The findings of this study are an asset to the developing countries where land is becoming more and more of a premium and labour is abundant and cheap while food, shortages are rampant. The cost of fertilizer is prohibitive and as such any method that benefit from low soil fertility would undoubtedly be considered superior to any other whose success depend on high soil fertility.

At this juncture, it is important to state that the principal objective of this study was to develop synthetic maize that will offer less shading to the understorey bean crop. Three distinct synthetic varieties were developed. The importance of synthetic varieties to small scale resource poor farmers is based on the following two reasons, (1) synthetic varieties are inexpensive superior cultivars which farmers can maintain themselves and (2) they provide source of material from which inbred lines can be obtained for the development of future hybrids. For instance maize breeding programmes in Kitale, in Western Kenya, a number of high yielding maize hybrids have been developed by crossing inbred lines obtained from Kitale synthetic II and Ecuador 573. The crosses gave greatest

improvement and the largest heterosis because the two varieties are sources of extreme genetic diversity.

In this study the rationale for utilization of Kakamega striga tolerant population (KSTP) to enhance intercropping possibilities is based on five principal arguments: (1) it is well adapted to local production constraints and therefore reduce genetic vulnerability to unpredictable biological and environmental hazards, (2) exploitation that can enhance yield of elite cultivars (3) KSTP can be a valuable donor of genes for special traits such as tolerance to striga (4) it is an unimproved open pollinated variety adapted to local conditions in western Kenya being tolerant to striga weeds, common weed in these region, gives it an edge over the rest maize germplasm and (5) most farmers in Kenya West and East of the Rift valley practice intercropping systems, mainly cases maize-bean intercrop

## 5.2 Summary

The objective of this study was to increase gene frequencies of the desirable traits in partially inbred progenies derived from KSTP using $S_1$ selection method. Breeding lines suitable for the intercropping with high genetic potential were also sought. Given success with this approach we then wished to evaluate agronomic performance and combining ability of the breeding lines in a diallel cross without reciprocal, and evaluations conducted at Egerton University. Acceptable performance across the lines indicated suitability of the germplasm for utilization by breeders. GCA effects for 12 agronomic and architectural traits estimated from field evaluation of a diallel scheme were used to

evaluate the genetic diversity and relationship of the breeding lines. Heterosis among the lines was also determined. The results showed that GCA effects could be used to measure the divergence in maize population. The KSTP population had heritable positive attributes transmitted to its progeny. Genetic effects were mostly additives, but a significant dominance effect was detected in all traits under study. A gain in heterosis for the crosses was detected, which might become feasible if selfing ($S_1$) selection method was continued. It was concluded that $S_1$ selection being intrapopulation improvement was the best in this case. Interpopulation selection methods such as reciprocal recurrent or use of testers would be ideal, if the strategy was to develop hybrids from two basic diversified breeding populations.

Recurrent selection using $S_1$ progeny is regarded as the fastest method of intra-population improvement for fixing and stabilizing the genes (Moll and Smith, 1981). The method capitalizes on genes with additive effects and is expected to rapidly eliminate deleterious recessive alleles that are evident soon after selfing (Hallauer and Maranda, 1988). It is especially well suited for traits with moderate values of narrow sense heritability ($h^2$) and when the frequency of favorable alleles is intermediate to high (St. Martin, 1986). It is effective for improving the population per se and, to a lesser extent, the population cross (Moreno-Gonzalez and Cubero, 1993). However, $S_1$- progeny selection must be used with caution, since genetic variability in the population decreases as homozygosity increases leading to inbreeding depression.

Finally, the result showed that KSTP population was responsive to selection for suitability to intercrop with bush bean and improved grain yield. Generally it seems that directly selected traits changed in the way that would most efficiently contribute to the desirable changes of the indirectly selected traits, such as grain yield and its component. There are two types of responses in a population undergoing selection, direct and indirect. The traits of main interest are evaluated and used as selection criteria; therefore, they respond directly to selection. Other traits change because they correlated with the directly selected traits due to either pleotropy, linkages or they may change because of the effects of inbreeding or genetic drift. They are considered to be indirectly selected traits and their responses to selection cannot always be anticipated. In this study, traits that were used as selection criteria included: leaf angle, plant height, number of leaves per plant and leaf area index. Traits such as yield and yields compounds were indirectly selected for.

**5.3 Conclusions**

The primary objective of the selection programme was achieved since $S_1$ selection was successful in improving the original KSTP population after only one cycle of selection, exploiting both additive and dominance effect. It is likely that few alleles have been lost after only one cycle of $S_1$ selection, thus the alleles responsible for the observed heterosis are likely to be present in improved KSTP but in increased frequency.

The study showed that for most traits the ratio of GCA:SCA was greater than one. This suggested that additive gene action appears to be the primary source of variation in the open-pollinated KSTP maize population. However for all traits a significant SCA was detected, suggesting that both additive and dominance gene actions were important in this

study. Narrow sense heritability ($h^2$) estimates also indicated that the additive genetic variance contributed a fair proportion of the genotypic variance of most of the traits studied. Estimates of heterosis also indicated a significant and positive heterosis values over the mid-parent, which can be exploited in the development of new hybrid cultivars which exploit the phenomena of heterosis.

Three potential/parental synthetic maize varieties, KSTP Synthetic Maize 1, KSTP Synthetic Maize 2 and KSTP Synthetic 3 were developed. KSTP Synthetic Maize 2 had the highest light transmission to the ground and gave the highest bean yield (23% reduction over bean monocrop) under intercrop system. It was the best for intercropping with beans. KSTP Synthetic 1 gave the highest maize grain yield (41% yield increase over KSTP) and it would be the best for monocropping. It was evident that intercropping with KSTP Synthetic Maize 2 offered the highest benefits. Both Njoro Synthetic Maize 1 and Njoro Synthetic Maize 2 gave almost equal total LER of 1.74 and 1.75, respectively. This indicated that both synthetic varieties would be suitable for intercropping system. Predicted yield and leaf angle of Syn-2 maize varieties also indicated KSTP Synthetic Maize 1 having the highest grain yield (2590.48 g/plot) while KSTP Synthetic 2 had the smallest leaf angle of 23.70°. The decline in predicted yield of KSTP Synthetic Maize 1 and KSTP Synthetic Maize 2 from those of Syn-1 is 10.0% and 10.5%, respectively. Based on the predicted grain yield and leaf angle, and bean grain yield under intercrop KSTP Synthetic Maize 1 and KSTP Synthetic Maize 2 were recommended for further evaluation and commercial use.

The potential Njoro synthetic maize varieties can be further improved using recurrent selection method. These synthetic maize varieties can be maintained by open pollination by farmers for a period of three to five seasons. These synthetics will be suitable for growing under monocropping and intercropping with common bean.

For two to three decades breeders have based their selection criteria on parameters such as days to flowering, root and stalk lodging, disease and pest attack, ear and plant height, variables which are not directly related to dry matter accumulation. Consequently, a slow progress in yield improvement has been achieved. This study has shown that in addition to the usual components of grain yield, focussing selection on photosynthetic apparatus achieved rapid progress in yield improvement. Our next move should be to look at the flow, intake and assimilation of carbon dioxide around the leaf canopy of plant since carbon forms the basic structure of carbohydrates.

**5.4 Recommendations**

Most of the maize varieties currently in the market are mainly hybrid maize, which were selected and bred for monoculture. It is therefore recommended that the procedure adopted in this particular study be applied to improve plant geometry of their parental lines before they are used in production of hybrids for two reasons (i) to make them suitable for intercropping and (ii) to improve their yields. The study recommends large scale evaluation and assessment of the developed potential/parental synthetic maize varieties, and the commercial hybrids in the market to test and confirm the findings in medium maturing agro-ecological zones in the region, and increase the seed.

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## Appendices

### Appendix 1: General characterization of maize germplasm.

Appendix 1a: Analysis of variance table for mean leaf angle at flower initiation.

| Source | df | SS | Ms | F value | P value |
|---|---|---|---|---|---|
| Replication | 3 | 23.03 | 7.68 | 1.98 | 0.14 |
| Treatments | 9 | 3929.99 | 436.67 | 112.43 | 0.00 |
| Error | 27 | 104.86 | 3.88 | | |
| Total | 39 | 4059.89 | | | |

Appendix 1b: Analysis of variance table for mean leaf angle at 50% flowering.

| Source | df | SS | Ms | F value | P value |
|---|---|---|---|---|---|
| Replication | 3 | 12.60 | 4.20 | 1.63 | 0.21 |
| Treatments | 9 | 4263.37 | 473.71 | 183.63 | 0.00 |
| Error | 27 | 69.65 | 2.58 | | |
| Total | 39 | 4345.62 | | | |

Appendix 1c: Analysis of variance table for mean leaf angle after flowering

| Source | df | SS | Ms | F value | P value |
|---|---|---|---|---|---|
| Replication | 3 | 7.30 | 2.43 | 1.51 | 0.24 |
| Treatments | 9 | 4193.23 | 465.91 | 288.70 | 0.00 |
| Error | 27 | 43.57 | 1.61 | | |
| Total | 39 | 4244.10 | | | |

Appendix 1d: Analysis of variance table for number of leaves per plant

| Source | df | SS | Ms | F value | P value |
|---|---|---|---|---|---|
| Replication | 3 | 3.54 | 1.81 | 1.21 | 0.33 |
| Treatments | 9 | 91.00 | 10.11 | 10.33 | 0.00 |
| Error | 27 | 26.42 | 0.98 | | |
| Total | 39 | 120.96 | | | |

Appendix 1e: Analysis of variance table for leaf area index.

| Source | df | SS | Ms | F value | P value |
|---|---|---|---|---|---|
| Replication | 3 | 2.32 | 0.77 | 3.96 | 0.02 |
| Treatments | 9 | 16.14 | 1.79 | 9.19 | 0.00 |
| Error | 27 | 5.27 | 0.20 | | |
| Total | 39 | 23.72 | | | |

Appendix 1f: Analysis of variance table for plant height.

| Source | df | SS | Ms | F value | P value |
|---|---|---|---|---|---|
| Replication | 3 | 1108.63 | 369.54 | 7.01 | 0.00 |
| Treatments | 9 | 59102.39 | 6566.93 | 124.58 | 0.00 |
| Error | 27 | 1423.27 | 52.71 | | |
| Total | 39 | 61634.30 | | | |

Appendix 1g: Analysis of variance table for ear height.

| Source | df | SS | Ms | F value | P value |
|---|---|---|---|---|---|
| Replication | 3 | 380.17 | 126.72 | 8.80 | 0.00 |
| Treatments | 9 | 31356.02 | 3484.00 | 242.05 | 0.00 |
| Error | 27 | 388.63 | 14.39 | | |
| Total | 39 | 32124.83 | | | |

**Appendix 2: Diallel evaluation trials.**

Appendix 2a: Means for diallel hybrids and the parental lines

| Entry | Grain yield | Leaf angle | Plant height | Number of leaves/plant | Leaf area index |
|---|---|---|---|---|---|
| KSTP001 | 1329.79 | 17.66 | 155.92 | 12.43 | 3.63 |
| KSTP001 X KSTP003 | 2698.58 | 27.81 | 179.94 | 14.41 | 4.27 |
| KSTP001 X KSTP004 | 2967.45 | 19.33 | 175.80 | 14.05 | 4.47 |
| KSTP001 X KSTP005 | 2090.64 | 18.91 | 202.63 | 14.61 | 3.93 |
| KSTP001 X KSTP008 | 1856.82 | 18.48 | 176.67 | 13.82 | 3.77 |
| KSTP001 X E2 | 2846.13 | 26.18 | 170.32 | 13.78 | 3.73 |
| KSTP001 X E3 | 2983.05 | 22.50 | 209.06 | 14.87 | 4.23 |
| KSTP003 | 1407.73 | 24.36 | 166.66 | 12.52 | 3.63 |
| KSTP003 X KSTP004 | 2711.02 | 28.92 | 184.75 | 14.12 | 3.70 |
| KSTP003 X KSTP005 | 2768.13 | 28.99 | 201.24 | 14.39 | 4.43 |
| KSTP003 X KSTP008 | 2078.73 | 24.15 | 177.83 | 13.51 | 3.70 |
| KSTP003 X E2 | 2815.92 | 27.95 | 176.59 | 13.29 | 3.77 |
| KSTP003 X E3 | 2958.47 | 28.99 | 205.41 | 14.44 | 4.13 |
| KSTP004 | 1254.60 | 27.87 | 166.89 | 12.50 | 3.67 |
| KSTP004 X KSTP005 | 2982.41 | 28.84 | 210.24 | 14.38 | 4.43 |
| KSTP004 X KSTP008 | 2832.74 | 22.87 | 175.03 | 13.52 | 3.60 |
| KSTP004 X E2 | 2962.84 | 28.55 | 172.36 | 13.59 | 4.23 |
| KSTP004 X E3 | 2932.66 | 28.93 | 200.49 | 14.29 | 4.30 |
| KSTP005 | 992.74 | 27.85 | 169.25 | 12.84 | 4.13 |
| KSTP005 X KSTP008 | 2697.47 | 22.92 | 208.20 | 14.44 | 3.77 |
| KSTP005 X E2 | 2643.40 | 29.50 | 202.10 | 13.99 | 4.13 |
| KSTP005 X E3 | 2993.87 | 28.81 | 216.54 | 14.62 | 4.40 |
| KSTP008 | 1413.11 | 20.73 | 159.51 | 11.65 | 3.20 |
| KSTP008 X E2 | 2785.61 | 21.32 | 169.50 | 13.26 | 4.50 |
| KSTP008 X E3 | 2794.72 | 23.13 | 199.52 | 13.93 | 4.53 |
| E2 | 1064.90 | 21.24 | 157.30 | 12.46 | 3.80 |
| E2 X E3 | 2901.65 | 29.82 | 179.62 | 14.83 | 4.57 |
| E3 | 2149.26 | 29.05 | 170.22 | 12.83 | 4.00 |

Grain yield was obtained from 20 randomly selected plants per plot

Appendix 2b: Analysis of variance for grain yield in grams per plot.

| Source | df | SS | Ms | F – value | F - criti cal at 5% level |
|---|---|---|---|---|---|
| Genotypes | 27 | 13499226.26 | 499971.34 | 123.81 | 1.65 |
| Blocks | 2 | 2663.68 | 1331.84 | 0.33 | |
| Error | 54 | 218061.54 | 4038.18 | | |
| Total | 83 | 13719951.47 | | | |

Appendix 2c: Analysis of variance for mean leaf angle at 50% flowering in degrees.

| Source | df | SS | Ms | F - value | F - critical at 5% level |
|---|---|---|---|---|---|
| Genotypes | 27 | 710.61 | 26.32 | 11.28 | 1.65 |
| Blocks | 2 | 0.294 | 0.15 | 0.06 | |
| Error | 54 | 125.99 | 2.33 | | |
| Total | 83 | 836.90 | | | |

Appendix 2d: Analysis of variance for plant height in cm.

| Source | df | SS | Ms | F - value | F - critical at 5% level |
|---|---|---|---|---|---|
| Genotypes | 27 | 34362.04 | 1272.67 | 31.27 | 1.65 |
| Blocks | 2 | 83.83 | 41.91 | 1.03 | |
| Error | 54 | 2197.98 | 40.70 | | |
| Total | 83 | 36643.85 | | | |

Appendix 2e: Analysis of variance for ear height in cm.

| Source | df | SS | Ms | F – value | F-critical at 5% level |
|---|---|---|---|---|---|
| Genotypes | 27 | 11434.84 | 423.51 | 22.83 | 1.65 |
| Blocks | 2 | 3.86 | 1.93 | 0.10 | |
| Error | 54 | 1001.63 | 18.55 | | |
| Total | 83 | 12440.33 | | | |

Appendix 2f: Analysis of variance for number of leaves per plant.

| Source | df | SS | Ms | F - value | F-critical at 5% level |
|---|---|---|---|---|---|
| Genotypes | 27 | 212.476 | 7.87 | 49.21 | 1.65 |
| Blocks | 2 | 0.01 | 0.01 | 0.04 | |
| Error | 54 | 8.64 | 0.16 | | |
| Total | 83 | 221.12 | | | |

Appendix 2g: Analysis of variance for leaf area index.

| Source | df | SS | Ms | F - value | F-critical at 5% level |
|---|---|---|---|---|---|
| Genotypes | 27 | 23.90 | 0.89 | 14.70 | 1.65 |
| Blocks | 2 | 0.02 | 0.01 | 0.12 | |
| Error | 54 | 3.25 | 0.06 | | |
| Total | 83 | 27.17 | | | |

Appendix 2h: Analysis of variance for cob length in cm.

| Source | df | SS | Ms | F - value | F-critical at 5% level |
|---|---|---|---|---|---|
| Genotypes | 27 | 2547.00 | 94.33 | 29.69 | 1.65 |
| Blocks | 2 | 8.49 | 4.25 | 1.34 | |
| Error | 54 | 171.55 | 3.18 | | |
| Total | 83 | 2727.04 | | | |

Appendix 2i: Analysis of variance for cod diameter in cm.

| Source | df | SS | Ms | F - value | F-critical at 5% level |
|---|---|---|---|---|---|
| Genotypes | 27 | 21.54 | 0.80 | 7.63 | 1.65 |
| Blocks | 2 | 0.09 | 0.05 | 0.44 | |
| Error | 54 | 5.64 | 0.10 | | |
| Total | 83 | 27.27 | | | |

Appendix 2j: Analysis of variance for number of lines per cob.

| Source | df | SS | Ms | F - value | F-critical at 5% level |
|---|---|---|---|---|---|
| Genotypes | 27 | 129.69 | 4.80 | 13.04 | 1.65 |
| Blocks | 2 | 1.96 | 0.98 | 2.66 | |
| Error | 54 | 19.89 | 0.37 | | |
| Total | 83 | 151.54 | | | |

Appendix 2k: Analysis of variance for number of seeds per line.

| Source | df | SS | Ms | F – value | F-critical at 5% level |
|---|---|---|---|---|---|
| Genotypes | 27 | 1756.38 | 65.05 | 13.53 | 1.65 |
| Blocks | 2 | 0.74 | 0.37 | 0.08 | |
| Error | 54 | 259.68 | 4.81 | | |
| Total | 83 | 2016.80 | | | |

Appendix 2l: Analysis of variance for 100 seed weight in grams.

| Source | df | SS | Ms | F – value | F-critical at 5% level |
|---|---|---|---|---|---|
| Genotypes | 27 | 692.66 | 25.65 | 8.55 | 1.65 |
| Blocks | 2 | 3.46 | 1.73 | 0.58 | |
| Error | 54 | 161.95 | 3.00 | | |
| Total | 83 | 858.07 | | | |

Appendix 2m: Analysis of variance, Griffing's general combining ability, method II, fixed model, for grain yield.

| Source | df | SS | Ms | F - value | F –critical at 5% |
|---|---|---|---|---|---|
| GCA | 6 | 10446470.57 | 1741078.43 | 431.15 | 2.25 |
| SCA | 21 | 12193417.44 | 580638.93 | 143.79 | 1.75 |
| Error | 54 | 218061.54 | 4038.18 | | |

Appendix 2n: Analysis of variance, Griffing's general combining ability, method II, fixed model, for mean leaf at 50% flowering.

| Source | df | SS | Ms | F - value | F –critical at 5% |
|---|---|---|---|---|---|
| GCA | 6 | 389.28 | 64.88 | 27.81 | 2.25 |
| SCA | 21 | 216.33 | 10.30 | 4.42 | 1.75 |
| Error | 54 | 125.99 | 2.33 | | |

Appendix 2o: Analysis of variance, Griffing's general combining ability, method II, fixed model, for plant height.

| Source | df | SS | Ms | F - value | F –critical at 5% |
|---|---|---|---|---|---|
| GCA | 6 | 20404.20 | 3400.70 | 83.55 | 2.25 |
| SCA | 21 | 24159.94 | 1150.47 | 28.26 | 1.75 |
| Error | 54 | 2197.98 | 40.70 | | |

Appendix 2p: Analysis of variance, Griffing's general combining ability, method II, fixed model, for number of leaves per plant.

| Source | df | SS | Ms | F - value | F –critical at 5% |
|---|---|---|---|---|---|
| GCA | 6 | 123.97 | 20.66 | 129.21 | 2.25 |
| SCA | 21 | 198.70 | 9.46 | 59.17 | 1.75 |
| Error | 54 | 8.64 | 0.16 | | |

Appendix 2q: Analysis of variance, Griffing's general combining ability, method II, fixed model, for leaf area index.

| Source | df | SS | Ms | F - value | F –critical at 5% |
|---|---|---|---|---|---|
| GCA | 6 | 10.25 | 1.71 | 28.38 | 2.25 |
| SCA | 21 | 20.48 | 0.98 | 16.19 | 1.75 |
| Error | 54 | 3.25 | 0.06 | | |

Appendix 2r: Analysis of variance, Griffing's general combining ability, method II, fixed model, for ear height.

| Source | df | SS | Ms | F - value | F –critical at 5% |
|---|---|---|---|---|---|
| GCA | 6 | 8727.98 | 1454.66 | 78.42 | 2.25 |
| SCA | 21 | 9252.85 | 440.61 | 23.75 | 1.75 |
| Error | 54 | 1001.63 | 18.55 | | |

Appendix 2s: Analysis of variance, Griffing's general combining ability, method II, fixed model, for cob length.

| Source | df | SS | Ms | F - value | F –critical at 5% |
|---|---|---|---|---|---|
| GCA | 6 | 1298.65 | 216.44 | 68.13 | 2.25 |
| SCA | 21 | 2114.12 | 100.67 | 31.69 | 1.75 |
| Error | 54 | 171.55 | 3.18 | | |

Appendix 2t: Analysis of variance, Griffing's general combining ability, method II, fixed model, for cob diameter.

| Source | df | SS | Ms | F - value | F –critical at 5% |
|---|---|---|---|---|---|
| GCA | 6 | 5.24 | 0.87 | 8.36 | 2.25 |
| SCA | 21 | 18.51 | 0.88 | 8.44 | 1.75 |
| Error | 54 | 5.64 | 0.10 | | |

Appendix 2u: Analysis of variance, Griffing's general combining ability, method II, fixed model, for number of lines per cob.

| Source | df | SS | Ms | F - value | F –critical at 5% |
|---|---|---|---|---|---|
| GCA | 6 | 135.00 | 22.50 | 61.09 | 2.25 |
| SCA | 21 | 124.29 | 5.92 | 16.07 | 1.75 |
| Error | 54 | 19.89 | 0.37 | | |

Appendix 2v: Analysis of variance, Griffing's general combining ability, method II, fixed model, for cob length.

| Source | df | SS | Ms | F - value | F –critical at 5% |
|---|---|---|---|---|---|
| GCA | 6 | 2192.80 | 365.47 | 76.00 | 2.25 |
| SCA | 21 | 1734.45 | 82.59 | 17.17 | 1.75 |
| Error | 54 | 259.68 | 4.81 | | |

Appendix 2w: Analysis of variance, Griffing's general combining ability, method II, fixed model, for seed weight.

| Source | df | SS | Ms | F - value | F –critical at 5% |
|---|---|---|---|---|---|
| GCA | 6 | 159.31 | 26.55 | 8.85 | 2.25 |
| SCA | 21 | 557.95 | 26.57 | 8.86 | 1.75 |
| Error | 54 | 161.95 | 3.00 | | |

Appendix 2x: Analysis of variance, Griffing's general combining ability, method II, fixed model, for days to 50% flowering.

| Source | df | SS | Ms | F - value | F –critical at 5% |
|---|---|---|---|---|---|
| GCA | 6 | 10.55 | 1.76 | 4.12 | 2.25 |
| SCA | 21 | 8.93 | 0.43 | 1.00 | 1.75 |
| Error | 54 | 23.02 | 0.43 | | |

**Appendix 3: Maize evaluation under both intercropping and monoculture**

Appendix 3a: Analysis of variance for mean leaf angle at 50% flowering

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 6.36 | 3.18 | 0.20 | 19.00 |
| Cropping system | 1 | 2.65 | 2.65 | 0.17 | 18.51 |
| Error | 2 | 31.90 | 15.95 | | |
| Maize genotype | 3 | 786.45 | 262.15 | 23.45 | 3.49 |
| Cropping system x Maize genotype interaction | 3 | 1.98 | 0.66 | 0.06 | 3.49 |
| Error | 12 | 134.16 | 11.18 | | |
| Total | 23 | 963.49 | | | |

Appendix 3b: Analysis of variance for days to 50% flowering

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 0.58 | 0.29 | 0.28 | 19.00 |
| Cropping system | 1 | 0.04 | 0.04 | 0.04 | 18.51 |
| Error | 2 | 2.08 | 1.04 | | |
| Maize genotype | 3 | 7.13 | 2.38 | 6.11 | 3.49 |
| Cropping system x Maize genotype interaction | 3 | 0.46 | 0.15 | 0.39 | 3.49 |
| Error | 12 | 4.67 | 0.39 | | |
| Total | 23 | 14.67 | | | |

Appendix 3c: Analysis of variance for plant height

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 29.43 | 14.72 | 0.11 | 19.00 |
| Cropping system | 1 | 7.42 | 7.42 | 0.06 | 18.51 |
| Error | 2 | 267.53 | 133.77 | | |
| Maize genotype | 3 | 7192.41 | 2397.47 | 55.75 | 3.49 |
| Cropping system x Maize genotype interaction | 3 | 88.88 | 29.63 | 0.69 | 3.49 |
| Error | 12 | 516.03 | 43.00 | | |
| Total | 23 | 8101.70 | | | |

Appendix 3d: Analysis of variance for ear height

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 15.23 | 7.62 | 19.92 | 19.00 |
| Cropping system | 1 | 1.86 | 1.86 | 4.86 | 18.51 |
| Error | 2 | 0.77 | 0.38 | | |
| Maize genotype | 3 | 1295.57 | 431.86 | 26.39 | 3.49 |
| Cropping system x Maize genotype interaction | 3 | 58.86 | 19.62 | 1.20 | 3.49 |
| Error | 12 | 196.39 | 16.37 | | |
| Total | 23 | 1568.67 | | | |

Appendix 3e: Analysis of variance for number of leaves/plant

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 0.38 | 0.19 | 0.29 | 19.00 |
| Cropping system | 1 | 0.02 | 0.02 | 0.03 | 18.51 |
| Error | 2 | 1.29 | 0.65 | | |
| Maize genotype | 3 | 13.91 | 4.64 | 24.68 | 3.49 |
| Cropping system x Maize genotype interaction | 3 | 0.03 | 0.01 | 0.05 | 3.49 |
| Error | 12 | 2.26 | 0.19 | | |
| Total | 23 | 17.89 | | | |

Appendix 3f: Analysis of variance for leaf area index

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 0.09 | 0.05 | 0.65 | 19.00 |
| Cropping system | 1 | 0.01 | 0.01 | 0.15 | 18.51 |
| Error | 2 | 0.14 | 0.07 | | |
| Maize genotype | 3 | 0.41 | 1.14 | 34.40 | 3.49 |
| Cropping system x Maize genotype interaction | 3 | 0.35 | 0.01 | 0.35 | 3.49 |
| Error | 12 | 0.40 | 0.03 | | |
| Total | 23 | 4.10 | | | |

Appendix 3g: Analysis of variance for cob length

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 0.72 | 0.36 | 0.13 | 19.00 |
| Cropping system | 1 | 2.31 | 2.31 | 0.80 | 18.51 |
| Error | 2 | 5.75 | 2.88 | | |
| Maize genotype | 3 | 787.34 | 262.45 | 62.53 | 3.49 |
| Cropping system x Maize genotype interaction | 3 | 1.40 | 0.47 | 0.11 | 3.49 |
| Error | 12 | 50.37 | 4.20 | | |
| Total | 23 | 847.89 | | | |

Appendix 3h: Analysis of variance for cob diameter

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 0.31 | 0.16 | 0.31 | 19.00 |
| Cropping system | 1 | 0.06 | 0.06 | 0.13 | 18.51 |
| Error | 2 | 1.00 | 0.50 | | |
| Maize genotype | 3 | 1.48 | 0.50 | 7.27 | 3.49 |
| Cropping system x Maize genotype interaction | 3 | 0.10 | 0.04 | 0.51 | 3.49 |
| Error | 12 | 0.82 | 0.07 | | |
| Total | 23 | 3.78 | | | |

Appendix 3i: Analysis of variance for number of lines/cob

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 0.55 | 0.27 | 3.74 | 19.00 |
| Cropping system | 1 | 0.03 | 0.03 | 0.46 | 18.51 |
| Error | 2 | 0.15 | 0.07 | | |
| Maize genotype | 3 | 0.13 | 0.04 | 0.33 | 3.49 |
| Cropping system x Maize genotype interaction | 3 | 0.03 | 0.01 | 0.07 | 3.49 |
| Error | 12 | 1.54 | 0.13 | | |
| Total | 23 | 2.42 | | | |

Appendix 3j: Analysis of variance for seeds/ line

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 53.00 | 26.50 | 117.29 | 19.00 |
| Cropping system | 1 | 19.97 | 19.97 | 88.37 | 18.51 |
| Error | 2 | 0.45 | 0.23 | | |
| Maize genotype | 3 | 68.04 | 22.68 | 1.99 | 3.49 |
| Cropping system x Maize genotype interaction | 3 | 12.82 | 4.27 | 0.37 | 3.49 |
| Error | 12 | 136.97 | 11.41 | | |
| Total | 23 | 291.24 | | | |

Appendix 3k: Analysis of variance for seed weight

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 14.13 | 7.07 | 0.50 | 19.00 |
| Cropping system | 1 | 4.85 | 4.85 | 0.34 | 18.51 |
| Error | 2 | 28.44 | 14.22 | | |
| Maize genotype | 3 | 22.06 | 7.36 | 1.44 | 3.49 |
| Cropping system x Maize genotype interaction | 3 | 3.89 | 1.30 | 0.25 | 3.49 |
| Error | 12 | 61.22 | 5.10 | | |
| Total | 23 | 134.59 | | | |

Appendix 3l: Analysis of variance for bean plant height.

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 0.18 | 0.09 | 0.25 | 4.10 |
| Treatments | 5 | 36.88 | 7.38 | 20.41 | 3.33 |
| Error | 10 | 3.61 | 0.36 | | |
| Total | 17 | 40.68 | | | |

Appendix 3m: Analysis of variance for number of branches per plant

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 0.01 | 0.01 | 1.53 | 4.10 |
| Treatments | 5 | 2.95 | 0.59 | 197.81 | 3.33 |
| Error | 10 | 0.03 | 0.003 | | |
| Total | 17 | 2.99 | | | |

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Appendix 3n: Analysis of variance for pods per plant.

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 0.21 | 0.10 | 0.73 | 4.10 |
| Treatments | 5 | 125.46 | 25.09 | 176.28 | 3.33 |
| Error | 10 | 1.42 | 0.14 | | |
| Total | 17 | 127.09 | | | |

Appendix 3o: Analysis of variance for bean 100 seed weight.

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 0.29 | 0.15 | 0.38 | 4.10 |
| Treatments | 5 | 45.23 | 9.05 | 23.68 | 3.33 |
| Error | 10 | 3.82 | 0.38 | | |
| Total | 17 | 49.34 | | | |

Appendix 3p: Analysis of variance for bean grain yield.

| Source | df | SS | Ms | F - value | F – critical at 5% level |
|---|---|---|---|---|---|
| Replication | 2 | 38322.50 | 19161.25 | 2.67 | 4.10 |
| Treatments | 5 | 2173251.76 | 434650.35 | 60.62 | 3.33 |
| Error | 10 | 71699.54 | | | |
| Total | 17 | | | | |