THE UNIVERSITY OF HULL

Studies on the Genetics and Breeding of Maize (*Zea mays L.*) for Cold Tolerance and Early Maturity.

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by

Obaid Tahir Hassan, B.Sc. and M.Sc. (Baghdad University)

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DEDICATION

To my family, and in the memory of my Mother and Father

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Summary of the Thesis Submitted for the Ph.D. Degree

By Obaid Tahir Hassan

Studies on the Genetics and Breeding of Maize (*Zea mays L.*) for Cold Tolerance and Early Maturity.

1. Thirty two double crosses (made from cold tolerant 'Cambridge' material) were evaluated for their germinability at 6 ^{0} C constant temperature. The five earliest germinating seeds from each double cross were selected, grown in the glasshouse, and evaluated for flowering and maturity, based on method of accumulated heat-unit degrees. All S_0 plants were selfed. S_1 progeny evaluation was carried out in the glasshouse and S_2 seeds were obtained. Germination tests and field evaluations were carried out for all the double crosses, 48 S_1 and 22 S_2 (selected and non selected) families and the following results obtained:

a) good response and variability for germination at low temperatures were found among the 32 double crosses and their response was found to be better than that for the single crosses from which they were obtained,

b) S_1 and S_2 families, developed from the selected seeds, germinated at 6 ^{0} C as well as the double crosses or better for some families,

c) the procedure used for selection for early flowering and early maturity under the glasshouse conditions, which based on less heat-unit degrees to maturity was found to be effective to distinguish the early maturing families,

d) selection for early maturity did not alter the cold tolerance and the other agronomic characters in these genotypes,

e) most of the variability for cold tolerance, and the flowering and maturity stages was due to additive genetic effects. No important G x E interaction was found in the field,

f) highly significant correlation among the emergence traits and seedling vigour traits was found, suggesting that the same genetic system controlled these traits. Similarity

between the germination test in the laboratory and the emergence in the field was also observed,

g) no significant differences were found between two heat-unit degrees methods (Gilmore-Rogers 1958 and the Ontario of Brown, 1975) in the evaluation of the flowering and maturity stages for all generations,

h) selecting of the earliest S_1 and S_2 families resulted in a positive selection differential and positive expected gain from selection for most traits studied. Promising families for further improvement were identified. No negative effect on the yield and other agronomic characters resulted from selection.

2. Five selected inbred lines from the Cambridge material were mated with 5 USA lines in a North Carolina mating design 2. Thirty nine F_1s and their F_2s were obtained. All materials were evaluated under controlled and uncontrolled conditions. The NC2 analysis was used to study the genetic variability and the general combining ability (GCA) and the specific combining ability (SCA) for both sets of inbred lines for two seasons (two years), and the following conclusions were obtained:

a) for any cold-tolerance study for these genotypes, measurements and analysis of the germination, emergence and seedling growth traits are required. Different behaviour was observed for some genotypes in the germination, emergence and seedling growth tests. The USA inbred lines were more vigourous in their seedling growth rate than the Cambridge lines.

b) highly positive heterosis for most of the traits studied was observed, and additive and non-additive genetic effects found to be important for most of the traits studied,

c) results for flowering and Maturity stages in both years were similar for both the GCA and SCA for the two sets of inbred lines. Both GCA and SCA were important,

d) some promising hybrids for early maturity with less range of spread of maturity were detected,

e) the production of new genotypes, combining together the early maturing characteristics of the Cambridge lines with the good agronomic traits of the USA

lines, is worthwhile and very promising for the establishment of grain-maize genotypes ideal for cold environments,

f) it was confirmed that the NC2 mating design is very satisfactory mating system to be followed to study genetic variation in hybrids produced from unrelated sets of inbred lines.

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CHAPTER ONE

INTRODUCTION

With a global harvest in 1986 of 480 million metric tonnes from 132 million hectare (ha), maize (*Zea mays L.*) ranked second to wheat among the world's cereal crops. It is the third most important cereal crop in the developing world after rice and wheat (Food and Agriculture Organization (FAO), 1986). The report by the Agency for International Development (AID) in 1988 stated that some 70 countries produce maize on 100,000 ha or more; 53 of these are developing countries. The so-called developed market economies account for 30% of the global area, but provide 50% of total production because of average yields that are three times higher than the world average. Developing countries account for approximately 60% of the total world maize area, but produce only 40% of the global harvest. During 1983-85, developing countries produced an average of 169 million tonnes of maize per year (AID, 1988). The estimated production of maize and the other cereal crops in 1986 is given in the table below.

Area harvested, production and yield per hectare of the main cereal crops in the World and in the developing countries, the 1986 means (FAO, 1986).

	World			Developing countries		
Crop	Area 1000 ha	Production 1000 MT	Yield kg/ha	Area 1000 ha	Production 1000 MT	Yield kg/ha
Wheat	228945	535842	2340	100967	218046	2056
Maize	**131475**	**480609**	**3656**	**80143**	**172524**	**2153**
Rice	145358	475533	3271	140960	449371	3188
Barley	79645	180441	2266	18043	25705	1425

Maize is used in more ways than any other cereal: as a human food, as feed grain, as a fodder crop, and for a large number of industrial products both food and non-food based. The grain, stalk, leaves, cobs, tassel, and silk all have commercial value in many situations, though that of the grain is the greatest. The most diversified uses of maize occur in the United States of America, where over 1000 products in a typical supermarket contain maize in some processed form or another (AID, 1988).

World-wide, about 66% of all maize is used for feeding livestock, 25% for human consumption, and 9% for industrial purposes and as commercial seed for further maize production. In the developing world, however, roughly 50% of all maize is consumed by humans as a direct food source, 43% is for livestock feed and the remainder is used for industrial and seed purposes (CIMMYT, 1984).

Tropical and subtropical environments contain 65% to 70% of the area over which maize is grown and the temperate environment accounts for the remainder. The biology of maize and its husbandry are vastly different from those of wheat and rice. This difference appears in many ways such as the use of breeding methods, technology and capability of seed production and distribution. The improvement of maize germplas m for local, national, or international purposes can be effected by several different breeding programmes with emphasis on population improvement, concentration on hybrids and inbred lines, or by combinations of both approaches.

Maize is grown in more diverse areas of the world than any other major crop. It is grown from sea level to 3800 m elevation near lake Titicaca in Bolivia and Peru, from desert oases to zones having 11,000 mm rainfall along the western coast of Colombia, and from about 42^{0} latitudes south near Chiloe Island to about 50^{0} latitudes north on the Gaspe Peninsula of New Brunswick, Canada. It is cultivated over a range from Northern Europe and Russia to South Africa, eastwards through Asia, the Himalayas, China, southeast Asia, and the Pacific Islands (AID, 1988).

The genetic diversity is enormous both between and within the different kinds of maize grown in the distinct locales of these disparate areas. The particular

conditions of soil, temperature, rainfall, relative humidity, photoperiod, and light intensity have all imposed selection pressures on the kinds of maize at each site.

The adaptation of maize to new environments and subsequent yield may often be limited by poor early vigour (seedling emergence and growth) caused by low soil and air temperatures during the early growing season in many temperate and higher altitude tropical regions of the world. On the other hand, adaptation and yield of maize is also limited by very high or by low temperatures at flowering time that can lead to poor pollination on hot and dry days or to incomplete grain filling in cool or frosty conditions. Thus it seems that the development of strains able to germinate and grow under cold conditions, with early flowering and maturity characteristics, could enable the crop to escape high temperature and drought stress during flowering and to complete grain filling before frost. Pendlton (1965) suggested that early planting of maize should result in the following advantages: (1) short plants with low ears and good standability, (2) drier grain and earlier harvest, (3) pollination before hot, dry days of late summer, (4) grain filling during the long-light days of the growing season which increases the efficiency in the use of sunlight energy, and (5) better utilization of stored subsoil moisture and reduction of soil water evaporation through early canopy development.

Mock and Skrdla in 1978 also discussed the advantages of the early planting of maize and stated that one of the major environmental factors limiting the range of production of maize is low temperature; especially low air and soil temperatures at planting time. In many high latitudes and high altitudes of the world, potential maize yields could be enhanced if maize genotypes of full-season maturity could be planted earlier than traditional planting dates. This yield increase would result from full-season genotypes using more solar energy throughout the growing season. Furthermore, early planting of maize in the central latitudes followed by normal growth and development of the plants would result in near-coincidence of the grain-filling period of the growing season. Consequently, more photosynthate could be available for deposition in the grain. For all these suggestions to be effective it is

necessary to obtain maize genotypes that are tolerant of cold temperatures during seed germination, seedling emergence, and growth.

However, to increase or maintain yields following early-spring planting, the seed must be able to germinate in cold, wet soil which presents an unfavourable environment for growth. Low temperatures can inhibit the germination and emergence of corn, with the minimum temperature for growth reputedly being approximately 10° C (Blacklow, 1972; Eagles and Hardacre, 1979a; Warrington and Kanemasu, 1983a). At and about this temperature, seedling emergence is slow and damage by soil micro organisms can be severe.

It has been reported by many researchers that cold tolerance of maize should be regarded as the ability to germinate, emerge and grow under cold conditions. It has been found that cold tolerance is a complex and quantitatively inherited trait (Pinnell, 1949; Ventura, 1961; Grogan, 1970; Pesev, 1970; Chapman, 1984, Maryam and Jones, 1983a; 1983b). In all these studies additive and/or dominance gene effects, and epistatic effects play important roles both for laboratory germination tests and for field emergence under low temperature conditions. The importance of these genetic effects varied according to the source of the genotypes used. Most of the work cited above also reported the existence of maternal effects for cold-test germination and emergence.

Many studies have determined the relative amount of genetic variation for cold tolerance present in different maize breeding materials (Grogan, 1970; Mock and Eberhart, 1972; Mock and Skrdla, 1978; Mock and McNeill, 1979; Eagles and Hardacre, 1979a, b; Hardacre and Eagles, 1980; Maryam and Jones, 1983a). In these studies estimations of many genetic parameters (genetic effects, heritability, correlation with other important growth and agronomic traits) were analysed for many cold tolerance traits (germination, emergence, seedling dry weight). Considerable genetic variation and genotype x environment variation were found for germination and growth at low temperatures (e.g. Mock and Eberhart, 1972; Mock and Skrdla, 1978; Mock and McNeill, 1979). Non-significant associations were found, in general,

between cold tolerance and most of the other traits. Some positive association was reported for early emergence and seedling vigour with final grain yield (Mock and McNeill, 1979 for example). In the papers listed above various selection programmes were suggested to improve the cold tolerance of maize. Grogan (1970), for example, suggested that the best approach for developing superior cold tolerance in maize would be by recurrent selection. Subsequently recurrent selection of selfed progenies from different maize cold tolerant populations was utilized and was found to be effective in improving of cold tolerance (Mock and Bakri, 1976; Hoard and Crosbie, 1985; 1986a).

One of the selection methods used extensively in maize breeding is S_1 and S_2 selection for the improvement of many traits, since the recurrent selection procedure has been proposed as system to maintain tested genotypes (Hallauer and Miranda, 1988). Genter and Alexander (1962) reported that S_1 progeny performance was more closely associated with general than with specific combining ability, and this corresponds with the observation by Lonnquist and Castro (1967) that S_1 recurrent selection is more effective with additive than non additive genetic variance. Mock and Bakri (1976) used S_1 recurrent selection for cold tolerance and they obtained some progress in response to this selection; percentage of emergence and dry weight increased 8.4% and 0.6 kg per cycle, respectively.

The breeding of varieties of maize that have the capability to emerge under cool and wet conditions has been of major interest in North-Western Europe since 1965. In a survey of research and breeding on maize in Britain, Bunting and Gunn (1973) gave historical details about the introduction and spread of maize in North-Western Europe. In England, they noted that since 1950 and especially after 1967 many flint and dent grain-maize strains have been introduced to Britain in order to establish a breeding programme to obtain hybrids that can be used for commercial grain-maize production. Grain maize production in Britain was initiated in 1967, when about 100 ha were grown. The area rose to 1500 ha in 1972 and decreased to 1000 ha in 1973. It seems that no further increase in the area under grain maize has occured

since then. The 1986 FAO report recorded 1000 ha planted with grain maize in Britain each year since 1979 (FAO, 1987). Bunting and Gunn also stated that the first serious study of factors affecting the productivity of grain maize in England was initiated by Professor G. E. Blackman in the 1940s, and continued in the Unit of Experimental Agronomy, Oxford, until 1970. Questions of crop production, utilisation and economics, with particular references to grain maize, also have been under consideration since 1965 at Wye College, where a Maize Unit was formed in 1970. Plant breeding programmes started at the Unit of Experimental Agronomy at Hurst Gunsons Ltd, was transferred to the Plant Breeding Institute at Cambridge in 1970. The Maize Development Association, formed in 1967, acts as a centre for collating information and advising grower members on all aspects of production and utilisation. Many attempts were concentrated on the developing of cold tolerance varieties in central and southern England, and those were reviewed by Bunting and Gunn (1973).

Successful progress in growing maize for forage has been reported (see below). Up to date improvment for forage still forms the main objective in the breeding of maize in Britain following on from similar studied reported before 1980 reviewed by Bunting (1978). It seems that no further important results have been reported on the breeding of the grain maize in Britain. Most of the work has been directed to forage maize (Kimber and Fenwick, 1981; and Kimber and Kichtly, 1984). They reported that over 20,000 hectares of forage maize were grown in the UK in 1980 compared with fewer than 1000 ha ten years earlier (1971). They also stated that the main impetus to that came from new hybrid varieties that enhanced the prospects for maize growing in northerly latitudes.

Experimental cold tests in the field have generally been disappointing because of weather changes and of the pathogens which attack slowly germinating maize in cold conditions. Thus controlled laboratory tests such as the 'germination test' and 'emergence test' have been used frequently by many researchers in different parts of the world (in the USA, UK, USSR, Yugoslavia, Hungary and New Zealand (Maryam,

1981)). The development of suitable laboratory techniques was essential for the improvement of cold tolerance for many crops (Christiansen and Lewis, 1982). However, Bunting and Gunn (1973) reported that, in field observations, flint material acclimatised to European conditions makes more rapid seedling growth under cool conditions than dent material from the USA. Much American dent material, however, has a higher yield potential and better resistance to lodging and consequently the breeding programmes in Northern Europe have been directed toward the development of hybrid varieties incorporating the better features of both European flint and American dent material. This approach has met with considerable success, and the flint x dent hybrids currently grown in Northern Europe are much more productive than the open pollinated flint varieties or American hybrids previously available.

It has been suggested that screening inbred lines or hybrids for their ability to germinate at low temperatures should be a satisfactory initial test in selecting for cold tolerance (Bunting, 1955; Walther, 1971, Zemetra, 1983). For her study on the genetics of maize for cold tolerance Maryam (1981) obtained inbred lines of dent and flint grain maize from the Plant Breeding Institute, Cambridge and another set of inbred lines from the USA (details about this material are given in Chapters 2 and 6 of this thesis). The seeds were screened for their germinability at 8° and 6° C constant temperature. A study of the generation means was carried out on the F_1, F_2, B_1 and B_2. Diallel crosses were made between selected lines from within each set to study the genetic system controlling the main characters for cold tolerance, flowering time, time to maturity and other important agronomic characters. It was found that the cold tolerance characters, flowering and maturity in the Cambridge lines was mainly controlled by additive-gene effects, and the lines contained good genetic diversity for these three characters. On the other hand, the genetic basis of these characters was found to be rather complex in the USA lines, with both additive and non-additive genetic factors being important. These USA lines do have many good agronomic characters (thick flexible stems, better root systems, and they remain green right up to harvest date. In 1985 Maryam obtained 32 double crosses by crossing as many as

possible of the best F_1s obtained from the Cambridge inbred lines. She also suggested that for further breeding a combination between the best Cambridge and USA lines would be desirable. She had shown that variability in this material for flowering and maturity would be sufficient for a good response to selection for earliness.

Maryam emphasised in her study that the genetic characteristics of this material are of great importance for growing grain maize in Britain, Pakistan and in many other countries. This material is also of importance for the improvement of maize production in Iraq. The advantages expected are similar to those reported by Maryam for Pakistan, because to some extent there are similarities in the weather condition between the two countries.

Iraq is situated in the South-West of Asia. Iraq lies between latitudes 29° 5// and 37° 22// North and between longitudes 38° 45// and 48° 45// East, with the moderate region. Its climate is continental and subtropical with a rainfall rather similar to the Mediterranean region. Rain occurs mostly in late Autumn, Winter and early Spring. There are three climatic regions in Iraq: The Northern mountainous area, is characterized by cool winters with snow falls on the mountains and moderate summers. Precipitation in the mountains ranges between (400-1000 mm) annually. A steppe climate occurs between the mountainous region in the North and the hot desert in the South, with 200-400 mm of rainfall. In the hot desert region there is 50-200 mm rainfall, but this has to be supplemented by irrigation from the Tigris and Euphrates rivers (Ministry of Planning Annual statistic report, Iraq, 1989).

Since the early 1970s maize has become an important grain and forage crop in Iraq. Many varieties and hybrids were introduced from different parts of the world, especially from the USA, to improve maize production and productivity in Iraq.

Maize is grown in Iraq in two seasons (two maize crops in the year); the first is the Spring season, with seeds sown early in March, and in the second crop is sown in July with the harvest in October and November. The summer crop usually gives the best yield.

The main problems facing the spring season are that in February the temperatures are too low to permit rapid germination of the existing varieties, especially in the North of Iraq. In the middle of Iraq, where the main crops of maize are grown, the monthly average temperatures for February 12.3°, 18.8°, 5.8° C for the average daily, the average maximum and the average minimum temperatures, respectively (Ministry of Planning Annual Statistical Report, Iraq, 1989). Unfortunately the temperatures in May and June are too high to enable a satisfactory seed set and pollen grains have a very short life. The establishment of hybrids or varieties with good cold tolerance and the ability to emerge earlier than the local varieties, together with early maturing characteristics would be major contribution to improving the productivity of maize in the spring season in Iraq, because the flowering time would be sufficiently early to escape the critical high temperatures in May and June. Furthermore, it would be also be possible to grow maize in the North of Iraq. This area depends mainly on the rainfall for irrigation, and the maturity stage could be reached before the dry Summer begins (Ministry of Agriculture, State Board for Applied Agricultural research in Iraq, 1986).

The results of two series of experiments are reported in this thesis:

1. The first series include the evaluation of the material and selection experiments carried out on the 32 double crosses made by Maryam 1985. Both, Controlled environment (in the growth chamber and in the glasshouse) and field conditions were used both for the evaluation and selection for cold tolerance and early flowering and maturity. S_1 and S_2 family selection was utilized. The following investigations are included in this part (Chapter 3, 4 and 5):

a) the 32 double crosses obtained by Maryam (1985) were evaluated for germination at a low temperature (6° C constant) and selections were made within and among them for this trait (Experiment A, Chapter 3),

b) the selected material was evaluated under glasshouse conditions for flowering, maturity, and the other agronomic characteristics and S_0 plants were selfed to obtain the S_1 generation (Experiment B, Chapter 3). Flowering and early maturity studies were based on two methods for calculating the heat-units degrees (HUD) required to reach each particular stage. It has been reported by many researchers that the heat-units degrees methods are more accurate for classifying maize genotypes for their flowering and maturity (details are given in Chapters 2 and 3). The calender day method was also used in the field experiments,

c) S_1 progenies were evaluated and tested under controlled conditions for the desired characters and at the same time S_2 seeds were obtained by selfing S_1 plants (Experiments C-Chapter 3),

d) variation for germinability at low temperature within the S_1 and the S_2 families was investigated (see Experiment D, Chapter 4),

e) an experiment was carried out in the field to evaluate all the double crosses and selected and non-selected S_1 and S_2 families for cold tolerance, early flowering, early maturity and for many other agronomic characters. In these experiments the phenotypic and the genotypic variability were studied and selection was made within S_1 and S_2 family for further breeding (Experiment E, Chapter 5).

2. In the second part of this work, the inbred lines selected by Maryam (1981) from the Cambridge and from the USA materials, on the basis of good cold tolerance and early maturity, were utilized as follows:

a) two sets of inbred lines, five from the Cambridge inbred lines and five from the USA inbred lines, were crossed in a North Carolina mating design 2 (NC2). F_1 and F_2 generations were obtained,

b) the inbred lines and their F_1s were tested, under controlled conditions, for germination at 6^0 C constant temperature and for emergence and seedling growth at 9-13^0 C, (Experiment F, Chapter 6),

c) field experiments over two seasons were carried out. In the first year all the material was evaluated and an investigation of the genetic variation and the combining ability of the two sets of inbred lines was undertaken. The F_1s were tested in the field for two seasons and the North Carolina 2 analysis was carried out (Experiment G, Chapter 7).

This study was designed to meet the following general objectives in addition to the specific objectives which will be explained later for each experiment individually:

1. to develop a better understanding of the genetics of cold tolerance and early maturity and to select suitable materials for further breeding,

2. to develop breeding methods for selection for both cold tolerance and earliness by using controlled and uncontrolled environment conditions,

3. to identify those inbred lines, families and hybrids superior for the desired characters of use in further breeding programmes.

CHAPTER TWO

MATERIAL AND METHODS

Source of Materials.

The experimental material used in this research consisted of 32 double crosses and ten inbred lines of grain maize (Zea mays L.) The double crosses were originally made in the Department of Plant Biology and Genetics, University of Hull, England, by Dr. B. Maryam (1985) and were available for this study. The single crosses used to form the 32 double crosses were obtained by crossing some selected inbred lines which had been developed at the Plant Breeding Institute in Cambridge to meet the climatic conditions of Cambridge from dent material obtained from Poland, France and the U.S.A, and flint material obtained from Switzerland and France (Maryam, 1981).

The inbred lines had been screened for their cold tolerance and for other agronomic characteristics (flowering and maturity), in a series of experiments conducted in a growth cabinet, the greenhouse and the field, at a latitude further north than the generally accepted limit of the crop in the U.K. (Maryam and Jones, 1985). These investigations were conducted in the Department of Plant Biology and Genetics between 1977 and 1985, and they found that some of the inbred lines showed good cold tolerance and, furthermore, that significant genetic variation for cold tolerance existed among them. The genetic basis of the cold tolerance in these inbred lines was mostly due to additive-gene effects. After an initial screening the most cold tolerant lines were included in an experiment to obtain and study the performance of F_1, F_2, B_1, and B_2 families. Subsequently the progeny of the single crosses were themselves crossed in the glasshouse in 1985, according to the availability of pollen and silks, to produce the double crosses which were used in this study. A total of 32 double crosses have been made. They are listed in table 1, both with the experimental code used in this study, and the germination characteristics at low temperature and the flowering characteristics of the inbred lines from which each double cross was

Table (1). The 32 double crosses that were made in the glass house in 1985, with their experimental codes and the germination and flowering characteristics of the inbred lines involved in their formation. E = early, M = medium, L = late.

No	Double crosses	Exp. code	Germination characteristic for their inbred lines	Flowering characteristic of the inbred lines
1	(GBO77xGBC115)x(GBO78xGBC233)	1	(LxE)x(ExM)	(ExM)x(ExE)
2	(GBO77xGBC115)x(GBC100xGBC115)	2A	(LxE)x(LxE)	(MxM)x(ExM)
3	(GBC100xGBC115)x(GBO77xGBC110)	2B	(LxE)x(LxL)	(ExM)x(MxE)
4	(GBO77xGBC108)x(GBO78xGBC233)	3A	(LxE)x(ExM)	(MxL)x(ExE)
5	(GBO77xGBC108)x(GBO77xGBC110)	4	(LxE)x(LxL)	(MxL)x(MxE)
6	(GBO77xGBC110)x(GBO78xGBC114)	5	(LxL)x(ExM)	(MxE)x(ExE)
7	(GBO77xGBC110)x(GBO78xGBC115)	6A	(LxL)x(ExE)	(MxE)x(ExM)
8	(GBO78xGBC115)x(GBO77xGBC110)	6B	(ExE)x(LxL)	(ExM)x(MxE)
9	(GBC77xGBC110)x(GBO78xGBC233)	7	(LxL)x(ExM)	(MxE)x(ExE)
10	(GBO77xGBC110)x(GBC100xGBC115)	8	(LxL)x(LxE)	(MxE)x(ExM)
11	(GBO77xGBC110)x(GBC105xGBC233)	$9A_2$	(LxL)x(ExM)	(MxE)x(MxE)
12	(GBO80xGBC102)x(GBO77xGBC110)	10	(LxM)x(LxL)	(MxE)x(MxE)
13	(GBC233xGBC105)x(GBO78xGBC115)	11A	(MxE)x(ExE)	(ExM)x(ExM)
14	(GBO78xGBC115)x(GBC105xGBC233)	11B	(ExE)x(ExM)	(ExM)x(MxE)
15	(GBO78xGBC115)x(GBO77xGBC108)	12A	(ExE)x(LxE)	(ExM)x(MxL)
16	(GBO78xGBC114)x(GBO77xGBC110)	13	(ExM)x(LxL)	(ExE)x(MxE)
17	(GBO78xGBC114)x(GBO77xGBC108)	14A	(ExM)x(LxE)	(ExE)x(MxL)
18	(GBO80xGBC102)x(GBO77xGBC108)	15	(LxM)x(LxE)	(MxE)x(MxL)
19	(GBC233xGBC105)x(GBO78xGBC233)	16A	(MxE)x(ExM)	(ExM)x(ExE)
20	(GBO78xGBC233)x(GBC105xGBC233)	16B	(ExM)x(ExM)	(ExE)x(MxE)
21	(GBC233xGBC105)x(GBO78xGBC114)	17A	(MxE)x(ExM)	(ExM)x(ExE)
22	(GBC105xGBC233)x(GBO78xGBC114)	18	(ExM)x(ExM)	(MxE)x(ExE)
23	(GBC105xGBC233)x(GBO77xGB0110)	$19A_2$	(ExM)x(LxL)	(MxE)x(MxE)
24	(GBC105xGBC233)x(GBO77xGBC108)	20	(ExM)x(LxE)	(MxE)x(MxL)
25	(GBC105xGB233)x(GBC100xGBC115)	21A	(ExM)x(LxE)	(MxE)x(ExM)
26	(GBC100xGBC115)x(GBC105xGBC233)	21B	(LxE)x(ExM)	(ExM)x(MxE)
27	(GBC100xGBC115)x(GBO78xGBC233)	22	(LxE)x(ExM)	(ExM)x(ExE)
28	(GBO78xGBC233)x(GBO78xGBC115)	23	(ExM)x(ExE)	(ExE)x(ExM)
29	(GBO80xGBC102)x(GBO78xGBC115)	24A	(LxM)x(ExE)	(MxE)x(ExM)
30	(GBO80xGBC102)x(GBC105xGBC233)	25A	(LxM)x(ExM)	(MxE)x(MxE)
31	(GBC105xGBC233)x(GBO80xGBC102)	25B	(ExM)x(LxM)	(MxE)x(MxE)
32	(GBC233xGBC105)x(GBO80xGBC102)	26A2	(MxE)x(LxM)	(ExM)x(MxE)

derived. All 32 double crosses were used in this study in evaluation and selection experiments conducted in the growth cabinet, the glasshouse, and in the experimental field.

For another experiment, ten inbred lines from the material obtained by Maryam were used. These were the most promising lines among the Cambridge material, and some other inbred lines which had been obtained directly from the U.S.A. and subjected to a selection study by Maryam (1981). The lines GBO78, GBC102, GBC108, GBC100, and GBC233 of the Cambridge lines, and Fr43, Fr619, HY2, A556 and Pa32 of the U.S.A. lines were chosen. The two different sets were used in a North Carolina mating design (2). Further details about these lines will be given in Chapter 6.

Environments and Traits Measured.

The different experiments were carried out under growth cabinet, glasshouse and field conditions. These different environmental conditions will be described in detail with each individual experiment.

The growth cabinet used for germination experiments was a Sherer Cel 44, with both temperature and humidity control. Kernels were placed on sterile Whatman filter paper No. 3, size 9 cm in a sterile petri dish. The kernels were treated with the fungicide Captan. Ten ml of sterile distilled water were added to each petri dish; the dishes were covered and placed in the growth cabinet at 6^0 C constant temperature in the dark. The dishes were screened each day during the following 21 days. A seed was considered to have germinated when the radicle and the coleoptile had broken through the pericarp (McConnell & Gard ner, 1979a). Any seed which had not germinated by the 21st day was ignord.

The glasshouses of the Botanic Garden of the University of Hull were used to conduct the glasshouse experiments. They were equipped with mercury vapour discharge lamps (MBRF/U) or with high pressure sodium plant irradiator lamps

(SON/T) set initially at 1 m above the glasshouse bench. These lamps gave a photon flux den ity of 360 to 390 micro-mole photons m^{-2} x s^{-1} at bench level.

Although maize is a short-day-length plant it does grow well in the north of the U.K. where in Summer the day length is very long (averaging 16 hours). Therefore the lamps were set at a 16 hours day-length. When experiments overlapped the Summer season, the lights were turned off, from the middle of May, leaving the plants subject to natural day-length and light.

In the glasshouse experiments seeds were sown in John Innes potting soil compost No. 2 into 90mm plastic pots. After 4 weeks all plants were transplanted into 250mm diameter plastic pots and the large pots were placed on the ground inside the glasshouse.

The minimum temperature in the glasshouse was set at not less than 12^0 C, a balance between ventilation and heating ensured that the temperature did not fall below 12^0 C and did not exceed 35^0 C. As and when necessary the plants were fumigated and sprayed against red spiders, aphids, sciarid flies and other insects before the male and female flowering took place.

The selfing procedure used in these experiments to obtain the S_1, S_2, S_3, and F_2 seeds was as described by Hays and Ammer (1942) and Poehlman, (1959). The technique used for monitoring the inbred lines and to make hybrid crosses was of Poehlman (1959, fig. 13.8 and 13.9). Glassine bags were used for ear-shoots and kraft bags for the tassel. Each plant and each ear, after selfing or crossing, was tagged with the appropriate information, written with marker pen.

The field experiments were carried out in the field of the Botanic Garden, Thwaite Street, Cottingham, Hull. Before sowing, the land was well rotavated and farmyard manure was added. Sowing and harvesting were done by hand. Weeding throughout the growing season was also done by hand. More details about the field experimental technique will be given in Chapters 5 and 7.

For the glasshouse and field experiments, the time to reach each stage of flowering was recorded by counting the number of days from sowing to the day that a

particular stage was observed for each plant. Plant height was measured as the distance from the soil surface to the tassel collar. The ear height was measured as the distance from the soil to the node on which the lowest cob existed. The days to harvest were scored as the number of days between sowing and the time the particular ear was harvested. The moisture content of the seeds at harvest was measured using an electronic moisture tester (Sinar Intec F6 Moisture Analyser). In order to ensure accurate measurement for seed moisture, each harvested cob was placed separately in a polythene bag and all samples were tested for moisture on the same day. Yield was obtained by counting the normal mature seeds on every ear using a Decca Master Count with a batch counter and the seeds were then weighed for each plant using an electronic balance (Mettler PC 2200)

The decimal code for the flowering stages (Zadoks *et al.*, 1974) was used as follows (Maryam, 1981):

Boots	Tassel inside the flag leaf.
51	Tip of the tassel just emerged
59	Emergence of the tassel fully completed.
61	Beginning of anthesis (pollen shedding).
65	Anthesis half way (pollen shedding half way).
69	Anthesis complete (pollen shedding finished)
Ear	Initiation of the ear (ear shoot of corn emerging from the leaf sheath).
Silk	Initiation of the silk (silk showing through the ear shoot).

It has been reported by many researchers (see chapter three for more explanation) that the use of the daily heat-unit degrees is the most satisfactory method for classifying maize hybrids for their flowering and maturity stages, being superior to the calendar day method (Gilmore and Rogers, 1958; Cross and Zuber, 1972; Mederiski *et al.*, 1973; Aspiazu and Shaw, 1972; Brown, 1969; Cowen, 1985). In the U.K. a similar suggestion was made by Bunting and Gunn (1973) Bunting, (1976); Carr, (1977); and Hough, (1975);. They reported that the accumulative daily heat unit

degrees can be used to specify maize varieties (for flowering and maturity) for given geographic regions, or as in Britain to delineate those areas likely to be most suitable for maize production. For that reason, two methods of calculation of the heat units were used in this study in addition to the calendar day method. Seven-day thermographs were placed in the glasshouse and in the experimental field to measure the temperature continuously. The heat-unit degrees required from sowing to the day that a particular stage was observed were calculated in two ways. A Fortran computer Programme was written for this purpose.

Growing degrees are defined as the number of degrees celsius by which the mean daily temperature exceeds a base minimum; but does not exceed a base maximum; where the minimum and maximum temperature are adjusted to the base minimum or maximum temperatures, if they fall short of or exceed the critical temperatures for each respective measurement.

The first method used in this study was the one used by Gilmore and Rogers (1958) and Cross and Zuber (1972). The accumulated growing heat-unit degrees were calculated using the formula:

$$\text{HUD on a day} = \frac{\text{Tmin}+\text{Tmax}}{2} - 10$$

Where Tmin is the daily minimum temperature, and Tmax is the daily maximum temperature. If Tmin $< 10^0$ C, then Tmin $= 10^0$ C, and if Tmax $> 30^0$ C then Tmax $= 30^0$ C. This method had been widely used in maize studies under suitable environments for growing the plant.

The second method was the"Ontario heat units method" which was suggested by Brown (1969;and 1975) in Ontario, Canada, as a more suitable method for classifying maize genotypes for their flowering and maturity in cold conditions. Bunting and Gunn (1973) suggested that this method is of greater potential interest for northern European conditions. They reported that the merit of this method for British conditions is currently under consideration. Carr and Hough (1978) reported that

although accumulated temperatures are widely used in many Northern-European countries to predict stages of maturity in maize or to identify suitable area of production, there appears to be no agreement as to which method is best. It is likely that differences in accuracy between methods are small, but some standardisation would be desirable. Although this detail was made 12 years ago, no results of the relevant experiments appear to have been published. In the Ontario method the response (Ymax) to maximum temperature, Tmax is assumed to be parabolic, with the maximum at (30^0 C) or 86^0 F and minimum at, or below (10^0 C) 50^0 F. The formula as suggested by Brown (1975) and outlined by Coelho and Dale (1980) and Tollenaar *et al.*(1979) is:

$$Ymax = 3.33 (Tmax - 10) - 0.084 (Tmax - 10)^2$$

If $Tmax > 30^0$, then $Tmax = 30^0$

and $Ymax = 0$ for $Tmax \leq 10^0$ C and

$Ymin = 1.8 (Tmin - 4.4)$ for $Tmin > 4.4^0$ C, and

$Ymin = 0$ for $Tmin \leq 4.4$ C.

Then the daily contribution in Ontario heat-unit degrees (DOHUD) is:

$$DOHUD = \frac{Ymax + Ymin}{2}$$

Because of the relatively high minimum and maximum temperatures in the glasshouse experiments the first method was used to study the flowering and maturity of the double crosses and their S_1. On the other hand all three methods (calendar days, Gilmore & Rogers, and the Ontario method) were used in the field studies.

The following abbreviations are used in the text and tables:

ER	Emergence rate (emergence index).
GI	Germination index.
SDW	Seedling dry weight (gm)
PH	Final plant height cm.
EH	Ear height cm.
Mat.	Maturity.
Silk-Mat	Silking to maturity.
HUD Ont.	Ontario heat-unit degrees.
HUD Rog.	Gilmore-Rogers heat-unit degrees.
Days.	Number of days required to the particular stage.
Ker no.	Number of Kernels per plant.
100 ker W	100 kernels weight (gm).
% H20	Grain moisture content %.
NC2	North Carolina mating design 2.

More explanation will be given about these characters in each individual experiment.

Data were analysed at the University of Hull, on the ICL 3980 mainframe Computer, using Genstat 4.04 (Alvey *et al.*, 1983). Programmes were written specially for each experiment by the author with the help of the Computer Centre staff (see acknowledgements).

The following statistical conventions have been used, unless otherwise stated (Steel & Torrie, 1980).

NS	Non-significant
*	Significant at level of probability $0.05 > p > 0.01$
**	Significant at level of probability $0.01 > p > 0.001$
***	Significant at level of probability $p < 0.001$.

PART ONE

THE STUDIES ON THE THIRTY TWO MAIZE DOUBLE CROSSES, THEIR S_1 AND S_2 FAMILIES.

CHAPTER THREE

EVALUATION OF 32 MAIZE (*ZEA MAYS L.*) DOUBLE CROSSES FOR GERMINATION AT LOW TEMPERATURE, FOR FLOWERING TIME AND FOR MATURITY UNDER CONTROLLED CONDITIONS.

Introduction:

Hybrids have been the ultimate commercial products of maize breeding programmes since Jones (1918) first suggested the use of double cross hybrids. Using mainly empirical methods, investigators have found that they could select lines and obtain new varieties for almost any combination of desired characters using corn hybrids, and the genetic diversity in them, as the basic source material. During the past four decades, plant breeding has dealt extensively with the problem of improving tolerance to low spring temperatures with the aim of producing maize genotypes (inbred lines and hybrids) with better germination, more vigorous emergence and faster early growth under adverse conditions of cold wet weather.

As grain-maize planting has moved into regions climatically less suited for its production, notably in "third world" countries and Northern Europe, increased research has been necessary to identify the climatic and physiological factors limiting development of the plant, primarily to assist the breeding programmes in these less suitable areas (Duncan, 1975).

Carr and Milbourn (1976) reported that breeding programmes in northern Europe have long been directed towards the development of hybrid varieties that combine the ability of European flint types able to grow at low temperatures with the high yield potential and resistance to lodging of early American dent material. This has led to the production of varieties with earlier flowering and maturity. Both types of maize have been used as the basis of the double cross hybrids that were obtained from the material used for an earlier study by Maryam (1981).

Carr and Milbourn (1976) also stated that, as a forage crop, maize has much to offer agriculture in northern Europe, but it is not yet known how far north the crop can be successfully and reliably grown. The unsuitably cold growing seasons throughout northern Europe emphasise the prime need to select for earliness of flowering, and varieties flowering six or seven days earlier than the existing earliest varieties (which would consequently mature perhaps up to two weeks sooner) should be available within the next decade.

In Britain this aim seems not to have been achieved yet, although a breeding programme for that purpose was started in the early seventies at the Plant Breeding Institute in Cambridge and at the University of Oxford, there appear to be no further important results have been reported in the UK after 1980, except those carried out by Maryam and Jones (1983a, 1983b, and 1985) on the genetics of grain maize for cold tolerance.

The results of the earlier work by Maryam (1981) on the original parental lines and single crosses showed the presence of directional dominance for all the traits studied, with significant additive and dominance effects. She suggested that it would be possible, through selection, to develop early germinating, early flowering and early maturing genotypes from the hybrid population of crosses made from these lines. Irrespective of the breeding procedure, the planning of the experiments and the choice of suitable parents, all the important characters in this breeding programme mainly show additive-dominance variation. Although experiments using double crosses appeared to be the best way to proceed it was still necessary to answer the following questions:

1. Is there sufficient genetic variation within them to allow improvement in the characters of importance?. Before any breeding programme can start it is essential to determine if variability exists and if it is enough for an adequate response to selection

2. How extensively must the material be tested to identify superior families (populations), or identify superior parents within these populations?

3. Which hybrids among them are most promising as a source of improved breeding material?

4. Which further breeding procedures will most rapidly produce an acceptable level of improvement in the important characters?.

In order to answer these questions, the cold tolerance and early maturity of 32 double crosses were determined in three series of experiments: (A) under controlled condition in the growth chamber; (b) in the greenhouse, followed by (c) tests in the experimental field. Details are given on the sources of the materials used in these experiments in Chapter Two.

EXPERIMENT A.

Evaluation of the 32 Double Crosses for Their Ability to Germinate at a Constant Temperature of 6° C.

Twenty kernels from each double cross (see table 1) were used for the cold germination test. The kernels were separated randomly into two sets of ten seeds each. They were subjected to 6° C constant temperature in the growth cabinet using the method described in Chapter 2. In 1985 Maryam had obtained several duplicates of her double crosses and these were included in the experiment as an additional control. As a result, germination experiments were established in 80 petridishes. On 9th January 1987 they were placed in the growth cabinet in the dark for 21 days.

Daily records were taken on the number of germinated seeds and the germination index was calculated as follows:

$$GI = \frac{\Sigma \text{ (Number of seeds germinated in a day) x (day after starting the experiment)}}{\text{total number of seeds germinated 21 days after starting}}$$

Then the analysis of variance was carried for the number of seeds germinated and germination index (rate of germination).

Result of Experiment A.

Analysis of variance of the number of germinated seeds and of GI (table A-2) showed that there was a highly significant difference between the double crosses for both traits. The number of germinated seeds and GI are shown in table A-1.

From table (A-2) it will be seen that, although 32 double crosses were used in the experiment, there are 39 degrees of freedom associated with the between double crosses . Eight of the original double crosses were done in duplicate (Eg 6A1 and 6B1) and the germination test has been carried for all the samples of each double cross separately.

From table (A-1) it can be seen that all the seeds of the double crosses 2A, 5, 12A and 13 germinated. At the other extreme the number of germinated seeds were 5, 5, and 7 for double crosses 18, 20, and 16A respectively. This indicates that there is much variation for the ability to germinate at low temperature among the double crosses. Similarly, there are highly significant differences between the 32 double crosses for the number of days required for germination (GI), varying from 14.80 days to 20.42 days. Thus there is also great variation between the double crosses for early germination at 6^0 C. This result leads to the conclusion that the variation would be sufficient for an adequate response to selection for germinability at low temperature.

The ability of maize to germinate at low temperature has been investigated by many researchers (Neal, 1949; Haskell and Singleton, 1949; Helgason, 1953; Pesev, 1970; Eagles and Hardacre, 1979b; and Faranets, 1981) and it has been used as one of the indicators for the ability of any maize germ plasm to tolerate cold. There is also much evidence that the variation in cold tolerance has a genetic basis (Neal, 1949; Haskell, 1949; Andrew, 1954; Ventura, 1961; Grogan, 1970; Pesev, 1970; Eagles and Hardacre, 1979a; Faranets, 1981; Maryam and Jones, 1983 a; 1983b).

Table (A-1) Number of germinated seeds and germination index (GI) for the 32 double crosses tested at 6◦ C constant temperature for 21 days.

(a total number of 20 seeds was used from each double cross).

No.	double cross code	Number of seeds germinated	GI	No.	double cross code	Number of seeds germinated	GI
1	**1**	17	16.17	18	**15**	14	17.19
2	**2A**	20	16.15	19	**16A**	7	19.30
3	**2B**	11	16.85	20	**16B**	12	16.07
4	**3A**	15	15.38	21	**17A1**	16	16.50
5	**4**	18	16.91		**17A2**	17	16.69
6	**5**	20	15.55	22	**18**	5	20.42
7	**6A1**	18	16.05	23	**19A1**	7	16.90
	6A2	19	16.19		**19A2**	14	17.43
8	**6B1**	19	15.15	24	**20**	5	18.83
	6B2	18	14.85	25	**21A**	12	16.92
9	**7**	14	16.50	26	**21B**	7	19.95
10	**8**	16	16.95	27	**22**	13	19.21
11	**9A**	16	15.65	28	**23**	14	16.50
12	**10**	10	20.00	29	**24A1**	16	18.05
13	**11A**	15	15.73		**24A2**	18	17.67
14	**11B**	17	15.31	30	**25A**	13	17.33
15	**12A1**	20	16.35	31	**25B**	11	16.77
	12A2	20	15.25	32	**26A1**	8	19.25
16	**13**	20	14.80		**26A2**	17	18.12
17	**14A**	18	16.83				
	14A2	8	19.92				

*L.S.D. at 1% level = 6.16 and 5.08 for number of seeds germinated and GI respectively

Table (A-2) Analysis of variance of the number of germinated seeds, and germination index (GI) for the 32 double crosses at 6⁰ C constant temperature.

Character	Source of variance	DF	MS	F	P
Number of germinated seeds	Between double crosses	39	10.04	4.43	**
	Within double crosses (error)	40	2.26		
Germination index	Between double crosses	39	4.59	3.53	**
	Within double crosses (error)	40	1.30		

* * significant difference at 1% level 0.01 > P > 0.001.

The work of Maryam and Jones (1983a, 1983b, 1985) showed that additive effects were important for the germination at low temperature (8⁰ C and 6⁰ C) of just those inbred lines and their F_1s that have been used to make the 32 double crosses under investigation. Thus we can compare the number of germinated seeds and GI of the double crosses with those which had been found by Maryam and Jones for the inbred lines and their F_1s at the 6⁰ C constant using the same growth cabinet (see table A-3). It is clear that the double crosses performed better than the inbred lines and the single crosses which, were used to make them, and that a gain in the ability to germinate at low temperature has been established. From table 1(Chapter 2) we can see that whereas at least one early germinating inbred line was included in the formation of each double cross most of them included two or three early or medium germinating lines. These would contribute to the good response of most of the double crosses to germinate early in this test (see table A-3), thus confirming that additive effects were important for this trait in this population (Maryam 1981). Similar results have been found by Pinnel 1949;Sokolov and Ivaknenko, 1971; Golik and Dzhioeva, 1975 and Bojarczuk, 1979. They found that the double crosses were superior in their germinability at low temperature to the single crosses and the inbred lines.

Table (A-3) Germination characteristics of the seeds at 6°C constant temperature for the inbred lines and their F_1s as found by Maryam (1981) and the germination characteristic for the double crosses derived from them as shown in Table (A-1) in this experiment.

6° C constant temperature				6° C constant temperature		
Inbred lines and F_1s	Germination character-stics	No. of seeds germinated per 10 seeds	GI	Double cross	No. of seeds germinated per 20 seeds	GI
lines				1	17	16.17
GBO78	E	10	29.50	2A	20	16.15
GBC115	E	10	35.00	2B	11	16.85
GBC102	M	2	35.00	3A	15	15.38
GBC108*	E	10	35.00	4	18	16.91
GBC114	M	2	31.25	5	20	15.55
GBC233	M	3	37.50	6A	18	16.05
GBC77	L	0	0	6B1	19	15.15
GBC80	L	0	0	7	14	16.50
GBC100	L	0	0	8	16	16.95
GBC110	L	0	0	9A	16	15.65
				q10	10	20.00
F1,s				11A	15	15.73
78 x 115	EXE	10	13.10	11B	17	15.31
115 x 78	EXE	6	29.66	12A1	20	16.35
78 x 114	EXM	10	32.60	13	20	14.80
78 x 233	EXM	-	-	14A1	18	16.83
115 x 77	EXL	8	35.00	15	14	17.19
78 x 110	EXL	8	32.75	16A	7	19.30
114 x 78	MXE	8	36.25	16B	12	16.07
233 x 78	MXE	-	-	17A1	16	16.50
102 x 80	MXL	0	-	18	5	20.42
77 x 155	LXE	2	35.50	19A2	14	17.43
101 x110	LXL	0	-	20	5	18.83
110 x 78	LXE	8	32.75	21A	12	16.92
80 x 102	LXM	0	-	21B	7	19.95
110 x 101	LXL	0	-	2	13	19.21
				23	14	16.50
				24A1	16	18.05
				25A	13	17.33
				25B	11	16.77
				26A2	17	18.25

* Data for this inbred line was at 8° C conistant temperature.

EXPERIMENT B.

Evaluation for Flowering Stages and Other Agronomic Characters of the Plants Grown from the Earliest 5 Seeds to Germinate from Each Double Cross.

During the course of Experiment A, the first seeds to germinate of each double cross were selected, sown and grown into mature plants in the glasshouse. This was the first stage of selection on the double cross material and for the purpose of the selection the seeds harvested from these plants, following selfing, will form the S_1 generation.

Experiment B had two purposes; firstly to study the variation between and within S_0 families for flowering stages, maturity and other agronomic characters, and secondly, to obtain S_1 seeds following selfing of the S_0 plants and to carry out the next stage in the selection.

Experimental Details.

This experiment was carried out between January 1987 and July 1987. The first 5 seeds to germinate from each double cross in Experiment A were sown in John Innes potting compost No. 2 into 90mm plastic pots in the glasshouse. After 4 weeks all plants were transplanted into 250mm diameter plastic pots and the large pots were placed on the ground inside the glasshouse and arranged randomly in a randomized complete design, under controlled conditions as described in Chapter 2. All plants were selfed to obtain S_1 seeds (see Chapter 2 for method). After noting the date of planting, daily records were taken for the following characters: emergence, date of the boots, 51, 59, 61, 65, 69 and silking stages of flowering as listed in Chapter 2. Final plant height in cm, ear height in cm, date of maturity, and seed moisture at harvest were also measured. Daily records of the temperature inside the glasshouse were taken using a thermograph which had been previously placed there. The total of

the accumulated heat units were counted for each individual plant using the Gilmore and Rogers formula (Chapter 2). Because the moisture tester was not available until the 30th June 1987, all the selfed plants were harvested on the same day and seed moisture percentage was measured respectively on the same day (30th June 1987). The date of maturity was recorded, however, when each individual plant reached the maturity stage.

Results of Experiment B.

Means for the heat-unit degrees, for all traits of flowering stages, maturity, and the period from silking to maturity and the other agronomic characters, are shown in Table B-1 for all the 32 double crosses.

Analysis of variance was carried out for the heat-unit degrees required to the boots, 65, silking, maturity, and for the period from silking to maturity, and also for the number of seeds per plant, seed moisture content and plant height (cm.). The analyses are shown in Table B-2.

There were significant differences between the S_0 selected plants of the double crosses, for the heat-unit degrees required to the boots stage, silking, maturity, and from silking to maturity, but there were no significant differences between double crosses for the heat-unit degrees required for the 65 stage, the number of seeds per plant and seed moisture at harvest or plant height.

Although 160 plants were grown in the experiment, it can be seen from Table B-2 that only 118 degrees of freedom are associated with the error (within double crosses) for boots stage, 104 for 65 stage, 81 for silking, maturity and number of seeds per plant, 73 for seed moisture and 119 for plant height. That was because some of the plants did not survive to the appropriate stage. Some were very small and did not reach the flowering stages, while others did not develop a tassel or did not shed pollen grains. Thus the calculations were based on the total number of plants which reached particular stages. There were only 73 degrees of freedom for within

double crosses for moisture content, even though there were 81 for the number of seeds per plant. This was because some of the mature plants gave too few seeds for moisture determination by the seed moisture tester. In addition to that, five plants were destroyed by mice when they were seedlings. They could not be replaced because all of the plants were grown from seeds which had been selected for their germinability at low temperature during Experiment A.

From Table B-1 it can be seen that high variability exists among the double crosses for the flowering stages, maturity, and the period from silking to maturity. The heat units required for the boots stage ranged between 605.33 and 668.50 heat-unit degrees. Among the earlier S_0 plants to reach boots stage were those from double crosses 23, 11B, 8, 2B, 12A, 20, 5, 3A and 11A. For the silking stage the HUDs required ranged between 795.75 to 905.17, and among the faster S_0 plants to silking were plants from double crosses 20, 4, 11B, 3A, 14A, 23, 8, 19A2 respectively. For maturity the S_0 plants of the double crosses 19A2, 18, 25A, 4, 20, 3A, 5 and 9A2 were the fastest to mature and they required fewer HUDs compared with the other double crosses. The requirements ranged from 1335.30 HUDs for the fastest double crosses to 1543.94 for the slowest double cross to mature (21A). From the same table (B-1) the HUD required from silking to maturity ranged from 510.60 (19A2) to 700.55 (2B).

We started with plants that had been selected for early germination at 6°C temperature and it is clear from the means of the double crosses in table B-1 that the plants from each double cross behaved differently for the heat-unit requirements for every stage. For example, double cross No. 20 was among the fastest of the double crosses to reach boots, silking, and maturity, but it required relatively more time than the others for the stage from silking to maturity. On the other hand some of those that were earlier to silk were also earlier to mature, for example double crosses 20, 19A2, 4, but others were not.

From this experiment an understanding of the range of variability within the 32 double crosses was obtained and thus the basis for the selection programme was

established, but it is still too early, however, to predict the direction and the genetics of this variability, since this experiment was carried out under glasshouse conditions.

The heat-unit degrees requirements for the flowering and maturity stages, with their variances (S^2) within each double cross plants are shown in Table (B-3). There is great variability within the families. The degree of this variability between plants differs from one double cross to another. This table of results suggests that variability exists within double cross plants in addition to those between them. This variability needs to be tested by another experiment to study the means of S_1 families within each double cross and, if the S_1 families showed this variability in their means, it could be concluded that the use of HUD method described earlier is effective to classify the double crosses for their maturity and flowering. As this variability has a genetic basis of additive-dominance as found by (Maryam, 1981), selection for the flowering stages and maturity can be done among and within families of the 32 double crosses.

The lack of variation among the plants for the 65 stage character may result from the high temperature at the top of the plants because of the design and installation of the heating in the glasshouse. The heating came from above, being driven down by a fan in a circulating water radiator fitted just under the roof. The tassels would be exposed to higher temperatures than other parts of the plant, which together with the heat from the sun would encourage faster pollen shedding among double crosses. Consequently the differences between the double crosses would be reduced. Support for this explanation can be seen in table (B-1); all the double crosses reached the half-way anthesis stage before silking took place.

The non-significant differences between the 32 double crosses for the number of seeds per plant may follow from the non-significant differences between the single crosses which had been used to make them, as found by Maryam (1981). The absence of significant differences for plant height and ear height may be because the short and undesirable plants did not reach the stage for measuring. It is not valid here to consider the non-significant effects between double crosses for moisture content

because the moisture determination was not carried out on the day of maturity, following the delay in the receiving of the moisture tester.

The high variability, which is shown in this experiment among double crosses and within plants of each double cross, suggests that the selection for germination at low temperature would not affect the variability for the other characters under investigation here, since this variability has been found by (Maryam, 1981) in the basic single crosses that were used to form the double crosses. This follows Hexum, 1984; Mock and Bakri, 1976; McConnell and Gardner, 1979b; Hoard and Crosbie, 1982 who showed that selection for cold tolerance did not affect the other agronomic characters they measured. This explanation will be clarified following the S_1 progeny test reported in the next experiment.

Finally, as a result of selfing the plants in this experiment, seeds of 113 S_1 families were obtained. The number ranged from 2 to 5 S_1 families per double cross.

Table (B-1) Means of Heat-Unit Degrees (HUD), no. of kernels per plant, grain moisture content %, and plant height cm for 50 plants of the 32 double crosses

No.	Double cross	Code	Heat Units degrees required to					No. of Seeds/ Plant	% H_2O	Plant Height cm
			Boots	Halfway	Silking	Maturity	Silk to maturity			
1	(GBO77xGBC115)x(GBO78xGBC233)	1	721.00	837.40	832.40	1510.15	681.45	154.00	18.78	161.00
2	(GBO77xGBC115)x(GBC100xGBC115)	2A	764.95	883.90	841.25	1454.00	640.00	157.50	17.55	207.00
3	(GBC100xGBC115)x(GBO77xGBC110)	2B	706.80	851.10	842.25	1542.80	700.55	137.80	18.55	190.00
4	(GBO77xGBC108)x(GBO78xGBC233)	3A	718.45	839.20	800.92	1412.67	611.75	142.33	16.77	195.00
5	(GBO77xGBC108)x(GBO77xGBC110)	4	724.00	848.31	797.25	1404.58	607.33	135.33	18.83	168.00
6	(GBO77xGBC110)x(GBO78xGBC114)	5	713.31	838.63	838.03	1416.13	577.50	110.50	18.05	162.50
7	(GBO77xGBC110)x(GBO78xGBC115)	6A	747.05	859.85	830.69	1471.56	641.00	137.25	17.93	173.00
8	(GBO78xGBC115)x(GBO77xGBC110)	6B	771.70	884.75	859.00	1493.25	634.25	150.00	19.33	178.00
9	(GBO77xGBC110)x(GBO78xGBC233)	7	779.81	882.25	882.25	1510.75	628.50	175.66	20.97	168.75
10	(GBO77xGBC110)x(GBC100xGBC115)	8	685.20	843.80	812.50	1505.58	693.08	132.67	17.77	185.00
11	(GBO77xGBC110)x(GBC105xGBC233)	$9A_2$	726.60	858.30	845.95	1419.60	573.65	250.80	18.58	177.00
12	(GBO80xGBC102)x(GBO77xGBC110)	10	738.70	899.35	869.95	1500.90	631.05	222.00	21.25	170.00
13	(GBC233xGBC105)x(GBO78XGBC115)	11A	719.85	877.75	832.64	1477.85	645.21	135.00	16.98	154.00
14	(GBO78xGBC115)x(GBC105xGBC233)	11B	675.44	821.63	799.63	1433.69	634.66	201.25	18.93	173.75
15	(GBO78xGBC115)x(GBO77xGBC108)	12A	732.80	890.60	863.30	1446.30	583.00	140.00	17.83	206.00
16	(GBO78xGBC114)x(GBO77xGBC110)	13	765.69	878.38	893.37	1503.50	655.13	79.00	17.40	155.00
17	(GBO78xGBC114)x(GBO77xGBC108)	14A	726.95	855.50	803.13	1503.50	700.36	133.50	20.10	147.00
18	(GBO80xGBC102)x(GBO77xGBC108)	15	757.60	906.90	889.8	1482.00	592.20	156.20	19.42	177.00
19	(GBC233xGBC105)x(GBO78xGBC233)	16A	789.00	907.75	889.50	1418.17	582.67	226.69	18.93	189.00
20	(GBO78xGBC233)x(GBC105xGBC233)	16B	758.80	870.45	837.94	1515.00	677.06	79.00	19.35	177.00
21	(GBC233xGB0105)x(GBO78xGBC114)	17A	722.90	912.08	845.50	1416.25	570.75	254.00	18.8	168.00
22	(GBC105xGBC233)x(GBO78xGBC114)	18	755.15	867.00	836.30	1399.68	563.38	143.25	16.75	173.00
23	(GBC105xGBC233)x(GBO77xGBC110)	$19A_2$	715.50	842.05	824.70	1335.30	510.60	233.40	16.70	173.00
24	(GBC105xGBC233)x(GBO77xGBC108)	20	709.16	842.25	795.75	1409.42	613.67	146.67	16.00	193.50
25	(GBC105xGBC233)x(GBC100xGBC115)	21A	773.92	878.75	844.38	1543.94	699.56	170.25	17.73	190.00
26	(GBC100xGBC115)x(GBC105xGBC233)	21B	749.55	875.45	827.69	1536.00	708.00	97.50	16.20	152.00
27	(GBC100xGBC115)x(GBO78xGBC233)	22	804.38	919.94	845.89	1465.13	619.25	202.00	19.35	180.00
28	(GBO78xGBC233)x(GBO78xGBC115)	23	668.50	820.88	805.33	1446.67	641.33	113.00	18.30	181.25
29	(GBO80xGBC102)x(GBO78xGBC115)	24A	805.33	934.83	905.17	1507.00	601.83	177.00	20.13	181.67
30	(GBO80xGBC102)x(GBC105xGBC233)	25A	707.65	834.44	844.17	1402.33	558.17	175.67	19.20	194.00
31	(GBC105xGBC233)x(GBO80xGBC102)	25B	763.33	895.35	858.63	1498.00	639.38	205.00	17.05	154.00
32	(GBC233xGBC105)x(GBO80xGBC102)	26A2	755.20	859.60	829.60	1453.75	624.15	190.00	18.22	173.00
	Probability		**	N.S.	**	*	**	N.S.	N.S.	N.S.

Table (B-2) Analysis of variance for the double crosses (So) in the glasshouse based on the heat-unit: degrees required (HUD) for different flowering stages, no. of kernels per plant, grain moisture content % and plant height.

Trait	Source of variance	D.F.	M.S.	F ratio	Prob-ability
HUD to Boots stage of the tassel	Between double crosses	31	9651.567	5.173	**
	Within double crosses, error	118	1865.638		
HUD to halfway of anthesis	Between double crosses	31	3387.684	1.220	N.S.
	Within double crosses, error	104	2776.146		
HUD to silking stage	Between double crosses	31	7552.169	10.24	**
	Within double crosses, error	81	737.169		
HUD to maturity	Between double crosses	31	9787.670	1.72	*
	Within double crosses, error	81	5697.987		
HUD from silking to maturity	Between double crosses	31	9708.790	1.98	**
	Within double crosses, error	81	4883.958		
No. of seeds per plant	Between double crosses	31	6691.702	1.39	N.S.
	Within double crosses, error	81	4809.567		
Seed moisture content	Between double crosses	31	6.143	1.56	N.S.
	Within double crosses, error	73	3.932		
Plant height cm	Between double crosses	31	858.956	0.728	N.S.
	Within double crosses	119	1178.795		

Table B-3. HUD required for Boots stage for the selected S_0 plants of the 32 double crosses.

	Double Cross No.	Plant No. 1	2	3	4	5	Mean	Variance S^2
1	1	765.50	681.25	705.75	820.75	631.75	721.00	73.67
2	2A	681.25	811.25	735.75	805.75	790.75	764.95	55.53
3	2B	666.75	695.00	656.00	695.00	821.25	706.80	66.26
4	3A	735.75	774.50	631.25	675.75	775.00	718.45	63.38
5	4	666.75	735.75	781.25	661.25	775.00	724.00	57.51
6	5	795.50	705.75	-	705.75	646.25	713.31	61.55
7	6A	705.75	826.25	841.75	661.25	700.25	747.05	81.39
8	6B	735.75	915.50	751.00	681.25	775.00	771.70	87.45
9	7	886.50	871.25	700.25	661.25	-	779.81	115.66
10	8	666.75	705.75	647.15	760.00	646.00	685.15	48.31
11	9A	780.00	636.75	705.75	765.50	745.00	726.60	57.47
12	10	769.25	695.25	816.75	770.50	641.75	738.70	69.50
13	11A	705.75	666.75	720.75	700.25	805.75	719.85	51.92
14	11B	738.50	631.25	646.75	-	685.25	675.44	47.78
15	12	705.75	681.25	720.75	811.25	745.00	732.80	49.59
16	13	735.75	765.50	-	705.75	855.75	765.69	64.81
17	14	666.75	681.25	720.75	715.25	850.75	726.95	72.83
18	15	826.25	705.75	710.00	695.25	850.75	757.60	74.55
19	16A	765.50	831.25	764.00	757.75	826.50	789.00	36.56
20	16B	725.00	769.50	769.50	755.00	775.00	758.80	20.30
21	17	811.25	811.25	930.50	681	725.25	791.85	95.78
22	18	816.75	736.00	757.75	668.25	797.00	755.150	58.03
23	19A	751.00	681.25	751.50	652.25	741.50	715.50	45.84
24	20	-	660.75	700.25	-	766.50	709.17	53.44
25	21A	790.00	759.50	755.00	755.00	805.75	773.05	23.40
26	21B	815.75	710.75	742.25	698.00	781.00	749.55	48.96
27	22	831.25	785.00	876.00	725.25	-	804.38	64.52
28	23	675.75	661.25	641.75	695.25	-	668.50	22.63
29	24	811.25	-	845.25	-	759.50	805.33	43.18
30	25A	811.25	725.25	670.50	670.50	660.75	707.65	63.25
31	25B	700.25	745.50	865.75	789.90	715.25	763.33	66.72
32	26A2	811.25	769.50	656.25	769.50	769.50	755.20	58.19

Continued/Table B-3
HUD required for Halfway anthesis of the tassel for the S_0 plants of the 32 double crosses.

	Double Cross No.	Plant No. 1	2	3	4	5	Mean	Variance S^2
1	1	855.75	826.25	826.25	925.00	775.00	837.65	61.34
2	2A	841.75	886.50	841.75	910.00	939.50	883.90	42.82
3	2B	811.25	905.00	769.50	845.25	924.50	851.10	64.37
4	3A	871.25	910.00	730.25	760.00	924.50	839.20	88.68
5	4	826.25	915.50	-	760.00	891.50	848.31	69.92
6	5	-	886.50	-	-	790.75	838.63	67.70
7	6A	855.75	915.50	901.00	805.75	821.25	859.85	48.02
8	6B	871.25	-	886.50	841.75	939.50	884.75	40.95
9	7	-	945.00	820.75	881	-	882.25	62.13
10	8	826.25	826.25	805.75	939.50	821.25	843.80	54.15
11	9A	915.50	751.00	847.25	871.25	906.50	858.30	65.95
12	10	934.50	876.00	920.00	920.00	846.25	899.35	36.92
13	11A	886.50	795.50	871.25	881.00	954.50	877.75	56.54
14	11B	871.25	790.00	790.00	-	835.25	821.62	39.36
15	12	826.25	841.75	915.50	945.00	924.50	890.60	53.06
16	13	-	930.50	-	826.25	-	878.38	73.72
17	14	795.50	915.00	-	-	-	855.25	84.49
18	15	915.50	871.25	876.00	876.00	995.75	906.90	52.79
19	16A	855.75	964.50	855.25	920.00	943.25	907.75	50.23
20	16B	831.25	860.75	845.25	905.00	910.00	870.45	35.44
21	17	-	-	1029.75	885.75	850.75	922.08	94.87
22	18	-	857.00	907.25	818.00	885.75	867.00	38.61
23	$19A_2$	826.25	826.25	871.25	780.00	906.50	842.05	48.36
24	20	-	805.75	835.25	-	885.75	842.25	40.46
25	21A	910.00	865.75	876.00	876.00	866.00	878.75	18.19
26	21B	905.00	905.00	818.00	849.00	900.25	875.45	39.88
27	22	905.00	949.50	964.50	860.00	-	919.75	47.17
28	23	820.75	805.75	820.75	836.25	-	820.88	12.45
29	24	945.00	-	920.00	-	939.50	934.83	13.14
30	25A	915.50	-	815.75	800.00	805.75	834.25	54.56
31	25B	836.25	881.00	939.50	939.50	880.50	895.35	44.21
32	26A2	901.00	860.75	785.00	860.75	890.50	859.60	45.38

Continued / Table B-3
HUD required for silking initiation for the S_0 plants of the 32 double crosses.

	Double Cross No.	Plant No. 1	2	3	4	5	Mean	Variance S^2
1	1	855.75	811.25	795.50	924.50	775.00	832.40	59.44
2	2A	811.00	871.25	-	-	-	841.13	42.60
3	2B	795.50	905.00	740.50	860.75	842.25	909.50	73.04
4	3A	826.25	855.75	720.75	-	-	800.92	70.98
5	4	826.25	-	-	730.25	835.25	797.25	58.20
6	5	-	886.50	-	-	790.75	838.63	67.71
7	6A	871.25	-	855.75	790.00	805.75	830.69	38.95
8	6B	-	-	826.25	811.25	939.50	859.00	70.12
9	7	-	945.00	820.75	881.00	-	882.25	62.13
10	8	-	-	841.75	790.00	805.75	812.50	26.52
11	9A	886.50	720.75	855.75	871.25	895.50	845.95	71.61
12	10	915.50	815.75	876.00	862.00	876.50	869.15	35.89
13	11A	826.25	765.50	826.25	820.75	924.50	832.65	57.38
14	11B	826.25	730.25	820.75	-	821.25	799.63	46.32
15	12	780.00	826.25	930.00	855.75	924.50	863.30	64.35
16	13	-	915.50	-	871.25	-	893.38	31.29
17	14	780.00	826.25	-	-	-	803.13	32.70
18	15	871.25	871.25	876.00	876.00	954.00	889.70	36.02
19	16A	871.25	-	825.75	-	971.50	889.50	74.57
20	16B	785.00	860.75	845.25	860.75	-	837.94	36.04
21	17	-	-	-	855.75	835.25	845.50	14.49
22	18	-	857.00	833.75	804.25	850.25	836.31	23.50
23	19A2	811.25	795.50	855.75	765.50	895.50	824.70	51.27
24	20	-	755.00	805.75	-	826.50	795.75	36.78
25	21A	-	820.75	860.75	845.25	850.75	844.38	17.01
26	21B	876.00	-	804.25	788.75	841.75	827.69	39.15
27	22	876.00	-	-	815.75	-	845.88	42.60
28	23	820.75	774.50	820.75	-	-	805.33	26.70
29	24A	915.50	-	905.00	-	895.00	905.17	10.25
30	25A	901.00	-	815.75	815.75	-	844.17	49.22
31	25B	836.25	881.00	-	-	-	858.63	31.64
32	26A2	855.75	831.25	755.00	845.25	860.75	829.60	43.21

Continued / Table B-3
Heat units degrees required to maturity for S_0 plant of the 32 double crosses.

	Double Cross No.	Plant No. 1	2	3	4	5	Mean	Variance S^2
1	1	1591.25	1447.75	1447.75	1539.50	1524.50	1510.15	62.11
2	2A	1405.00	1503.50	-	-	-	1454.25	69.65
3	2B	1503.50	1494.00	1581.00	1534.50	1601.00	1542.8	47.01
4	3A	1513.50	1405.25	1319.25	-	-	1412.67	97.34
5	4	1503.50	-	-	1283.00	1427.00	1404.50	111.96
6	5	-	1447.50	-	-	1384.75	1416.13	44.37
7	6A	1545.00	-	1503.50	1313.75	1524.50	1471.69	106.65
8	6B	1503.50	-	-	1405.25	1571.00	1493.25	83.35
9	7	1591.50	-	1498.50	1442.25	-	1510.75	75.38
10	8	1503.50	-	1586.00	-	1427.25	1505.58	79.40
11	9A	1503.50	1319.25	1332.25	1432.25	1510.50	1419.60	91.06
12	10	1493.00	1493.00	1478.50	1520.00	1520.00	1500.90	18.41
13	11A	1405.25	1319.25	1447.75	1616.00	1601.00	1477.85	128.05
14	11B	1621.50	1326.75	1359.25	-	1427.25	1433.69	132.03
15	12	1405.25	1447.75	1447.75	1503.50	1427.25	1446.30	36.48
16	13	-	1503.50	-	1503.50	-	1503.50	0.00
17	14	1503.50	1503.50	-	-	-	1503.50	0.00
18	15	1447.75	1503.50	1581.00	1493.00	1384.75	1482.00	72.48
19	16A	1405.25	-	1272.50	-	1576.75	1418.17	152.53
20	16B	1493.00	1493.00	1581.00	-	1493.00	1515.00	44.00
21	17	-	-	-	1405.25	1427.25	1416.25	15.56
22	18	-	1418.25	1367.50	1410.00	1403.00	1399.69	22.25
23	19A	1319.25	1319.25	1288.50	1364.50	1384.75	1335.30	38.79
24	20	-	1384.75	1384.75	-	1458.75	1409.42	42.72
25	21A	-	1586.00	1581.00	1581.00	1427.25	1543.81	77.74
26	21B	-	1553.75	1507.75	1546.75	1535.75	1536.00	20.24
27	22	1493.00	-	-	1437.25	-	1465.13	39.42
28	23	1399.75	1442.25	-	1498.00	-	1446.67	49.27
29	24	1503.50	-	1534.50	-	1483.00	1507.00	25.93
30	25A	1503.50	-	1308.75	1394.75	-	1402.33	97.60
31	25B	1498.00	1498.00	-	-	-	1498.00	0.00
32	26A2	1591.50	1493.00	1394.75	1394.75	1394.75	1453.75	87.98

Continued/Table B-3

Heat units degrees required from silking to maturity for S_0 plants of the 32 double crosses.

No.	Double Cross Code	Plant No. 1	2	3	4	5	Mean	Variance S^2
1	1	735.50	636.50	652.25	615.00	769.00	681.45	67.02
2	2A	593.75	686.25	-	-	-	640.00	65.41
3	2B	708.00	589.00	840.50	673.75	691.50	700.55	90.67
4	3A	687.25	549.50	598.50	-	-	611.75	69.80
5	4	677.25	-	-	552.75	592.00	607.33	63.65
6	5	-	561.00	-	-	594.00	577.50	23.33
7	6A	673.75	-	647.75	523.75	718.75	641.00	83.49
8	6B	-	-	677.25	594.00	631.50	634.25	41.69
9	7	-	646.50	677.75	561.25	-	628.50	60.30
10	8	661.75	-	796.00	-	621.50	693.08	91.37
11	9A	617.00	598.50	476.50	561.25	615.00	573.65	58.73
12	10	573.50	677.25	602.50	658.50	643.50	631.95	42.34
13	11A	579.00	553.79	621.50	795.25	676.50	645.21	95.91
14	11B	795.25	596.50	538.50	-	606.00	634.06	111.52
15	12	625.25	621.50	517.75	647.75	502.75	583.00	67.37
16	13	-	588.00	-	722.25	-	655.13	94.93
17	14	723.50	677.22	-	-	-	700.36	32.73
18	15	576.50	632.25	705.00	617.00	430.25	592.20	101.76
19	16A	534.00	-	446.75	-	605.25	528.67	79.38
20	16B	708.00	632.25	735.75	632.25	-	677.06	52.97
21	17	-	-	-	549.50	592.00	570.75	30.05
22	18	-	561.25	533.75	605.75	552.75	563.38	30.50
3	19A2	508.00	523.75	432.75	599.25	489.25	510.60	60.32
24	20	-	629.75	579.00	-	632.25	613.67	30.05
25	21A	-	765.25	720.25	736.25	576.50	699.56	84.13
26	21B	658.50	-	749.50	719.00	705.00	708.00	37.87
27	22	617.00	-	-	621.50	-	619.25	3.18
28	23	579.00	667.75	-	677.25	-	641.33	54.19
29	24A	588.00	-	629.50	-	588.00	601.83	23.96
30	25A	602.50	-	493.00	579.00	-	558.17	57.65
31	25B	661.75	617.00	-	-	-	639.38	31.64
32	26A2	735.75	661.75	639.75	549.50	534.00	624.15	83.38

EXPERIMENT C.

Tests of the Progenies (S_1) of the Selfed S_0 Plants for heat-unit Requirements and Some Other Agronomic Characters.

S_1 families of six double crosses were selected for this experiment. Because of a limit on the space available inside the glasshouse, it was not possible to include all the 113 S_1 families of the 32 double crosses in an experiment to be carried out during the winter.

The families of the six double crosses, which are shown in Table (C-1), were selected according to the degree of variance between families within double crosses that are shown in Table (B-3) from Experiment B. Because we are interested in the genetic basis of the variation, in parallel with the selection programme, some of the slow maturing families were included in this experiment such as family 1 from double cross 4, families 1, and 5 from 16A, families 4, and 5 from 11A, and families 3 and 1 from double crosses 9A and 25A respectively. S_0 families of double cross 4, 11A, 16A, showed large variances, families of double cross 9A, 25A showed smaller variances, while there was a very low variance between families of double cross 19A. The main purpose of this experiment was to test the S_1 of the double crosses to determine (a) the genetic basis of the variation that appeared within S_1 progenies and (b) whether the behaviour of the S_1 generation is similar to that of the S_0.

Ten seeds from each of the selfed plants (family) included in this experiment were treated with Captan against fungal infections and were sown directly into John Innes potting compost No 2 in the glasshouse, on the 10th of November 1987, using the method described in Experiment B. Twenty two families from six double crosses were used in this experiment giving a total of 220 plants (Table C-1). Families of each double cross were distributed randomly inside the glasshouse in a complete randomized block design of 10 blocks. Although the randomization of plants is normal experimental practice, it was particularly important for this experiment

Table (C-1) The double crosses and their selfed families (S_1) used in experiment C.

Double cross	S_0 plants from which S_1 families were derived	HUD required to maturity by S_0 plant in exp. B	Variance within families
4	1 *	1503.50	111.96
	4	1283.00	
	5	1427.00	
9A	2	1319.25	91.06
	3	1332.25	
	5	1510.50	
11A	1	1405.25	128.05
	2	1319.25	
	3	1447.75	
	4	1616.00	
	5	1601.00	
16A	1	1405.25	152.53
	3	1272.50	
	5	1576.75	
19A2	1	1319.25	38.79
	2	1319.25	
	3	1288.50	
	4	1364.75	
	5	1384.75	
25A	1	1503.50	97.60
	3	1308.75	
	4	1394.75	

* this is plant No. 1 from double cross number 4 in experiment B (see table B-3 maturity).

because of possible variation in the light, while the experiment was carried out during the winter. Supplementation of light and the control of temperature were as described for experiment B.

The plants were screened daily and records were made in the way described in Chapter 2 and for Experiment B. Cobs were cut as soon as they matured and the moisture content was determined on the day of harvest. Two to five S_1 plants were selfed to obtain S_2 seeds from the 22 S_1 families.

Heat-unit degrees requirements were calculated (see Chapter 2) according to the Gilmore and Rogers method for each character, and then the analysis of variance was carried out for families derived from each double cross separately.

Results of Experiment C.

The means of heat-unit degrees required for the boots stage, 65, silking, maturity and for the period from silking to maturity with the means of number of seeds per plant, seeds moisture content, PHcm, and EHcm, are presented in Table C-2. The results of the analysis of variance for the S_1 families of the six double crosses are found in Table (C-3 and C-4).

From Table (C-3), significant family differences are found between S_1 families of double cross 4, 9A, 19A, for the HUDs required to boots stage, the same double crosses and also 11A showing significant differences between their families for the HUDs required to the 65 stage.

All S_1 families within double crosses, except 16A, showed significant differences for the HUDs required to reach silking and to reach maturity. Only S_1 families of double cross 11A showed a significant difference for the HUDs required from silking to maturity. There is no significant difference between families for the six double crosses (except D.C. 11A) for the number of seeds per plant. For seed moisture content only families of D.C. 9A showed a significant difference. For plant height (cm) only double crosses 11A, 19A, and 25A showed significant differences

between their families. The only differences for ear height (cm) were between families of double cross 9A.

From table (C-2) it can be seen that family 4 from double cross 4 was superior to families 1, 5 from the same double cross, for all flowering and maturity stages. It required fewer HUDs to flowering and maturity stages. This behaviour is similar to the result in Experiment B for the original S_0 plants for these families. It gave a higher number of seeds and less moisture content compared with its sister families.

Comparing the results of S_1 means of D.C.4 families (Table C-2) with the result of the original plants (S_0) from which they were derived (Table B-3), it can be seen that variation exists between these families for flowering and maturity stages. The same conclusion can be drawn from the results with the S_1 families of double crosses 9A, 11A, 19A, 25A. The families that were faster to flowering and maturity among the S_0 plants were also faster in the S_1; even for double cross 16A there is a similarity between its S_0 plants and their S_1 families means although the differences were not significant between S_1 families for this double cross.

Taking the heat-unit degrees required to maturity as the most important character in assessing these results, it can be seen from Table C-2 that among the faster families to mature were family 4, from D.C. 4, families 2, 3, 4 from D.C. 19A, and families 3, 4 from double cross 25A. S_0 plants of these families were faster in Experiment B (Table B-3). The non-significant difference between the families of double cross 16A in S_2 might be as a result of the lack of segregation in S_1, because in fact only three inbred lines were involved in its formation. They are GBC233, GBC105 and GBO78, both of it's parental single crosses are sharing the inbred line GBC233. Similar results have been found by Pinnell (1949), where there was a lack of diversity in double crosses that were derived from closely related sources.

The non-significant effect for the HUDs required from silking to maturity for S_1 between families of all the double crosses (except S_1s families of double cross 11A which showed significant differences at 5% level) is due to the relatively low variance between S_0 plants (Table B-3) for this character except for S_0 plants of double cross

11A which included both of the highest variances among the 6 double crosses. A similar interpretation could be made on the few significant differences which appeared in the other agronomic traits.

From these experimental results it can be concluded that there is much genetic variation for the flowering stages and maturity within the S_1 families of the six double crosses that were used in this experiment. This result would support and confirm the early conclusion from experiment B, that the selection for early germination would not effect the variation in other agronomic characters. Since this experiment was carried on the 22 S_1 families which were chosen to represent the 113 S_1 families obtained from experiment B , it is to be expected that the other 91 families are also a good source material for further and wide ranging selection for the important characters.

Table C-2 Means of the different traits of the different S_1 families for all double crosses.

Code	Double cross	Families	Mean of heat units degrees required to reach					Mean of no. of seeds per plant	Seed moisture content % at harvest	Plant height cm	Ear height cm
			Boots Stage	Halfway anthesis	Silking	Maturity	Silking to maturity				
	(GB077xGBC108)	1	653.30	742.90	775.60	1152.00	386.00	113.00	24.78	171.40	114.60
4	x	4	588.40	674.30	704.90	1071.00	378.00	127.00	26.56	161.50	99.90
	(GB077xGBC110)	5	662.80	747.50	756.40	1200.00	436.00	72.00	26.90	148.80	86.10
	L.S.D.	1%	51.17	36.58	54.22	110.41					N.S.
							N.S.	N.S.	N.S.	N.S.	
		5%	37.33	26.68	39.55	80.55					17.78
	(GB077xGBC100)	2	643.20	723.00	765.70	1178.00	417.00	89.00	26.19	145.40	88.30
9A	x	3	642.00	765.00	800.00	1234.00	380.00	115.80	28.74	143.30	82.90
	(GBC105xGBC233)	5	775.30	873.00	883.90	1292.00	408.00	83.30	28.59[2]	136.60	91.10
	L.S.D.	1%	62.40	79.91	64.51	N.S.			N.S.		
							N.S.	N.S		N.S.	N.S.
		5%	45.52	58.29	47.06	83.47			1.85		
		1	645.70	769.70	763.60	1106.00	348.60	124.00	26.99	179.80	108.00
	(GBC233xGBC105)	2	635.10	747.00	761.80	1134.00	386.50	93.10	27.31	151.00	87.30
11A	x	3	668.00	785.70	790.00	1190.00	401.10	88.50	28.47	143.10	90.30
	(GB078xGBC115)	4	697.40	787.20	798.30	1290.00	489.00	87.20	27.17	117.30	64.40
		5	691.80	753.60	772.50	1193.00	413.00	141.8[1]	29.42	160.10	87.00
		1%				91.23	70.07	N.S.			N.S.
	L.S.D.		N.S.	N.S.	N.S.				N.S.	N.S.	
		5%				68.09	52.29	43.37			19.74
	(GBC233xGBC105)	1	795.00	847.00	875.00	1289.00	410.00	123.00	28.61	139.40	74.40
16A	x	3	753.00	842.00	862.00	1240.00	381.00	154.00	28.38	140.90	72.80
	(GB078xGBC233)	5	782.00	888.00	923.00	1311.00	388.00	169.00	29.20	135.40	64.50
	L.S.D.	1%	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
		5%									
		1	692.70	759.00	820.00	1216.00	402.90	63.10	27.29	104.30	58.80
	(GBC105xGBC102)	2	613.90	673.00	702.40	1112.00	382.20	120.10	27.13	132.60	72.40
19A2	x	3	605.50	767.00	710.80	1121.00	410.60	138.20	28.61	128.40	70.50
	(GB077xGBC110)	4	578.40	672.00	687.10	1051.00	364.10	123.70	28.01	142.50	80.00
		5	733.20	810.00	870.20	1277.00	406.30	132.80	27.31	127.00	73.70
		1%	78.81	91.89	89.41	123.94				N.S.	
	L.S.D.						N.S.	N.S.	N.S.		N.S.
		5%	58.81	68.58	63.02	92.50				20.93	
	(GBC80xGBC102)	1	675.00	782.00	800.00	1206.00	405.40	150.00	29.99	143.30	77.00
25A	x	3	604.00	698.00	713.00	1078.00	364.30	178.00	28.05	156.20	90.40
	(GBC105xGBC233)	4	606.00	690.00	711.00	1100.00	389.50	123.00	28.56	122.50	62.40
		1%		N.S.	N.S.	N.S.				N.S.	N.S.
	L.S.D.		N.S.				N.S.	N.S.	N.S.		
		5%		74.48	81.40	99.94				21.64	19.29

Table (C-3) Analysis of variance of heat units degrees required to flowering maturity stages, and some of the other agronomic characters of the S_1 families of six double crosses.

D.C.	Double crosses	Source of variance	DF	HUD to Boots stage		HUD to 65 stage		silking stage	
				MS	F	MS	F	MS	F
4	GBO77xGBC108 x GBO77xGBC110	Bet. blocks Bet. fams Error	9 2 18	4074 16412 1578	2.58* 10.40**	4207 16816 806	5.22** 20.84**	4038 13360 1772	2.28 7.54**
9A2	GBO77xGBC100 x GBC105xGBC233	Bet. blocks Bet. fams Error18	9 2 18	5329 58757 2347	2.27** 25.03**	5837 60238 2348	1.51** 15.65**	4381 36978 2509	3.34* 14.74**
11A	GBC233xGBC105 x GBO78xGBC115	Bet. blocks Bet. fams Error	9 4 36	4207 6710 3843	1.09 1.75	6147 3321 1751	3.51* 1.90	7144 2637 2374	3.01 1.11
16A	GBC233xGBC105 x GB078xGBC233	Bet. blocks Bet. fams Error	9 2 18	13712 4594 10736	1.28 0.13	10744 5255 12903	0.08 0.48	13257 10129 10898	1.22 0.93
19A	GBC105xGBC102 x GBO77xGBC110	Bet. blocks Bet. fams Error	9 4 36	5618 42536 4197	1.34 10.14**	4160 37535 5706	0.73 6.58**	6650 66942 4819	1.26 13.89**
25A	GBC80xGBC102 x GBC105xgBC233	Bet. blocks Bet. fams Error	9 2 18	13331 16586 5657	2.37 2.93	20916 26120 6285	3.33* 4.16*	20719 25901 7506	2.76* 3.45

Continued Table (C-3).

D.C	Double crosses	Source of variance	DF	HUD to maturity stage		HUD from silk to mat stage		Kernels No. per plant	
				MS	F	MS	F	MS	F
4	GBO77xGBC108 x GBO77xGBC110)	Bet. blocks Bet. fams Error	9 2 18	35355 42457 4394	8.05** 9.66**	14419 9821 4303	3.35* 2.28	5964 8180 3169	1.88 2.58
9A2	GBO77xGBC100 x GBC105xGBC233	Bet. blocks Bet. fams Error	9 2 18	26122 32537 7891	3.31* 4.12*	5767 3731 3598	1.60 1.04	3161 3012 1742	1.81 1.73
11A	GBC233xGBC105 x GBO78xGBC115	Bet. blocks Bet. fams Error	9 4 36	23616 49760 5625	4.15** 8.85**	6874 29097 3318	2.07 8.77**	2837 6069 2282	1.24 2.66*
16A	GBC233xGBC105 x GB078xGBC233	Bet. blocks Bet. fams Error	9 2 18	21240 13415 14931	1.42 0.90	7505 2229 3705	2.03 0.60	1982 5383 5551	0.36 0.97
19A	GBC105xGBC102 x GBO77xGBC110	Bet. blocks Bet. fams Error	9 4 36	17741 80836 10382	1.71 7.79**	10606 3839 2553	4.15** 1.50	5581 9122 3504	1.59 2.60
25A	GBC80xGBC102 x GBC105xgBC233	Bet. blocks Bet. fams Error	9 2 18	34387 46594 11314	3.04* 4.12*	2394 4238 1813	0.05 2.37	4845 7426 4825	1.00 1.54

Continued table (C-3).

D.C.	Double crosses	Source of variance	Df	Grain moisture content		Plant height (cm)		Ear height (cm)	
				MS	F	MS	F	MS	F
4	GBO77xGBC108 x GBO77xGBC110)	Bet. blocks Bet. fams Error	9 2 18	4.52 12.96 6.00	0.75 2.16	1960.1 1283.4 899.2	2.18 1.43	1845.9 2031.3 357.9	5.16* 5.68*
9A2	GBO77xGBC100 x GBC105xGBC233	Bet. blocks Bet. fams Error	9 2 18	4.70 20.64 3.89	1.21 10.32**	835.8 196.0 584.5	1.43 0.34	1027.8 173.7 300.3	3.42* 0.58
11A	GBC233xGBC105 x GBO78xGBC115	Bet. blocks Bet. fams Error	9 4 36	7.14 10.85 6.44	1.11 1.69	2020.8 5269.0 983.6	2.05 5.36**	601.0 2404.8 472.9	1.27 5.09**
16A	GBC233xGBC105 x GB078xGBC233	Bet. blocks Bet. fams Error	9 2 18	6.61 1.78 7.48	0.88 0.24	651.7 80.8 403.1	1.53 0.20	497.9 282.4 126.6	3.93* 2.23
19A	GBC105xGBC102 x GBO77xGBC110	Bet. blocks Bet. fams Error	9 4 36	5.13 3.91 3.55	1.46 1.10	2091.5 1972.1 531.3	3.94** 3.71*	1403.1 663.9 324.0	4.33** 2.10
25A	GBC80xGBC102 x GBC105xGBC233	Bet. blocks Bet. fams Error	9 2 18	4.21 10.11 5.80	0.73 1.74	878.0 2891.2 530.3	1.66 5.45*	296.4 1961.2 575.3	0.52 3.41

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

Table C-4

Summary of the analysis of variance of the diffrent characters for S_1 families of the diffrent double crosses

Double cross no.	Source of variance	HUD to Boots stage	HUD to Halfway stage	HUD to silking	HUD to maturity	HUD from silking to maturity	No. of seeds per plant	% H_2O at harvest	Plant height cm
4	Bet.Block	N.S.	**	N.S.	**	*	N.S.	N.S.	N.S.
	Bet.Families	**	**	**	**	N.S.	N.S.	N.S.	N.S.
9A	Bet.Blocks	N.S.	N.S.	*	*	N.S.	N.S.	N.S.	N.S.
	Bet.Families	**	**	**	*	N.S.	N.S.	**	N.S.
11A	Bet.Blocks	N.S.	*	*	**	N.S.	N.S.	N.S.	N.S.
	Bet.Families	N.S.	N.S.	N.S.	**	**	*	N.S.	**
16A	Bet.Blocks	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	Bet.Families	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
19A	Bet.Blocks	N.S.	N.S.	N.S.	N.S.	**	N.S.	N.S.	**
	Bet.Families	**	**	**	**	N.S.	N.S.	N.S.	*
25A	Bet.Blocks	N.S.	*	*	*	N.S.	N.S.	N.S.	N.S.
	Bet.Families	N.S.	*	N.S.	*	N.S.	N.S.	N.S.	*

** significant at 1% level of probability

* significant at 5% level of probability

N.S. non-significant

Discussion and Conclusion.

The results of Experiments A, B and C show that much variability exists both between and within the 32 double crosses. The characters showing the variability are the ability and the rate of germination at low temperature (Table A-1, A-2), and for various flowering stages, and maturity for S_0 plants of double crosses (Table B-2, B-3), and between families in S_1 (Table C-2, C-3). This variation would be sufficient for effective selection between and within the families, for cold tolerance and early flowering and maturity. Since all these screening experiments were carried out in the glasshouse, the next task is to test this variation under conditions of direct sowing in the experimental field, as well as testing selected families from the greenhouse experiments in the field. These results complement those of Maryam (1981). Maryam (1981) also found in her study on the inbred lines and their F_1s (single crosses), (the same F_1s that have been used to produce these 32 double crosses), that there was an agreement between the results obtained in the glasshouse and in the field for flowering characters. The early flowering lines in the glasshouse were early flowering lines in the field. She also found significant differences between the inbred lines for flowering time and these differences were mainly controlled by additive and dominance genetic factors, suggesting that appropriate hybrids or varieties could be developed by the combination of the desired characteristics of early flowering, maturity, and early germination. Consequently, another cycle of selection can be done among and within the new hybrids to develop new lines from various hybrids.

Research efforts from the mid 1970's to the present have been primarily interested in establishing whether sufficient genetic variability existed within the maize population to permit successful selection for cold tolerance. Both exotic and adapted corn-belt populations were evaluated in these studies. Mock and Skrdla (1978) evaluated 144 plant introductions for cold tolerance traits. Their results, based on growth chamber evaluation, indicated sufficient genetic variability existed for cold characters, and the selection for cold tolerance would be possible. Miedema (1979),

Hardacre and Eagles (1980), Eagles and Brooking (1981), and Eagles, et al. (1983) have found that sufficient genetic variability existed within the germplasms which they used for various cold tolerance characters.

In most of the studies on maize cold tolerance described above, and in many other studies, laboratory tests were used alongside the field studies for the screening of the material and for the prediction of the variation within any maize population for cold traits. The main reason for that was to attempt to reduce the time which was needed for the breeding programme.

Eagles and Hardacre (1979a) derived S_1 families by selfing (families derived from maize population (pool 5) a population with a wide germplasm base and yellow dent kernels developed by "CIMMYT" for highland areas, which was developed from many maize populations for the high land of Mexico). They found that more genetic variation was observed within S_1 families than within full- sib families for all traits. They explained these observations by the segregation of genes with dominant effects. Cowen (1985) studied S_1 and S_2 selections for cold tolerance and concluded that selection which capitalizes on additive and maternal genetic variances should effectively increase cold tolerance in all environments.

It is also clear from results of experiments A, B, and C that the use of the accumulated heat-unit degrees is a good method to classify maize hybrids for their flowering and maturity stages. The field study on these genotypes would indicate if the glasshouse study was effective to evaluate and study the variation between and within these double crosses, their S_1 and S_2 generations

The heat-unit degrees method has been used by many researchers for that purpose. Gilmore and Rogers (1958) compared the precision of the HUD index method for corn with that of four other heat-unit methods. They identified the best method as that having the smallest coefficient of variation in heat-unit sums from planting to silking for 10 corn hybrids, 10 inbred, and 5 different planting dates. They concluded the best was an "effective degree" method in which any daily minimum temperature below 10° C was assumed to be 10° C, and any daily maximum

temperature above 30° C was corrected to 30° C. Cross and Zuber (1972), using six planting dates in 1968 and 1969, compared 32 thermal unit methods for predicting the number of days from planting to corn pollen shedding, from which they identified the HUD method as the 'heat stress' method. They concluded from their data that the heat stress method was the best. Gilmore and Rogers (1958) and Cross and Zuber (1972) confirmed that the heat-unit degrees method was superior to the calendar day method for predicting flowering and maturity of maize.

Mederski *et al.* (1973) used the accumulated heat units for classifying corn hybrid maturity and they concluded that this method of classifying corn hybrids was superior to calendar days and should enable a better fit of variety to climatic region. Aspiazu and Shaw (1972) stated that the use of the accumulated heat-unit growing degrees can improve the accuracy of predicting maturity of corn over calendar day techniques. Many other researchers reported that the use of temperature to classify development or maturity of corn based on temperature appears to be useful (Andrew, 1956; Arnold, 1959; Brown, 1969; Cross and Zuber, 1972).

Temperature is one of the main factors affecting the growth of plants. In many ways, from root growth and emergence to maturity, it has a major influence on plant development. For this reason many thermal indices have been used to predict dates of flowering and maturity. One of the most commonly used indices for measuring plant growth is the growing degree day (GDD) index which is defined as the difference between the daily mean temperature, usually estimated as the average of the daily maximum and minimum temperature, and growth threshold temperature, which for corn (*Zea mays L.*) usually is taken as 10° C (50° F), the summing of the GDD from planting to the phase of plant under study (flowering, and maturity in most studies).

The importance of using GDD to classify corn maturity and flowering stages is that the classification may be applied in different areas and in different years (Gilmore and Rogers, 1958). They, and Gunn and Christiansen (1963), reported that the number of accumulated heat units required for silking remain relatively constant

for corn grown in different environments, while the number of calendar days varied widely. However, in one of these studies (Gunn and Christiansen, 1963), and in other work (Andrew, *et al.* 1956), and in the work of Maryam (1981) there are indications that the time interval from silking to physiological maturity is not constant, but appears to vary with climate and the population hybrid being examined. An evaluation of the accumulated heat units classification of hybrids should extend from planting to maturity rather than from planting to silking.

The principle objective of the experiments reported in this chapter was to develop a good understanding of the variation within and between the 32 double crosses for the cold tolerance traits, flowering and maturity. Having established that there is genetic variation in these double crosses for the characters of importance in the breeding programme, the next stage is to carry out a field study on the double crosses, their S_1, and the selected S_2 families to meet the following objectives:

1. To assess the genetic variability and breeding potential for improvement of cold tolerance, early flowering and early maturity within and between these double crosses.

2. To study the association of cold tolerance traits with other plant traits.

3. While points 1, 2 are studied, selection among and within the 32 double crosses can be done, since understanding about the genetics of the desired characters in the basic populations is already available from B. Maryam (1981) studies.

4. Finally, to predict the most effective selection and breeding programme to improve the desired characters.

CHAPTER FOUR

VARIATION FOR GERMINABILITY AT LOW TEMPERATURE (6° C CONSTANT) WITHIN S_1 AND S_2 FAMILIES OF MAIZE (*Zea mays L*) DERIVED FROM DOUBLE CROSSES.

Experiment D.

One of the major environmental factors limiting the range of adaptation for maize is low temperature at planting time. Whereas certain differences between genotypes are not evident under favourable germination conditions, these variations appear clearly when seeds of different genotypes are exposed to unfavourable germinating conditions. Tests under unfavourable conditions can provide very valuable information supplementing tests carried out under favourable conditions. In studies on maize for cold tolerance, germination cold tests are used as an aid in evaluating genotypes for their cold tolerance.

Early and recent studies have shown that there is a positive correlation between the germinability at low temperature and the rate of emergence in the field under cold conditions (Andrew, 1954; Pinnell, 1949; Pesev, 1970; Eagels and Brooking, 1981; and Martin, Smith & Neil, 1988). In our study the evaluation of the S_1 and S_2 families was to be carried out under field conditions and, because the S_1 and S_2 families were at the early and, therefore, segregating stages of inbreeding, a survey of their germination capability at low temperature was required. This survey is also necessary as the basis of any selection programme because of the need to distinguish desired families.

Experimental Material.

The maize material used in this experiment consisted of two sets. The first set was 33 S_1 families which included all the families used in experiment C (chapter 3) and, in addition, those S_1 families derived from double crosses 2A, 21B and 26A.

The S_1 families of these last three double crosses were included in the experiment because they were among the most promising double crosses with early maturity (as observed in the field experiment which will be described later in Chapter 5).

The second set of experimental material was twenty two S_2 families, most of which were selected, on the basis of early maturity, from seventy one S_2 families obtained by selfing during the course of experiment C. The same families were used in the field experiment. It is necessary to mention here that the S_1 seeds, from which S_2 families were developed, were not selected for their germination ability at low temperature (see experiment C).

A summary of the materials used in this experiment, that is the S_1, S_2 families, and the heat-unit degrees required to maturity of the S_1 plants from which S_2 seeds were obtained are shown in table D-1. Both S_1 and S_2 seeds were obtained from the glasshouse experiments B, and C, by selfing S_0, and S_1 plants respectively.

In order to reduce to a minimum any effect on germination from other environmental factors related to the seed condition, care was taken to ensure good maturity before they were harvested. The seeds were hand shelled and dried in laboratory conditions at 18^0 to 25^{0}C, and then stored in a well ventilated area to allow moisture equilibration to occur.

Seeds of the S_1 families were harvested in June 1987. To allow comparisons for germination capability at 6^{0}C between the double crosses and their S_1 families the S_1 seeds were stored in the same area in which seeds of the double crosses were stored. They were also left for a similar period of time before they were subjected to the germination test (seeds of the double crosses harvested in April and May 1985 were tested for germination in January 1987). Then on the 9th of January 1989 S_1 and S_2 seeds were tested in this experiment at 6^{0}C constant temperature.

S_2 seeds were harvested in April and May 1988 from experiment C (Chapter 3). They were dried and stored in the same conditions described before for the S_1

Table D-1. Symbols of double crosses, S_1, and S_2 families used in experiment D. The table includes the heat units required to reach maturity by the S_1 plants. The S_2 seeds were obtained by selfing S_1 plants under the glasshouse conditions. The number of S_1 plants that were selfed is given.

Double cross	S_1 family	No. of S_1 plants selfed	selected S_2 family	HUD required to maturity by S_1 plant
	1	-	-	-
2A	2	-	-	-
	1 [1*]	4 [2*]	9 [3*]	1525.00
4	4	5	2	1383.00
	5	2	9	1469.25
	2	3	1	1623.50
9A2	3	5	2	1728.75
	5	2	4	1825.00
	1	4	5	1485.25
	2	4	4	1525.00
11A	3	2	10	1491.25
	4	2	6	1908.00
	5	3	1	1623.50
	1	3	4	1770.75
16A	3	2	7	2069.50
	5	2	6	1862.75
	1	2	2	1686.00
	2	4	4	1537.00
19A2	3	5	10	1441.25
	4	5	7	1383.00
	5	2	1	1623.00
	1	-	-	-
21B	3	-	-	-
	4	-	-	-
	5	-	-	-
	1	2	9	1623.50
25A	3	5	5	1383.00
	4	3	3	1525.00
	1	-	-	-
	2	-	-	-
26A2	3	-	-	-
	4	-	-	-
	5	-	-	-

1* this is S_1 family no 1 from double cross 4.

2* four plants selfed from 1* to form S_2 seeds.

3* plant No 9 of 1*.

seeds. The moisture content of the S_1 and S_2 seeds was checked before they were tested for low temperature germination at 6°C constant temperature.

The germination tests were carried out on the S_1 and S_2 families simultaneously using the same growth cabinet. The experimental technique used in this experiment was as described in Chapter 2 and in experiment A in Chapter 3. Twenty seeds from each S_1 and S_2 family were used. They were divided into two replications each of ten seeds.

Analysis of variance was calculated on the number of seeds germinated by 21 days and for the germination index (GI), for S_1 and S_2 families. An analysis of variance was also carried out separately for S_1 and S_2 families derived from each double cross.

The simple correlation coefficient between number of seeds germinated and number of days to germination (GI) for S_1 and S_2 families was also computed. Correlation analysis was used instead of analysis of variance of regression, because neither of the variables could be regarded as independent

Result and Conclusions.

The number of seeds germinated and the germination index for all S_1 and S_2 families are presented in table D-2. The results of the analysis of variance for S_1 and S_2 families for both germination characters are found in table D-3 , and for S_1 and S_2 families derived from each double cross separately are shown in table D-4.

Result of S_1 Families.

Highly significant differences ($P < 0.001$) occurred among S_1 families for the number of germinated seeds and for the time required for germination (table D-3). The data in table D-2 indicate that there is a good response from S_1 families for germination at 6°C constant temperature. The number of seeds germinated from samples of 20 seeds used in this experiment ranged between 2 to 18 seeds and for the

Table D-2. Number of seeds germinated and GI for S_1, and S_2 families in experiment D.

Double cross	family S_1	family S_2	No. of seeds Germinated S_1	No. of seeds Germinated S_2	Germination index S_1	Germination index S_2
2A	1	-	6	-	15.83	-
	2	-	13	-	16.50	-
4	1	9	11	10	16.12	14.10
	4	2	12	15	15.51	14.44
	5	9	10	3	16.55	18.00
9A2	1	-	7	-	17.16	-
	2	1	12	18	15.95	13.62
	3	2	12	5	16.41	17.08
	4	-	16	-	15.98	-
	5	2	18	15	15.22	14.85
11A	1	5	-	17	-	13.27
	2	4	18	19	14.77	13.88
	3	10	16	16	14.06	12.85
	4	6	11	4	16.33	14.16
	5	1	12	17	17.20	14.43
16A	1	4	13	10	15.86	16.13
	3	7	0	0	-	-
	5	6	9	2	17.85	17.50
19A2	1	2	14	2	18.37	16.00
	2	4	17	2	17.92	15.50
	3	10	7	17	16.70	14.77
	4	7	10	20	17.04	15.05
	5	1	18	20	15.66	14.40
21B	1	-	13	-	14.42	-
	3	-	6	-	18.16	-
	4	-	5	-	18.00	-
	5	-	3		19.50	-
25A	1	9	2	0	19.00	-
	3	5	2	8	19.00	17.75
	4	3	12	14	16.49	15.49
26A2	1	-	4	-	17.66	-
	2	-	8	-	17.66	-
	3	-	9	-	17.41	-
	4	-	5	-	17.33	-
	5	-	5	-	18.16	-
L.S.D. at 5%			2.28	1.91	1.28	1.76
at 1%			3.06	2.60	1.71	2.41

- Seed of S_1 or S_2 were not available or not sufficient.

0 No seed germinated by 21 days.

germination index the range was 14.06 to 19.50 days to germinate. Although all the S_1 families were developed from S_0 plants, which were grown from seeds selected for early germination ability at low temperature, such variation was to be expected because these S_1 families were developed from different double crosses of different germinability at low temperature, demonstrated in the results of experiment A (table A-1, and A-2).

Table D-3. Analysis of variance of the number of seeds germinated and the germination index for S_1 and their S_2 families used in experiment D.

Families	Characters	Source of variance	DF	MS	F	P
S_1	No. of seeds germinated	Between families	32	11.26	9.06	***
		Within families	33	1.24		
	Germination Index	Between families	32	3.53	9.05	***
		Within families	33	0.39		
S_2	No. of seeds germinated	Between families	21	26.65	31.69	***
		Within families	22	0.84		
	Germination Index	Between families	19	4.49	6.58	***
		Within families	20	0.68		

This range of variability among S_1 families indicates that selection based on family means, when compared with the overall mean of all S_1 families, will detect those S_1 families superior to others in this experiment. Hallauer and Miranda (1988) stated that this method was effective for selection among S_1 families.

The result in table D-4 of the analysis of variance for S_1 families derived from each double cross separately, shows that the degree of variability within S_1 families from each double cross was sometimes lower than the variability between S_1 families

Table D-4. Analysis of variance of the number of seeds germinated and the germination index of S_1, and S_2 families from each double cross.

		S_1 families				S_2 families			
D.C treat	Source of var.	Df	M.S	F ratio	P	Df	M.S.	F ratio	P
No.of seeds 2A	Bet.fams.	1	12.25	49.00	*	-	-	-	
	Error	2	0.25			-	-	-	
GI	Bet.fams	1	0.45	0.28	N.S	-	-	-	
	Error	2	1.62 -			-	-	-	
No.of seeds 4	Bet.fams	2	0.50	0.60	N.S	2	18.16	10.90	*
	Error	3	0.83			3	1.66		
GI	Bet fams	2	0.49	4.18	N.S	2	9.33	101.15	***
	Error	3	0.12			3	0.09		
No.of seeds 9A2	Bet.fams	4	9.00	10.00	*	2	23.16	9.93	*
	Error	5	0.90			3	2.33		
GI	Bet.fams	4	1.02	3.11	N.S	2	6.15	9.79	*
	Error	5	0.33			3	0.62		
No.of seeds 11A	Bet.fams	3	5.46	43.66	***	4	17.90	22.37	*
	Error	4	0.13			5	0.80		
GI	Bet.fams	3	4.10	25.18	***	4	0.83	0.88	N.S
	Error	4	0.16			5	0.25		
No.of seeds 16A	Bet.fams	1	4.00	8.00	N.S	2	14.00	21.00	*
	Error	2	0.50			3	0.66		
GI	Bet.fams	1	3.96	27.86	*	1	1.89	4.84	N.S
	Error	2	0.14			2	0.39		
No.of seeds 19A2	Bet.fams	4	10.85	4.94	N.S	4	49.00	496.00	***
	Error	5	2.20			5	0.10		
GI	Bet.fams	4	2.26	27.35	***	4	0.77	0.67	N.S
	Error	5	0.08			5	1.15		
No.of seeds 21B	Bet.fams	3	9.49	6.87	N.S	-	-	-	
	Error	4	1.37			-	-		
GI	Bet.fams	3	9.43	35.53	***	-	-	-	
	Error	4	0.26			-	-		
No.of seeds 25A	Bet.fams	2	16.67	-	***	2	2.46	-	***
	Error	3	0.00			3	0.00		
GI	Bet.fams	2	4.18	55.91	***	1	5.08	46.77	*
	Error	3	0.07			2	0.10		
No.of seeds 26A	Bet.fams	4	2.35	0.76	N.S	-	-	-	
	Error	5	3.10			-	-		
GI	Bet.fams	4	0.21	o.21	N.S	-	-	-	
	Error	5	0.99			-	-		

derived from different double crosses. This conclusion is clear when the data in table D-2 and the analysis in table D-4 are compared. They show no significant differences between the S_1 families of double crosses 4 and 26A for both germination characters. There are no significant differences also between S_1 families of double crosses 16A, 19A2, and 21B for number of seeds germinated, and also between S_1 families of double crosses 2A, and 19A for number of days to germination.

Significant differences at the 1% level of probability were observed between S_1 families of double crosses 11A and 25A for both characters and for the germination index alone between families of double crosses 19A2 and 21B, and at the 5% level among families of double cross 16A for the same characters.

For the number of seeds germinated by 21 days significant differences at the 5% level of probability were found between S_1 families from the double crosses 2A and 9A2.

This reduced variability was to be expected because the S_1 families were generated following selection of the earliest seeds to germinate which would inevitably reduce the variation among them. On the other hand, the significant variation between S_1 families of some of the double crosses may result partly from the segregation expected to occur among the S_1 generation individuals, and also from the variation between the S_0 seeds which were used to developed S_1 families within each double cross. Furthermore, the selection of plants for the S_1 generation was based on the first five seeds of each double cross to germinate in Experiment A. By the nature of the experiment, not all these seeds will be germinated on the same day.

It was explained earlier that care was taken to subject seeds of the S_1 families to the same environmental conditions as those experienced by the S_0 seeds before they were tested in experiment A. Thus it is possible here to compare the results of the S_1 generation in table D-2, D-3, and D-4 with those for the S_0 seeds in table A-1 and A-2. A summary to aid that comparison is given in table D-5. We see that the earliest double crosses to germinate in experiment A (among those from which the S_1 families used in experiment D were derived) were double crosses 9A2 and 11A. They

required 15.65 and 15.73 days to germinate respectively. The result of experiment D shows that the faster S_1 families to germinate were again among those families developed from double crosses 9A2 and 11A. These families were 3-11A, 2-11A, and 5-9A. They required 14.06, 14.77, and 15.22 days respectively to germinate. Interestingly they were also faster than their parent double crosses. This result reflects the genetic basis which controls the inheritance of this character. This result also shows that progress to improve the ability to germinate at low temperature has been made in that the mean of number of days to germinate for some S_1 families was less than that required by the double crosses from which they derived, in spite of the inbreeding effect which may result in reducing the viability of the seeds.

These results indicate that the selection for germinability at low temperature was effective both to distinguish and to create S_1 families with good response to this treatment. Furthermore these data confirm the predictions of Maryam (1981). She found from her studies on the basic material (the original inbred lines from which the double crosses were derived, F_1, F_2, B_1, and B_1) that the ability for germination at 6° C by this population was mainly controlled by additive genetic factors. Hallauer and Miranda (1988) stated that selection based on inbred progenies (S_1, S_2, etc.) is theoretically more effective for changing frequencies of genes having additive effects than the test cross method of selection.

The simple correlation coefficient between the number of seeds germinated at 6 °C constant temperature and number of days required to germination among the S_1 families was -0.71 for 33 degrees of freedom ($0.01 > P > 0.001$). Essentially, therefore, if a seed were going to germinate at 6 ° C then it was also an early germinator. This result is clear in table D-2, from which we can see that the fastest S_1 families to germinate gave the highest number of germinated seeds by 21 days.

This result agrees with the results of earlier studies on the germination and emergence of maize obtained from both controlled and field environments, (Mock and Eberhart, 1972; Mock and Skrdla, 1978; Eagles and Hardacre, 1979a; Mock and McNeill, 1979; Eagles and Brooking, 1981. They found that there is a positive

association between rate of germination or emergence and the percentage of germination or emergence. It needs emphasizing, however, that these tests of tolerance of maize to cold conditions were for a range of temperatures none of which were as low as the 6°C used in this experiment.

Result of S_2 Families.

There were twenty two S_2 families used in this experiment and the results of the S_2 families are included in tables D-2, D-3, and D-4.

From the data on the number of seeds germinated by 21 days and for the germination index, and from the result of analysis of variance of all S_2 families for both characters, there were highly significant differences at 0.001 level of probability for both characters between the S_2 families, similar to those observed in S_1 families.

It is not possible here to compare directly the results from the S_2 with the S_1 families because of the differences in the ages of the seeds. On the other hand, seeds of both generations were stored under the same conditions and there was no differences between them in the moisture content before they tested. But what is clear from the S_2 result is that those families which were faster to germinate among the S_1 generation were also the faster among the S_2 and most of S_2 families showed a good response to this test, excluding two of them that did not germinate by 21 days (family 7-3-16A, and 9-1-25A2).

The separate analysis of variance for S_2 families derived from each double crosses shows less variability in a way similar to that observed among S_1 families, but with some differences in the degree of variability. For instance S_1 families derived from double cross 4 showed no significant differences, but in the S_2 generation significant differences appeared among them (table D-4). Similar changes toward more or fewer differences were observed among S_2 families of the other double crosses. One reason behind this may be that the S_2 seeds were obtained from selfing S_1 plants that had been selected for early maturity and not for the ability to germinate

at 6^0 C. More likely, however we are seeing the effects of segregation in the third generation of selfing of the original double crosses. It is encouraging that the good performance of this population in the cold test for germination has occurred when no selection was carried out between the S_1 and S_2 generations. From these results it can be concluded that the selection for early maturity would not effect the capability to germinate at low temperature in this population.

The simple correlation coefficient between the number of seeds germinated at 6°C constant temperature and number of days to germination among the S_2 families was -0.68 for 22 degrees of freedom ($0.01 > p > 0.001$). This association is similar to that in S_1 families. Thus the result we obtained from the S_2 families germination test would lead to the same conclusion which we reached for the S_1 families.

Table D-5. Comparison of the result of the germination test for S_1, and S_2 families obtained in experiment D with those for their parental double crosses obtained from experiment A (table A-1).

Double crosses			S_1 families			S_2 families		
Code	No.of* S.G.	GI	code	No.of S.G	GI	code	No.of S.G	GI
2A	20	16.15	1	6	15.83	-	-	-
			2	13	16.50	-	-	-
			1	11	16.12	9	10	14.10
4	18	16.91	4	12	15.51	2	15	14.44
			5	10	16.50	9	3	18.00
			1	7	17.16	-	-	-
			2	12	15.95	1	18	13.62
9A2	16	15.65	3	12	16.41	2	5	17.08
			4	16	15.98	-	-	-
			5	18	15.22	4	15	14.85
			1	-	-	5	17	13.27
			2	18	14.77	4	19	13.88
11A	15	15.73	3	16	14.06	10	16	12.85
			4	11	16.33	6	4	14.16
			5	12	17.20	1	17	14.43
			1	13	15.86	4	10	16.13
16A	7	19.30	3	0	-	7	0	-
			5	9	17.50	6	2	17.50
			1	14	18.37	2	2	16.00
			2	17	17.92	4	2	15.50
19A2	14	17.43	3	7	16.70	10	17	14.77
			4	10	17.04	7	20	15.05
			5	18	15.66	1	20	14.40
			1	13	14.42	-	-	-
			3	6	18.16	-	-	-
21B	7	19.95	4	5	18.00	-	-	-
			5	3	19.50	-	-	-
			1	2	19.00	9	0	-
25A	13	17.33	3	2	19.00	5	8	17.75
			4	12	16.49	3	14	15.49
			1	4	17.66	-	-	-
			2	8	17.66	-	-	-
26A2			3	9	17.41	-	-	-
			4	5	17.33	-	-	-
			5	5	18.16	-	-	-

* Number of seeds germinated.

CHAPTER FIVE

FIELD EVALUATION OF MAIZE DOUBLE CROSSES AND THE S_1 AND S_2 FAMILIES DEVELOPED FROM THEM: FAMILY SELECTION AMONG AND WITHIN THE DOUBLE CROSSES FOR COLD TOLERANCE, EARLY FLOWERING AND MATURITY IN THE NORTH EAST OF ENGLAND.

Experiment E.

Introduction.

The development of cultivars of maize with the ability to grow under relatively unfavourable conditions has been a major objective of maize breeders in temperate regions where there is a short growing season.

McConnell and Gardner (1979b) stated that when the weather conditions are unfavourable the ability of maize seeds to germinate rapidly and produce a vigourous seedling may mean the difference between a successful crop and failure. The weather conditions in England and in the North of Iraq at sowing time are colder and wetter than those in which grain maize varieties have been grown traditionally. Thus the environment of North East England is a suitable one in which to evaluate the cold tolerance of grain maize from seed through to harvest.

Cold tolerance of maize has been defined by many researchers (Pendleton, 1965; McConnel and Gardner, 1979b; Mock, 1979; Cowen, 1985) as the ability to germinate, emerge, and grow under cold conditions. All of these factors are necessary for the early planting of maize which should allow pollination to occur earlier, and thus under the most favourable conditions (Pendleton, 1965), and then promote an earlier harvest.

Cold tolerance of maize as defined by percentage emergence, emergence rate, and seedling dry weight is genetically controlled and heritable (Mock and Eberhart, 1972; Mock and Skirdla, 1978; Mock and McNeill, 1979; Mock 1979).

Cowen (1985) suggested that any breeding programme designed to increase cold tolerance requires the selection of lines or hybrids with rapid uniform emergence, plus vigorous growth and rapid dry matter accumulation; and successful selection clearly requires the existence of heritable variation.

The improvement both in early seedling emergence and in the rate of seedling emergence of maize under cold conditions has been an objective of maize breeding programmes in cold regions for many years. Hoard and Crosbie (1986b) for example reported that cold tolerance is an aggregate trait important to the establishment of dependable stands in many environments. Selection for improved cold tolerance at germination and establishment must not interfere with improvement of other traits that are important later in the growing season. Burris (1975) reported that earlier tasselling and silking were associated with seedling vigour. Mock and Eberhart (1972) , however, found that the correlation between cold tolerance traits and tasselling date were low. Mock and McNiell (1979) found poor phenotypic correlation between percentage emergence (r= 0.22) or rate of emergence (r= 0.20) and yield, but seedling dry weight at 42 days after planting was significantly correlated with yield (r= 0.48). Suwantaradon *et al.*(1975) found a significant correlation between yield and rate of emergence. Marshall (1982) suggested that field selection for cold tolerance, supported by laboratory studies, would be effective to improve this trait. So it is clear that any breeding programme to improve cold tolerance in maize, by obtaining hybrids or lines with improved cold tolerance and early flowering and \ or early maturity, requires information on many important characters, such as emergence, emergence rate, dry matter accumulation, growth vigour, flowering stages, and maturity. Yield and yield components clearly need to be addressed throughout the selection programme.

The objectives of the experiments described in this chapter were:

a) to determine the advantage of laboratory and glasshouse selection for early germination and early maturity,

b) with the results of this experiment, together with results obtained from the previous experiments (A, B, C, and D) to identify those double cross hybrids, S_1, and S_2 families which are most promising as a source for further breeding to meet the aims of this programme,

c) to collect information about the important agronomic characters (emergence, emergence rate, seedling vigour,flowering stages, maturity, plant height, ear height, and yield and its components) of these materials when they grown in the experimental field. These data would form the basis of further work.

d) to determine if those hybrids, S_1, and S_2 families which would be classified as being cold tolerant and early maturing show an improvement in any of the other fitness characters listed in c above.

Material, Methods and Experimental Techniques:

Material and Methods.

This field evaluation was the main experiment in a series testing the double crosses together with their S_1 and the S_2 families obtained during the glasshouse experiments.

The materials used in this experiment were 102 genotypes consisting of a) all the 32 double cross hybrids used in experiments A and B (chapter 3); b) 48 S_1 families which included 22 S_1 families used in experiment C (derived from double crosses 4, 9A2, 11A, 16A, 19A2, and 25A) and 26 S_1 families selected from the other double crosses at the rate of one family from each, selected on the basis of early maturity (the fewer heat-unit degrees required to reach maturity according to the Gilmore-Rogers method); c) all 22 S_2 families which were used in experiment D and were obtained from experiment C.

The remnant seeds for the 32 double crosses, the 48 S_1, and the 22 S_2 families from those used in experiment A, B, C, and D were used in this experiment. Seeds of all generations were stored in the same conditions as described in experiment D.

For this experiment and to aid field randomization, the 102 genotypes were given the symbols from 1 to 102 as shown, together with the cross-referencing to previous experiments in table E-1. Throughout the discussion of the results of this experiment the genotypes will be referred to by their real names.

Experimental Technique.

The plan of the experiment was a generalized complete randomized block design in three blocks (Steel and Torrie, 1981). Five plants of each entry of the 102 genotypes were grown. A total number of 510 plants were grown in each block making a total of 1530 plants in the three blocks. In order to obtain a uniform stand and to enable the study of the emergence and seedling vigour, 15 kernels (treated with the fungicide Captan) from each double cross, S_1, and S_2 family were sown in each block in the rate of 3 kernels in each hill. Kernels were hand sown at 5 cm depth directly into the soil. When the plants were thirty one days old, each hill was thinned to one plant. The inter plant distance was 33 cm and the rows were 40 cm apart. The whole experiment was surrounded by guard plants derived from spare seeds of the experimental material. Each experimental and guard plant was labelled.

Block 1 and block 2 were sown on the 8th of May 1988, while block 3 was planted on the 15th of May 1988. The experiment was carried out in the Botanic Garden of the University of Hull in Cottingham (see chapter 2 for soil preparation). Missing hills at the early stages were replaced by transplanting from the guard plants of the same genotype (three kernels were also sown in each hill of the guard plants for that purpose). Data measurements were taken on an individual plant basis.

Table E-1. Summary of the experimental materials used in the field experiment (E), their symbols and nomenclature.

D. C.		S_1 Fams		S_2 fams	
no.	code	no.	code	no.	code
1	1	33	2	-	-
2	2A	34	1	-	-
3	2B	35	1	-	-
4	3A	36	3	-	-
5	4*	37	1*	81	9*
-	-	38	4	82	2
-	-	39	5	83	9
6	5	40	5	-	-
7	6A	41	4	-	-
8	6B	42	4	-	-
9	7	43	4	-	-
10	8	44	5	-	-
11	9A2	45	2	84	1
-	-	46	3	85	2
-	-	47	5	86	4
12	10	48	3	-	-
13	11A	49	1	87	5
-	-	50	2	88	4
-	-	51		89	10
-	-	52	4	90	6
-	-	53	5	91	1
14	11B	54	3	-	-
15	12A	55	1	-	-
16	13	56	2	-	-
17	14	57	1	-	-
18	15	58	5	-	-
19	16A	59	1	92	4
-	-	60	3	93	7
-	-	61	5	94	6
20	16B	62	4	-	-
21	17	63	4	-	-
22	18	64	3	-	-
23	19A2	65	1	95	2
-	-	66	2	96	4
-	-	67	3	97	10
-	-	68	4	98	7
-	-	69	5	99	1
24	20	70	2	-	-
25	21A	71	5	-	-
26	21B	72	4	-	-
27	22	73	4	-	-
28	23	74	1	-	-
29	24A	75	5	-	-
30	25A	76	1	100	9
-	-	77	3	101	5
-	-	78	4	102	3
31	25B	79	2	-	-
32	26A	80	3	-	-

Note: in this table S_1 and S_2 families are listed against the double crosses from which they were derived.

4* = Double cross hybrid 4

1* = S_1 family 1-4.

9* = S_2 family 9-1-4.

Traits Measured.

It has been reported by many researchers (Mock and Eberhart, 1972; Cowen, 1985; Hoard and Crosbie, 1985), that 'cold tolerance' should not be simply a measure based on test of germination and / or emergence percent; it should account for continued growth and dry matter production and so would be an aggregate trait. Therefore, all the characters which are related to maize cold tolerance and to early maturity were measured for these genotypes. These characters were:

a) Number of seedings emerged by 21 days from sowing and the rate of emergence on a day.

b) seedling dry weight per plant after 31 days from planting and seedling vigour after 42 days from planting.

c) the flowering and the maturity stages (boots, 65 stage of male flowering, silking, time from silking to maturity, and maturity). These latter were scored both on calendar day and on heat-unit degrees based on the Ontario and on the Gilmore-Rogers methods (see chapter 2 for methods of calculation).

d) the other agronomic characters studied were, plant height (cm), ear height (cm), grain moisture content (percentage), number of kernels per plant, grain weight per plant (gm) and weight of 100 kernels per plant (gm). A total of 15 characters were evaluated.

The number of seedlings that emerged above ground for each entry was recorded each day from sowing for a period of 21 days. These counts were used to compute the rate of emergence on a day using a modification of Smith and Millett's (1964) method.

Emergence rate (ER) on a day was calculated as follows:

$$ER = \frac{\Sigma \text{ (Number of seedlings emerged on a day) x (number of days after planting).}}{\text{Total number of seedlings emerged by 21 days.}}$$

In order to measure seedling dry weight, all hills were thinned to one plant after 31 days by hand. Plants were cut off at ground level and the plants obtained from each hill were put in a marked paper bags. Seedlings were dried at (37 40 °C) (Cowen, 1985) for one week. After that they were placed in a glass desiccator. Seedlings were weighed to the nearest 0.01 gm using an electronic balance. Seedling dry weight was calculated per plant; when two seedlings were obtained from a hill the mean was taken.

A visual assessment of seedling vigour was made at 42 days of age. This rating was based on the leafiness, greeness and height. Values ranged from 1-5 with one being excellent and five being poor. The choice of 31 and 42 days followed the practice as in previous studies (Mock and Eberhart, 1972; Mock and Bakri, 1976; Cowen, 1985).

The scoring of the flowering characters, maturity, plant height and ear height, and the study of all yield components were as described in Chapter 2 and experiments B and C.

Grain harvested from all of the experimental plants were stored under the same conditions in the laboratory until they had reached the moisture content of 14-15 percent. They were then weighed using an electronic blance to obtain the grain yield in gm / plant. The 100 kernel weights were obtained as follows using a Fortran computer programme.

100 kernels weight gm = grain yield gm per plant / number of grain per plant x 100.

Plants were examined every day from the time the earliest plants reached the boots stage until the day when the last plant reached the silking stage. Later the plants were also screened daily for maturity after the first plant to mature was observed. Again Ontario heat-units, the Gilmore-Rogers heat-units and the calender day methods were used for the evaluation of the flowering and maturity stages (see Chapter 2 for the reasons and methods of calculation).

Methods of Statistical and Genetics Analyses:

Statistical Analysis.

The one hundred and two genotypes used in this experiment consisted of 32 double crosses, 48 S_1, and 22 S_2 families. This material was not randomly drawn from the reference population, but was selected, from the lines and families which showed the most promise. The double crosses, as described earlier in chapter two, were obtained by crossing the selected single crosses obtained from Maryam's study (1981). Thus they are not a random sample from the original population. Furthermore, there is no doubt that all the S_1 and the S_2 families are selected materials. Then all the genotypes used in this study have a fixed effect. The three blocks and their environment were not chosen at random from all the environments of maize, but it was our choice to evaluate this material in this environment. The blocks also have a fixed effect. Thus the analysis of variance was based on Model 1, ie the error (within families) was the correct mean square agaist which to test the genotypes, the interaction, and the block effects.

Rawlings and Cockerham (1961) presented an analysis for double cross hybrids. This analysis provides a means of obtaining information, both genetic and non genetic, from a complete set of double crosses and it clarifies the interaction system involved in the double cross hybrid structure. An orthogonal analysis of variance was presented and then interpreted in term of the variance of the effect. One of the main conditions for using this analysis of variance is that the data should be from a complete set of double crosses from P lines. Unfortunately it is not possible for us to follow that model compeletly because our double crosses were not a complete set from the inbred lines used to develop them.

The linear model which they used is similar to the linear model of the analysis of variance of model 1. The main formula for the model is:

$$Y(ij)(kl)m = U + rm + G(ij)(kl) + E(ij)(kl)m$$

Y (ij) (kl) m = the observation on double cross hybrids (ij) (kl) grown in replication m = 1,...,r i, j, k and l = 1,...,p where no two of i, j, k, and l can be the same.

U = a contribution common to all entries,

r = the effect of replication m,

G (ij) (kl) = the genotypic effect of the double cross hybrid (ij) (kl) and E (ij) (kl) m = a random error associated with the genotypic effect due to double cross hybrids (G) as a linear function of correlation effects.

Moreover, this suggested analysis of variance partitions the main genotypic (G) effects into the separate effects of each inbred line involved in the formation of the double cross hybrid. It was designed mainly for this purpose, but this is not the major interest in the experiments described in this chapter. Our main interest here is the genetic variation among the double cross hybrids in general.

The use of model 1 (fixed model) analysis of variance, which is described by Steel and Torrie (1981) for a randomized complete block design, will be sufficient to study the genotypic variation among the double-cross hybrids. The general formula for this model is similar to that of Rawling and Cockerham (1961) described above.

Model 1 will give an estimates for the genetic variance, and the blocks x genotypes interaction, which is the genotype x environment interaction variance in our experiment, in addition to the experimental error. Our data were collected on an individual plant basis and the plants were distributed randomly for all genotypes, so there is no plots effect. The model is given in table E-2.

Table E-2. The fixed model, with interaction, of the analysis of variance for the complete randomized block design used in this experiment, as was described by Steel and Torrie (1981).

The general formula for the means is:

$Y_{ijk} = U + G_i + B_j + (GB)_{ij} + S_{ijk}$

Source of variance	*DF*	*M.S*	*Expectation of means square*
Between Blocks	*r-1*	*V1*	$\sigma^2 + sg \Sigma Bi^2 / r-1$
Between genotypes	*g-1*	*V2*	$\sigma^2 + sr \Sigma Gi^2 / g-1$
B x G	*(r-1)(g-1)*	*V3*	$\sigma^2 + s \Sigma (GB)^2ij / (r-1)(g-1)$
Error	*rg(s-1)*	*V4*	σ^2

Where G and B are the genotype and the blocks respectively, r = number of blocks, g = number of genotypes, and s = number of observations (number of plants from each genotype in each block).

In this model all the components of variance (between blocks, between genotypes, and the interaction) were tested against the residual (error effect).

Similar design with interaction was also described to evaluate the variation between the S_1 and S_2 families by Hallauer and Miranda (1988, p 171). They described the structure of the analysis of variance for family evaluation for maize in a randomized complete block design in one environment, when estimates of all parameters are obtained on an individual plant bases. This model is equivalent to the one described above.

The structure of this model is given in table E-3, and modified according to the fixed model.

Table E-3 Structure of the analysis of variance for family evaluation in a randomized complete block design in one environment.

Source of variance	*Df*	*M.S*	*Expected mean square*
Replications	*r-1*		$\sigma^2 + sf\Sigma B^2_j / r\text{-}1$
Families	*f-1*	*M1*	$\sigma^2 + sr\Sigma F^2_i / f\text{-}1$
F x B	*(r-1)(f-1)*	*M2*	$\sigma^2 + s\Sigma FB^2_{ij} / (r\text{-}1)(f\text{-}1)$
Error	*rf(s-1)*	*M3*	σ^2

Where F and B are the families and the replications (blocks) respectively, r, f, and s are the number of blocks, the number of S_1 or S_2 families, and the number of plants from each family in each block respectively.

Because block one and block two in these experiments were planted at the same time, and block three was planted one week later, it is possible to investigate whether there is any genotype x environment interaction. For this purpose three different analyses of variance were carried out for each trait for the double crosses, the S_1 and the S_2 families separately.

The first analysis was from the three pooled blocks. The second analysis was for block 1 + block 2 together. The third analysis was for block three only. For flowering stages and for maturity all these analyses were conducted on the basis of the calender days, the heat-unit degrees of the Ontario method, and the heat-unit degrees of the Gilmore-Rogers method.

A similar analysis was used for the S_1 and S_2 families derived from each of double crosses 4, 9A2, 11A, 16A, 19A2, and 25A2 separately.

Method of Genetic Analysis.

Estimation of the Genetic Components of Variance, Heritability, Selection Differentials, and the Expected Genetic Gain from Selection.

The genetic components of variance (genotypic variance $\sigma^2 F$, genotype x environment variance $\hat{\sigma}^2 F \times B$, and the error variance $\hat{\sigma}^2$) were estimated by using expected mean squares as described by Anderson and Bancroft (1952). Hallauer and Miranda (1988) stated that any selection methods that use progeny information for selecting the best individuals to recombine for population improvement will provide estimates of genetic variance (under the assumption of no nonadditive effects), genetic-environmental interaction variance, and experimental error and direct estimates of these components can be determined from linear functions of the mean squares. Genetic composition of the estimate of the genetic effects depends on the type of progeny evaluation. They also stated that if S_1 or S_2 progenies are evaluated, σ^2 G (genetic effect) = σ^2 A (additive effect) for S_1 or = 3/2 σ^2 A for S_2 families under the above assumption . These estimations were based on the results obtained from the ANOVA of the S_1 and S_2 families using blocks 1 and 2 for all traits studied.

The estimation of the genetic components of variance for the flowering and maturity stages was based on the results using the Gilmore-Rogers heat-unit degrees method. This was mainly because of the similarity of the results obtained by using any of the three methods used to evaluate these characters. From table E-3 the estimated component of variance were calculated as follows:

Estimated genetic variance between S_1 or S_2 families

$$\hat{\sigma}^2 F = \frac{M1 - M3}{rn}$$

$$\hat{\sigma}^2 B \times F = \frac{M2 - M3}{n}$$

Estimated error variance $\hat{\sigma}^2 = \sigma^2$.

In these formulae all parameters have the same meaning as in table E-3.

Heritability (narrow sense heritability) for S_1 and S_2 families for the different traits were calculated by using the estimated genetic components as described by Hallauer and Miranda (1988, p 71) as follows:

$$h^2 = \frac{\hat{\sigma}^2 A}{\hat{\sigma}^2 p}$$

Where $\hat{\sigma}^2 A$ is the additive genetic variance which equals $\hat{\sigma}^2 F$ for S_1 families and $3/2\ \hat{\sigma}^2 F$ for S_2 families assuming that the dominance genetic effect was not important for most of the characters studied. The narrow sense heritability estimate was also based on the analysis of variance of block 1 and 2 , and on the basis of individual plant data.

The formula used to calculate the phenotypic variance was:

$$\hat{\sigma}^2 p = \hat{\sigma}^2 F + \frac{\hat{\sigma}^2 B \times F}{r} + \frac{\hat{\sigma}^2}{nr}$$

Where $\hat{\sigma}^2 F$ = the genetic variance between families for one environment; $\sigma^2 B \times F$ = estimated environmental variance (block x family interaction); $\hat{\sigma}^2$ = within families (estimated error variance); r = number of blocks and n = number of individual plants used in each block (number of plants per plot).

The selection differential (D) was calculated for each trait for the S_1 and S_2 families as follows (Hallauer and Miranda, 1988; and Rogers *et al.*, 1977):

D = mean of selected families - grand mean of all families.

The expected genetic gain from selection of the earliest ten families among the 48 S_1 families (20.8 % selection intensity), and from the earliest five S_2 families to mature among the 22 S_2 families (22.7 % selection intensity) was calculated. Assuming that, the faster 20.8 % S_1 families or the faster 22.7 % S_2 families were recombined. Low values for all flowering, maturity, ER, 1-5 vigour scale, plant height and ear height are desirable, thus negative responses to selection are expected. Positive gains are expected for the rest of the traits studied.

The formula used to calculate the expected genetic gain from a given selection intensity was also as described by Hallauer and Miranda (1988) as fallows:

$$G\ gain = \frac{k\,\hat{\sigma}^2 F}{2\,\hat{\sigma}\ p} \qquad \text{for } S_1 \text{ families}$$

$$\text{and } G\ gain = \frac{K3/2\,\hat{\sigma}^2 F}{2\,\hat{\sigma}\ p} \qquad \text{for } S_2 \text{ families}$$

Where G gain = the expected responce to selection; $\hat{\sigma}^2 F$ = the genetic variance among families and it is equal to the additive variance among S_1 families and 3/2 the additive variance among S_2 families; $\hat{\sigma}\ p$ = the square root of the phenotypic variance; 2 is the number of years per cycle of selection and k = the selection differential in standard deviation units.

The k values for S_1 and S_2 were calculated for the selection intensities of 20.8 % and 22.7 % for S_1 and S_2 respectively as mentioned above using the method described by Hallauer and Miranda (1988).

The values of k then were obtained from table XX of Fisher and Yates (1963). That was because the group of families from which we selected had a size of N < 50 and we decided to select 10 families from S_1 families and 5 families from S_2 familles. Hallauer and Miranda (1988) reported that, if n families in the range from 1-25 is selected from a sample of N families (N < 50), then the expected value of k is the average of the first n values in the column corresponding to N in table XX (Fisher and Yates, 1963).

In our case we selected 10 S_1 families from a total of 48 families, and 5 from 22 S_2 families. Thus from table XX (Fisher and Yates, 1963) the k value for S_1 families is:

$$k_{s1} = 2.23 + 1.84 + 1.61 + 1.44 + 1.31 + 1.19 + 1.09 + 1.00 + 0.92 + 0.84 / 10 = 1.347$$

and k for S_2 is:

$$k_{s2} = 1.91 + 1.46 + 1.19 + 0.98 + 0.82 / 5 = 1.272$$

Results and Conclusions:

1. Seedling Emergence and Seedling Vigour for the Double Crosses ,the S_1, and the S_2 Families.

a. Number of seedlings Emerged and Seedling Emergence Rate (ER).

The number of seedlings that emerged for each of the 102 genotypes and the means of the number of days required for emergence are given in table (E-4) for block 1 + block 2, and for block 3 separately.

The results of the analysis of variance for these two characters for the double crosses, the S_1, and the S_2, for block 1, 2, and 3 together, block 1 and 2, and block 3 are given in table E-5. The separated analysis of variance for the S_1 and S_2 families derived from each of the double crosses 4, 9A2, 11A, 16A, 19A2, and 25A are given in tables E-6a and E-6b respectively. All these analyses were performed for the three blocks, and for the two blocks and for block 3 separately. A summary of the ANOVA results is presented in table E-9c.

From table (E-4) it is clear that most of the double crosses, the S_1, and the S_2 families showed good early emergence under the conditions of this experiment. This was mainly due to the relatively high suitable temperatures at the time of planting this experiment especially for the block 1 and block 2 planting date (8th May, 1987).

The means of the number of seedling emerged from 15 kernels sown from each entry in each block ranged from 12.5-15, 11.5-15, 7.5-15 seedlings in blocks 1 and 2, and 8-15, 10-15, and 8-15 in block three, for the double crosses, the S_1, the S_2 families respectively. Among the double crosses, number 4 gave the lowest number of the emerged seedlings for both dates of planting. Also most of the S_1 families and the S_2 families showed good response with early emergence. Among the S_1 families, family number 3, which was derived from double cross 16A, gave the lowest number of seedlings emerging in the block 1 + 2 result, but in block three it was S_1 family no 5 from double cross 11A. Among the S_2 families, families 10-3-19A2, 2-3-9A2, 5-1-11A, and 9-1-25A gave the least number of emerged seedlings.

The means of the emergence rate (ER) ranged between 11.18 (24A) - 14.7 (21A), 11.02 (5-5) - 14.07 (3-16A), and 11.21 (2-19A2) - 14.58 (3-16A) in block 1 + 2 , for the double crosses, the S_1, and the S_2 families respectively. While in block three the ranges were 13.00 (7 and 25B) - 16.57 (16B), 13.66 (2-11A) - 17.36 (3-16A), and 13.31 (4-4) -17.53 (2-9A2, respectively.

These results indicated that most of the genotypes emerged faster in block 1 + 2 than they did in block 3. The decrease in the minimum and maximum temperature that occurred in the first week after the planting of block 3 may be the main reason for this.

The analysis of variance for the number of the emerged seedlings, in table E-5, showed important differences between the double crosses and between the S_2 families in both cases (for blocks 1, 2, and three, and block 1 and 2 respectively). On the other hand there were no significant differences between S_1 families in either of the analyses of variance for this trait.

In the ER there were significant differences between the double crosses, between S_1 families, and between S_2 families in both analyses.

Although the ANOVA results in table E-5 showed significant differences for most effects in the analysis, table E-4 clearly shows that most of the entries emerged early, with a high number of emerged seedlings, and with only a very limited number of genotypes having delayed emergence. It is very clear that the variability among the double crosses, the S_1, and the S_2 families was higher in block three. That was mainly due to the decrease in the minimum and the maximum daily temperature which happened at the time of planting the third block (see appendix 1) which shows the daily minimum and maximum temperature throughout the course of this experiment.

The block x genotypes interaction cannot be tested for these traits because the analysis was done on the basis of plot means, but it is clear that all genotypes responded differently in the two planting dates and any further test carried out in the field with this material should be under more severe conditions, to allow variability

between the genotypes to appear. Thus it can be concluded that the mild conditions prevailing at the time of this experiment was the cause of the low variability between the double crosses and between the S_1 families.

The degree of variation was higher among the S_2 families for both traits. A decrease in the number of seedlings emergening is noticeable when comparing the S_2 generation with the S_0 and S_1 generation. This was to be expected as a result of inbreeding and the segregation which should take place in that generation.

The results of the ANOVA in table E-6a and E-6b for the separate analysis of S_1 and S_2 families derived from double crosses 4, 9A2, 11A, 16A, 19A2, and 25A revealed only a few significant differences between S_1 families derived from the same double crosses; between S_1 families of double cross 4 for the combined blocks ANOVA of ER and between families of double cross 9A2 for ER, for two blocks analysis. The same analysis for the S_2 families showed a similar result to that obtained with the S_1 families. For the analysis of variance of two blocks a difference at the 5 % level of probability appeared only between S_2 families of 19A2 for emergence rate. For the three blocks ANOVA, there are some significant differences at the 5 % level only for the emergence rate of the S_2 families derived from the double crosses 4, 9A2, and 11A, and at the 1 % level for 19A2. These can probably be attributed to the differences in the environment of block 3 from block 1 and 2, mainly due to the temperature differences. This result means that the S_2 families showed some genotype x environment interaction just for the emergence rate.

The means of the emergence rates of the S_1 and S_2 families derived from the same double crosses in table E-4 indicated that most of the faster S_2 families to emerge (2-4-4, 4-2-11A, 4-2-19A2, 10-3-19A2, and 1-5-19A2) were those families developed from the faster S_1 families (4-4, 2-11A, 2-19A2, 3-19A2, and 5-19A2).

This result was similar to the one obtained from the germination test in experiment D with the same families. Furthermore families which were late to emerge (eg 7-3-16A, 10-3-11A, 2-3-9A2, 7-4-19A2) among the S_2 generation were also the late among S_1 families. It is essential to mention here that the S_1 seeds of S_2

family 7-3-16A, which was the slowest family in this experiment, did not germinate in the germination test in experiment D.

Overall, the field test confirmed the results of the laboratory germination test described in chapter 4 and thus we can conclude that the laboratory test is an acceptable predictor of field germination.

Although the variation among the double crosses, the S_1, and the S_2 for both traits was not great, there were some S_1 and S_2 families which were faster than others and they have potential for any further breeding and selection for these two characters. Among the S_1 these families were 1-4, 4-4, 5-5, 2-11A, 4-16B and all S_1 families derived from double cross 19A2. Among the S_2 families the faster families were 2-4-4, 4-2-11A, 4-2-19A2, 10-3-19A2, and 1-5-19A2.

Table E-4. Means for number of seedlings emerged (no. of ES) and means of the emergence rate (ER) for blocks 1 + 2 and block three for all the double crosses, S_1, and S_2 families.

D C	no. of ES		ER		S_1	no. of ES		ER		S_2	no. of ES		ER	
	B_1+B_2	B_3	B_1+B_2	B_3		B_1+B_2	B_3	B_1+B_2	B_3		B_1+B_2	B_3	B_1+B_2	B_3
1	14.5	15	11.3	15.7	2	15.0	14	12.7	15.9	-	-	-	-	-
2A	15.0	15	11.3	15.6	1	15.0	14	12.2	15.7		-	-	-	-
2B	13.5	15	11.5	14.1	2	15.0	15	12.9	16.3		-	-	-	-
3A	14.5	15	11.5	14.2	3	15.0	15	12.6	16.9	-	-	-	-	-
4	12.5	8	11.4	15.1	1	14.0	15	11.5	14.6	9	13.0	14	12.4	15.3
	-	-	-	-	4	15.0	15	11.4	15.0	2	14.0	14	11.5	13.3
	-	-	-	-	5	13.0	15	12.8	15.6	9	15.0	14	13.6	16.3
5	15.0	15	12.2	15.6	5	13.5	15	11.1	15.8	-	-	-	-	-
6A	15.0	15	11.3	14.1	4	14.0	15	12.3	13.9	-	-	-	-	-
6B	15.0	13	11.5	14.7	4	13.5	15	12.7	15.3	-	-	-	-	-
7	14.5	15	12.0	13.0	4	14.0	15	12.0	16.6	-	-	-	-	-
8	14.5	15	11.3	13.9	5	14.5	15	13.5	15.8	-	-	-	-	-
9A2	14.0	13	12.7	13.4	2	14.0	11	12.5	15.3	1	13.0	15	14.5	17.5
	-	-	-	-	3	12.5	11	13.0	16.7	2	8.5	13	13.9	16.7
	-	-	-	-	5	14.5	15	12.2	14.5	4	12.0	13	13.2	15.7
10	14.5	15	11.7	15.4	3	15.0	15	11.4	15.6	-	-	-	-	-
11A	13.5	15	12.4	14.4	1	14.0	14	12.3	15.1	5	9.0	13	11.3	14.5
	-	-	-	-	2	14.0	15	11.7	13.6	4	12.5	15	11.5	14.2
	-	-	-	-	3	14.0	15	12.3	16.3	10	11.0	14	12.1	15.3
	-	-	-	-	4	13.0	14	12.4	16.0	6	14.5	11	12.3	14.6
	-	-	-	-	5	15.5	10	11.8	15.7	1	13.0	15	13.2	16.3
11B	14.5	15	11.4	16.0	3	14.0	14	11.6	16.5	-	-	-	-	-
12A	14.5	15	11.8	14.8	1	15.0	14	11.4	14.5	-	-	-	-	-
13	15.0	15	11.3	14.4	2	13.5	15	11.4	16.2	-	-	-	-	-
14	13.5	14	11.1	14.2	1	14.0	15	12.3	15.4	-	-	-	-	-
15	13.0	15	11.8	14.9	5	14.4	15	11.6	16.5	-	-	-	-	-
16A	13.5	15	13.2	14.9	1	14.0	13	11.4	15.6	4	11.5	11	13.4	16.5
	-	-	-	-	3	11.5	14	14.4	17.3	7	12.0	12	14.5	18.5
	-	-	-	-	5	13.5	14	13.7	14.7	6	11.0	14	14.3	15.4
16B	14.5	14	11.5	16.5	4	15.0	14	11.3	16.7	-	-	-	-	-
17A	15.0	14	12.1	14.0	4	14.5	14	12.0	15.0	-	-	-	-	-
18	13.0	14	12.7	15.7	3	14.5	14	11.3	14.7	-	-	-	-	-
19A2	15.0	15	12.2	15.1	1	13.5	15	11.3	16.4	2	7.5	14	13.5	17.5
	-	-	-	-	2	14.5	13	11.4	16.8	4	11.5	14	11.2	16.1
	-	-	-	-	3	14.5	14	11.7	15.9	10	14.5	14	12.0	13.8
	-	-	-	-	4	14.0	14	11.4	17.7	7	12.5	15	12.2	15.4
	-	-	-	-	5	14.5	14	11.3	14.9	1	14.5	14	11.6	14.4
20	15.0	15	11.5	15	2	14.5	14	11.4	15.5	-	-	-	-	-
21A	14.0	15	14.0	15.0	5	13.0	13	11.8	15.1	-	-	-	-	-
21B	12.5	15	11.8	13.7	4	14.0	13	12.7	15.0	-	-	-	-	-
22	14.1	14	11.8	15.0	4	13.5	14	12.4	15.7	-	-	-	-	-
23	14.5	15	11.4	13.7	1	13.5	14	12.3	15.3	-	-	-	-	-
24A	14.5	15	11.8	14.6	5	14.5	15	11.5	15.4	-	-	-	-	-
25A	14.5	15	12.6	14.3	1	14.0	15	11.4	15.2	9	9.0	8	13.5	15.5
	-	-	-	-	3	14.5	13	12.8	15.4	5	10.5	15	13.3	17.3
	-	-	-	-	4	14.5	15	12.3	15.5	3	14.5	15	13.2	15.9
25B	14.0	13	12.4	13.0	2	14.0	15	11.4	14.4	-	-	-	-	-
26A	15.0	13	11.3	16.3	3	14.5	15	12.5	15.8	-	-	-	-	-

Table E-5. Results of the ANOVA of number of seedlings emerged and emergence rate for double crosses (D C), S_1, and S_2 families.

Gen	Source of variance	DF	No.of seedling M.S.	F	P	Emergence rate M.S.	F	P
D.C	B1+B2+B3							
	Bet. blocks	2	0.844	1.229	N.S	75.120	138.342	***
	Bet. D.C.	31	1.852	2.479	***	0.612	1.126	N.S
	Error	62	0.747			0.543		
	B1+B2							
	Bet. blocks	1	1.265	3.492	N.S	0.080	0.643	N.S
	Bet. D.C	31	1.118	3.114	***	0.844	6.750	***
	Error	31	0.362			0.125		
S_1	B1+B2+B3							
	Bet. blocks	2	0.924	1.033	N.S	162.270	369.492	***
	bet. fams	47	1.244	1.390	N.S	0.750	1.710	*
	Error	94	0.895			0.439		
	B1+B2							
	Bet. blocks	1	2.041	2.740	N.S	0.322	3.114	N.S
	Bet. fams	47	1.062	1.429	N.S	0.981	9.480	***
	Error	47	0.743			0.103		
S_2	B1+B2+B3							
	Bet. blocks	2	16.010	4.650	*	50.208	145.109	***
	Bet.fams	21	8.560	2.480	**	3.266	9.440	***
	Error	42	3.440			0.346		
	B1+B2							
	Bet.blocks	1	0.023	0.006	N.S	0.144	0.980	N.S
	Bet. fams	21	9.213	2.780	*	2.247	15.340	***
	Error	21	3.308			0.146		

Table E-6a. Results of the ANOVA of number of seedlings emerged and emergence rate for S_1, families derived from the same double cross.

D.C	Source of variance	DF	No.of seedling M.S.	F	P	Emergence rate M.S.	F	P
4	B1+B2+B3							
	Bet. blocks	2	1.00	3.03	N.S	8.86	73.00	***
	Bet. fams	2	1.33	4.00	N.S	1.16	9.34	*
	Error	4	0.33			0.12		
	B1+B2							
	Bet. blocks	1	0.00	0.00	N.S	0.00	0.00	N.S
	Bet. fams	2	2.00	-	-	1.36	9.66	N.S
	Error	2	0.00			0.1405		
9A	B1+B2+B3							
	Bet. blocks	2	2.11	1.90	N.S	8.67	48.16	***
	bet. fams	2	5.44	4.90	N.S	1.18	6.48	N.S
	Error	4	1.11			0.18		
	B1+B2							
	Bet. blocks	1	0.666	3.99	N.S	0.375	7500.00	***
	Bet. fams	2	2.16	13.00	N.S	0.294	5814.61	***
	Error	2	0.166			0.00005		
11A	B1+B2+B3							
	Bet. blocks	2	0.467	0.16	N.S	16.62	54.49	***
	Bet.fams	4	0.767	0.26	N.S	1.06	3.47	N.S
	Error	8	2.967			0.305		
	B1+B2							
	Bet.blocks	1	0.400	0.28	N.S	0.216	4.68	N.S
	Bet. fams	4	1.000	0.71	N.S	0.199	4.33	N.S
	Error	4	1.40			0.0461		
16A	B1+B2+B3							
	Bet. blocks	2	0.77	0.36	N.S	7.07	10.02	*
	Bet. fams	2	1.77	0.84	N.S	2.98	4.22	N.S
	Error	4	2.11			0.70		
	B1+B2							
	Bet. blocks	1	0.667	0.30	N.S	0.0006	0.0002	N.S
	Bet. fams	2	3.500	1.61	N.S	4.0176	16.83	N.S
	Error	2	2.167			0.2387		
19A2	B1+B2+B3							
	Bet. blocks	2	0.66	0.10	N.S	28.66	102.35	***
	Bet. fams	4	0.10	0.15	N.s	0.35	1.26	N.S
	Error	8	0.65			0.28		
	B1+B2							
	Bet. blocks	1	0.00	0.00	N.S	0.0941	0.49	N.S
	Bet. fams	4	0.40	0.80	N.S	0.0417	0.21	N.S
	Error	4	0.50			0.1920		
25A	B1+B2+B3							
	Bet. blocks	2	1.33	2.01	N.S	7.86	78.45	***
	Bet.fams	2	0.33	0.50	N.S	0.09	0.84	N.S
	Error	4	0.66			0.10		
	B1+B2							
	Bet.blocks	1	2.666	15.99	N.S	0.062	0.80	N.S
	Bet. fams	2	0.166	1.00	N.S	0.922	12.03	N.S
	Error	2	0.166			0.0766		

Table E-6b. Results of the ANOVA of number of seedlings emerged and emergence rate for S_2, families derived from the same double cross.

D.C	Source of variance	DF	No.of seedling M.S.	F	P	Emergence rate M.S.	F	P
4	B1+B2+B3							
	Bet. blocks	2	1.33	2.00	N.S	4.49	20.40	**
	Bet. fams	2	1.33	2.00	N.S	3.04	13.83	*
	Error	4	0.66			0.22		
	B1+B2							
	Bet. blocks	1	2.666	3.999	N.S	0.0620	0.163	N.S
	Bet. fams	2	2.000	3.000	N.S	2.0245	5.341	N.S
	Error	2	0.6667			0.3790		
9A	B1+B2+B3							
	Bet. blocks	2	7.00	1.10	N.S	7.29	21.44	**
	bet. fams	2	10.33	1.63	N.S	2.48	7.31	*
	Error	4	6.33			0.34		
	B1+B2							
	Bet. blocks	1	1.50	0.14	N.S	0.2321	0.7516	N.s
	Bet. fams	2	11.17	1.063	N.s	0.9179	2.972	N.s
	Error	2	10.50			0.3088		
11A	B1+B2+B3							
	Bet. blocks	2	4.46	1.12	N.S	11.90	49.33	***
	Bet.fams	4	5.76	1.45	N.S	1.38	5.72	*
	Error	8	3.96			0.24		
	B1+B2							
	Bet.blocks	1	0.400	0.18	N.S	0.18225	0.299	N.S
	Bet. fams	4	8.750	4.07	N.S	1.1712	1.926	N.s
	Error	4	2.150			0.6080		
16A	B1+B2+B3							
	Bet. blocks	2	2.77	1.56	N.S	6.86	8.36	*
	Bet. fams	2	0.44	0.25	N.S	2.69	3.28	N.S
	Error	4	1.77			0.82		
	B1+B2							
	Bet. blocks	1	4.167	3.570	N.S	0.2904	1.756	N.S
	Bet. fams	2	0.500	0.429	N.S	0.6767	4.093	N.S
	Error	2	1.167			0.1653		
19A2	B1+B2+B3							
	Bet. blocks	2	8.60	2.010	N.S	14.11	42.00	***
	bet. fams	4	11.26	2.640	N.S	2.60	7.80	**
	Error	8	4.26			0.33		
	B1+B2							
	Bet. blocks	1	2.500	0.833	N.S	0.0672	0.667	N.S
	Bet. fams	4	16.600	5.533	N.S	1.5181	15.092	*
	Error	4	3.000			0.1006		
25A	B1+B2+B3							
	Bet. blocks	2	1.77	0.290	N.S	6.21	8.19	*
	Bet.fams	2	27.11	4.560	N.S	0.50	0.66	N.S
	Error	4	5.94			0.75		
	B1+B2							
	Bet.blocks	1	0.000	0.000	N.S	0.00167	0.0035	N.S
	Bet. fams	2	16.167	2.487	N.S	0.02555	0.5320	N.S
	Error	2	6.500			0.04802		

b. Seedling Dry Weight and 1-5 Vigour Scale.

The mean of seedling dry weight, gm /seedling and the means for the vigour scale for blocks 1 and 2, and block 3 are given separately in table E-7. Tables E-8, E-9a, and E-9b, respectively, give the results of the ANOVA for both traits for the double crosses, S_1, and S_2 families overall, and also for the individual S_1 and S_2 families in the same format as described for the emergence and the emergence rate. The ANOVA of block three was included for these characters and also for the following characters which will discused later in this chapter. A summary of these result is given in table E-9c. It should be noted that the degrees of freedom which are associated with the error for seedling dry weight (SDW) were sometimes less than those associated with the 1-5 vigour scale. This situation arises when no seedlings were available from some hills at seedling harvest; these were treated as missing hills for the purpose of the ANOVA.

Results for Seedling Dry Weights (SDW).

In table E-7 the means for seedling dry weight (SDW) for the double crosses in block 1 and block 2 ranged from 0.19 (18, 21B, and 25B) to 0.40 gm (10). For block 3 the range for the double crosses was 0.14 (18) to 0.36 gm (4,and 7). The ANOVA in table E-8 shows highly significant differences between the double crosses in the three analysis (pooled 3 blocks, blocks 1 + 2, and block 3). There were no significant block x genotype interactions in both analyses of the three blocks and the analysis of the two blocks (1 and 2). Thus there is no obvious genotype x environment interaction.

Similar variation was found between S_1 families (see table E-7 and E-8) for the S_1 generation. Table E-7 shows a decrease in the SDW in the S_1 generation compared with the original double crosses in general. The means of the SDW for S_1 families ranged between 0.15 (1-16A, and 4-17A) and 0.33 gm (1-11A) and 0.12 (4-17A)to 0.31 (5-24A) for blocks 1 and 2 and for block 3 respectively. This decrease in

the vigour of S_1 was not unexpected because of inbreeding. In spite of that, some of S_1 families performed better than the double cross from which they were derived (eg families 1, 2,and 3 from 11A, 4-16B, 4-21B, 4-22, 1-23, and 5-24A). The means obtained in block three were lower than those in blocks 1 and 2; this can be interpreted as a consequance of the lower temperature at the time block 3 was planted. There was also no block x families interaction for the S_1 families (table E-8).

For S_2 families the results show that there was a sharp decrease in the means of SDW compared with the S_0 and the S_1 generation means. S_2 family means ranged between 0.10 (3-3-11A) and 0.22 gm (10-3-19A2) and from 0.11 (2-3-11A) to 0.22 gm (10-3-19A2) for blocks 1 + 2 and for block 3 respectively. Table E-8 indicates that while there is significant variability among S_2 families, there is also significant genotypes x blocks interaction.

Overall these results suggest that selection for this character can be done in the S_1 generation whereas for the S_2 generation an evaluation requires the experiment to be repeated in more than one environment

Tables E-9a and E-9b indicate that variability among families derived from the same double cross was less than that among S_1 and S_2 families derived from different double crosses (see table E-8).

Significant differences appeared among families derived from double cross 4, 11A, and 19A2 in both S_1 and S_2 generation, but higher differences were observed in the S_2 generation for the same double crosses. The only significant family x blocks interaction was between families of double cross 19A2 in both generations. From table E-7 it is clear that some S_2 families derived from S_1 families which were superior were also superior (eg S_2 families 2-4-4, 4-2-11A, and 10-3-19A2). This also could mean that the selection for early maturity applied to this material between the S_1 and S_2 generations (chapter 3 Exp. C) did not effect the SDW.

Seedling Vigour scale.

The means and ANOVA results obtained for blocks 1+2 and block 3 for this vigour scale are shown in tables E-7, E-8, E-9a, and E-9b alongside the results of SDW. For block 1+2 the means ranged from 1.25 (24A) to 2.40 (25B), 1.9 (1-11A and 4-25A) to 3.30 (2-16A) and 2.22 (3-4-25A) to 3.62 (2-3-9A2) for the double crosses, the S_1, and the S_2 families respectively. The means of this character in block 3 were 1.00 (7) to 3.60 (4), 2 (5-24A, 4-4)to 4.90 (3-16A), and 2.43 (6-4-11A, 10-3-19A2, 1-5-19A2, and 3-4-25A) to 3.75 (7-3-16A).

Most of the results obtained for this character were similar to those for SDW. There were highly significant differences between the double crosses, between the S_1 families and between the S_2 families for the vigour scale. There was no important B x G interaction in any of the analyses included.

The results of the separated analyses of variance for the vigour scale (table E-9a and E-9b) for those families derived from the same double cross, also were similar to those obtained from the SDW in most cases. There was, however, a significant difference for the 1-5 scale of vigour for between S_2 families of double cross 25A, which was not significant for SDW. There were no significant differences among S_2 families derived from double cross 4 as were found for SDW. This exception can be attributed to the visual estimate of the vigour scale compared with the SDW which was not visually estimated. In addition both characters were evaluated at different ages (31 days and 42 days after sowing for SDW and 1-5 scale respectively). The association between the two characters was clear (table E-7), in that most of those double crosses , S_1, S_2 families which gave the highest SDW after 31 days were the best on the seedling vigour scale (lowest scale value).

Table E-7. Means for seedling dry weight (gm) and means of the 1-5 seedling vigor scale for blocks 1+2 and block 3 for all the DC, S_1, and S_2 families.

DC	SDW		V.scale		S_1	SDW		V.scale		S_2	SDW		V.scale	
	B_1+B_2	B_3	B_1+B_2	B_3		B_1+B_2	B_3	B_1+B_2	B_3		B_1+B_2	B_3	B_1+B_2	B_3
1	0.31	0.29	1.9	2.0	2	0.27	0.24	2.4	2.5	-	-	-	-	-
2A	0.32	0.24	1.5	2.3	1	0.26	0.25	2.3	2.7	-	-	-	-	-
2B	0.27	0.26	1.9	2.1	2	0.26	0.24	2.4	2.5	-	-	-	-	-
3A	0.28	0.32	1.9	2.3	3	0.25	0.22	2.2	2.6	-	-	-	-	-
4	0.29	0.36	2.2	3.6	1	0.30	0.30	2.4	2.2	9	0.15	0.16	2.8	2.3
	-	-	-	-	4	0.28	0.27	2.1	2.0	2	0.18	0.19	2.4	3.0
	-	-	-	-	5	0.24	0.22	2.8	3.2	9	0.11	0.11	2.7	2.8
5	0.28	0.31	1.6	1.6	5	0.25	0.24	2.7	2.9	-	-	-	-	-
6A	0.24	0.29	2.0	1.9	4	0.28	0.24	2.2	2.4	-	-	-	-	-
6B	0.28	0.26	1.93	1.8	4	0.25	0.28	2.3	2.4	-	-	-	-	-
7	0.31	0.36	1.4	1.0	4	0.23	0.17	2.3	3.8	-	-	-	-	-
8	0.28	0.33	2.3	2.3	5	0.27	0.30	2.6	2.6	-	-	-	-	-
9A2	0.30	0.27	2.0	1.9	2	0.19	0.19	2.5	2.8	1	0.12	0.12	3.2	3.0
	-	-	-	-	3	0.19	0.23	2.7	2.9	2	0.10	0.11	3.6	2.7
	-	-	-	-	5	0.22	0.20	3.0	2.5	4	0.12	0.11	2.8	3.0
10	0.04	0.32	1.5	2.0	3	0.26	0.23	2.6	3.0	-	-	-	-	-
11A	0.25	0.21	2.3	3.3	1	0.33	0.27	1.9	2.1	5	0.10	0.13	3.0	3.0
	-	-	-	-	2	0.27	0.28	2.6	2.2	4	0.17	0.17	2.9	2.6
	-	-	-	-	3	0.24	0.25	2.3	3.1	10	0.12	0.14	3.3	3.2
	-	-	-	-	4	0.20	0.25	2.4	2.3	6	0.17	0.14	2.5	3.7
	-	-	-	-	5	0.29	0.29	2.3	2.6	1	0.15	0.14	2.8	2.5
11B	0.35	0.33	1.6	1.9	3	0.25	0.16	2.1	3.2	-	-	-	-	-
12A	0.23	0.18	2.1	2.6	1	0.25	0.27	2.4	2.6	-	-	-	-	-
13	0.32	0.33	1.8	1.7	2	0.26	0.22	2.2	2.3	-	-	-	-	-
14	0.23	0.17	2.4	2.5	1	0.23	0.19	2.7	3.5	-	-	-	-	-
15	0.31	0.31	2.5	2.0	5	0.25	0.25	2.6	2.4	-	-	-	-	-
16A	0.23	0.20	2.0	1.9	1	0.15	0.16	3.3	2.4	4	0.15	0.12	3.4	3.5
	-	-	-	-	3	0.20	0.16	3.1	4.9	7	0.12	0.16	3.2	3.7
	-	-	-	-	5	0.16	0.25	3.2	2.3	6	0.12	0.16	3.0	2.7
16B	0.24	0.28	1.9	1.6	4	0.23	0.25	2.1	2.4	-	-	-	-	-
17A	0.23	0.23	2.0	2.0	4	0.17	0.12	3.2	3.3	-	-	-	-	-
18	0.19	0.14	2.4	3.2	3	0.23	0.16	2.5	2.8	-	-	-	-	-
19A2	0.26	0.24	1.6	2.4	1	0.23	0.22	2.5	2.5	2	0.11	0.15	3.4	2.8
	-	-	-	-	2	0.21	0.18	2.4	2.9	4	0.12	0.12	3.6	3.7
	-	-	-	-	3	0.25	0.23	2.9	2.7	10	0.22	0.22	2.5	2.8
	-	-	-	-	4	0.26	0.21	2.3	2.9	7	0.20	0.17	3.0	3.3
	-	-	-	-	5	0.19	0.16	2.5	2.9	1	0.18	0.15	2.5	2.6
20	0.23	0.19	2.1	2.6	2	0.20	0.24	2.8	3.0	-	-	-	-	-
21A	0.30	0.22	1.9	2.3	5	0.25	0.26	2.3	2.3	-	-	-	-	-
21B	0.19	0.32	2.2	3.1	4	0.25	0.23	2.7	2.2	-	-	-	-	-
22	0.22	0.19	2.0	2.0	4	0.28	0.30	2.3	2.4	-	-	-	-	-
23	0.26	0.24	1.6	2.0	1	0.28	0.28	2.5	2.9	-	-	-	-	-
24A	0.37	0.35	1.2	1.5	5	0.28	0.31	2.2	2.0	-	-	-	-	-
25A	0.30	0.27	1.6	2.1	1	0.28	0.25	2.7	3.0	9	0.11	0.16	3.6	2.9
	-	-	-	-	3	0.23	0.21	2.6	2.6	5	0.12	0.15	3.3	2.5
	-	-	-	-	4	0.24	0.25	1.9	2.2	3	0.15	0.16	2.2	2.8
25B	0.19	0.21	2.4	2.5	2	0.23	0.24	2.2	3.1	-	-	-	-	-
26A	0.22	0.24	1.9	2.3	3	0.25	0.25	2.4	2.2	-	-	-	-	-

Table E-8. Results of the ANOVA of seedling dry weight and 1-5 seedling vigor scale for the DC, the S_1, and the S_2 families.

Gen	Source of variance	SDW DF	SDW M.S.	SDW F	SDW P	1-5 vigor scole DF	1-5 vigor scole M.S.	1-5 vigor scole F	1-5 vigor scole P
D.C.	B1+B2+B3								
	Bet. blocks	2	0.010121	1.949	N.S	2	5.7095	11.105	***
	Bet. D.C.	31	0.036515	7.031	***	31	1.6468	3.203	***
	D.C. x blocks	62	0.005663	1.090	N.S	62	0.4621	0.899	N.S
	Error	376	0.005193			384	0.6024		
	B1+B2								
	Bet. blocks	1	0.016798	3.552	N.S	1	5.0000	10.447	**
	Bet. D.C.	31	0.026880	5.636	***	31	0.9266	1.936	**
	D.C. x blocks	31	0.003530	0.740	N.S	31	0.5020	1.049	N.S
	Error	251	0.004769			256	0.4787		
	B3								
	Bet.D.C.	31	0.017446	2.886	***	31	1.1423	1.952	**
	Error	125	0.006045			128	0.5852		
S_1	B1+B2+B3								
	Bet. blocks	2	0.025406	6.151	***	2	3.2691	6.421	***
	Bet. fams	47	0.020683	5.007	***	47	1.4725	2.892	***
	Fams x blocks	94	0.004533	1.098	N.s	94	0.6941	1.363	*
	Error	549	0.004131			576	0.5092		
	B1+B2								
	Bet. blocks	1	0.027745	6.775	**	1	1.6591	3.128	N.S
	Bet. fams	47	0.015233	3.720	***	47	0.9757	1.840	**
	Fams x blocks	47	0.005232	1.278	N.S	47	0.5413	1.021	N.S
	Error	363	0.004095			384	0.5304		
	B3								
	Bet. fams	47	0.009290	2.212	***	47	1.3436	2.879	**
	Error	186	0.004200			192	0.4667		
S_2	B1+B2+B3								
	Bet. blocks	2	0.014301	8.923	***	2	1.3789	3.086	N.S
	Bet. fams	21	0.012465	7.777	***	21	1.6439	3.679	**
	Fams x blocks	42	0.002582	1.611	*	42	0.5610	1.255	N.s
	Error	212	0.001603			264	0.4469		
	B1+B2								
	Bet. blocks	1	0.023248	17.095	***	1	2.5639	5.561	*
	Bet. fams	21	0.010880	8.000	***	21	1.6682	3.618	**
	Fams x blocks	21	0.003187	2.343	**	21	0.4127	0.895	N.S
	Error	132	0.001360			176	0.4611		
	B3								
	Bet. fams	21	0.003570	1.782	*	21	0.6850	1.637	N.S
	Error	80	0.002003			88	0.4184		

Table E-9a. Results of the ANOVA of seedling dry weight and 1-5 seedling vigor scale for the S_1 families derived from the same double cross.

D.C.	Source of variance	SDW DF	SDW M.S.	SDW F	SDW P	1-5 vigor scole DF	1-5 vigor scole M:S.	1-5 vigor scole F	1-5 vigor scole P
4	B1+B2+B3								
	Bet. blocks	2	0.001179	0.381	N.s	2	0.0842	0.135	N.S
	Bet. fams	2	0.020136	6.508	***	2	2.7642	4.419	*
	Fams x blocks	4	0.001799	0.581	N.s	4	0.2155	0.344	N.S
	Error	34	0.003094			36	0.6255		
	B1+B2								
	Bet. blocks	1	0.000867	0.308	N.S	1	0.1613	0.249	N.S
	Bet. fams	2	0.012421	4.411	*	2	1.2076	1.865	N.S
	Fams x blocks	2	0.003468	1.232	N.s	2	0.1001	0.155	N.S
	Error	22	0.002816			24	0.6476		
	B3								
	Bet. fams	2	0.007845	2.177	N.S	2	1.8875	3.247	N.S
	Error	12	0.003604			12	0.5812		
9A2	B1+B2+B3								
	Bet. blocks	2	0.000336	0.074	N.S	2	0.4222	0.583	N.S
	Bet. fams	2	0.002409	0.533	N.S	2	0.1847	0.255	N.S
	Fams x blocks	4	0.002222	0.492	N.S	4	0.5535	0.765	N.S
	Error	33	0.004519			36	0.7236		
	B1+B2								
	Bet. blocks	1	0.000083	0.017	N.S	1	0.8333	1.231	N.S
	Bet. fams	2	0.004083	0.837	N.S	2	0.8396	1.240	N.S
	Fams x blocks	2	0.000443	0.091	N.S	2	0.1021	0.151	N.S
	Error23	23	0.004880			24	0.6771		
	B3								
	Bet. fams	2	0.002327	0.631	N.S	2	0.3500	0.429	N.S
	Error	10	0.003687			12	0.8167		
11A	B1+B2+B3								
	Bet. blocks	2	0.000989	0.198	N.S	2	0.1433	0.292	N.S
	Bet. fams	4	0.019104	3.815	**	4	0.7304	1.488	*
	Fams x blocks	8	0.007078	1.414	N.S	8	0.05954	1.213	N.S
	Error	56	0.005007			60	0.4908		
	B1+B2								
	Bet. blocks	1	0.001969	0.448	N.S	1	0.0050	0.009	N.s
	Bet. fams	4	0.023467	5.346	**	4	0.5356	0.916	N.S
	Fams x blocks	4	0.008553	1.948	N.S	4	0.4394	0.751	N.S
	Error	36	0.004392			40	0.5850		
	B3								
	Bet. fams	4	0.001231	0.201	N.S	4	0.9462	3.128	N.S
	Error	20	0.006115			20	0.3024		

Continued Table E-9a

D.C.	Source of variance	SDW DF	SDW M.S.	SDW F	SDW P	1-5 vigor scale DF	1-5 vigor scale M.S.	1-5 vigor scale F	1-5 vigor scale P
16A	B1+B2+B3								
	Bet. blocks	2	0.002973	0.770	N.S	2	0.1056	0.202	N.S
	Bet. fams	2	0.007240	1.876	N.s	2	2.7764	5.302	*
	Fams x blocks	4	0.011707	3.033	*	4	5.2305	9.989	***
	Error	34	0.003860			36	0.5236		
	B1+B2								
	Bet. blocks	1	0.003126	0.650	N.S	1	0.2083	0.284	N.S
	Bet. fams	2	0.008188	1.703	N.S	2	0.1000	0.136	N.S
	Fams x blocks	2	0.008815	1.834	N.S	2	2.5083	3.416	N.S
	Error	22	0.004807			24	0.7344		
	B3								
	Bet. fams	2	0.013652	6.429	*	2	10.6292	104.122	***
	Error	12	0.00212			12	0.1021		
19A2	B1+B2+B3								
	Bet. blocks	2	0.020254	6.468	**	2	0.2633	0.581	N.S
	Bet. fams	4	0.012136	3.821	**	4	0.1487	0.328	N.S
	Fams x blocks	8	0.005578	1.756	N.s	8	0.7800	1.722	N.S
	Error	58	0.003176			60	0.4529		
	B1+B2								
	Bet. blocks	1	0.030381	10.669	**	1	0.0450	0.111	N.S
	Bet. fams	4	0.008403	2.951	*	4	0.5044	1.242	N.S
	Fams x blocks	4	0.010085	3.542	*	4	0.9356	2.303	N.S
	Error	38	0.002848			40	0.4062		
	B3								
	Bet. fams	4	0.004804	1.264	N.S	4	0.2687	0.492	N.S
	Error	20	0.003801			20	0.5462		
25A	B1+B2+B3								
	Bet. blocks	2	0.004425	1.181	N.S	2	0.1056	0.139	N.S
	Bet. fams	2	0.011202	2.991	N.S	2	3.2764	4.317	*
	Fams x blocks	4	0.003615	0.964	N.S	4	0.2326	0.306	N.S
	Error	33	0.003748			36	0.7590		
	B1+B2								
	Bet. blocks	1	0.006362	2.595	N.S	1	0.0333	0.043	N.S
	Bet. fams	2	0.010215	4.166	*	2	2.5646	3.291	N.S
	Fams x blocks	2	0.005352	2.183	N.S	2	0.3771	0.484	N.S
	Error	21	0.002452			24	0.7792		
	B3								
	Bet. fams	2	0.002872	0.477	N.S	2	0.8000	1.113	N.S
	Error	12	0.006016			12	0.7187		

Table E-9b Results of the ANOVA of seedling dry weight and 1-5 seedling vigor scale for the S_2 families.derived from the same double cross.

D.C.	Source of variance	SDW DF	SDW M.S.	SDW F	SDW P	1-5 vigor scale DF	1-5 vigor scale M.S.	1-5 vigor scale F	1-5 vigor scale P
4	B1+B2+B3								
	Bet. blocks	2	0.000212	0.189	N.S	2	0.1931	0.607	N.S
	Bet. fams	2	0.018329	16.285	***	2	0.0347	0.109	N.S
	Fams x blocks	4	0.000129	0.115	N.S	4	0.5743	1.806	N.S
	Error	32	0.001126			36	0.3181		
	B1+B2								
	Bet. blocks	1	0.000037	0.027	N.s	1	0.3521	1.341	N.S
	Bet. fams	2	0.011513	8.393	***	2	0.3646	1.389	N.S
	Fams x blocks	2	0.000095	0.069	N.S	2	0.0896	0.341	N.S
	Error	20	0.001372			24	0.2625		
	B3								
	Bet. fams	2	0.006980	9.762	***	2	0.7292	1.699	N.S
	Error	12	0.000715			12	0.4292		
9A2	B1+B2+B3								
	Bet. blocks	2	0.004870	2.697	N.S	2	1.0792	1.977	N.S
	Bet. fams	2	0.001339	0.741	N.S	2	0.6000	1.099	N.S
	Fams x blocks	4	0.005114	2.831	*	4	0.9542	1.748	N.S
	Error	26	0.001806			36	0.5458		
	B1+B2								
	Bet. blocks	1	0.009684	6.502	*	1	1.1021	1.593	N.S
	Bet. fams	2	0.001725	1.158	N.S	2	1.4255	2.060	N.S
	Fams x blocks	2	0.009799	6.579	**	2	0.9333	1.349	N.S
	Error	15	0.001489			24	0.6917		
	B3								
	Bet. fams	2	0.000047	0.021	N.S	2	0.1500	0.590	N.S
	Error	11	0.002238			12	0.2542		
11A	B1+B2+B3								
	Bet. blocks	2	0.007854	5.099	*	2	0.0522	0.128	N.S
	Bet. fams	4	0.009611	6.239	***	4	1.1195	2.745	*
	Fams xblocks	8	0.002107	1.368	N.S	8	0.6260	1.535	N.S
	Error	48	0.001540			60	0.4078		
	B1+B2								
	Bet. blocks	1	0.014397	8.526	**	1	0.0200	0.050	N.S
	Bet. fams	4	0.009624	5.700	**	4	0.1731	2.915	*
	Fams x blocks	4	0.002560	1.516	N.S	4	0.7606	1.890	N.S
	Error	29	0.001689			40	0.4025		
	B3								
	Bet. fams	4	0.001642	1.250	N.S	4	0.4377	1.046	N.S
	Error	19	0.001314			20	0.4185		

Continued Table E-9b.

D.C.	Source of variance	SDW DF	SDW M.S.	SDW F	SDW P	1-5 vigor scale DF	1-5 vigor scale M.S.	1-5 vigor scale F	1-5 vigor scale P
16A	B1+B2+B3								
	Bet. blocks	2	0.008002	6.676	**	2	0.9764	1.601	N.S
	Bet. fams	2	0.000130	0.108	N.S	2	0.9056	1.485	N.S
	Fams x blocks	4	0.003441	2.871	*	4	0.3806	0.620	N.S
	Error	28	0.001199			36	0.6097		
	B1+B2								
	Bet. blocks	1	0.013646	12.166	**	1	1.5187	2.398	N.S
	Bet. fams	2	0.002608	2.325	N.S	2	0.1187	0.188	N.S
	Fams x blocks	2	0.001633	1.456	N.S	2	0.1937	0.306	N.S
	Error	19	0.001122			24	0.6333		
	B3								
	Bet. fams	2	0.002772	2.037	N.S	2	1.3542	2.407	N.S
	Error	9	0.001361			12	0.5625		
19A2	B1+B2+B3								
	Bet. blocks	2	0.0000676	0.473	N.S	2	0.3158	0.757	N.S
	Bet. fams	4	0.026220	18.347	***	4	3.1554	7.565	***
	Fams x blocks	8	0.003477	2.433	*	8	0.2054	0.493	N.S
	Error	51	0.001429			60	0.4171		
	B1+B2								
	Bet. blocks	1	0.000938	0.931	N.S	1	0.6050	1.471	N.S
	Bet. fams	4	0.022128	21.960	***	4	2.5825	6.280	***
	Fams x blocks	4	0.004217	4.185	**	4	0.0175	0.048	N.S
	Error	32	0.001008			40	0.4112		
	B3								
	Bet. fams	4	0.006836	3.196	*	4	0.9662	2.258	N.S
	Error	19	0.002139			20	0.4287		
25A	B1+B2+B3								
	Bet. blocks	2	0.005206	1.839	N.S	2	0.5597	1.306	N.S
	Bet. fams	2	0.002713	0.958	N.S	2	3.5097	8.191	**
	Fams x blocks	4	0.001003	0.354	N.S	4	1.4201	3.314	*
	Error	27	0.002831			36	0.4285		
	B1+B2								
	Bet. blocks	1	0.000089	0.055	N.S	1	0.4083	0.933	N.S
	Bet. fams	2	0.003807	2.378	N.S	2	5.2937	12.100	**
	Fams x blocks	2	0.000618	0.386	N.S	2	0.8396	1.919	N.S
	Error	17	0.001606			24	0.4375		
	B3								
	Bet. fams	2	0.000296	0.060	N.S	2	0.2167	0.528	N.S
	Error	10	0.004922			12	0.4104		

Table E.9c. Summary of the ANOVA result for the emergence and seedling vigor traits.

Gen	Sour-ce	No.of S. 3*	2*	ER 3	2	SDW 3	2	1*	1-5 vigor sc. 3	2	1
DC	B	N.S	N.S	***	N.S	N.S	N.S	-	***	**	-
	G	***	***	N.S	***	***	***	***	***	**	**
	G x B	-	-	-	-	N.S	N.S	-	N.S	N.S	-
S_1	B	N.S	N.S	***	N.S	***	**	-	***	N.S	-
	F	N.S	N.S	*	***	***	***	***	***	**	**
	F x B	-	-	-	-	N.S	N.S	-	*	N.S	-
S_2	B	*	N.S	***	N.S	***	***	-	N.S	*	-
	F	**	*	***	***	***	***	*	**	**	N.S
	F x B	-	-	-	-	*	**	-	N.S	N.S	-
DC4	B	N.S	N.S	*	N.S	N.S	N.S	-	N.S	N.S	-
S_1	F	N.S	**	*	N.S	***	*	N.S	*	N.S	N.S
	F x B	-	-	-	-	N.S	N.S	-	N.S	N.S	-
S_2	B	N.S	N.S	**	N.S	N.S	N.S	-	N.S	N.S	-
	F	N.S	N.S	*	N.S	***	***	N.S	N.S	N.S	N.S
	F x B	-	-	-	-	N.S	N.S	-	N.S	N.S	-
9A	B	N.S	N.S	*	***	N.S	N.S	-	N.S	N.S	-
S_1	F	N.S	N.S	N.S	***	N.S	N.S	N.S	N.S	N.S	N.S
	F x B	-	-	-	-	N.S	N.S	-	N.S	N.S	-
S_2	B	N.S	N.S	**	N.S	N.S	*	-	N.S	N.S	-
	F	N.S	N.S	*	N.S	N.S	N.S	N.S	N.S	N.S	N.S
	F x B	-	-	-	-	*	**	-	N.S	N.S	-
11A	B	N.S	N.S	**	N.S	N.S	N.S	-	N.S	N.S	-
S_1	F	N.S	N.S	N.S	N.S	**	**	N.S	*	N.S	N.S
	F x B	-	-	-	-	N.S	N.S	-	N.S	N.S	-
S_2	B	N.S	N.S	***	N.S	*	**	-	N.S	N.S	-
	F	N.S	N.S	*	N.S	***	**	N.S	*	*	N.S
	F x B	-	-	-	-	N.S	N.S	-	N.S	N.S	-
16A	B	N.S	N.S	*	N.S	N.S	N.S	-	N.S	N.S	-
S_1	F	N.S	N.S	N.S	N.S	N.S	N.S	*	*	N.S	***
	F x B	-	-	-	-	*	N.S	-	***	N.S	-
S_2	B	N.S	N.S	*	N.S	**	**	-	N.S	N.S	-
	F	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S
	F x B	-	-	-	-	*	N.S	-	N.S	N.S	-
19A	B	N.S	N.S	***	N.S	**	**	-	N.S	N.S	-
S_1	F	N.S	N.S	N.S	N.S	**	*	N.S	N.S	N.S	N.S
	F x B	-	-	-	-	N.S	*	-	N.S	N.S	-
S_2	B	N.S	N.S	**	N.S	N.S	N.S	-	N.S	N.S	-
	F	N.S	N.S	**	*	***	***	*	***	***	N.S
	F x B	-	-	-	-	*	**	-	N.S	N.S	-
25A	B	N.S	N.S	*	N.S	N.S	N.S	-	N.S	N.S	-
S_1	F	N.S	N.S	N.S	N.S	N.S	*	N.S	*	N.S	N.S
	F x B	-	-	-	-	N.S	N.S.	-	N.S	N.S	-
S_2	B	N.S	N.S	*	N.S	N.S	N.S	-	N.S	N.S	-
	F	N.S	N.S	N.S	N.S	N.S	N.S	N.S	**	**	N.S
	F x B	-	-	-	-	N.S	N.S	-	*	N.S	-

3*, 2*, and 1* are pooled 3 blocks, block 1+2, and block 3 ANOVA results respectively.

The Correlation Between Seedling Emergence and Seedling Vigour Traits.

Based on the data as presented in table E-4 and E-7 the correlation coefficients given in table E-10 show negative correlations between the number of seedlings emerged and emergence time rate and between SDW and emergence time rate for all the situations assumed. This means that the high number of seedling emerged is associated with early emergence and high seedling dry weight is also associated with early emergence. Although this association was not high and it was significant in some occasions and not in the others, but the direction of the association is consistent in the three generations. It is also very clear that the correlation coefficient between SDW and emergence time was increased by selection through S_0 to S_2 generation. In general it is thought that the degree of the association was weakened by the lack of the variation especially for emergence traits as a result of the relatively high temperature at planting time (see appendix 1).

Table E-10 Simple correlation coefficients between the number of seedlings emerged and ER , and between SDW and ER for the double crosses , the S_1, and the S_2 families.

	Correlation Coefficient			
	E, ER		SDW, ER	
Gen	B1 + B2	B3	B1 + B2	B3
S_0	-0.303*	-0.052	-0.048	-0.092
S_1	-0.393**	-0.111	-0.151	-0.233
S_2	-0.221	-0.013	-0.484**	-0.482**

This result shows that the three characters could be used as the basis for selection to improve the cold tolerance of this population although that need to be tested under colder conditions. This result also confirms the conclusions drawn from the germination test experiment D. It is also very encouraging to find that the families which germinated earliest at 6 ° C constant temperature also have a good

response in the field test compared with the others. There is the posibility, therefore, that the germination character and seedling vigour may be controlled by the same genetic system. Maryam (1981) found that the genetic system controlling the germination of this population (the source population) mainly consisted of additive gene effects, and so additive effects could be also important for seedling vigour. Therefore selection on the S_1, and the S_2 families should be effective in improving these cold tolerance characters.

It is well known that, "in general" the greater the proportion of the heritable variation that is of the additive kind, the greater the effectiveness of selection" (Mather and Jinks, 1982). The response to selection, when the simple additive-dominance model is adequate, has been shown to be $R = h^2 S$, where R is the response to selection, h^2 the narrow sense heritability and S the selection differential (Falconer, 1989). In the context of the work described in this thesis, there is the additional comment by Hallauer and Miranda (1988) that characters which are controlled mainly by additive effects can be improved by S_1 and S_2 family selection.

Mock and Eberhart (1972) reported on the results of a recurrent selection programme for cold tolerance evaluating S_1 progeny. They based their selection on the percentage emergence, rate of emergence, and seedling dry weight in two environments, early field planting, and planting in a growth chamber. Their data indicated that the same genetic system controlled cold tolerance in the field and in the growth chamber.

Mock and Bakri (1976) evaluated the progress during several cycles of recurrent selection for cold tolerance also based on early planting dates, percentage emergence and seedling dry weight. Comparison between the cycles selected in the growth chamber and those selected in the field showed that the best genotypes in the cycles of the selection were essentially the same.

Several other researchers have reported similar associations between percentage emergence, emergence rate and SDW (Mock and McNeill, 1979; Mock and Skrdla, 1978; Eagles and Hardacre, 1979a; Eagles and Brooking, 1981; Chapman,

1984). The conclusion was drawn that this favourable association is widespread in maize. These studies and many other studies (Pinnell, 1949; Ventura, 1961, Grogan, 1970; Pesev,1970; and McConnell and Gardner, 1979b) reported that emergence, ER, and SDW are quantitatively inherited traits and additive, dominance and epistatic effects play important roles for both laboratory germination and field emergence under low temperature condition.

Mock and Eberhart (1972), in their study on S_1 recurrent selection for cold tolerance in maize, also reported that genes controlling these cold tolerance traits were independent of the genes controlling maturity under normal planting conditions. It was also determined that field selection for cold tolerance would be more effective. Most of these studies reported that early vigour is a moderately to highly heritable trait, and that visual selection for early vigour should be an effective means for improving cold tolerance quickly (one year per cycle) and with relatively little effort (Hexum, 1984).

2. Flowering Stages and Maturity.

Three flowering stages (boots, 65 stage of male flowering, and silking) were studied in this experiment, in addition to the time taken from silking to maturity and the overall time to maturity for all the double crosses, S_1, and S_2 families.

The time taken by each plant to reach each particular stage was expressed in three scales; firstly in terms of the number of days, secondly in terms of 'heat-unit degrees accumulation' using the Ontario method, thirdly in terms of 'heat-unit degrees accumulation' using the Gilmore-Rogers method (see Chapter 2 for methods of calculation and more details).

The means of each set of 10 plants (blocks 1 and 2 combined) and of 5 plants (block 3), for the three methods and for the five stages, are given in tables E-11, E-12, E-13, E14, and E-15. The corresponding ANOVAs for the double crosses , the S_1, and the S_2 families are given in tables E-16, E-17, E-18, E-19, and E-20.

The results of the separate ANOVAs for the S_1 or S_2 families derived from double crosses 4, 9A2, 11A, 16A, 19A2, and 25A are given in tables E-21a and E-21b , E-22a and b, E-23a and b, E-24a and b, and E-25a and b for boots, 65, silking, silking to maturity, and maturity respectively (the a tables were for S_1 and b tables for S_2 families). A summary of all the results of the ANOVAs is given in tables E-26a and E-26b.

As was explained earlier the ANOVAs are presented for the three blocks pooled, for block 1 and block 2 together, and for block 3 separately, in order to investigate any B x G interaction that may result from the different dates of planting. The numbers of degrees of freedom associated with the experimental error vary for the different stages. This is because some plants did not survive to the particular stage or did not form a tassel, a cob or kernels.

Evaluation of the Calender Day and the Accumulated Heat-Unit Degrees Methods for the Study of Variation in the Flowering and Maturity Stages.

It is not in the scope of this study to explain this topic in details, but because our experiments were carried out in one environment, it seems useful to use the accumulated heat-unit degrees methods in addition to the calender day method to evaluate the flowering stages both for the reasons explained earlier in chapter 2 and to obtain more reliable evaluation.

With a few notable exceptions, the ANOVAs calculated for the combined blocks, block 1 and block 2, and block 3 gave very similar results, irrespective of whether they were based on the number of days, or on the accumulated heat-unit degrees in the Ontario and the Gilmore-Rogers methods. The similarity between the two heat-unit degrees methods was also clearer when comparing the significance levels (see table E-26a, and E-26b). This is supported by the very similar coefficients of variation obtained (see table E-27 which gives a summary for the coefficients of variation obtained by the three methods for all events). For some traits, the calender

day gave a relatively smaller coefficient of variation than that obtained by the heat-unit degrees methods, but the differences between the days and the heat-units degrees methods were not too high. Gilmore and Rogers (1958) considered the best method was the one with the smallest coefficients of variation for most of the traits studied. In their study there was a difference of 4 to 5 between the highest coefficient of variation and the least one, while in our study the greatest difference is 3.2 . The results also indicated that there were greater differences between the coefficients of variation for the double crosses, S_1, and S_2 using the same method than between the three methods.

On the other hand, for the maturity stage the heat-unit methods were approximately half as variable as the calendar day method. This result is similar to that of Mederski *et al.* (1973), when they studied the variation in the maturity of many maize hybrids. They reported that all the heat-unit methods used, including the Ontario and the Gilmore Rogers methods gave a C.V. half that size of that one obtained using calender days.

Mederski *et al.* (1973) also stated that the use of the heat-unit methods to classify maize genotypes for flowering stages and for maturity was more accurate than the calendar day method; essentially because they produced the more consistent results over years. It is noticeable, however, that the highest C.V. for any character was obtained using heat units. The report by Aspiaza and Shaw (1972) also does not indicate a significant difference in variance between the calendar day methods and several of the commonly used growing degrees units methods for flowering stages, but when the period went to maturity, the variance values were larger than the values for the heat-unit methods.

The results described in this chapter suggest that any of the three methods (calendar day, Ontario, and Gilmore-Rogers heat-unit methods) can be used to study the variation in S_0, S_1, and S_2 families and the use of any one of them would not make a major difference to the evaluation of the results of our experiments. Thus any discussions or conclusions drawn from one analysis using one method will be

equivalent to the other two. Any exception will be mentioned in the appropriate place.

Comparisons of the number of days required to maturity with the heat units required by any given genotype for the two planting dates (blocks 1 and 2, and block 3) indicate that the means of the accumulated heat-unit degrees were relatively more consistent than the means of the calendar days in both dates; eg double crosses 3A, 4, and 5. Thus, if these experiments were repeated in many different environments or in different year or locations, then one should expect more consistency will be obtained by using the heat-unit methods. Therefore, in spite of the similar result obtained in this experiment by using any of the three methods discussed , we suggest that the heat-unit degrees methods is preferable for greater accuracy. For any study classifying this material for maturity or for flowering time, either of the heat-unit degrees methods can be used.

Results of the Double Crosses for Flowering stages and Maturity.

There were highly significant differences at the 1 % and 0.1 % levels of probability between the double crosses (tables E-16 to E-20) for most of the different flowering stages and for maturity. For the silking stage in the analysis of blocks 1 and 2 and the analysis of block 3 the differences were significant at the 5 % level. There were no significant differences between the double crosses for the boots stage and for maturity in block three nor for time from silking to maturity in the heat-unit degrees required to this stage.

There were no significant block x genotype interactions for any stage in any of the blocks no matter which method of analysis was used.

There were significant differences among the blocks in the analysis of the three blocks together. That was a result of the differences in the time of the planting of block three compared with blocks 1 and 2. The only exception was for maturity, where there were no significant differences between the three blocks. On the other

hand, the result of the analysis of variance from block 1 and 2 showed no significant differences among them for most cases and no genotype x block interactions. This ANOVA result indicates that there is genetic variation for flowering and maturity stages among the double crosses, thus confirming the results of the glasshouse experiment B, which was performed on the same double crosses. The absence of genotype x environment interaction suggested that non-additive gene effects are not important for these traits. In other words, it means that the additive genetic effect is important for the flowering and maturity traits, as was found in the parental material of these double crosses by Maryam (1981).

The non-significant differences between the hybrids for the period from silking to maturity in the ANOVA of blocks 1 and 2, and the significant differences for this stage in the results of block three could indicate non consistency of this stage for some of the double crosses. Mederski *et al.* (1973) stated that the time interval from silking to maturity is not constant, but appears to vary with climate and hybrids. They suggested that evaluation based on the accumulated heat-unit degrees should be extended from planting to maturity rather than from planting to silking.

Despite the variation in block three for this stage (silking to maturity), the result of blocks 1 and 2 was similar to that obtained from the glasshouse experiment B, when most of the double crosses showed no significant differences for this stage. This result leads to the conclusion that for these hybrids this stage seems to be almost constant for some hybrids and non constant for others. It appears that the silking stage can now be used, to some extent, for predicting the probable maturity of the hybrids, although this will depend both on the hybrid itself and on the requirements of the accumulated heat-unit degrees. Mederski *et al.* (1973) also stated that this objective can clearly be achieved if the time interval from silking to maturity was constant.

In tables E-13 (silking means) and E-15 (maturity) most of the double crosses that were faster to silking were also earlier to mature (eg 2A, 4, 7, 11B, 21B, 22). Under the relatively cool conditions of an English summer, Bunting and Gunn (1973)

reported a high negative correlation between silking date and the percentage dry matter in the grain at the harvest time. Selection for early flowering in breeding material at the Plant Breeding Institute has been accompanied by a significant advance in maturity date. Troyer (1978) and Gunn (1974) confirm that this effect is clear with maize grown under unfavourable conditions; they reported that early silking would allow more time for kernels to form under the slightly more suitable temperature of an English summer before the onset of autumn low temperatures.

There were differences in the degree of the variability between the 65 stage (half way anthesis) and the silking. More variation was observed for the former which could be attributed to the fact that the male flowering is more susceptible to daily, sudden environmental changes.

The means in tables E-11, and E-13 for the boots and silking, respectively, also indicate that most of the double crosses that were earliest to reach the boots stage were not the earliest to silk. It appears that under the conditions of this experiment an early boots stage is not an indicator for early silking.

<u>S_1 and S_2 Families; Results for Flowering and Maturity Stages</u>.

The S_1 and S_2 family means in tables E-11 to E-15 for the five characters, and the analysis of variance in tables E-16 to E-20 for the same families indicate highly significant differences at the 0.1 % level among the S_1 and among the S_2 families, for all stages of flowering and maturity. A similar result was obtained for all three methods (days, Ontario, and Gilmore-Rogers). As was found for the double crosses, in most cases there were no block x family interactions except for the 65 stage for the pooled blocks analysis; this interaction was not significant in the analysis of block 1 and 2 in the S_1 generation. The S_2 generation also showed a significant interaction between families and blocks for the same stage at the 5 % level for the three blocks combined and for the two blocks analysis. This families x blocks interaction was expected because pollen shedding is a character more dependable on the weather conditions. The extent of this interaction was less for the S_2 families because these S_2

families were derived from only 6 double crosses while the S_1 families were derived from 32 double crosses. Consequently a wider range of variation would be expected between S_1 families. The S_2 families showed some significant families x blocks interaction at the 5 % level for the maturity stage. This may be the result of some S_2 families not reaching maturity.

The S_1 and S_2 families results indicate significant families x blocks interaction for the period from silking to maturity in contrast to the results with the double crosses. Thus this period of development also showed less consistency for the S_1 and the S_2 generations than for the hybrids. It is also clear from any comparison between S_1 family means and between S_2 family means that this period depends on the S_1 and S_2 family itself; most of the families that were earlier to silk were earlier to mature. The greater variation for the time from silking to maturity in the S_1 and the S_2 generations could be partly a result of the selection applied on these families in the glasshouse experiments for early maturity, and partly the result of segregation expected to take place in these generations.

Although the superiority of the double crosses over most of the S_1 and the S_2 families was not unexpected, due to the inbreeding effect, there are many S_1 families that flowered or matured earlier or at the same time as the double crosses. The S_1 families 3-26A, 4-4, 5-8, 2-9A2, 2-13, 3-18, 2-19A2, 3-19A2, and 4-19A2 reached silking at the same time as the double crosses from which they were derived or even earlier. These families and families 3-3A, 4-6B, 1-11A, 5-11A, 1-14, and 4-25A also were the fastest S_1 families to mature, and some of them matured even earlier than the double crosses. For example, S_1 families 3-26A and 4-4 matured earlier than any double cross or any other S_1 family used. S_1 family 3-26A required 149 and 148.2 days to mature in block 1+2 and in block 3 respectively , and S_1 family 4-4 required 151.7 and 147.6 days to mature. On the other hand, the earliest double crosses to mature were 21B and 4 and these required 151.1 and 151.9 days, respectively, in the earlier planting and 154.8 and 153.8 days in block three.

The S_2 families in general also flowered or matured later than the S_1 families. It is possible that this is mainly the result of the differences in the vigour between the three generations. Usually the double crosses were more vigourous than the S_1 and the latter more vigc. rous than the S_2 generation, presumably as a result of inbreeding and inbreeding depression.

Among the faster S_1 families to mature were 4-4, 2-9A2, 3-19A2, 4-19A2, and 4-25A. All of these families were derived from double crosses 4, 9A2, 11A, 16A, 19A2, and 25A which were selected during the course of the glasshouse experiments A, B, and C. Most of S_2 families derived from these families were also the earliest to flower and to mature (eg. families 2-4-4, 9-4-4, 1-2-9A2, 10-3-19A2, and 3-4-25A). Furthermore, table E-28 shows the faster families to reach each particular stage of the flowering and the maturity stages including some other S_1 families derived from the rest double crosses. These results are in agreement with those obtained from the glasshouse experiment.

The absence of family x block interactions and the similarity of the glasshouse and the field results suggests strongly that most of the variability observed was genetic and could be attributed to the additive genetic effects that were basically important for the control of these traits in the reference population of these generations (Maryam, 1981).

This result also means that the programme used to evaluate this population was effective to distinguish those genotypes that were the most suitable for further breeding and hence to meet the aims of this programme. Furthermore these results will help distinguish those S_1 and S_2 families that will be useful for further inbreeding to obtain new inbred lines.

In contrast, the separate ANOVA for those S_1 and S_2 families derived from the same double crosses (that are presented in tables E-21a and b to E-25a and b and summarized in table E-26b), indicated that there was very low variability among S_1 families derived from the same double crosses, especially in the S_1 generation, for all flowering and maturity stages. Only the S_1 families derived from double cross 9A2

showed important differences for all stages. There were also significant differences at the 5 % level of probability for maturity in the S_1 families of double cross 4, 19A2 (Gilmore-Rogers method), and 25A. Most of these S_1 results were similar to those obtained from the glasshouse experiment C, see tables (E-26b, and C-4) for comparison, except for double cross 4, and 19A2 for boots and 65 and silking stages and double cross 11A for the silking to maturity and 25A for silking.

The tables of means (E-11 to E-15) and the analysis of variance tables (21b, 22b, 23b, 24b, and 25b) indicate that there is some variability between S_2 families derived from the same double crosses . This variability was, to some extent, greater than it was between S_1 families, especially for the S_2 families of double crosses 4, 11A, 16A and 19A. This may be a result of the selection which was practiced on the S_1 to obtain the S_2 generation families. This selection could change the nature of the variation in the S_2 from that in the S_1 generation, in addition to the segregation effect in the S_2 generation. The results also indicated that within the families derived from the same double cross the faster S_2 families to silk and to mature were those developed from the faster S_1 families to mature. For instance among families derived from double cross 4 S_1 family 4-4 and S_2 family 2-4-4 was superior to the other families at both generations respectively. The same thing could be said for 1-2-9A2, 5-1-11A, 6-4-11A, 10-3-19A2, 7-4-19A2, and 3-4-25A families. All of these families and the S_1 families from which they were derived are the most promising families for any further inbreeding or any recombinations between S_1 or S_2 families.

Table E-11 Boots stage for the double crosses, and the S_1 and S_2 families at two planting dates. Means of number of days and means of the heat-unit degrees in Ontario and in Gilmore-Rogers units.

Double crosses						S_1 families						S_2 families					
DC	Days		Ontario		Gilmore		F	Days		Ontario		Gilmore		F	Days		Ontario		Gilmore	
	B1+B2	B3	B1+B2	B3	B1+B2	B3		B1+B2	B3	B1+B2	B3	B1+B2	B3		B1+B2	B3	B1+B2	B3	B1+B2	B3
1	73.1	74.0	1069.4	1151.4	307.1	339.9	2	78.1	79.2	1166.6	1242.0	334.5	367.2		-	-	-	-	-	-
2A	70.7	73.6	984.5	1147.5	280.3	339.3	1	77.3	78.2	1148.4	1226.9	331.8	362.9		-	-	-	-	-	-
2B	67.5	71.8	960.2	1114.5	272.2	329.2	2	74.3	72.4	1093.2	1124.6	314.7	322.1		-	-	-	-	-	-
3A	73.3	74.8	1071.5	1163.4	307.4	343.3	3	74.5	74.8	1094.0	1168.6	314.5	345.6	-	-	-	-	-	-	-
4	73.9	73.4	1086.8	1141.8	312.9	337.3	1	78.3	77.6	1168.8	1218.1	336.6	360.8	9	79.2	81.4	1187.6	1278.0	344.7	377.7
-	-	-	-	-	-	-	4	74.4	74.8	1092.1	1164.3	313.8	343.7	2	76.7	70.6	1139.9	1087.2	329.6	319.7
-	-	-	-	-	-	-	5	75.4	79.0	1113.3	1237.9	320.9	365.9	9	85.5	85.8	1304.1	1373.4	380.6	409.1
5	68.4	71.6	977.2	1106.0	277.9	325.7	5	73.8	75.4	1081.3	1177.0	310.5	347.7	-	-	-	-	-	-	-
6A	71.7	69.6	1041.1	1088.7	297.9	321.2	4	81.0	78.4	1219.9	1228.2	354.5	363.3	-	-	-	-	-	-	-
6B	72.4	72.2	1051.1	1122.7	300.0	331.8	4	80.0	79.0	1205.4	1246.2	350.8	369.7	-	-	-	-	-	-	-
7	70.4	70.2	1018.2	1083.3	291.0	319.2	4	78.6	81.2	1175.4	1282.6	340.7	380.4	-	-	-	-	-	-	-
8	74.0	75.8	1084.3	1186.9	311.4	351.2	5	66.5	71.6	943.6	1095.9	267.8	320.9	-	-	-	-	-	-	-
9A2	74.7	70.2	1101.9	1082.4	317.6	318.8	2	71.5	72.0	1038.8	1108.5	297.4	325.6	1	79.7	83.0	1200.0	1313.1	348.8	389.4
-	-	-	-	-	-	-	3	77.0	80.5	1141.6	1269.5	329.5	376.3	2	88.0	82.0	1361.3	1294.8	398.2	383.6
-	-	-	-	-	-	-	5	88.4	75.6	1359.3	1179.3	398.1	348.4	4	82.9	86.2	1250.4	1377.2	363.2	409.5
10	68.0	70.0	971.3	1076.8	276.1	316.7	3	73.9	78.0	1085.7	1217.7	318.4	359.2	-	-	-	-	-	-	-
11A	73.4	77.8	1076.5	1218.0	309.5	360.0	1	77.6	73.6	1165.4	1147.1	338.7	339.1	5	85.3	84.2	1300.4	1338.1	379.4	397.3
-	-	-	-	-	-	-	2	79.8	74.8	1200.2	1167.5	348.8	345.2	4	80.9	84.8	1217.7	1350.3	357.4	401.3
-	-	-	-	-	-	-	3	76.0	79.4	1124.2	1249.8	323.7	370.3	10	83.1	80.2	1257.2	1261.4	370.3	373.0
-	-	-	-	-	-	-	4	77.1	73.4	1140.6	1143.0	329.3	337.7	6	77.5	74.8	1152.7	1163.5	313.3	342.8
-	-	-	-	-	-	-	5	79.5	77.6	1197.8	1220.4	348.6	361.7	1	81.8	82.6	1239.7	1300.0	361.4	384.6
11B	71.7	75.4	1043.4	1183.9	299.0	351.1	3	75.1	78.4	1108.2	1224.7	319.4	361.6	-	-	-	-	-	-	-
12A	74.2	72.8	1055.1	1128.4	302.1	332.7	1	76.9	76.8	1143.6	1197.2	330.7	355.3	-	-	-	-	-	-	-
13	72.0	69.6	1050.2	1070.8	301.4	315.1	2	70.0	75.2	1009.4	1172.1	287.3	346.2	-	-	-	-	-	-	-
14	71.3	70.6	1036.0	1090.5	299.4	321.4	1	77.4	76.6	1149.3	1196.0	331.8	353.2	-	-	-	-	-	-	-
15	70.0	75.4	1007.4	1185.8	291.1	351.8	5	76.8	80.5	1141.7	1263.3	330.1	373.5	-	-	-	-	-	-	-
16A	73.0	78.0	1062.6	1227.0	304.4	363.5	1	87.3	80.2	1340.4	1262.3	392.2	373.9	4	91.4	84.0	1418.0	1342.6	416.5	399.7
-	-	-	-	-	-	-	3	80.0	82.4	1199.3	1310.0	348.2	389.3	7	84.6	86.9	1284.9	1397.0	374.2	416.9
-	-	-	-	-	-	-	5	82.7	73.6	1255.4	1142.0	366.1	336.7	6	81.1	75.2	1223.0	1174.2	355.7	346.8
16B	69.2	72.4	996.4	1124.6	293.5	332.1	4	75.8	81.8	1118.9	1287.7	322.3	381.2	-	-	-	-	-	-	-
17	72.2	71.2	1051.0	1095.5	301.0	321.9	4	79.5	78.4	1190.9	1224.5	345.7	361.5	-	-	-	-	-	-	-
18	72.8	77.0	1065.5	1207.6	316.2	357.4	3	73.0	75.2	1065.5	1173.5	305.5	346.8	-	-	-	-	-	-	-
19A	72.3	78.0	1055.8	1225.5	303.0	362.9	1	76.9	75.2	1140.9	1172.5	329.5	346.4	2	84.8	81.6	1293.6	1289.1	377.8	382.0
-	-	-	-	-	-	-	2	73.3	74.2	1074.6	1157.4	309.0	342.1	4	79.7	78.0	1192.2	1222.0	345.5	361.5
-	-	-	-	-	-	-	3	74.6	72.0	1098.9	1116.1	319.5	329.3	10	67.7	70.6	963.8	1088.3	273.8	320.0
-	-	-	-	-	-	-	4	73.7	77.8	1079.5	1217.0	310.0	359.6	7	74.9	79.8	1105.4	1255.0	318.8	374.2
-	-	-	-	-	-	-	5	73.1	80.6	1070.4	1259.9	307.0	371.5	1	78.8	78.0	1179.7	1220.5	342.1	360.6
20	76.0	74.4	1126.4	1160.6	325.3	343.1	2	78.3	80.0	1167.9	1263.7	338.2	374.9	-	-	-	-	-	-	-
21A	70.4	71.0	1015.3	1099.0	289.9	324.2	5	77.7	78.6	1156.8	1229.9	334.5	363.2	-	-	-	-	-	-	-
21B	73.0	72.4	1069.6	1115.7	307.5	327.9	4	75.7	69.4	1118.3	1064.3	322.2	312.6	-	-	-	-	-	-	-
22	71.0	70.6	1027.7	1090.5	293.6	321.4	4	75.5	76.0	1119.1	1184.3	323.2	349.5	-	-	-	-	-	-	-
23	70.7	70.8	1023.7	1095.8	292.8	323.3	1	75.7	76.2	1139.7	1189.7	329.9	351.3	-	-	-	-	-	-	-
24A	69.4	72.0	995.1	1117.4	283.1	329.9	5	76.1	74.8	1127.3	1169.6	325.2	346.6	-	-	-	-	-	-	-
25A	69.0	76.4	988.2	1203.0	281.0	356.9	1	77.2	73.8	1153.8	1142.0	334.7	336.0	9	83.6	77.4	1272.2	1213.1	371.2	358.8
-	-	-	-	-	-	-	3	76.8	71.4	1140.0	1097.4	329.4	322.1	5	82.8	81.2	1256.9	1275.3	386.5	376.7
-	-	-	-	-	-	-	4	74.9	74.8	1103.1	1156.7	317.6	340.0	3	78.9	78.6	1182.7	1249.4	363.0	371.1
25B	77.0	71.6	1146.3	1104.4	329.9	324.9	2	74.7	76.6	1098.9	1195.0	315.3	352.6	-	-	-	-	-	-	-
26A	72.2	71.0	1031.7	1096.1	295.0	323.0	3	70.2	69.0	1011.0	1056.2	288.3	309.9	-	-	-	-	-	-	-

Table E-12 The 65 stage of male flowering for the double crosses, and the S1 and S2 families at two planting dates. Means of number of days and means of the heat-unit degrees in Ontario and in Gilmore-Rogers units.

Double crosses						S1 families						S2 families					
DC	Days B1+B2	B3	Ontario B1+B2	B3	Gilmore B1+B2	B3	F	Days B1+B2	B3	Ontario B1+B2	B3	Gilmore B1+B2	B3	F	Days B1+B2	B3	Ontario B1+B2	B3	Gilmore B1+B2	B3
1	93.1	91.4	1449.8	1490.0	426.6	447.2	2	98.0	96.6	1555.9	1600.3	461.7	483.1	-	-	-	-	-	-	-
2A	91.7	93.0	1420.3	1524.3	417.1	458.3	1	97.0	95.6	1540.2	1575.4	456.5	474.5	-	-	-	-	-	-	-
2B	92.9	91.6	1448.0	1495.8	425.7	450.6	2	96.7	94.4	1527.1	1555.1	452.2	468.6	-	-	-	-	-	-	-
3A	94.5	93.0	1481.1	1525.6	437.2	461.9	3	96.3	96.6	1518.5	1599.8	447.2	483.2	-	-	-	-	-	-	-
4	94.7	92.2	1484.4	1514.7	438.2	458.1	1	98.2	97.0	1560.1	1599.4	463.1	482.4	9	102.3	94.8	1641.8	1558.8	489.2	467.7
-	-	-	-	-	-	-	4	94.8	94.0	1487.6	1544.8	439.3	465.0	2	96.0	94.0	1513.0	1546.1	447.7	465.5
-	-	-	-	-	-	-	5	96.0	96.5	1513.3	1598.0	447.7	482.6	9	102.7	101.6	1642.1	1695.6	498.0	513.1
5	92.8	91.6	1443.8	1494.1	424.8	448.5	5	95.7	95.2	1506.5	1571.6	445.5	473.7	-	-	-	-	-	-	-
6A	94.9	91.8	1489.5	1498.4	440.0	449.9	4	99.7	95.6	1591.4	1577.7	473.2	475.7	-	-	-	-	-	-	-
6B	93.9	93.4	1468.3	1533.2	433.0	461.3	4	96.4	97.0	1521.0	1609.0	448.5	486.2	-	-	-	-	-	-	-
7	92.9	88.8	1446.8	1436.0	426.0	429.6	4	99.2	99.6	1578.3	1653.4	467.5	499.1	-	-	-	-	-	-	-
8	94.0	94.2	1468.9	1548.2	432.9	466.0	5	93.1	92.6	1450.2	1515.5	427.0	455.6	-	-	-	-	-	-	-
9A2	97.2	92.0	1536.8	1502.1	455.1	450.9	2	96.7	96.6	1527.1	1603.0	450.5	484.4	1	102.2	98.2	1651.1	1636.2	493.0	495.3
-	-	-	-	-	-	-	3	100.2	98.7	1599.2	1637.8	475.3	494.5	2	103.2	101.2	1662.9	1690.0	494.0	511.8
-	-	-	-	-	-	-	5	105.4	96.0	1707.8	1587.9	509.7	479.2	4	107.2	98.0	1740.5	1618.2	520.8	487.6
10	92.2	91.6	1427.9	1495.9	419.6	449.4	3	96.6	97.6	1525.6	1619.8	452.2	498.4	-	-	-	-	-	-	-
11A	96.5	97.0	1524.1	1598.9	451.3	482.4	1	100.8	96.4	1613.9	1598.5	480.5	483.0	5	107.7	105.8	1742.6	1771.3	521.8	534.9
-	-	-	-	-	-	-	2	101.7	95.4	1632.6	1572.3	486.5	472.8	4	104.1	102.2	1684.9	1706.1	503.8	516.2
-	-	-	-	-	-	-	3	97.7	98.0	1569.1	1616.5	465.9	486.6	10	102.4	102.3	1747.7	1709.1	491.5	517.1
-	-	-	-	-	-	-	4	98.0	96.0	1551.7	1587.4	459.8	478.9	6	100.9	106.6	1615.6	1777.5	482.2	536.0
-	-	-	-	-	-	-	5	98.8	96.4	1572.2	1592.7	466.8	480.3	1	102.5	98.4	1649.9	1639.3	492.2	496.2
11B	94.3	95.8	1475.7	1576.3	435.3	481.3	3	97.7	98.4	1548.5	1635.0	458.3	494.3	-	-	-	-	-	-	-
12A	95.4	93.0	1500.9	1524.6	443.8	458.6	1	98.2	95.6	1558.8	1582.9	462.3	477.5	-	-	-	-	-	-	-
13	94.3	92.2	1475.5	1506.7	434.6	452.5	2	94.8	95.8	1487.6	1582.9	439.3	477.3	-	-	-	-	-	-	-
14	95.4	93.4	1500.4	1535.1	443.5	465.0	1	97.7	98.2	1547.8	1632.8	458.8	493.7	-	-	-	-	-	-	-
15	94.3	91.4	1475.8	1491.2	435.2	447.7	5	97.8	97.5	1551.0	1617.8	460.0	488.8	-	-	-	-	-	-	-
16A	94.7	96.0	1484.6	1585.0	438.1	477.8	1	102.8	100.6	1625.2	1677.2	492.4	507.4	4	111.8	107.0	1825.5	1794.6	546.8	543.1
-	-	-	-	-	-	-	3	103.4	87.4	1667.8	1409.0	497.3	421.4	7	103.3	103.8	1666.4	1733.0	497.7	523.9
-	-	-	-	-	-	-	5	103.8	97.4	1676.0	1613.1	500.5	486.8	6	104.6	99.0	1691.9	1647.8	505.5	498.3
16B	91.9	92.8	1423.1	1519.8	417.8	456.8	4	98.4	101.0	1564.4	1686.7	464.0	511.6	-	-	-	-	-	-	-
17	94.7	92.8	1485.1	1520.8	438.4	457.4	4	102.5	101.6	1646.8	1694.2	489.5	512.4	-	-	-	-	-	-	-
18	95.1	98.2	1499.1	1629.4	443.1	492.2	3	93.7	97.4	1463.8	1614.7	431.4	487.6	-	-	-	-	-	-	-
19A	96.0	98.0	1520.8	1625.9	448.6	491.1	1	98.1	95.0	1557.6	1567.7	461.4	472.7	2	109.2	105.8	1780.3	1769.7	533.1	535.1
-	-	-	-	-	-	-	2	95.8	94.6	1508.9	1559.0	446.0	469.7	4	103.5	99.0	1661.4	1646.6	494.6	497.9
-	-	-	-	-	-	-	3	96.0	94.2	1512.2	1551.8	447.2	476.4	10	95.1	94.4	1494.3	1555.3	441.4	468.7
-	-	-	-	-	-	-	4	95.6	92.6	1504.6	1514.2	444.9	455.3	7	97.2	95.5	1536.4	1577.3	455.0	477.3
-	-	-	-	-	-	-	5	101.0	100.8	1616.5	1684.3	481.1	510.1	1	101.5	100.4	1626.9	1675.2	484.4	507.2
20	96.8	95.6	1528.3	1610.7	452.4	476.9	2	102.5	101.0	1648.6	1682.8	491.8	508.7	-	-	-	-	-	-	-
21A	93.0	92.6	1449.1	1576.1	426.6	455.5	5	97.8	96.4	1550.4	1598.8	459.8	483.1	-	-	-	-	-	-	-
21B	93.5	91.2	1460.4	1483.5	430.7	445.3	4	95.9	92.6	1511.2	1515.3	447.1	455.4	-	-	-	-	-	-	-
22	92.8	91.0	1444.2	1479.9	425.0	443.6	4	94.9	98.8	1491.5	1636.1	442.8	493.2	-	-	-	-	-	-	-
23	94.5	96.6	1479.1	1516.3	436.2	455.9	1	96.8	98.8	1528.9	1647.9	452.6	499.1	-	-	-	-	-	-	-
24A	92.7	90.4	1443.8	1469.3	425.1	440.5	5	100.1	97.4	1596.7	1619.1	474.6	489.6	-	-	-	-	-	-	-
25A	92.0	91.8	1427.4	1499.1	449.6	450.1	1	99.7	101.6	1590.6	1691.4	472.2	510.7	9	100.1	100.2	1599.6	1666.5	475.0	505.1
-	-	-	-	-	-	-	3	97.4	96.2	1541.6	1595.8	456.9	482.2	5	104.2	100.8	1680.0	1683.6	501.3	509.9
-	-	-	-	-	-	-	4	94.8	90.7	1488.6	1477.9	433.1	443.4	3	98.6	97.2	1567.4	1611.1	463.3	486.7
25B	96.6	92.4	1531.5	1513.1	453.7	454.9	2	96.8	97.2	1529.5	1608.7	453.0	485.4	-	-	-	-	-	-	-
26A	92.7	92.2	1443.7	1506.8	425.0	452.6	3	91.0	91.0	1407.1	1481.7	413.0	444.4	-	-	-	-	-	-	-

Table E-13. The silking stage for the double crosses, and the S_1 and S_2 families at two planting dates. Means of number of days and means of the heat-unit degrees in Ontario and in Gilmore-Rogers units.

Double crosses				S_1 families				S_2 families			
DC	Days B1+B2 B3	Ontario B1+B2 B3	Gilmore B1+B2 B3	F	Days B1+B2 B3	Ontario B1+B2 B3	Gilmore B1+B2 B3	F	Days B1+B2 B3	Ontario B1+B2 B3	Gilmore B1+B2 B3
1	92.0 88.0	1425.8 1419.1	418.8 424.1	2	97.6 95.0	1555.9 1567.1	461.5 472.6	-	- -	- -	- -
2A	88.4 89.4	1374.7 1447.6	402.4 433.3	1	97.8 96.4	1548.9 1584.5	459.0 476.2	-	- -	- -	- -
2B	92.0 87.0	1426.5 1393.4	419.1 415.0	2	98.3 94.0	1558.2 1547.4	462.0 466.2	-	- -	- -	- -
3A	92.1 91.9	1445.3 1492.1	419.8 447.7	3	94.0 95.8	1469.5 1580.6	433.3 476.5	-	- -	- -	- -
4	92.3 91.4	1435.1 1482.7	422.3 445.0	1	98.7 97.4	1570.1 1607.7	466.2 484.4	9	100.3 93.0	1604.6 1523.1	477.5 458.1
-	- - -	- -	- -	4	93.9 90.6	1465.7 1474.8	431.8 442.4	2	96.0 95.0	1510.9 1526.0	447.0 457.7
-	- - -	- -	- -	5	95.3 96.4	1498.2 1588.9	442.9 478.8	9	101.3 99.4	1625.2 1658.2	484.3 502.0
5	92.1 90.6	1428.3 1473.5	419.7 441.8	5	94.8 94.0	1484.5 1547.2	438.0 466.0	-	- -	- -	- -
6A	93.7 87.6	1462.8 1411.5	431.1 421.8	4	98.0 94.8	1554.8 1562.3	461.1 470.8	-	- -	- -	- -
6B	93.5 90.4	1458.0 1470.3	429.0 438.0	4	94.8 95.4	1488.2 1572.3	439.7 473.7	-	- -	- -	- -
7	90.9 87.0	1402.9 1396.8	411.3 416.7	4	99.0 103.4	1578.8 1723.2	468.9 520.5	-	- -	- -	- -
8	92.3 91.8	1433.0 1496.7	443.3 449.1	5	92.1 91.4	1429.9 1492.0	420.3 449.2	-	- -	- -	- -
9A2	95.8 91.8	1506.4 1499.2	445.4 450.1	2	92.8 90.6	1444.0 1474.5	424.8 442.3	1	99.9 96.4	1610.7 1599.1	470.1 481.3
-	- - -	- -	- -	3	100.0 106.0	1592.4 1771.8	472.9 534.6	2	110.1 101.8	1793.1 1701.9	537.5 515.5
-	- - -	- -	- -	5	105.0 94.2	1693.1 1547.3	505.0 465.5	4	109.6 107.0	1782.4 1792.4	533.6 541.1
10	92.5 91.4	1437.9 1490.6	422.8 447.3	3	95.7 95.8	1504.9 1585.6	444.7 478.7	-	- -	- -	- -
11A	93.7 93.0	1461.9 1523.1	430.6 457.7	1	98.6 96.4	1563.5 1593.6	463.4 480.6	5	107.4 104.8	1744.2 1765.5	521.5 531.4
-	- - -	- -	- -	2	99.0 91.6	1577.5 1495.1	468.8 448.9	4	104.4 102.0	1686.8 1705.1	503.9 516.2
-	- - -	- -	- -	3	96.0 91.2	1526.9 1486.1	446.2 446.0	10	102.2 98.7	1620.5 1634.7	482.4 492.5
-	- - -	- -	- -	4	97.7 95.4	1551.5 1574.7	460.2 474.9	6	99.8 104.6	1589.7 1742.1	472.6 526.0
-	- - -	- -	- -	5	96.0 93.2	1512.9 1527.5	447.5 459.4	1	99.6 96.4	1589.4 1597.2	472.2 482.3
11B	90.6 93.2	1398.5 1522.1	410.1 456.9	3	96.1 97.2	1514.2 1612.1	448.0 487.1	-	- -	- -	- -
12A	92.6 91.0	1438.5 1483.5	422.8 442.8	1	94.9 90.2	1483.8 1465.4	437.2 439.5	-	- -	- -	- -
13	93.7 90.0	1463.4 1460.7	429.9 437.6	2	94.5 95.2	1480.5 1569.8	443.0 471.1	-	- -	- -	- -
14	95.9 92.0	1509.4 1503.7	441.5 451.7	1	97.9 97.2	1549.2 1608.7	458.9 485.6	-	- -	- -	- -
15	95.2 92.0	1493.9 1505.0	441.0 452.3	5	97.6 93.0	1546.4 1524.5	458.5 458 5	-	- -	- -	- -
16A	92.7 95.2	1441.2 1565.8	423.9 471.3	1	106.6 99.6	1722.2 1655.0	521.2 499.9	4	110.1 109.3	1793.9 1837.3	536.4 556.5
-	- - -	- -	- -	3	105.4 112.2	1708.7 1878.1	510.8 566.5	7	105.1 99.2	1698.0 1651.9	507.0 499.2
-	- - -	- -	- -	5	108.2 94.4	1744.9 1551.2	519.6 466.9	6	109.1 95.7	1773.9 1584.6	526.3 477.9
16B	90.3 91.8	1394.1 1499.7	408.8 450.5	4	97.1 99.0	1535.6 1652.9	454.9 500.2	-	- -	- -	- -
17	92.7 89.4	1442.4 1446.9	424.5 432.9	4	104.2 101.4	1681.1 1687.7	501.8 509.8	-	- -	- -	- -
18	93.8 95.8	1465.7 1579.5	432.0 476.0	3	94.0 96.6	1469.6 1598.3	433.3 482.3	-	- -	- -	- -
19A	94.8 96.6	1485.5 1595.2	438.3 481.8	1	98.0 92.8	1554.4 1521.4	461.1 457.7	2	107.0 102.6	1735.6 1712.1	521.1 516.0
-	- - -	- -	- -	2	95.9 92.0	1508.6 1504.3	445.9 452.7	4	99.5 100.0	1586.3 1664.9	471.4 507.1
-	- - -	- -	- -	3	96.5 92.8	1517.6 1550.5	448.8 456.9	10	93.8 93.4	1465.4 1534.0	431.9 461.6
-	- - -	- -	- -	4	96.7 94.0	1527.8 1541.4	452.4 463.6	7	97.2 97.0	1539.6 1601.0	456.4 482.1
-	- - -	- -	- -	5	101.9 102.0	1636.5 1726.6	487.8 522.8	1	101.4 99.4	1625.0 1656.4	483.9 501.1
20	95.9 92.6	1503.6 1515.4	443.4 455.4	2	102.2 99.6	1641.0 1657.7	489.0 501.4	-	- -	- -	- -
21A	91.5 88.2	1415.8 1422.9	415.6 425.3	5	95.5 93.2	1501.3 1528.6	443.7 459.7	-	- -	- -	- -
21B	90.9 87.6	1405.7 1408.9	412.6 420.4	4	93.0 85.8	1447.1 1372.6	425.7 408.8	-	- -	- -	- -
22	90.4 86.4	1401.6 1385.1	410.7 413.1	4	94.7 90.4	1485.2 1470.0	438.6 440.9	-	- -	- -	- -
23	90.5 87.4	1402.3 1406.0	412.1 419.8	1	97.1 97.6	1554.1 1622.6	460.2 490.7	-	- -	- -	- -
24A	91.7 86.8	1423.0 1414.2	418.3 419.1	5	102.4 96.0	1635.4 1587.5	486.7 479.1	-	- -	- -	- -
25A	90.1 88.8	1384.8 1435.7	405.3 429.5	1	100.5 100.8	1605.9 1673.9	477.6 505.0	9	102.5 99.6	1645.2 1655.7	490.0 500.0
-	- - -	- -	- -	3	97.2 93.0	1534.1 1524.1	454.5 458.2	5	105.7 98.6	1709.9 1637.5	510.8 494.5
-	- - -	- -	- -	4	93.8 94.6	1462.3 1545.6	432.4 463.6	3	98.0 98.2	1572.2 1628.3	461.5 491.6
25B	95.9 89.2	1508.1 1446.5	445.5 433.5	2	96.9 98.2	1529.7 1626.2	452.8 490.6	-	- -	- -	- -
26A	92.0 88.8	1429.1 1435.1	420.1 429.4	3	88.5 87.6	1359.8 1410.2	398.2 422.4	-	- -	- -	- -

Table E-14 The period from silking to maturity for the double crosses, and the S_1 and S_2 families at two planting dates. Means of number of days and means of the heat-unit degrees in Ontario and in Gilmore-Rogers units.

Double crosses				S_1 families				S_2 families			
DC	Days B1+B2 B3	Ontario B1+B2 B3	Gilmore B1+B2 B3	F	Days B1+B2 B3	Ontario B1+B2 B3	Gilmore B1+B2 B3	F	Days B1+B2 B3	Ontario B1+B2 B3	Gilmore B1+B2 B3
1	62.5 65.0	982.1 959.4	289.4 276.8	2	61.8 65.2	894.4 875.8	256.2 243.1	-	- -	- -	- -
2A	62.6 66.2	1011.3 954.3	300.0 272.9	1	57.8 60.0	870.6 831.6	251.2 233.8	-	- -	- -	- -
2B	64.7 71.0	998.5 1023.1	293.3 294.6	2	60.7 66.2	885.7 899.6	253.4 250.5	-	- -	- -	- -
3A	63.4 65.6	968.9 921.1	289.5 261.2	3	61.8 61.6	946.9 839.5	276.7 234.0	-	- -	- -	- -
4	59.6 62.4	950.8 907.9	280.8 259.1	1	62.9 60.8	901.7 808.5	256.4 225.0	9	59.0 59.6	843.6 854.1	239.3 242.9
-	- - -	- - -	- - -	4	57.8 57.0	934.6 858.7	270.6 248.8	2	59.5 58.4	901.8 857.5	261.4 244.4
-	- - -	- - -	- - -	5	61.9 65.6	930.3 863.5	270.1 239.6	9	61.8 66.0	850.9 835.7	239.4 225.5
5	61.6 65.4	970.2 930.7	286.2 265.3	5	60.4 61.4	928.0 854.5	271.0 240.2	-	- -	- -	- -
6A	62.2 67.6	955.8 988.9	279.1 284.2	4	61.1 64.0	890.4 867.5	255.1 241.2	-	- -	- -	- -
6B	66.6 66.4	993.5 939.9	289.6 270.6	4	61.7 63.6	933.7 864.4	270.1 240.6	-	- -	- -	- -
7	62.5 63.4	993.9 957.1	294.4 278.9	4	61.1 62.4	876.0 759.9	249.9 204.8	-	- -	- -	- -
8	62.7 69.6	979.7 923.1	287.9 263.6	5	65.2 65.8	1000.0 929.5	292.1 261.4	-	- -	- -	- -
9A2	63.2 67.2	940.4 931.9	271.0 262.9	2	60.7 68.2	956.4 959.7	281.4 271.4	1	59.7 63.0	825.3 839.0	244.7 233.3
-	- - -	- - -	- - -	3	62.4 61.6	887.0 710.4	251.5 190.4	2	63.7 69.0	769.8 808.6	205.9 216.1
-	- - -	- - -	- - -	5	64.7 63.8	840.5 879.6	231.4 246.5	4	64.1 61.2	772.4 718.4	207.9 189.9
10	67.9 71.2	1020.6 949.2	296.7 273.3	3	67.3 69.6	974.1 909.4	279.5 249.2	-	- -	- -	- -
11A	66.6 62.8	991.8 875.7	286.6 248.3	1	62.3 68.4	898.2 896.0	256.4 246.3	5	58.2 63.0	745.1 735.1	210.6 197.5
-	- - -	- - -	- - -	2	64.2 62.8	906.7 895.7	256.2 254.8	4	68.5 67.2	880.2 805.5	240.4 215.4
-	- - -	- - -	- - -	3	66.1 71.2	943.8 978.1	275.4 274.7	10	69.9 67.7	934.2 856.9	259.1 234.5
-	- - -	- - -	- - -	4	66.8 64.8	937.2 859.4	266.0 239.0	6	65.4 63.8	917.3 759.2	257.8 203.5
-	- - -	- - -	- - -	5	61.5 62.0	920.1 870.3	266.0 246.2	1	64.8 63.2	895.3 840.0	253.1 232.1
11B	62.6 63.8	996.6 897.2	295.4 253.4	3	61.5 68.0	917.4 866.4	265.1 237.1	-	- -	- -	- -
12A	61.5 66.0	964.9 935.1	283.7 267.5	1	58.9 60.0	916.8 893.8	263.1 257.1	-	- -	- -	- -
13	63.9 67.4	967.2 959.8	283.7 272.9	2	58.4 63.6	911.4 851.2	260.9 234.1	-	- -	- -	- -
14	65.8 64.0	956.3 904.2	279.3 256.0	1	58.8 63.6	875.5 838.7	252.7 231.3	-	- -	- -	- -
15	66.6 72.0	978.1 975.1	279.9 268.4	5	62.2 67.6	904.2 926.7	258.9 259.2	-	- -	- -	- -
16A	64.9 66.4	992.8 890.4	290.0 247.6	1	62.2 69.0	803.0 840.0	213.7 227.9	4	65 5 62.5	791.4 634.3	212.8 163.6
-	- - -	- - -	- - -	3	64.6 58.3	795.1 628.9	215.2 164.3	7	62.0 67.3	837.9 825.9	232.4 222.2
-	- - -	- - -	- - -	5	65.2 63.8	861.1 864.4	237.8 242.6	6	63.0 69.5	783.0 907.2	216.0 248.3
16B	62.0 64.0	993.9 905.6	292.9 256.6	4	63.9 70.8	928.7 857.3	266.4 231.4	-	- -	- -	- -
17	65.4 66.4	992.2 963.5	289.5 275 8	4	66.1 65.8	859.8 796.5	236.5 215.2	-	- -	- -	- -
18	62.0 65.8	962.8 863.8	281.4 240.0	3	58.6 61.4	921.3 825.8	271.0 228.6	-	- -	- -	- -
19A	62.4 67.6	947.9 878.9	275.7 241.2	1	58.8 68.6	871.2 896.0	250.7 258.1	2	66.1 63.2	838.7 769.0	224.9 208.8
-	- - -	- - -	- - -	2	64.7 65.2	951.9 915.5	270.8 258.2	4	67.7 64.6	919.9 788.1	257.4 217.3
-	- - -	- - -	- - -	3	58.7 65.0	895.3 875.7	260.8 255.0	10	59.3 65.8	938.2 904.6	274.0 253.4
-	- - -	- - -	- - -	4	61.2 66.2	906.5 894.0	261.5 250.5	7	58.8 60.2	880.7 816.3	254.2 227.5
-	- - -	- - -	- - -	5	61.7 67.8	847.6 756.7	237.5 208.8	1	68.3 71.8	916.0 845.4	254.6 228.4
20	61.3 69.2	927.0 942.3	271.6 263.8	2	66.5 69.0	881.7 824.5	245.0 223.6	-	- -	- -	- -
21A	62.9 68.0	990.5 983.6	292.2 282.1	5	62.1 66.6	930.8 917.1	269.5 256.6	-	- -	- -	- -
21B	60.2 67.2	971.5 981.4	289 2 283.8	4	61.6 62.2	962.8 964.5	283.0 283.6	-	- -	- -	- -
22	62.6 65.8	992.3 982.5	294.5 285.3	4	61.1 64.4	933.5 927.2	272.0 264.4	-	- -	- -	- -
23	66.2 67.2	1024.1 986.5	300.4 284.3	1	63.3 69.2	905.4 879.7	359.4 238.9	-	- -	- -	- -
24A	65.9 73.0	1011.2 1031.7	295.2 300.5	5	63.4 67.0	864.0 875.3	241.9 241.1	-	- -	- -	- -
25A	66.6 72.2	1038.8 1023.5	306.3 289.9	1	66.6 65.0	908.3 810.0	254.5 220.3	9	65.2 69.2	868.7 839.9	242.7 227.9
-	- - -	- - -	- - -	3	67.7 66.6	963.3 917.9	273.8 256.6	5	63.2 65.0	819.3 837.4	224.6 228.5
-	- - -	- - -	- - -	4	63.0 63.8	963.6 882.5	279.8 248.9	3	57.2 59.4	840.0 792.4	249.3 219.1
25B	68.0 70.8	980.0 998.7	279.0 282.9	2	64.4 67.7	936.4 853.9	268.8 233.9	-	- -	- -	- -
26A	66.8 71.0	1041.8 1009.6	295.9 286.9	3	60.5 60.6	1004.3 928.2	300.5 269.6	-	- -	- -	- -

Table E-15 The maturity stage for the double crosses, and the S1 and S2 families at two planting dates. Means of number of days and means of the heat-unit degrees in Ontario and in Gilmore-Rogers units.

Double crosses						S1 families						S2 families					
	Days		Ontario		Gilmore			Days		Ontario		Gilmore			Days		Ontario		Gilmore	
DC	B1+B2	B3	B1+B2	B3	B1+B2	B3	F	B1+B2	B3	B1+B2	B3	B1+B2	B3	F	B1+B2	B3	B1+B2	B3	B1+B2	B3
1	154.5	153.0	2407.9	2378.5	708.2	700.9	2	159.4	160.2	2450.3	2442.9	717.7	715.0	-	-	-	-	-	-	-
2A	152.0	155.6	2386.0	2401.9	702.3	706.2	1	155.6	156.0	2419.5	2416.1	710.2	710.0	-	-	-	-	-	-	-
2B	156.7	158.0	2425.0	2416.5	711.4	709.9	2	159.0	160.2	2443.9	2446.9	715.9	716.6	-	-	-	-	-	-	-
3A	155.5	157.0	2414.2	2413.2	709.3	709.0	3	155.8	157.4	2416.4	2420.1	710.0	710.4	-	-	-	-	-	-	-
4	151.9	153.8	2385.9	2390.6	705.0	704.1	1	161.6	158.2	2471.8	2416.2	722.6	709.3	9	159.3	152.6	2448.1	2377.4	716.8	701.0
-	-	-	-	-	-	-	4	151.7	147.6	2386.0	2333.5	702.3	691.2	2	155.5	153.4	2412.8	2383.8	708.3	702.1
-	-	-	-	-	-	-	5	157.2	162.0	2428.5	2452.4	713.0	718.1	9	163.1	165.4	2476.1	2493.5	723.7	727.5
5	153.7	156.0	2398.5	2404.1	705.9	707.1	5	155.2	155.4	2412.5	2401.7	709.0	706.2	-	-	-	-	-	-	-
6A	155.9	155.2	2418.6	2400.8	710.1	706.0	4	159.1	158.8	2445.1	2429.8	716.2	712.6	-	-	-	-	-	-	-
6B	160.1	156.8	2451.5	2410.2	718.6	708.6	4	156.5	159.0	2421.9	2436.7	709.7	714.2	-	-	-	-	-	-	-
7	153.4	150.4	2396.8	2353.9	705.7	695.6	4	160.3	165.8	2454.8	2483.2	718.8	725.2	-	-	-	-	-	-	-
8	155.0	161.4	2412.7	2419.8	709.1	712.7	5	157.3	157.2	2429.8	2421.5	712.4	710.5	-	-	-	-	-	-	-
9A2	159.0	159.0	2446.8	2431.2	716.4	703.9	2	153.5	158.8	2400.3	2434.2	706.1	713.6	1	159.0	159.4	2436.1	2437.6	714.8	714.7
-	-	-	-	-	-	-	3	162.4	167.6	2479.5	2482.5	724.3	724.9	2	173.9	170.8	2562.9	2510.2	743.3	731.6
-	-	-	-	-	-	-	5	169.7	158.0	2533.6	2426.9	736.4	712.0	4	173.7	168.2	2554.9	2510.2	741.5	731.6
10	160.4	162.6	2458.5	2439.8	719.4	720.7	3	163.0	165.4	2479.0	2495.0	724.1	727.8	-	-	-	-	-	-	-
11A	160.3	155.8	2453.7	2398.8	717.1	706.0	1	160.9	164.8	2461.7	2489.6	719.7	726.8	5	165.6	167.8	2489.3	2499.7	732.0	728.9
-	-	-	-	-	-	-	2	163.2	154.4	2484.2	2390.8	724.9	703.7	4	172.9	169.2	2567.0	2510.2	744.2	731.6
-	-	-	-	-	-	-	3	162.1	162.4	2470.7	2464.2	721.5	720.6	10	171.1	166.5	2554.7	2491.0	741.4	727.0
-	-	-	-	-	-	-	4	164.5	160.2	2488.7	2434.1	726.2	713.8	6	165.2	168.4	2507.1	2501.4	730.3	729.5
-	-	-	-	-	-	-	5	157.5	155.2	2433.0	2397.8	713.5	705.5	1	164.4	157.6	2484.7	2436.9	725.3	714.4
11B	153.2	157.0	2395.1	2419.3	705.4	710.3	3	157.6	165.2	2431.6	2478.5	713.1	724.2	-	-	-	-	-	-	-
12A	154.1	157.0	2403.3	2418.7	706.5	710.3	1	153.8	150.8	2400.7	2359.3	706.9	696.5	-	-	-	-	-	-	-
13	157.6	157.4	2430.6	2420.5	713.6	710.5	2	152.9	158.8	2391.9	2421.0	704.3	707.1	-	-	-	-	-	-	-
14	161.7	156.0	2465.7	2407.9	720.8	707.7	1	156.7	160.8	2424.7	2447.5	711.5	716.8	-	-	-	-	-	-	-
15	161.7	164.0	2472.0	2480.1	722.6	720.7	5	159.8	160.6	2450.6	2451.2	717.4	717.6	-	-	-	-	-	-	-
16A	157.6	161.6	2433.9	2456.1	713.9	718.9	1	168.8	168.6	2525.2	2495.0	734.9	727.8	4	174.7	173.9	2577.3	2509.8	746.7	731.5
-	-	-	-	-	-	-	3	172.3	170.5	2546.4	2507.0	739.5	730.8	7	165.1	168.0	2500.3	2505.8	728.5	730.5
-	-	-	-	-	-	-	5	169.6	158.2	2535.9	2415.5	735.5	709.5	6	172.2	165.2	2556.8	2490.9	742.2	726.3
16B	152.3	155.8	2388.1	2405.3	701.7	707.0	4	161.0	170.0	2464.3	2510.2	721.3	731.5	-	-	-	-	-	-	-
17	158.1	155.8	2434.6	2410.4	713.9	708.7	4	170.3	167.2	2540.9	2484.2	738.1	724.9	-	-	-	-	-	-	-
18	155.8	161.6	2428.5	2443.3	713.2	716.0	3	152.6	158.0	2390.9	2424.1	704.2	710.9	-	-	-	-	-	-	-
19A	157.2	164.2	2433.4	2474.1	713.9	723.0	1	156.8	161.4	2425.7	2417.4	711.7	715.8	2	173.1	165.8	2574.4	2480.8	745.9	724.8
-	-	-	-	-	-	-	2	160.6	157.2	2460.5	2419.7	716.6	710.2	4	168.7	164.6	2526.5	2452.7	734.9	724.4
-	-	-	-	-	-	-	3	155.2	157.8	2412.9	2426.2	709.2	711.8	10	153.1	159.2	2403.6	2438.2	705.4	715.0
-	-	-	-	-	-	-	4	157.9	160.2	2418.7	2435.5	713.9	714.1	7	156.0	157.2	2420.3	2416.8	710.5	709.6
-	-	-	-	-	-	-	5	163.6	169.8	2484.1	2483.4	725.2	731.5	1	169.7	171.2	2541.0	2501.4	738.4	729.5
20	157.2	161.8	2430.6	2457.8	715.0	719.2	2	168.7	168.6	2522.7	2482.2	734.0	724.9	-	-	-	-	-	-	-
21A	154.4	156.2	2406.4	2406.5	707.8	707.3	5	157.6	159.8	2432.1	2445.7	713.2	716.3	-	-	-	-	-	-	-
21B	151.1	154.8	2377.2	2390.3	701.7	704.2	4	154.6	148.0	2409.9	2337.1	708.7	692.4	-	-	-	-	-	-	-
22	153.0	152.2	2393.9	2367.6	705.2	698.4	4	155.8	154.8	2418.7	2397.2	710.5	705.2	-	-	-	-	-	-	-
23	156.7	154.6	2426.4	2392.5	712.5	704.1	1	160.4	166.8	2459.4	2502.3	719.5	729.5	-	-	-	-	-	-	-
24A	157.6	159.8	2434.2	2445.8	713.5	716.5	5	165.4	163.0	2499.4	2462.8	728.5	720.1	-	-	-	-	-	-	-
25A	156.7	161.0	2423.6	2459.2	711.5	719.4	1	167.1	165 8	2514.2	2483.9	732.1	725.2	9	167.7	168.8	2513.9	2494.8	732.6	727.9
-	-	-	-	-	-	-	3	164.9	159.6	2497.4	2442.1	728.2	714.8	5	168.9	163.6	2529.5	2474.8	735.4	723.0
-	-	-	-	-	-	-	4	156.8	158.4	2425.9	2428.1	712.2	712.4	3	155.2	157.6	2412.1	2420.3	710.7	710.0
25B	163.9	160.0	2488.1	2445.2	724.4	716.3	2	161.3	165.8	2466.1	2480.1	721.1	724.5	-	-	-	-	-	-	-
26A	158.8	159.8	2443.8	2444.7	716.0	716.3	3	149.0	148.2	2364.1	2338.5	698.6	692.0	-	-	-	-	-	-	-

Table E-16 The ANOVA of the boots stage for the DC, the S_1, and the S_2 families based on calendar days and heat-unit degrees.

Ge	Source of variance	Df	Days M.S	F	P	Ontario M.S	F	P	Gilmore-Rogers M.S	F	P
DC	B1+B2+B3										
	Bet. B.	2	78.97	2.814	N.S	462855	46.198	***	69151.8	69.323	***
	Bet. D.C.	31	53.95	1.923	**	19509	1.947	**	1951.8	9.290	***
	D.C. x B.	62	28.89	1.030	N.S	10999	1.098	N.S	1121.2	1.124	N.S
	Error	384	28.06			10019			997.5		
	B1+B2										
	Bet. B.	1	9.11	0.330	N.S	9933	1.029	N.S	1053.9	1.091	N.S
	Bet. D.C.	31	50.09	1.837	**	19369	2.006	***	1921.7	1.990	***
	D.C. x B.	31	27.80	1.019	N.S	10658	1.104	N.S	1163.8	1.205	N.S
	Error	256	27.27			9656			9654.6		
	B3										
	Bet. fams	31	33.84	1.142	N.S	11479	1.068	N.S	1110.0	1.046	N.S
	Error	128	29.65			10745			1061.0		
S_1	B1+B2+B3										
	Bet. B.	2	6.95	0.183	N.S	266955	19.940	***	47301	35.663	***
	Bet. fams	47	144.99	3.825	***	52695	3.936	***	5272	3.975	***
	Fams x B.	94	46.02	1.214	N.S	16289	1.217	N.S	1604	1.209	N.S
	Error	560	37.90			13388			1326		
	B1+B2										
	Bet. B.	1	11.27	0.269	N.S	4251	0.275	N.S	381	0.247	N.S
	Bet. fams	47	145.25	3.370	***	53401	3.452	***	5354	3.460	***
	Fams x B.	47	39.97	0.927	N.S	14531	0.939	N.S	1464	0.946	N.S
	Error	374	43.10			15469			1547		
	B3										
	Bet. fams	47	51.83	1.889	**	17333	1.884	**	1660.6	1.883	***
	Error	186	27.44			9202			882.0		
S_2	B1+B2+B3										
	Bet. B.	2	73.59	1.834	N.S	70303	4.826	**	11682	7.800	***
	Bet. fams	21	299.54	7.465	***	106991	7.344	***	10379	6.929	***
	Fams x B.	42	55.39	1.380	N.S	19577	1.344	N.S	2146	1.433	N.S
	Error	242	40.13			14568			1498		
	B1+B2										
	Bet. B.	1	71.15	1.616	N.S	25242	1.602	N.S	1024	0.632	N.S
	Bet. fams	21	240.39	5.460	***	87211	5.536	***	8497	5.247	***
	Fams x B.	21	63.97	1.45	N.S	22309	1.416	N.S	2626	1.62	N.S
	Error	159	44.03			15754			1620		
	B3										
	Bet. fams	21	105.95	3.246	**	36650	2.980	***	3550	2.808	***
	Error	83	32.64			12297			1264		

Table E-17. The ANOVA of the 65 stage of half-way anthesis for the DC, the S_1, and the S_2 families.

Gen	Source of variance	Df	Days M.S	F	P	Ontario M.S	F	P	Gilmore-Rogers M.S	F	P
DC	B1+B2+B3										
	Bet. B.	2	71.37	5.294	**	148748	24.996	***	30863.7	50.023	***
	Bet. D.C.	31	34.60	2.567	**	16079	2.702	***	1672.7	2.711	***
	D.C. x B.	62	11.66	0.865	N.S	5374	0.903	N.S	546.0	0.885	N.S
	Error	383	13.48			5951			617.0		
	B1+B2										
	Bet. B.	1	0.90	0.067	N.S	439	0.073	N.S	29.4	0.046	N.S
	Bet. D.C.	31	23.49	1.748	*	10919	1.818	**	1161.7	1.330	**
	D.C. x B.	31	11.52	0.857	N.S	5241	0.873	N.S	559.9	0.882	N.S
	Error	255	13.44			6006			634.9		
	B3										
	Bet. fams	31	22.92	1.690	*	10668	1.827	*	1043.1	1.794	*
	Error	128	13.57			5840			581.0		
S_1	B1+B2+B3										
	Bet. B.	2	176.41	9.330	***	138869	17.394	***	35384	42.696	***
	Bet. fams	47	91.56	4.842	***	38988	4.884	***	4098.4	4.945	***
	Fams x B.	94	27.33	1.445	**	11587	1.451	**	1221.7	1.467	**
	Error	544	18.91			7984			828.8		
	B1+B2										
	Bet. B.	1	2.71	0.149	N.S	1468	0.182	N.S	139.0	0.163	N.S
	Bet. fams	47	86.09	4.727	***	37454	4.638	**	3973.8	4.669	***
	Fams x B.	47	18.89	1.037	N.S	7972	0.987	N.S	850.3	0.999	N.S
	Error	365	18.21			8076			851.2		
	B3										
	Bet. fams	47	41.28	2.039	**	16669	1.138	**	1695.9	21.166	**
	Error	179	20.33			7796			783.1		
S_2	B1+B2+B3										
	Bet. B.	2	226.88	9.224	***	13444	1.431	N.S	5577.1	5.786	***
	Bet. fams	21	206.08	8.379	***	80382	8.559	***	8133.5	8.439	***
	Fams x B.	42	37.95	1.543	***	14714	1.567	N.S	1491.7	1.548	*
	Error	221	24.60			9392			963.8		
	B1+B2										
	Bet. B.	1	11.80	0.463	N.S	4306	0.455	N.S	720.3	0.716	N.S
	Bet. fams	21	160.67	6.662	***	64819	6.851	**	6689.9	6.650	**
	Fams x B.	21	44.43	1.842	*	17817	1.883	*	1830.9	1.820	*
	Error	146	24.12			9462			1006.0		
	B3										
	Bet. fams	21	76.88	3.021	**	27156	2.934	**	2597.7	2.945	**
	Error	75	25.52			9256			882.1		

Table E-18. The ANOVA of the silking stage for the double crosses, the S_1, and the S_2 families.

Gen	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
DC	B1+B2+B3										
	Bet. B.	2	252.89	12.186	***	44454	4.905	**	14877.2	15.918	***
	Bet.D.C.	31	49.40	2.381	**	20772	2.292	**	2150.8	2.301	***
	D.C. x B.	62	18.78	0.905	N.S	7820	0.863	N.S	840.3	0.899	N.S
	Error	383	20.75			9062			934.6		
	B1+B2										
	Bet. B.	1	0.09	0.004	N.S	77	0.009	N.S	12.2	0.013	N.S
	Bet. D.C.	31	33.83	1.639	*	14063	1.557	*	141.6	1.528	*
	D.C. x B.	31	17.49	0.847	N.S	7483	0.828	N.S	803.4	0.869	N.S
	Error	255	20.64			9034			934.6		
	B3										
	Bet. D.C.	31	35.64	1.699	*	14866	1.630	*	1616.3	1.692	*
	Error	128	20.97			9119			955.5		
S_1	B1+B2+B3										
	Bet. B.	2	330.51	10.582	***	75841	5.909	**	21654	16.482	***
	Bet. fams	47	210.51	6.740	***	85322	6.647	***	8856	6.741	***
	Fams x B.	94	40.58	1.299	*	15464	1.205	N.S	1602	1.220	N.S
	Error	559	31.23			12835			1314		
	B1+B2										
	Bet. B.	1	9.24	0.297	N.S	3003	0.230	N.S	63	0.046	N.S
	Bet. fams	47	152.47	4.905	**	62787	4.819	***	6616	4.914	***
	Fams x B.	47	32.50	1.046	N.S	12733	0.977	N.S	1410	1.047	N.S
	Error	371	31.08			13029			1347		
	B3										
	Bet. fams	47	106.33	3.372	***	40733	3.271	***	4037	3.233	***
	Error	188	31.53			12453			1249		
S_2	B1+B2+B3										
	Bet. B.	2	436.56	13.99	***	35560	2.974	*	7004	5.729	**
	Bet. fams	21	271.12	8.693	***	106383	8.898	***	10894	8.911	***
	Fams x B.	42	42.07	1.349	N.S	15166	1.268	N.S	1554	1.271	***
	Error	248	31.19			11956			1223		
	B1+B2										
	Bet. B.	1	195.85	6.639	*	69646	6.002	*	8346	6.847	**
	Bet. fams	21	229.28	7.773	***	88692	7.643	***	9186	7.536	**
	Fams x B.	21	37.86	1.284	N.S	13670	1.178	N.S	1473	1.208	N.S
	Error	248	31.19			11604			1219		
	B3										
	Bet. fams	21	88.11	2.546	**	34352	2.712	**	3344	2.718	N.S
	Error	82	43.52			12668			1230		

Table E-19. The ANOVA of the silking to maturity stage for the double crosses, the S_1, and the S_2 families.

Gen	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
DC	B1+B2+B3										
	Bet. B.	2	612.19	20.253	***	61884	11.597	***	16959.0	30.538	***
	Bet. D.C.	31	70.96	2.347	**	11268	2.112	**	1247.1	2.246	**
	D.C. x B.	62	26.74	0.885	N.S	4727	0.886	N.S	558.9	1.006	N.S
	Error	383	30.23			5336			555.3		
	B1+B2										
	Bet. B.	1	11.63	0.420	N.S	1148	0.242	N.S	0.0	0.000	N.S
	Bet. D.C.	31	52.15	1.885	**	6509	1.375	N.S	696.8	1.334	N.S
	D.C. x B.	31	30.67	1.109	N.S	4017	0.848	N.S	498.2	0.954	N.S
	Error	255	27.66			4734			522.2		
	B3										
	Bet. D.C.	31	41.62	1.177	N.S	10197	1.560	*	1169.9	1.883	**
	Error	128	35.35			6535			621.4		
S_1	B1+B2+B3										
	Bet. B.	2	477.57	14.525	***	163285	22.210	***	29904.4	36.111	***
	Bet. fams	47	87.61	2.665	**	30683	4.174	***	4290.2	5.181	***
	Fams x B.	94	38.14	1.160	N.S	9811	1.334	N.S	1094.3	1.321	***
	Error	557	22.88			7352			828.1		
	B1+B2										
	Bet. B.	1	3.57	0.108	N.S	4006	0.582	N.S	102.3	0.125	***
	Bet. fams	47	69.35	2.093	**	19125	2.779	**	2951.1	3.605	**
	Fams x B.	47	41.23	1.244	N.S	11578	1.682	**	1261.2	1.541	*
	Error	369	33.14			6882			818.5		
	B3										
	Bet. fams	47	53.18	1.643	**	40733	2.372	**	2272.1	2.683	**
	Error	188	32.37			12453			487.0		
S_2	B1+B2+B3										
	Bet. B.	2	163.33	4.614	*	95802	11.147	***	15876.3	17.794	***
	Bet. fams	21	167.91	4.743	***	38165	4.441	***	4792.2	5.371	***
	Fams x B.	42	37.83	1.069	N.S	10519	1.224	N.S	1045.8	1.172	N.S
	Error	241	35.40			8595			892.2		
	B1+B2										
	Bet. B.	1	187.56	5.253	*	69169	8.605	**	9657.8	11.128	***
	Bet. fams	21	139.45	3.905	**	32722	4.071	**	3896.4	4.490	**
	Fams x B.	21	37.69	1.055	N.S	7379	0.918	N.S	886.5	1.021	N.S
	Error	161	35.71			8038			867.9		
	B3										
	Bet. fams	21	66.44	1.910	*	19100	1.966	*	2104.3	2.236	**
	Error	80	34.79			9714			941.2		

Table E-20. The ANOVA of the maturity stage for the double crosses, the S_1, and the S_2 families.

Gen	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
DC	B1+B2+B3										
	Bet. B.	2	82.96	1.507	N.S	1674	0.406	N.S	83.5	0.404	N.S
	Bet. D.C.	31	126.01	2.288	**	9558	2.318	**	480.3	2.321	**
	D.C. x B.	62	45.83	0.832	N.S	3165	0.768	N.S	146.8	0.709	N.S
	Error	383	55.06			4123			207.0		
	B1+B2										
	Bet. B.	1	13.72	0.262	N.S	630	0.160	N.S	16.0	0.083	N.S
	Bet. D.C.	31	102.62	1.959	**	7474	1.902	**	364.8	1.897	**
	D.C x B.	31	56.32	1.075	N.S	4014	1.021	N.S	178.7	0.929	**
	Error	255	52.38			3930			192.3		
	B3										
	Bet. D.C	31	58.73	0.972	N.S	4401	0.976	N.S	230.5	0.976	N.
	Error	128	60.41			4507			236.1		
S_1	B1+B2+B3										
	Bet. B.	2	18.96	0.334	N.S	15408	3.708	*	592.6	2.786	N.S
	Bet. fams	47	377.73	6.653	***	23851	5.740	***	1317.7	6.195	***
	Fams x B.	94	59.53	1.049	N.S	4404	1.060	N.S	225.5	1.060	N.S
	Error	557	56.78			4155			212.7		
	B1+B2										
	Bet. B.	1	4.96	0.082	N.S	0	0.000	N.S	1.9	0.008	N.S
	Bet. fams	47	289.97	4.805	***	19615	4.373	***	1065.3	4.650	***
	Fams x B.	47	47.74	0.791	N.S	3605	0.804	N.S	187.3	0.817	N.S
	Error	369	60.35			4485			229.1		
	B3										
	Bet. fams	47	158.72	3.189	***	9420	2.686	***	515.4	2.855	***
	Error	188	49.77			3508			180.5		
S_2	B1+B2+B3										
	Bet. B.	2	78.72	1.821	N.S	38856	12.393	***	1973.6	12.542	***
	Bet. fams	21	591.76	13.691	***	38574	12.303	***	2054.3	13.054	***
	Fams x B.	42	66.32	1.534	*	4882	1.557	*	243.6	1.548	*
	Error	243	43.22			3135			157.4		
	B1+B2										
	Bet. B.	1	4.30	0.092	N.S	1192	0.339	N.S	12.9	0.074	N.S
	Bet. fams	21	472.35	10.083	***	33915	9.642	***	1777.9	10.165	***
	Fams x B.	21	81.07	1.731	*	5480	1.558	N.S	288.4	1.649	*
	Error	163	46.84			3318			174.9		
	B3										
	Bet. fams	21	171.04	4.771	***	8935	3.792	***	475.1	3.906	***
	Error	80	3585			2357			121.6		

Table E-21a. The ANOVA of boots stage for the S_1 families derived from the same double cross.

DC	Source of variance	Df	Days M.S	F	P	Ontario M.S	F	P	Gilmore-Rogers M.S	F	P
4	B1+B2+B3										
	Bet. B.	2	46.07	1.515	N.S	49550	4.680	*	7304	6.822	**
	Bet. D.C.	2	47.27	1.554	N.S	17976	1.698	N.S	1649	1.536	N.S
	D.C. x B.	4	8.83	0.290	N.S	2791	0.264	N.S	237	0.220	N.s
	Error	36	30.41			10586			1074		
	B1+B2										
	Bet. B.	1	80.03	2.643	N.S	31734	2.837	N.S	3699	3.12	N.S
	Bet. D.C.	2	41.03	1.355	N.S	15677	1.401	N.S	1363	1.153	N.S
	D.C. x B.	2	1.03	0.034	N.S	615	0.055	N.S	83	0.071	N.S
	Error	24	30.28			11187			1182		
	B3										
	Bet. fams	2	22.87	0.746	N.S	7264	0.774	N.S	676.2	0.789	N.S
	Error	12	30.67			9386			856.6		
9A2	B1+B2+B3										
	Bet. B.	2	73.84	1.507	N.S	11779	0.673	N.s	1525	0.883	N.S
	Bet. fams	2	583.17	11.904	***	211136	12.062	***	20957	12.135	***
	Fams x B.	4	138.16	2.820	*	49291	2.816	*	4828	2.796	*
	Error	35	48.99			17504			1727		
	B1+B2										
	Bet. B.	1	61.63	1.222	N.S	23209	1.265	N.S	2339	1.281	N.S
	Bet. fams	2	743.03	14.733	***	267791	14.591	***	26467	14.491	***
	Fams x B.	2	25.43	0.504	N.S	9368	0.510	N.S	923	0.505	N.S
	Error	24	50.43			18353			1826		
	B3										
	Bet. fams	2	91.02	1.986	N.S	32559	2.080	N.S	3223	2.135	N.S
	Error	11	45.84			15652			1510		
11A	B1+B2+B3										
	Bet. B.	2	54.77	1.462	N.S	7146	0.550	N.S	1811	1.409	N.S
	Bet. D.C.	4	23.58	0.629	N.S	9531	0.733	N.S	1001	0.778	N.S
	D.C. x B.	8	24.45	0.629	N.S	8809	0.678	N.S	905	0.703	N.S
	Error	60	37.47			12995			1286		
	B1+B2										
	Bet. B.	1	25.92	0.607	N.S	7666	0.515	N.S	802	0.539	N.S
	Bet. D.C.	4	26.15	0.612	N.S	11419	0.767	N.S	1270	0.853	N.S
	D.C. x B.	4	11.77	0.276	N.S	4526	0.304	N.S	492	0.331	N.S
	Error	40	42.71			14896			1488		
	B3										
	Bet. fams	4	34.74	1.288	N.S.	11204	1.219	N.S	1048.4	1.188	N.S
	Error	20	26.98			9192			882.5		

Continued Table E-21a

DC	Source of variance	Df	Days M.S	F	P	Ontario M.S	F	P	Gilmore-Rogers M.S	F	P
16A	B1+B2+B3										
	Bet. B.	2	212.36	2.784	N.S	38607	1.442	N.S	3252	1.261	N.S
	Bet. fams	2	116.38	1.526	N.S	39599	1.479	N.S	3761	1.458	N.S
	D.C. x fams	4	97.08	1.273	N.S	35353	1.321	N.S	3446	1.336	N.S
	Error	28	76.28			26766			2579		
	B1+B2										
	Bet. B.	1	212.63	2.145	N.S	69928	1.999	N.S	6452	1.912	N.S
	Bet. fams	2	138.54	1.398	N.S	50554	1.445	N.S	4898	1.451	N.S
	Fams x B.	2	65.56	0.661	N.S	22018	0.629	N.S	2079	0.614	N.S
	Error	19	99.13			34980			3375		
	B3										
	Bet. fams	2	106.51	3.796	N.S	37819	4.021	N.S	3694	4.101	N.S
	Error	9	28.06			9427			900		
19A	B1+B2+B3										
	Bet. B.	2	23.85	0.658	N.S	70994	5.407	**	10511	7.995	**
	Bet. D.C.	4	21.07	0.581	N.s	6356	0.484	N.S	574	0.436	N.S
	D.C. x B.	8	67.29	1.855	N.S	22867	1.742	N.S	2209	1.680	N.S
	Error	60	36.27			13129			1315		
	B1+B2										
	Bet. B.	1	2.88	0.059		1819	0.102	N.S	209	0.116	N.S
	Bet. D.C.	4	24.12	0.498	N.S	8406	0.471	N.S	826	0.458	N.S
	D.C. x B.	4	76.18	1.572	N.S	28321	1.585	N.S	2848	1.576	N.S
	Error	40	48.47			17866			1803		
	B3										
	Bet. fams	4	55.34	4.65	**	15363	4.202	*	1322	3.921	*
	Error	20	11.88			3656			337		
25A	B1+B1+B3										
	Bet. B.	2	44.42	1.154	N.S	115	0.008	N.S	162	0.116	N.S
	Bet. fams	2	6.49	0.169	N.S	3585	0.257	N.S	427	0.308	N.S
	Fams x B.	4	24.66	0.641	N.S	8841	0.634	N.S	882	0.635	N.S
	Error	35	38.49			13954			1388		
	B1+B2										
	Bet. B.	1	0.83	0.023	N.S	230	0.017	N.S	20	0.015	N.S
	Bet. fams	2	15.10	0.415	N.S	6849	0.508	N.S	766	0.565	N.S
	Fams x B.	2	25.43	0.699	N.S	9645	0.715	N.S	982	0.724	N.S
	Error	23	36.37			13481			1356		
	B3										
	Bet. fams	2	15.27	0.395	N.S	4772	0.321	N.S	443	0.306	N.S
	Error	12	42.57			14861			1449		

Table E-21b. The ANOVA of boots stage for the S_2 families derived from the same double cross.based on the calendar day and the heat-units degrees.

DC	Source of variance	Df	Days M.S	F	P	Ontario M.S	F	P	Gilmore-Rogers M.S	F	P
4	B1+B2+B3										
	Bet. B.	2	10.44	0.585	N.S	7440	1.145	N.S	15998	2.460	N.S
	Bet. fams	2	451.24	25.286	**	157447	24.239	***	15309.7	23.545	***
	Fams x B.	4	53.01	2.970	*	17837	2.74	*	1713.6	2.635	N.S
	Error	35	17.85			6496			650.3		
	B1+B2										
	Bet. B.	1	6.08	0.314	N.S	2271	0.341	N.S	231.4	0.356	N.S
	Bet.fams	2	208.16	10.749	***	71337	10.709	***	6883.3	10.591	***
	Fams x B.	2	43.22	2.232	N.S	15795	2.371	N.S	1578.1	2.428	N.S
	Error	23	19.37			6662			649.9		
	B3										
	Bet. fams	2	305.87	20.48	***	105988	17.157	***	10275.6	15.784	***
	Error	12	14.93			6177			651.0		
9A2	B1+B2+B3										
	Bet. B.	2	237.56	4.872	*	98156	5.436	**	11180	6.314	**
	Bet. fams	2	104.33	2.139	N.S	38597	2.138	N.S	3604	2.035	N.S
	Fams x B.	4	75.65	1.551	N.S	28405	1.573	N.S	2860	1.615	N.S
	Error	30	48.77			18056			1771		
	B1+B2										
	Bet. B.	1	475.24	7.400	*	163457	7.137	*	16561	7.547	*
	Bet. fams	2	176.62	2.750	N.s	68132	2.975	N.S	6456	2.942	N.S
	Fams x B.	2	54.23	0.844	N.S	17958	0.784	N.S	1948	0.888	N.S
	Error	19	64.22			22903			2194		
	B3										
	Bet. fams	2	24.69	1.119	N.S	9332	0.963	N.S	922	0.887	N.S
	Error	11	22.07			9686			1039		
11A	B1+B2+B3										
	Bet. B.	2	2.68	0.067	N.S	20360	1.43	N.S	3390	2.462	N.S
	Bet. fams	4	138.79	3.457	*	49037	3.443	*	4948	3.594	*
	Fams x B.	8	68.12	1.697	N.S	24623	1.729	N.S	2638	1.916	N.S
	Error	57	40.15			14243			1377		
	B1+B2										
	Bet. B.	1	2.76	0.055	N.S	1022	0.058	N.S	475	0.283	N.S
	Bet. fams	4	82.92	1.658	N.S	29616	1.690	N.S	3014	1.794	N.S
	Fams x B.	4	110.00	2.200	N.S	40303	2.299	N.S	4449	2.649	N.S
	Error	38	50.01			17529			1679		
	B3										
	Bet. fams	4	82.12	4.018	*	28364	3.698	*	2761.4	3.579	*
	Error	19	20.44			7671			771.5		

Continued Table E-21b.

DC	Source of variance	Df	Days M.S	F	P	Ontario M.S	F	P	Gilmore-Rogers M.S	F	P
16A	B1+B2+B3										
	Bet. B.	2	69.64	2.190	N.S	699	0.060	N.S	220	0.188	N.S
	Bet. fams	2	374.11	11.762	***	132756	11.358	***	12927	11.094	***
	Fams x B.	4	49.46	1.555	N.S	17949	1.536	N.S	1797	1.542	N.S
	Error	28	31.80			11689			1165		
	B1+B2										
	Bet. B.	1	3.86	0.173	N.S	1203	0.151	N.S	115.4	0.147	N.S
	Bet. fams	2	279.67	12.540	***	99470	12.512	***	9742.6	12.421	***
	Fams x B.	2	5.59	0.251	N.S	1263	0.159	N.S	97.8	0.125	N.S
	Error	16	22.30			7950			784.3		
	B3										
	Bet. fams	2	187.71	3.619	N.S	67994	3.472	N.S	6679	3.391	N.s
	Error	9	51.87			19582			1969		
19A	B1+B2+B3										
	Bet. B.	2	1.60	0.040	N.s	38397	2.698	N.S	6571	4.559	*
	Bet. fams	4	456.80	11.457	***	164428	11.555	***	16123	11.168	**
	Fams x B.	8	45.28	1.136	N.S	15808	1.111	N.S	1602	1.112	N.S
	Error	57	39.87			14230			5042		
	B1+B2										
	Bet. B.	1	0.40	0.009	N.S	62	0.004	N.S	6	0.004	N.S
	Bet. fams	4	407.14	9.479	***	149698	9.774	***	14836	9.866	***
	Fams x B.	4	52.51	1.222	N.S	17177	1.122	N.S	1635	1.087	N.S
	Error	37	42.96			15316			1504		
	B3										
	Bet. fams4		87.70	2.567	N.S	29160	2.386	N.S	2856	2.15	N.S
	Error	20	34.16			12222			1326		
25A	B1+B2+B3										
	Bet. B.	2	38.88	0.627	N.S	1317	0.057	N.S	249	0.093	N.S
	Bet. fams	2	50.58	0.815	N.S	14290	0.620	N.S	67	0.025	N.S
	Fams x B.	4	33.10	0.534	N.S	12625	0.548	N.S	1943	0.729	N.S
	Error	35	62.03			23036			2666		
	B1+B2										
	Bet. B.	1	3.50	0.657	N.S	1936	0.084	N.S	462	0.159	N.S
	Bet. fams	2	64.63	1.045	N.S	22899	0.989	N.S	169	0.059	N.S
	Fams x B.	2	33.28	0.538	N.s	11859	0.512	N.S	2364	1.163	N.S
	Error	23	61.82			23161			2898		
	B3										
	Bet. fams	2	18.87	0.302	N.S	4782	0.210	N.S	418	0.187	N.S
	Error	12	62.43			22798			2234		

Table E-22a. The ANOVA of the 65 flowering stage for the S_1 families derived from the same double cross.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
4	B1+B2+B3										
	Bet. B.	2	2.92	0.139	N.S	19025	2.073	N.S	3631.9	3.746	*
	Bet. fams	2	40.02	1.870	N.S	16609	1.810	N.S	1759.3	1.815	N.S
	Fams x B.	4	2.18	0.100	N.S	1221	0.133	N.S	137.9	0.142	N.S
	Error	34	21.39			9179			969.6		
	B1+B2										
	Bet. B.	1	3.33	0.184	N.S	1612	0.195	N.S	182.0	0.204	N.S
	Bet. fams	2	29.73	1.642	N.S	15314	0.631	N.S	1454.4	1.634	N.S
	Fams x B.	2	1.75	0.096	N.S	689	0.083	N.S	67.7	0.076	N.S
	Error	23	18.10			8248			890.1		
	B3										
	Bet. fams	2	12.92	0.457	N.S	4848	0.439	N.S	513	0.452	N.S
	Error	11	28.27			11049			1136		
9A2	B1+B2+B3										
	Bet. B.	2	67.23	3.336	*	37	0.004	N.S	284.4	0.329	N.S
	Bet. fams	2	118.00	5.855	**	49959	6.067	**	5343.3	6.186	**
	Fams x B.	4	66.93	3.321	*	27272	3.213	*	2846.9	3.296	*
	Error	32	20.15			8235			863.8		
	B1+B2										
	Bet. B.	1	0.00	0.000	N.S	40	0.004	N.s	3.6	0.004	N.S
	Bet. fams	2	191.36	8.355	N.S	82697	8.769	**	8848.8	8.888	**
	Fams x B.	2	51.44	2.246	N.S	18533	1.965	N.S	1886.4	1.895	N.S
	Error	2	22.90			9430			995.6		
	B3										
	Bet. fams	2	10.43	0.701	N.s	3272	0.550	N.S	301.9	0.493	N.s
	Error	11	14.90			5953			612.2		
11A	B1+B2+B3										
	Bet. B.	2	78.77	3.155	*	4899	0.447	N.S	1071	0.952	N.S
	Bet. fams	4	14.88	0.596	N.S	6370	0.581	N.S	692	0.615	N.S
	Fams x B.	8	13.39	0.536	N.S	4402	0.401	N.S	464	0.412	N.S
	Error	60	24.79			10970			1125		
	B1+B2										
	Bet. B.	1	11.52	0.543	N.S	9276	0.896	N.S	957	0.883	N.S
	Bet. fams	4	31.15	1.469	N.S	11450	1.106	N.S	1240	1.145	N.S
	Fams x B.	4	5.78	0.277	N.S	2419	0.234	N.S	249	0.230	N.S
	Error	40	21.12			10352			1083		
	B3										
	Bet. fams	4	4.64	0.143	N.S	1306	0.107	N.S	131	0.108	N.S
	Error	20	32.48			12207			1211		

Continued Table E-22a.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
16A	B1+B2+B3										
	Bet. B.	2	353.17	12.595	***	55490	4.919	*	3835	3.264	N.S
	Bet. fams	2	270.19	2.503	N.S	28584	2.534	N.S	2999	2.552	N.S
	Fams x B.	4	92.57	3.301	*	39413	3.494	*	4035	3.434	*
	Error	26	28.04			11280			1175		
	B1+B2										
	Bet. B.	1	42.34	1.385	N.S	14430	1.149	N.S	1560	1.179	N.S
	Bet. fams	2	2.61	0.086	N.S	1459	0.166	N.S	167	0.126	N.S
	Bet. B.	2	25.39	0.831	N.S	9662	0.769	N.S	961	0.726	N.S
	Error	18	30.56			12557			1324		
	B3										
	Bet. fams	2	233.54	10.455	**	97239	11.572	**	9985.2	11.883	***
	Error	8	22.34			8403			840.3		
19A	B1+B2+B3										
	Bet. B.	2	35.81	2.333	N.S	13179	1.968	N.S	3836.6	5.43	*
	Bet. fams	4	96.97	6.318	**	41327	6.171	**	4159.2	5.88	*
	Fams x B.	8	5.90	0.384	N.S	2654	0.396	N.S	333.2	0.472	N.S
	Error	58	15.35			6696			706.4		
	B1+B2										
	Bet. B.	1	11.76	0.674	N.s	5414	0.696	N.S	537.8	0.654	N.S
	Bet. fams	4	52.35	3.001	**	22883	2.943	*	2397.8	2.915	*
	Fams x B.	4	6.65	0.381	N.S	3151	0.405	N.S	377.8	0.459	N.S
	Error	39	17.44			7776			822.6		
	B3										
	Bet. fams	4	49.76	4.506	**	20601	4.598	**	2050.0	4.380	*
	Error	19	11.04			4480			468.1		
25A	B1+B2+B3										
	Bet. B.	2	8.10	0.318	N.S	12247	1.186	N.S	3048	2.967	N.S
	Bet. fams	2	175.14	6.871	***	72735	7.043	***	8932	8.696	***
	Fams x B.	4	18.70	0.734	N.S	6742	0.653	N.S	623	0.606	N.S
	Error	34	25.49			10327			1027		
	B1+B2										
	Bet. B.	1	3.17	0.161	N.S	1379	0.154	N.S	1.5	0.002	N.S
	Bet. fams	2	58.24	2.951	*	26009	2.910	N.S	3887.8	4.248	*
	Fams x B.	2	7.14	0.362	N.S	3027	0.339	N.S	583.4	0.637	N.S
	Error	23	19.74			8937			915.2		
	B3										
	Bet. fams	2	147.15	3.922	N.S	57184	4.321	*	5707	4.525	*
	Error	11	37.52			13234			1261		

Table E-22b. The ANOVA of the 65 flowering stage for the S_2 families derived from the same double cross.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
4	1+B2+B3										
	Bet. B.	2	79.62	4.363	*	9033	1.273	N.S	1738.9	1.851	N.s
	Bet. fams	2	170.16	9.333	***	71731	10.110	***	9205.6	9.799	***
	Fams x B.	4	24.16	1.323	N.S	9449	1.332	N.S	877.1	0.934	N.S
	Error	35	18.25			7095			939.4		N.S
	B1+B2										
	Bet. B.	1	48.13	2.636	N.S	18051	2.619	N.s	3335	3.272	N.S
	Bet. fams	2	128.23	7.009	**	55465	8.047	**	7210	7.076	**
	Fams x B.	2	3.03	0.166	N.S	824	0.120	N.S	148	0.146	N.S
	Error	23	18.30			6893			1019		
	B3										
	Bet. fams	2	87.20	4.800	*	34340	4.590	*	3601.4	4.575	*
	Error	12	18.17			7481			787.0		
9A	B1+B2+B3										
	Bet. B.	2	166.00	4.799	*	17160	1.187	N.S	1102	0.740	N.S
	Bet. fams	2	35.09	1.014	N.S	10811	0.748	N.S	979	0.658	N.S
	Fams x B.	4	66.88	1.933	N.S	30623	2.119	N.S	3189	2.141	N.S
	Error	29	34.59			14452			1489		
	B1+B2										
	Bet. B.	1	49.73	1.347	N.S	20854	1.353	N.S	2013	1.267	N.S
	Bet. fams	2	59.73	1.347	N.S	23643	1.534	N.S	2496	1.572	N.S
	Fams x B.	2	92.99	2.538	N.S	41441	2.689	N.S	4101	2.582	N.S
	Error	18	36.64			15414			1588		
	B3										
	Bet. fams	2	16.07	0.514	N.S	6981	0.542	N.S	761	0.573	N.S
	Error	11	31.24			12879			1327		
11A	B1+B2+B3										
	Bet. B.	2	6.43	0.272	N.S	25386	2.941	N.S	4182.5	4.960	*
	Bet. fams	4	65.00	2.752	*	24633	2.853	*	2381.5	2.824	*
	Fams x B.	8	34.01	1.439	N.s	12235	1.417	N.S	1121.9	1.330	N.S
	Error	49	23.62			8633			843.3		
	B1+B2										
	Bet. B.	1	10.72	0.573	N.S	4897	0.643	N.S	979.7	1.234	N.S
	Bet. fams	4	56.49	3.019	*	23313	3.059	*	2307.8	2.908	*
	Fams x B.	4	22.21	1.187	N.S	9855	1.290	N.S	979.7	1.234	N.S
	Error	33	18.71			7620			973.7		
	B3										
	Bet. fams	4	54.32	1.609	N.S	15944	1.487	N.S	1336.8	1.414	N.S
	Error	16	33.76			10720			945.5		

Continued table E-22b.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
16A	B1+B2+B3										
	Bet. B.	2	55.35	4.459	N.S	401	0.051	N.S	177,2	0.237	N.S
	Bet. fams	2	250.94	11.149	***	87725	11.176	***	8413.7	11.244	***
	Fams x B.	4	49.11	2.182	N.S	16878	2.150	N.S	1600.4	2.139	N.S
	Error	24	22.51			7849			748.3		
	B1+B2										
	Bet. B.	1	4.56	0.174	N.S	758	0.083	N.S	50.1	0.058	N.S
	Bet. fams	2	208.31	7.941	***	73099	8.038	***	7086.2	8.218	**
	Fams x B.	2	208.31	7.941	***	21100	8.038	***	7086.2	8.218	**
	Error	18	26.23			9094			862.3		
	B3										
	Bet. fams	2	81.41	7.182	*	27251	6.621	*	2235.6	6.242	N.S
	Error	6	11.33			4116			406.2		
19A	B1+B2+B3										
	Bet. B.	2	47.80	1.853	N.S	7329	0.766	N.S	2258.8	2.427	N.S
	Bet. fams	4	401.07	15.547	***	157875	16.493	***	15839.7	17.020	***
	Fams x B.	8	39.35	1.525	N.S	15634	1.633	N.S	1597.2	1.716	N.S
	Error	51	25.80			9572			930.6		
	B1+B2										
	Bet. B.	1	6.90	0.268	N.S	4270	0.436	N.S	505.9	0.519	N.S
	Bet. fams	4	307.77	11.928	**	125615	12.824	***	12887.5	13.235	***
	Fams x B.	4	70.08	2.716	*	27153	2.772	*	2720.6	2.794	*
	Error	33	25.80			9795			973.8		
	B3										
	Bet. fams	4	102.01	3.95	*	36373	3.969	8	3428.2	4.026	8
	Error	18	25.79			9163			851.5		
25A	B1+B2+B3										
	Bet. B.	2	32.27	1.365	N.S	14788	1.584	N.S	2888.6	3.157	N.S
	Bet. fams	2	92.16	3.898	*	37494	4.010	**	4144.1	4.529	*
	Fams x B.	4	31.40	1.328	N.s	11651	1.245	N.S	1208.6	1.321	N.S
	Error	33	23.64			9352			915.0		
	B1+B2										
	Bet. B.	1	39.26	1.649	N.S	15058	1.527	N.S	1505.6	1.507	N.S
	Bet. fams	2	83.46	3.506	*	33688	3.417	*	3797.7	3.801	*
	Fams x B.	2	52.91	2.223	N.S	19896	2.018	N.s	2012.6	2.014	N.S
	Error	21	23.80			9858			999.1		
	B3										
	Bet. fams	2	18.60	0.796	N.S	7208	0.852	N.S	751.0	0.978	N.S
	Error	12	23.37			8465			7680		

Table E-23a. The ANOVA of the silking stage for the S_1 families derived from the same double cross.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
4	B1+B2+B3										
	Bet. B.	2	53.62	1.695	N.S	31835	2.354	N.S	4606	3.249	N.S
	Bet. fams	2	112.16	3.544	*	48656	3.597	**	5133	3.621	*
	Fams x B.	4	10.56	0.334	N.S	3871	0.286	N.S	280	0.268	N.S
	Error	36	31.64			13526			1418		
	B1+B2										
	Bet. B.	1	93.63	4.030	N.S	42696	3.995	N.S	4594	3.984	N.S
	Bet. fams	2	60.93	2.623	N.S	28527	2.669	N.S	3079	2.686	N.S
	Fams x B.	2	4.93	0.212	N.S	2015	0.189	N.S	209	0.182	N.S
	Error	24	23.23			10688			1153		
	B3										
	Bet. fams	2	67.40	1.391	N.S	25856	1.346	N.S	2587	1.329	N.S
	Error	12	48.47			19204			1947		
9A2	B1+B2+B3										
	Bet. B.	2	28.42	0.671	N.S	2434	0.148	N.S	881	0.533	N.S
	Bet. fams	2	463.75	10.956	***	188862	11.465	**	19276	11.858	***
	Fams x B.	4	150.29	3.551	*	57450	3.488	*	5667	3.428	*
	Error	35	42.33			16473			1653		
	B1+B2										
	Bet. B.	1	2.00	0.058	N.S	359	0.026	N.S	13	0.010	N.S
	Bet. fams	2	374.52	10.930	***	157092	11.442	***	16315	11.668	***
	Fams x B.	2	65.35	1.909	N.S	26590	1.937	N.S	2757	1.972	N.S
	Error	23	34.24			13729			1398		
	B3										
	Bet. fams	2	324.47	5.610	*	120081	5.526	*	11538	5.385	*
	Error	12	57.83			21731			2142		
11A	B1+B2+B3										
	Bet. B.	2	145.24	5.138	**	7385	0.588	N.S	1202	0.907	N.S
	Bet. fams	4	29.79	1.054	N.S	10351	0.825	N.S	1393	1.074	N.S
	Fams x B.	8	27.56	0.975	N.S	10042	0.800	N.S	1283	0.990	N.S
	Error	60	28.27			12553			1296		
	B1+B2										
	Bet. B.	1	36.98	1.236	N.S	12734	0.944	N.S	2031	1.469	N.S
	Bet. fams	4	19.98	0.668	N.S	6962	0.516	N.S	992	0.717	N.S
	Fams x B.	4	38.68	1.293	N.S	12173	0.902	N.S	1788	1.293	N.S
	Error	40	29.92			13496			1383		
	B3										
	Bet. fams	4	26.24	1.051	N.S	11301	1.059	N.s	1181	1.051	N.S
	Error	20	24.96			10667			1123		

Continued table E-23a.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
16A	B1+B2+B3										
	Bet. B.	2	107.76	1.360	N>S	4387	0.153	N.S	345	0.121	N.S
	Bet. fams	2	78.62	0.992	N.S	30800	1.077	N.S	2910	1.022	N.S
	Fams x B.	4	231.50	2.695	N.S	66804	2.233	N.S	6578	2.309	N.S
	Error	23	79.23			28608			2848		
	B1+B2										
	Bet. B.	1	2.3	0.022	N.S	455	0.012	N.s	316	0.086	N.S
	Bet. fams	2	18.3	0.175	N.S	3391	0.092	N.S	316	0.086	N.S
	Fams x B.	2	48.2	0.462	N.S	16342	0.442	N.S	2419	0.660	N.S
	Error	15	104.2			36977			3662		
	B3										
	Bet. fams	2	426.23	13.169	***	141981	10.984	***	13111	9.900	**
	Error	8	32.37			12926			1324		
19A	B1+B2+B3										
	Bet. B.	2	130.89	5.291	**	24214	2.270	N.S	3236	2.980	N.S
	Bet. fams	4	130.59	5.278	**	60254	5.648	**	6567	6.048	***
	Fams x B.	8	24.83	1.004	N.S	11499	1.078	N.S	1178	1.085	N.s
	Error	60	24.74			10668			1086		
	B1+B2										
	Bet. B.	1	103.68	3.610	N.S	41850	3.478	N.S	4273	3.412	N.S
	Bet. fams	4	58.40	2.033	N.S	26860	2.232	N.S	2903	2.319	N.s
	Fams x B.	4	36.48	1.270	N.S	15888	1.321	N.S	1683	1.344	N.S
	Error	40	28.72			12031			1252		
	B3										
	Bet. fams	4	85.36	5.087	*	40504	5.101	*	4337.4	5.760	**
	Error	20	16.78			7941			753.0		
25A	B1+B2+B3										
	Bet. B.	2	14.16	0.297	N.S	15019	0.797	N.S	2613	1.398	N.S
	Bet. fams	2	171.82	3.604	N.S	75970	4.030	*	7647	4.092	*
	Fams x B.	4	23.96	0.502	N.S	9187	0.487	N.S	817	0.437	N.S
	Error	35	47.68			18852			1869		
	B1+B2										
	Bet. B.	1	17.63	0.533	N.S	7842	0.534	N.S	915	0.608	N.S
	Bet. fams	2	112.23	3.393	*	51530	3.511	*	5102	3.387	*
	Fams x B.	2	22.63	0.684	N.S	10015	0.682	N.S	899	0.597	N.S
	Error	23	33.08			14677			1506		
	B3										
	Bet. fams	2	84.87	1.122	N.S	32798	1.221	N.S	3279	1.279	N.S
	Error	12	75.67			26854			2564		

Table E-23b. The ANOVA of the silking stage for the S_2 families derived from the same double crosses.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
4	B1+B2+B3										
	Bet. B.	2	61.07	5.897	**	2270	0.477	N.S	223.2	0.449	N.S
	Bet. fams	2	94.20	9.097	***	53992	11.341	***	5891.9	11.853	***
	Fams x B.	4	20.37	1.967	N.S	6586	1.383	N.S	679.9	1.368	N.S
	Error	36	10.36			4761			497.1		
	B1+B2										
	Bet. B.	1	6.533	0.883	N.S	3315	0.933	N.S	354.9	0.930	N.S
	Bet. fams	2	79.300	10.716	***	37064	10.428	**	3950.2	10.349	**
	Fams x B.	2	2.033	0.275	N.S	600	0.169	N.S	56.4	0.148	N.S
	Error	24	7.400			3554			381.7		
	B3										
	Bet. fams	2	53.60	3.295	*	29501	4.112	*	3245.1	4.459	*
	Error	12	16.27			7174			727.8		
9A2	B1+B2+B3										
	Bet. B.	2	180.81	6.828	**	24959	2.547	N.S	2079.3	2.341	N.S
	Bet. fams	2	438.26	16.551	***	142164	14.507	***	17766.2	20.001	***
	Fams x B.	4	93.24	3.521	*	30045	3.066	*	3339.9	3.760	*
	Error	31	26.48			9800			888.3		
	B1+B2										
	Bet. B.	1	127.48	5.090	*	40039	3.995	N.S	4150.6	4.547	*
	Bet. fams	2	329.68	13.164	**	104783	10.456	**	14302.3	15.670	**
	Fams x B.	2	154.63	6.175	*	50693	5.058	*	5558.1	6.089	*
	Error	20	25.04			10022			912.7		
	B3										
	Bet. fams	2	140.47	4.829	*	46765	4.977	*	4585.6	5.435	*
	Error	11	29.09			9396			843.8		
11A	B1+B2+B3										
	Bet. B.	2	60.41	1.646	N.S	35275	2.461	N.S	5193	3.594	*
	Bet. fams	4	142.73	3.889	**	58483	4.080	*	5709	3.951	**
	Fams x B.	8	25.83	0.704	N.S	8903	0.621	N.S	872	0.603	N.S
	Error	59	36.70			14333			1445		
	B1+B2										
	Bet. B.	1	98.00	3.063	N.S	40637	3.054	N.S	523	0.375	N.S
	Bet. fams	4	112.52	3.517	*	45814	3.443	*	4651	3.333	*
	Fams x B.	4	14.20	0.444	N.S	5106	0.384	N.S	523	0.375	N.S
	Error	40	31.99			13308			1396		
	B3										
	Bet. fams	4	67.68	1.451	N.S	25367	1.538	N.S	2278	1.471	N.S
	Error	19	46.62			16492			1548		

Continued table E-23b.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
16A	B1+B2+B3										
	Bet. B.	2	222.46	4.968	*	20833	1.391	N.S	726	0.439	N.S
	Bet. fams	2	185.88	4.151	*	65663	4.383	*	6540	3.954	*
	Fams x B.	4	76.63	1.711	N.S	26213	1.750	N.S	2085	1.260	N.S
	Error	28	44.78			14979			1654		
	B1+B2										
	Bet. B.	1	0.75	0.014	N.S	276	0.015	N.S	15	0.007	N.S
	Bet. fams	2	70.47	0.306	N.S	25630	1.426	N.S	2233	1.096	N.S
	Fams x B.	2	20.21	0.374	N.S	6055	0.337	N.S	208	0.102	N.S
	Error	20	53.98			17968			696.3		
	B3										
	Bet. fams	2	248.56	11.417	**	86381	11.504	**	8266.5	11.873	**
	Error	8	21.77			7509			696.3		
19A	B1+B2+B3										
	Bet. B.	2	32.57	0.79	N.s	23745	1.789	N.S	5012	3.649	*
	Bet. fams	4	290.48	8.688	**	118898	8.956	**	12529	9.121	***
	Fams x B.	8	17.59	0.526	N.S	7751	0.584	N.S	1097	0.799	N.S
	Error	58	33.43			13276			1374		
	B1+B2										
	Bet. B.	1	36.98	1.316	N.S	16821	1.428	N.S	2913	2.334	N.S
	Bet. fams	4	234.12	8.654	***	101253	8.596	***	11001	8.816	***
	Fams x B.	4	22.38	0.797	N.S	9825	0.834	N.S	1355	1.086	N.S
	Error	38	28.09			11779			1248		
	B3										
	Bet. fams	4	60.16	1.380	N.S	23322	1.447	N.S	2368	1.468	N.S
	Error	20	43.58			16121			1613		
25A	B1+B2+B3										
	Bet. B.	2	82.76	2.519	N.S	8215	0.650	N.S	1652	1.278	N.S
	Bet. fams	2	107.49	3.272	*	34345	2.719	N.S	4407	3.410	*
	Fams x B.	4	62.92	1.915	N.S	23224	1.839	N.S	2334	1.806	N.S
	Error	36	32.86			12632			1289		
	B1+B2										
	Bet. B.	1	58.80	1.783	N.S	16375	1.305	N.S	2673	2.074	N.s
	Bet. fams	2	149.63	4.537	*	47445	3.780	*	6114	4.744	**
	Fams x B.	2	81.10	2.459	N.S	32406	2.582	N.S	2870	2.227	N.S
	Error	24	32.98			12552			1289		
	B3										
	Bet. fams	2	2.60	0.080	N.S	942	0.074	N.S	92	0.071	N.S
	Error	12	32.60			12790			1300		

Table E-24a. The ANOVA of silking to maturity stage for the S_1 families derived from the same double cross.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
4	B1+B2+B3										
	Bet. B.	2	0.96	0.042	N.S	41405	7.416	**	5014.1	6.977	**
	Bet. fams	2	135.02	5.925	**	7230	1.295	N.s	1275.8	1.775	N.S
	Fams x B.	4	26.39	1.158	N.S	1925	0.345	N.S	73.9	0.103	N.S
	Error	36	22.79			5584			718.7		
	B1+B2										
	Bet. B.	1	1.20	0.047	N.S	20983	4.406	*	650.5	1.115	N.S
	Bet. fams	2	73.03	2.834	N.S	3194	0.671	N.S	650.5	1.115	N.S
	Fams x B.	2	21.90	0.850	N.S	3253	0.683	N.S	52.4	0.090	N.S
	Error	24	35.77			4762			583.5		
	B3										
	Bet. fams	2	92.87	5.517	*	4634	0.641	N.S	720.7	0.729	N.S
	Error	12	16.83			7226			989.2		
9A2	B1+B2+B3										
	Bet. B.	2	31.91	0.839	N.S	12250	1.197	N.S	1864	1.700	N.S
	Bet. fams	2	19.27	0.507	N.S	70452	6.884	**	9918	9.045	**
	Fams x B.	4	40.69	1.071	N.S	26142	2.554	N.S	3112	2.839	*
	Error	35	38.01			10234			1096		
	B1+B2										
	Bet. B.	1	27.07	1.049	N.S	4500	0.746	N.S	247.4	0.343	N.S
	Bet. fams	2	39.36	1.526	N.S	34016	5.638	*	6320.1	8.760	**
	Fams x B.	2	4.83	0.187	N.S	7698	1.276	N.S	1203.1	1.668	N.S
	Error	23	25.80			6033			721.5		
	B3										
	Bet. fams	2	56.47	0.920	N.S	81022	4.431	*	8619	4.749	*
	Error	12	61.40			18286			1815		
11A	B1+B2+B3										
	Bet. B.	2	48.97	1.320	N.S	12375	1.506	N.S	2359.2	2.711	N.S
	Bet. fams	4	82.23	2.217	N.S	8275	1.007	N.S	1145.5	1.316	N.S
	Fams x B.	8	26.27	0.708	N.S	5846	0.711	N.S	784.0	0.901	N.S
	Error	60	37.09			8217			870.3		
	B1+B2										
	Bet. B.	1	52.02	1.478	N.S	17195	2.011	N.S	2393.1	2.641	N.S
	Bet. fams	4	53.17	1.511	N.S	3762	0.440	N.S	641.7	0.708	N.S
	Fams x B.	4	6.17	0.175	N.S	5387	0.630	N.S	1126.2	1.243	N.S
	Error	40	35.20			8550			906.1		
	B3										
	Bet. fams	4	75.44	1.845	N.S	10881	1.432	N.S	945.5	1.184	N.S
	Error	20	40.88			7552			798.6		

Continued table E-24a.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
16A	B1+B2+B3										
	Bet. B.	2	22.26	0.297	N.S	12051	0.829	N.S	603	0.397	N.S
	Bet. fams	2	22.01	0.293	N.S	57858	3.978	*	6432	4.234	*
	Fams x B.	4	260.25	3.469	*	76534	5.263	**	7543	4.965	*
	Error	21	75.03			14543			1519		
	B1+B2										
	Bet. B.	1	42.94	0.640	N.S	5907	0.912	N.S	1805	1.146	N.S
	Bet. fams	2	25.71	0.383	N.S	12876	0.912	N.S	1805	1.146	N.S
	Fams x B.	2	372.31	5.546	*	112513	7.971	**	10842	6.879	*
	Error	13	67.13			14116			1576		
	B3										
	Bet. fams	2	141.96	1.616	N.S	85085	5.583	*	8816	6.177	*
	Error	8	87.87			15239			1427		
19A	B1+B2+B3										
	Bet. B.	2	261.05	5.748	**	19698	2.244	N.S	2145.4	2.613	n.s
	Bet. fams	4	36.23	0.798	N.S	21720	3.385	*	3271.5	3.985	*
	Fams x B.	8	38.35	0.845	N.S	9319	1.061	N.S	899.0	1.095	N.S
	Error	60	45.41			8779			820.9		
	B1+B2										
	Bet. B.	1	10.58	0.176	N.S	27303	2.785	N.S	2583	2.530	N.S
	Bet. fams	4	60.87	1.015	N.S	15456	1.576	N.S	1608	1.575	N.S
	Fams x B.	4	39.43	0.657	N.S	12711	1.296	N.S	1234	1.209	N.S
	Error	40	59.98			9804			1021		
	B3										
	Bet. fams	4	12.64	0.776	N.S	20191	3.000	*	2226.7	5.293	**
	Error	20	16.28			6730			420.6		
25A	B1+B2+B3										
	Bet. B.	2	22.77	0.961	N.S	28065	2.836	N.S	3799	3.364	*
	Bet. fams	2	64.38	2.716	N.S	22858	2.310	N.S	3308	2.929	N.S
	Fams x B.	4	36.26	1.530	N.S	1392	0.141	N.S	172	0.153	N.S
	Error	35	23.70			9896			1129		
	B1+B2										
	Bet. B.	1	41.42	1.915	N.S	7	0.001	N.S	72.6	0.093	N.S
	Bet. fams	2	59.74	2.762	N.S	10142	1.651	N.S	1747.9	2.231	N.S
	Fams x B.	2	67.29	3.111	N.S	350	0.057	N.S	71.8	0.092	N.S
	Error	23	21.63			6141			783.6		
	B3										
	Bet. fams	2	9.87	0.357	N.S	15149	0.886	N.S	1833	1.023	N.S
	Error	12	27.67			17091			1792		

Table E-24b. The ANOVA of silking to maturity stage for the S_2 families derived from the same double cross.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
4	B1+B2+B3										
	Bet. B.	2	50.96	1.719	N.S	2276	0.558	N.S	426.0	1.091	N.S
	Bet. fams	4	281.36	2.744	N.S	8238	2.020	N.S	236.1	0.605	N.S
	Fams x B.	4	15.86	0.535	N.S	1792	0.439	N.S	236.1	0.605	N.S
	Error	36	29.64			4078			390.5		
	B1+B2										
	Bet. B.	1	86.70	2.265	N.S	1883	0.376	N.S	25.7	0.063	N.S
	Bet. fams	2	22.30	0.582	N.S	10068	2.009	N.S	1615.3	3.927	*
	Fams x B.	2	7.30	0.191	N.S	1064	0.212	N.S	59.1	0.144	N.S
	Error	24	38.28			5012			411.3		
	B3										
	Bet. fams	2	83.47	6.749	*	690	0.312	N.S	553.2	1.585	N.S
	Error	12	12.37			2210			3490		
9A2	B1+B2+B3										
	Bet. B.	2	49.08	1.617	N.S	1886	0.279	N.S	734.7	1.147	N.S
	Bet. fams	2	99.39	3.274	N.S	21809	3.226	N.S	6435.3	10.050	*
	Fams x B.	4	66.40	2.188	N.S	13203	1.953	N.S	1673.2	4.666	*
	Error	31	30.35			6761			640.3		
	B1+B2										
	Bet. B.	1	54.29	2.797.	N.S	3770	0.680	N.S	1064.1	1.894	N.S
	Bet. fams	2	79.28	4.085	*	9831	1.774	N.S	4759.4	8.471	**
	Fams x B.	2	70.28	3.621	*	18721	3.378	N.S	2621.7	4.666	*
	Error	24	19.41			5541			561.9		
	B3										
	Bet. fams	2	82.60	1.644	N.S	19662	2.190	N.S	2399.2	3.064	N.S
	Error	11	50.25			8978			782.9		
11A	B1+B2+B3										
	Bet. B.	2	97.18	3.558	*	65849	6.827	**	8961	8.279	**
	Bet. fams	4	203.33	7.444	**	60365	6.259	**	4632	4.280	**
	Fams x B.	8	38.14	1.396	N.S	7511	0.779	N.S	654	0.605	N.S
	Error	59	27.31			9645			1082		
	B1+B2										
	Bet. B.	1	192.08	7.758	*	37765	4.833	*	5250.4	5.380	*
	Bet. fams	4	205.13	8.285	**	56549	7.237	**	4079.7	4.181	**
	Fams x B.	4	48.13	1.944	N.S	5418	0.693	N.S	490.5	0.503	N.S
	Error	40	24.76			7814			975.9		
	B3										
	Bet. fams	4	26.35	0.806	N.S	13421	0.994	N.S	1371	1.049	N.S
	Error	19	32.69			13500			1307		

Continued table E-24b.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
16A	B1+B2+B3										
	Bet. B.	2	84.22	2.318	N.S	14134	1.439	N.S	1164	0.999	N.S
	Bet. fams	2	7.94	0.219	N.S	41106	4.186	*	4995	4.284	*
	Fams x B.	4	62.43	1.718	N.S	36691	3.732	*	3112	2.669	N.S
	Error	22	36.33			9820			1166		
	B1+B2										
	Bet. B.	1	83.29	1.945	N.S	25990	2.337	N.S	1519	1.094	N.S
	Bet. fams	2	32.01	0.748	N.S	8741	0.786	N.S	1111	0.801	N.S
	Fams x B.	2	36.91	0.862	N.S	7173	0.645	N.S	678	0.488	N.S
	Error	16	42.82			11123			1388		
	B3										
	Bet. fams	2	64.10	3.369	N.S	98794	15.568	**	9451.4	16.462	**
	Error	6	19.03			6346			574.1		
19A2	B1+B2+B3										
	Bet. B.	2	12.44	0.280	N.S	48233	4.643	*	6458	6.351	**
	Bet. fams	4	248.69	5.597	**	25474	2.451	N.S	4268	4.197	*
	Fams x B.	8	35.31	0.795	N.S	5686	0.547	N.S	745	0.732	N.S
	Error	57	44.43			10396			1017		
	B1+B2										
	Bet. B.	1	5.47	0.124	N.S	5213	0.578	N.S	1726.0	1.853	N.S
	Bet. fams	4	214.36	0.871	N.S	15565	1.727	N.S	3136.5	3.367	*
	Fams x B.	4	13.38	0.304	N.S	7122	0.790	N.S	1216.7	1.306	N.S
	Error	37	44.01			9014			931.6		
	B3										
	Bet. fams	4	91.56	2.025	N.S	14159	1.093	N.S	1403	1.195	N.S
	Error	20	45.22			12951			1175		
25A	B1+B2+B3										
	Bet. B.	2	48.62	1.108	N.S	7105	0.758	N.S	1836.o	1.966	N.S
	Bet. fams	2	289.62	6.597	**	5911	0.631	N.S	800.2	0.856	N.S
	Fams x B.	4	16.36	0.373	N.S	10657	1.138	N.S	1323.3	1.416	N.S
	Error	36	43.90			9368			934.4		
	B1+B2										
	Bet. B.	1	26.13	0.551	N.S	10434	1.048	N.S	1792.9	1.878	N.S
	Bet. fams	2	173.33	3.654	*	6145	0.617	N.S	1629.9	1.707	N.S
	Fams x B.	2	28.13	0.593	N.S	17509	1.758	N.S	1677.4	1.757	N.S
	Error	24	47.43			9959			954.8		
	B3										
	Bet. fams	2	120.87	3.281	N.S	3571	0.436	N.S	139.5	0.156	N.S
	Error	12	36.83			8186			893.7		

Table E-25a. The ANOVA of maturity stage for the S_1 families derived from the same double cross.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
4	B1+B2+B3										
	Bet. B.	2	62.07	0.939	N.S	7298	1.527	N.S	414.9	1.778	N.S
	Bet. fams	2	442.87	6.697	**	23375	4.889	**	1637.4	7.015	**
	Fams x B.	4	63.13	0.955	N.S	7232	1.513	N.S	253.0	1.084	N.S
	Error	36	66.13			4781			233.4		
	B1+B2										
	Bet. B.	1	116.03	1.927	N.S	3816	0.764	N.S	418.0	1.754	N.S
	Bet. fams	2	246.03	4.087	*	12969	2.596	N.S	1031.4	4.329	*
	Fams x B.	2	44.63	0.741	N.S	6316	1.264	N.S	170.6	0.716	N.S
	Error	24	60.20			4996			238.3		
	B3										
	Bet. fams	2	278.47	5.570	*	18555	4.263	*	941.4	4.208	*
	Error	12	78.00			4352			223.7		
9A	B1+B2+B3										
	Bet. B.	2	8.08	0.132	N.S	3955	0.831	N.S	220.6	0.884	N.S
	Bet. fams	2	476.03	7.764	***	31264	6.566	**	1633.0	6.542	**
	Fams x B.	4	205.15	3.346	*	11965	2.513	N.S	632.6	2.534	N.S
	Error	35	61.31			4761			249.6		
	B1+B2										
	Bet. B.	1	14.35	0.227	N.S	2448	0.482	N.S	145.7	0.566	N.S
	Bet. fams	2	651.98	10.314	***	44908	8.842	***	2326.4	8.873	***
	Fams x B.	2	92.48	1.463	N.S	5779	1.138	N.S	323.2	1.233	N.S
	Error	23	63.22			5079			262.2		
	B3										
	Bet. fams	2	141.87	2.460	N.S	4506	1.085	N.S	248.6	1.102	N.S
	Error	12	57.67			4153			225.6		
11A	B1+B2+B3										
	Bet. B.	2	42.45	0.727	N.S	8885	2.111	N.S	425.8	1.950	N.S
	Bet. fams	4	96.89	1.660	N.S	6751	1.604	N.S	344.6	1.578	N.S
	Fams x B.	8	45.74	0.783	N.S	4274	1.015	N.S	235.3	1.078	N.S
	Error	60	58.38			4210			218.3		
	B1+B2										
	Bet. B.	1	1.28	0.222	N.S	334	0.080	N.S	14.9	0.069	N.S
	Bet. fams	4	71.28	1.227	N.S	4902	1.669	N.S	251.6	1.169	N.S
	Fams x B.	4	15.28	0.263	N.S	1445	0.345	N.S	80.6	0.374	N.S
	Error	40	58.10			4193			215.3		
	B3										
	Bet. fams	4	101.80	1.727	N.S	8953	2.110	N.S	483.0	2.152	N.S
	Error	20	58.94			4243			244.5		

Continued table E-25a.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
16A	B1+B2+B3										
	Bet. B.	2	111.18	1.242	N.S	20767	4.150	*	1012.0	3.809	*
	Bet. fams	2	132.51	1.480	N.S	5411	1.081	N.S	349.5	1.315	N.S
	Fams x B.	4	71.22	0.796	N.S	5177	1.035	N.S	228.5	0.860	N.S
	Error	21	89.52			5007			265.7		
	B1+B2										
	Bet. B.	1	25.6	0.251	N.S	2350	0.373	N.S	96.8	0.290	N.S
	Bet. fams	2	32.3	0.317	N.S	1124	0.178	N.S	57.4	0.172	N.S
	Fams x B.	2	14.3	0.141	N.S	1767	0.281	N.S	56.5	0.169	N.S
	Error	13	102.0			6298			334.0		
	B3										
	Bet. fams	2	223.74	3.230	N.S	12530	4.315	N.S	675.1	4.365	*
	Error	8	69.26			2904			154.7		
19A	B1+B2+B3										
	Bet. B.	2	74.44	1.158	N.S	1190	0.227	N.S	121.3	0.408	N.S
	Bet. fams	4	194.15	3.020	*	10482	1.998	N.S	668.8	2.249	N.S
	Fams x B.	8	44.52	0.693	N.S	2414	0.460	N.S	106.8	0.359	N.S
	Error	60	64.29			5245			297.4		
	B1+B2										
	Bet. B.	1	48.02	0.608	N.S	1547	0.261	N.S	211.6	0.596	N.S
	Bet. fams	4	110.12	1.395	N.S	8174	0.381	N.S	381.1	1.074	N.S
	Fams x B.	4	44.92	0.569	N.S	3449	0.583	N.S	134.7	0.380	N.S
	Error	40	78.93			5918			354.8		
	B3										
	Bet. fams	4	128.16	3.660	*	3686	0.946	N.S	366.5	2.007	N.S
	Error	20	35.02			3898			182.6		
25A	B1+B2+B3										
	Bet. B.	2	70.58	1.273	N.S	8020	2.025	N.S	458.4	2.224	N.S
	Bet. fams	2	331.83	5.987	**	23412	5.911	**	1184.5	5.746	**
	Fams x B.	4	102.42	1.848	N.S	7170	1.810	N.S	366.5	1.778	N.S
	Error	35	55.43			3961			206.1		
	B1+B2										
	Bet. B.	1	113.10	1.860	N.S	8309	1.879	N.S	472.2	2.046	N.S
	Bet. fams	2	292.70	4.813	*	21986	4.970	*	1106.9	4.795	*
	Fams x B.	2	165.10	2.715	N.S	11557	2.613	N.S	578.3	2.505	N.S
	Error	23	60.82			4423			230.8		
	B3										
	Bet. fams	2	78.87	1.749	N.S	4209	1.369	N.S	232.2	1.462	N.S
	Error	12	45.1			3074			158.8		

Table E-25b. The ANOVA of maturity stage for the S_2 families derived from the same double cross.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
4	B1+B2+B3										
	Bet. B.	2	93.89	2.575	N.S	8853	3.069	N.S	469.8	3.290	N.S
	Bet. fams	2	333.96	9.158	**	24876	8.624	**	1394.4	9.764	**
	Fams x B.	4	34.62	0.949	N.S	3323	1.152	N.S	161.7	1.133	N.S
	Error	36	36.47			2885			142.8		
	B1+B2										
	Bet. B.	1	140.83	3.561	N.S	10195	3.244	N.S	571.9	3.680	N.S
	Bet. fams	2	144.40	3.651	N.S	10067	3.204	N.S	591.5	3.806	N.S
	Fams x B.	2	1.73	0.044	N.S	169	0.054	N.S	2.5	0.016	N.S
	Error	24	39.55			3142			155.4		
	B3										
	Bet. fams	2	257.07	8.484	**	21287	8.985	**	1123.8	9.554	**
	Error	12	30.30			2369			117.6		
9A	B1+B2+B3										
	Bet. B.	2	211.73	6.117	**	14705	6.746	**	772.0	6.518	**
	Bet. fams	2	880.80	25.449	***	56406	25.877	***	2904.6	24.523	***
	Fams x B.	4	144.47	4.174	*8	9377	4.302	**	478.1	4.036	**
	Error	31	34.61			2180			118.4		
	B1+B2										
	Bet. B.	1	348.16	4.357	**	19205	8.544	**	1012.3	8.189	**
	Bet. fams	2	730.54	19.634	***	50453	22.444	***	2560.3	20.711	***
	Fams x B.	2	260.26	6.995	**	15905	7.076	**	824.5	6.669	**
	Error	20	37.21			2248			123.6		
	B3										
	Bet. fams	2	178.99	5.989	*	8803	4.282	*	476.0	4.366	*
	Error	11	29.89			2056			109.0		
11A	B1+B2+B3										
	Bet. B.	2	27.60	0.696	N.S	8941	3.205	N.S	614.7	4.468	*
	Bet. fams	4	174.20	4.394	*	15074	5.403	*	736.1	5.351	*
	Fams x B.	8	55.78	1.407	N.S	4614	1.654	N.S	215.3	1.565	N.S
	Error	59	39.64			2790			137.6		
	B1+B2										
	Bet. B.	1	15.68	0.325	N.S	53	0.015	N.S	51.6	0.293	N.S
	Bet. fams	4	150.13	3.115	*	14416	3.976	*	623.9	3.548	*
	Fams x B.	4	60.63	1.258	N.S	5592	1.542	N.S	309.8	1.762	N.S
	Error	40	48.20			3632			175.8		
	B3										
	Bet. fams	4	75.00	3.467	*	2494	4.169	*	232.90	4.082	*
	Error	19	21.63			1030			57.06		

Continued table E-25b.

DC	Source of variance	Df	Days M.S	Days F	Days P	Ontario M.S	Ontario F	Ontario P	Gilmore-Rogers M.S	Gilmore-Rogers F	Gilmore-Rogers P
16A	B1+B2+B3										
	Bet. B.	2	13.22	0.440	N.S	9147	4.645	*	479.6	4.671	*
	Bet. fams	2	262.60	8.745	***	10687	5.427	**	599.1	5.835	**
	Fams x B.	4	48.79	1.625	N.S	3349	1.701	N.S	198.7	1.935	N.S
	Error	23	30.03			1969			102.7		
	B1+B2										
	Bet. B.	1	0.39	0.010	N.S	269	0.103	N.S	10.8	0.080	N.S
	Bet. fams	2	244.51	6.455	**	15927	6.093	**	901.5	6.684	**
	Fams x B.	2	15.83	0.418	N.S	929	0.355	N.S	54.7	0.405	N.S
	Error	17	37.88			2614			134.9		
	B3										
	Bet. fams	2	100.019	12.837	**	513.5	3.609	N.S	39.33	3.435	N.S
	Error	6	7.792			142.3			11.45		
19A	B1+B2+B3										
	Bet. B.	2	3.55	0.065	N.S	10728	2.499	N.S	357.2	1.657	N.S
	Bet. fams	4	864.7	15.726	***	54963	12.801	***	3076.0	14.271	***
	Fams x B.	8	73.62	1.339	N.S	6525	1.520	N.S	293.8	1.363	N.S
	Error	58	54.98			4294			215.5		
	B1+B2										
	Bet. B.	1	2.42	0.045	N.S	827	0.186	N.S	15.0	0.067	N.S
	Bet. fams	4	801.47	14.751	***	58318	13.131	***	3174.8	14.223	***
	Fams x B.	4	55.57	1.023	N.S	4046	0.911	N.S	160.3	0.718	N.S
	Error	38	54.33			4441			223.2		
	B3										
	Bet. fams	4	154.90	2.755	N.S	5649	1.408	N.S	328.6	1.635	N.S
	Error	20	56.22			4013			200.9		
25A	B1+B2+B3										
	Bet. B.	2	5.07	0.096	N.S	2702	0.739	N.S	210.6	1.176	N.S
	Bet. fams	2	676.07	12.818	***	44642	12.216	***	2091.4	11.679	***
	Fams x B.	4	71.43	1.354	N.S	4764	1.304	N.S	233.0	1.301	N.S
	Error	36	52.74			3654			179.1		
	B1+B2										
	Bet. B.	1	6.53	0.120	N.S	667	0.169	N.S	87.6	0.467	N.S
	Bet. fams	2	575.63	10.581	***	40470	10.250	***	1821.9	9.720	***
	Fams x B.	2	86.23	1.585	N.S	6254	1.584	N.S	338.1	1.804	N.S
	Error	24	54.40			3948			187.4		
	B3										
	Bet. fams	2	157.07	3.177	N.S	7446	2.428	N.S	397.4	2.448	N.S
	Error	12	49.43			3076			162.4		

Table 26a. Summury of the ANOVA of flowering and maturity stages for the double crosses, the S_1 and S_2 families.

Trait	Method	Hybrids			S_1 fams			S_2 fams		
ANOVA		B	G	GxB	B	F	FxB	B	F	FxB
Boots	Days	N.S	**	N.S	N.S	***	N.S	N.S	***	N.S
3 blk	Ontario	***	**	N.S	***	***	N.S	**	***	N.S
	Gilmore	***	***	N.S	***	***	N.S	***	***	N.S
2 blk										
	Days	N.S	**	N.S	N.S	***	N.S	N.S	***	N.S
	Ontario	N.S	***	N.S	N.S	***	N.S	N.S	***	N.S
	Gilmore	N.S	***	N.S	N.S	***	N.S	N.S	***	N.S
1 blk.										
	Days	-	N.S	-	-	**	-	-	**	-
	Ontario	-	N.S	-	-	**	-	-	***	-
	Gilmore		N.S	-	-	***	-	-	***	
65	Days	**	**	n.s	***	***	**	***	***	***
3 blk	Ontario	***	***	N.S	***	***	**	N.S	***	N.S
	Gilmore	***	***	N.S	***	***	**	***	***	N.S
2 blk										
	Days	N.S	*	N.S	N.S	***	N.S	N.S	***	*
	Ontario	N.S	**	N.S	N.S	**	N.S	N.S	**	*
	Gilmore	N.S	**	N.S	N.S	***	N.S	N.S	**	*
1 blk.										
	Days	-	*	-	-	**	-	-	**	-
	Ontario	-	*	-	-	**	-	-	**	-
	Gilmore	-	*	-	-	**	-	-	***	-
Silk.	Days	***	**	N.S	***	***	*	***	***	N.S
3 blk	Ontario	**	**	N.S	**	***	N.S	*	***	N.S
	Gilmore	***	***	N.S	**	***	N.S	**	***	N.S
2 blk										
	Days	N.S	*	N.S	N.S	**	N.S	*	***	N.S
	Ontario	N.S	*	N.S	N.S	***	N.S	*	***	N.S
	Gilmore	N.S	*	N.S	N.S	**	N.S	**	**	N.S
1 blk										
	Days	-	*	-	-	***	-	-	**	-
	Ontario	-	*	-	-	***	-	-	**	-
	Gilmore	-	*	-	-	***	-	-	**	-
S-M	Days	***	**	N.S	***	**	N.S	*	***	N.S
3 blk	Ontario	***	**	N.S	***	**	N.S	***	***	N.S
	Gilmore	***	**	N.S	***	***	N.S	***	***	N.S
2 blk										
	Days	N.S	**	N.S	N.S	**	N.S	*	**	N.S
	Ontario	N.S	N.S	N.S	N.S	**	*	**	**	N.S
	Gilmore	N.S	N.S	N.S	N.S	***	*	***	**	N.S
1 blk.										
	Days	-	N.S	-	-	**	-	-	*	-
	Ontario	-	*	-	-	**	-	-	*	-
	Gilmore	-	**	-	-	**	-	-	*	-
Mat.	Days	N.S	**	N.S	N.S	***	N.S	N.S	***	*
3 blk	Ontario	N.S	**	N.S	*	***	N.S	***	***	*
	Gilmore	N.S	**	N.S	N.S	***	N.S	***	***	*
2 blk										
	Days	N.S	**	N.S	N.S	***	N.S	N.S	***	*
	Ontario	N.S	**	N.S	N.S	***	N.S	N.S	***	N.S
	Gilmore	N.S	**	N.S	N.S	***	N.S	N.S	***	*
1 blk.										
	Days	-	N.S	-	-	***	-	-	***	-
	Ontario	-	N.S	-	-	***	-	-	***	-
	Gilmore	-	N.S	-	-	***	-	-	***	-

Table E-26b. Summary of the ANOVA results of S_1 and S_2 families which derived from each of the double crosses 4, 9A2, 11A, 16A, 19A2, and 25A for flowering and maturity stages.

Trait and O.C.	Source of Var.	S_1 families: Days 3	Days 2	Days 1	Ontario HUD 3	Ontario HUD 2	Ontario HUD 1	Gilmore HUD 3	Gilmore HUD 2	Gilmore HUD 1	S_2 families: Days 3	Days 2	Days 1	Ontario HUD 3	Ontario HUD 2	Ontario HUD 1	Gilmore HUD 3	Gilmore HUD 2	Gilmore HUD 1
4 Boots	B	N.S	N.S	-	*	N.S	-	**	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	**	***	***	***	***	***	***	***	***
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	*	N.S	-	*	N.S	-	N.S	N.S	-
65	B	N.S	N.S	-	N.S	N.S	-	*	N.S	-	*	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	***	***	*	***	**	*	***	**	*
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	*
Silks	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	**	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	*	N.S	N.S	**	N.S	N.S	*	N.S	N.S	***	***	*	***	**	*	***	**	*
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
Silk-Mat.	B	N.S	N.S	-	**	*	-	**	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	**	N.S	*	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	*	N.S	N.S	N.S	*	*	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
Matu-rity	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	**	*	*	*	N.S	*	**	*	*	**	N.S	**	**	N.S	**	**	N.S	**
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
9A2 Boots	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	*	*	-	**	*	-	**	*	-
	F	***	***	N.S	***	***	N.S	***	***	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S
	F x B	*	N.S	-	*	N.S	-	*	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
65	B	*	N.S	-	N.S	N.S	-	N.S	N.S	-	*	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	**	**	N.S	**	**	N.S	**	**	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S
	F x B	*	N.S	-	*	N.S	-	*	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
Silks	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	**	*	-	N.S	N.S	-	N.S	8	-
	F	***	***	*	**	***	*	***	***	*	***	**	*	***	**	*	***	**	*
	F x B	*	N.S	-	*	N.S	-	*	N.S	-	*	*	-	*	*	-	*	*	-
Silk-Mat.	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	N.S	N.S	N.S	**	*	*	**	**	*	N.S	*	N.S	N.S	N.S	N.S	*	**	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	*	N.S	-	N.S	*	-	N.S	N.S	-	N.S	*	-
Matu-rity	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	***	**	-	**	**	-	**	**	-
	F	***	***	N.S	**	**	N.S	**	***	N.S	***	***	*	***	***	*	***	***	*
	F x B	*	N.S	-	N.S	N.S	-	N.S	N.S	-	**	**	-	**	**	*	**	**	-
11A Boots	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	*	N.S	*	*	N.S	*	*	N.S	*
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
65	B	*	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	*	N.S	-
	F	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	*	*	N.S	*	*	N.S	*	*	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
Silks	B	**	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	*	N.S	-
	F	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	**	*	N.S	*	*	N.S	**	*	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
Silk-Mat.	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	*	*	-	**	*	-	**	*	-
	F	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	**	**	*	**	**	*	**	**	**
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
Matu-rity	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	*	N.S	-
	F	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	*	*	*	*	*	*	*	*	*
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-

Continued table 26b.

Trait and D.C.	Source of Var.	S_1 families: Days 3^s	2^s	1^s	S_1 families: Ontario HUD 3	2	1	S_1 families: Gilmore HUD 3	2	1	S_2 families: Days 3	2	1	S_2 families: Ontario HUD 3	2	1	S_2 families: Gilmore HUD 3	2	1
16A Boots	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	***	***	N.S	***	***	N.S	***	***	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
65	B	***	N.S	-	*	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	N.S	N.S	**	N.S	N.S	**	N.S	N.S	***	***	***	*	***	***	*	***	***	*
	F x B	*	N.S	-	*	N.S	-	*	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
Silks	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	*	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	N.S	N.S	***	N.S	N.S	***	N.S	N.S	***	*	N.S	**	*	N.S	**	*	N.S	**
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
Silk-Mat.	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	N.S	N.S	N.S	*	N.S	*	*	N.S	*	N.S	N.S	N.S	*	N.S	**	*	N.S	**
	F x B	*	*	-	**	**	-	*	*	-	N.S	N.S	-	*	N.S	-	N.S	N.S	-
Matu-rity	B	N.S	N.S	-	*	N.S	-	*	N.S	-	N.S	N.S	-	*	N.S	-	*	N.S	-
	F	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	*	***	**	**	*	**	N.S	**	**	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
19A Boots	B	N.S	N.S	-	**	N.S	-	**	N.S	-	N.S	N.S	-	N.S	N.S	-	*	N.S	-
	F	N.S	N.S	**	N.S	N.S	*	N.S	N.S	*	N.S	N.S	*	***	***	N.S	***	***	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
65	B	N.S	N.S	-	N.S	N.S	-	*	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	**	**	**	**	*	**	*	*	*	***	**	*	***	***	*	***	***	*
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	*	-	N.S	*	-	N.S	*	-
Silks	B	**	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	*	N.S	-
	F	**	N.S	*	**	N.S	*	***	N.S	*	**	**	N.S	**	**	N.S	***	***	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
Silk-Mat.	B	**	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	*	N.S	-	**	N.S	-
	F	N.S	N.S	N.S	*	N.S	*	*	N.S	**	**	N.S	N.S	N.S	N.S	N.S	*	*	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
Matu-rity	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	*	N.S	*	N.S	N.S	N.S	N.S	N.S	N.S	***	***	N.S	***	***	N.S	***	***	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
25A Boots	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
65	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	***	*	*	***	N.S	*	***	*	*	*	*	*	**	*	*	*	*	*
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
Silks	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	N.S	*	N.S	*	*	N.S	*	*	N.S	*	*	N.S	N.S	*	N.S	*	**	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
Silk-Mat.	B	N.S	N.S	-	N.S	N.S	-	*	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	**	*	N.S	N.S	N.S	N.S	N.S	N.S	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
Matu-rity	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	**	*	N.S	**	*	N.S	**	*	N.S	***	***	N.S	***	***	N.S	***	***	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-

3^s, 2^s, and 1^s are the ANOVA results for B1+B2+B3, B1+B2, and B3 respectively.

Table 27. Coefficient of variation from the ANOVA for flowering and maturity stages for the calendar days and heat unit-degrees methods.

Coefficient of variation										
Stage and		Three blocks			Two blocks			One block		
Generation		day	Ont.	Gil.	day	Ont	Gil.	day	Ont	Gil
boots	D.C	7.8	9.7	10.6	7.3	9.4	10.4	7.5	9.1	9.7
	S_1	8.1	10.0	10.8	8.6	11.0	12.0	6.9	8.0	8.4
	S_2	7.3	9.3	10.2	8.2	10.2	11.2	7.1	8.8	9.5
65 stage	D.C	3.9	5.2	5.6	3.9	5.3	5.8	4.0	5.0	5.3
	S_1	4.5	5.7	6.2	4.4	5.8	6.3	4.7	5.5	5.8
	S_2	4.9	5.8	6.3	4.8	5.9	6.4	5.0	5.8	5.9
silking stage	D.C	5.0	6.6	7.1	4.9	6.6	7.2	5.1	6.5	7.0
	S_1	5.8	7.3	7.8	5.7	7.4	8.0	5.9	7.1	7.5
	S_2	5.5	6.6	7.1	5.3	6.5	7.1	5.9	6.8	7.0
silking to maturity	D.C	8.5	7.5	8.4	8.2	7.0	7.9	8.8	8.5	9.2
	S_1	9.1	9.6	11.3	9.2	9.1	11.0	8.8	10.5	12.1
	S_2	9.3	11.0	12.8	9.5	10.5	12.3	9.1	12.1	13.8
maturity stage	D.C	4.7	2.7	2.0	4.6	2.6	1.9	4.9	2.8	2.2
	S_1	4.7	2.6	2.0	4.9	2.7	2.1	4.4	2.4	1.9
	S_2	4.0	2.2	1.7	4.1	2.4	1.8	3.6	2.0	1.5

Table E-28. The faster S_1 and S_2 families reached the different flowering and maturity stages.(see tables E-11 to E-15 for the means)*.

Boots		65 stage		Silking		Silking		Maturity	
S_1	S2	S1	S2	S1	S2	S1	S2	S1	S2
5-8	10-3-19A2	3-26A	10-3-19A2	3-26A	10-3-19A2	1-16A	2-3-9A2	3-26A	10-3-19A2
2-13	6-4 11A	5-8	2-4-4	5-8	2-4-4	3-16A	4-5-9A2	4-4	2-4-4
3-26A	7-4-19A2	3-18	7-4-19A2	2-9A2	3-4-25A	5-9A2	5-1-11A	3-18	7-4-19A2
3-18	2-4-4	4-25A	3-4-25A	4-21B	1-2-9A2	4-17	4-1-16A	2-13	3-4-25A
5-19A2	9-1-4	4-4		4-4	4-2-19A2	5-19A2	6-5-16A	2-9A2	1-2-9A2
2-19A2		2-13		4-25A	1-5-11A	5-16A		1-12A	9-1-4
4-19A2		4-22		3-3A	6-4-11A	5-24A		4-21B	
3-10		4-19A2		3-18	9-1-4	2-20		5-5	
4-4		2-19A2		1-12A		4-7		3-19A2	
2-2B		3-19A2		5-5		1-19A		4-6B	
3-3A		3-3A		4-22				3-3A	
3-19A2								1-2A	
								1-4A	

* Families are listed in order. The first one is the earliest and the last is the latest for any given stage.

3. Results for the Other Agronomic Characters.

Plant Height and Ear Height.

Means of plant height (cm) and ear height (cm) are presented in table E-29 for all double cross hybrids, S_1, and S_2 families. The results of the ANOVA are shown in tables E-30, E-31a, and E-31b for the double crosses, S_1, and S_2 overall, and for the individual S_1 and for the S_2 families derived from the same double cross respectively. Summaries of these results also are presented in tables E-35a, and E-35b.

There were no significant differences between the 32 double crosses for plant height, but there were significant differences among them at 1 % level for ear height overall in blocks 1 and 2, but not in the analysis of block 3. No significant genotype x blocks interaction was observed for either trait in all generations. The non-significant differences for plant height among the double crosses could be because they have been developed from closely related single crosses, derived from the same set of inbred lines.

The analysis of variance indicated significant differences at the 1 % level among both the S_1 families and S_2 families for both traits in the two dates of planting. Comparisons between the means of these traits in blocks 1 and block 2 with those obtained from block 3 (date 2) show that plant height and ear height are greater for most of the genotypes in block three. There was, however no significant families x blocks interaction in any of these ANOVA. This result means that the limits for every genotype is determined by the environmental conditions. The variation among S_1 and the S_2 families for plant height probably results from the selection and segregation although it may attributed to dominant gene effects, as were found to be important for plant height in the basic material used to developed this population (Maryam, 1984). Gamble (1961) also found that dominant genes were an important contributor to the inheritance of plant height.

Plant height ranged between 137 - 162 ,105 - 163, and 95 - 140 cm for the double crosses, the S_1, and the S_2 families respectively. The ear height for the three

generations respectively ranged between 45 - 75, 38 - 87, and 32 - 84 cm in the mean of block 1 and 2.

Less variability was found among S_1 and S_2 families derived from the same double cross (tables E-31a, E-31b). In most cases the differences were not significant or significant only at the 5% level. The only significant differences at the 1% level of probability were between S_1 families of double cross 11A, and 19A2 for plant height, and 4, and 19A2 for ear height. In the S_2 generation, significant differences were found at the 1 % level among families derived from double cross 11A, and 25A for the plant height cm, and among 11A and 16A families for ear height cm.

A majority of the most promising families among the S_1 and the S_2 for cold tolerance and the flowering stages, were those that were intermediate in plant height and intermediate in the ear height. It is clear from this result that these traits showed some inconsistency over the three generations, and thus they need to be monitored carefully throughout any selection programme with this population. In most cases, it seems that selection for early maturity would have no important effects on plant height and ear height among the S_1 and S_2 generations. This conclusion is obvious from table E-29 where we can see that S_2 families with smallar means for plant height and ear height were among those derived from S_1 families also with smaller mean plant height and ear height (Eg. families 5-9A2, 4-11A, and 3-19A2).

Grain Moisture Content at Maturity

Means for grain moisture content at maturity are shown in table E-29. A description of the criterion for judging maturity was given in chapter two and in experiment B in chapter three. Cobs were harvested and immediately placed in plastic bags to be transferred to the laboratory and the moisture measurements were carried out on the same day. The ANOVA for the three generations S_0, S_1, and S_2 are shown in table E-30. The summary of the results is presented in table E-35a.

There were significant differences at the 5 % level of probability between the double crosses for grain moisture content at harvest, but no significant genotype x blocks interaction was found for the double crosses. Highly significant differences were found between the S_1 and between the S_2 families at the 1 % level for grain moisture content. There was also no significant families x blocks interaction for the S_1 families, but for S_2 families there was significant families x blocks interaction at the 5 % level only in the analysis of variance of blocks 1 and 2.

The means of grain moisture content ranged from 30.4 - 34.3, 29.9 - 34.5, and 32.00 - 35.7 for the double crosses ,the S_1, and the S_2 families respectively. These ranges indicate that while there are some changes in the degree of variability observed for this character between the three generation there were no important changes in the limits of the grain moisture at harvest as a result from the selection either for germination at low temperature or for early maturity . In other words it seems that selection for cold tolerance and for early maturity have no important negative effects on grain moisture content at harvest in this population.

The results in tables E-31a, E-31b, and E-35b for the ANOVA of the S_1 and S_2 families derived from the same double cross, showed for all but 4 families no significant differences in the moisture content of the grains among these groups of families. The exceptions were between the S_1 families derived from double crosses 16A and 25A, where there were significant differences at the 5 % and 1 % levels respectively and between S_2 families derived from double crosses 4 and 19A2. These results again confirm that the high variability observed among S_1 and among S_2 families was mainly due to the variability between families from the different double crosses and not due to the differences between families derived from the same double cross. As was found for most of the previous traits there was no significant blocks x families interaction for this trait.

The limits of grain moisture at harvest ranged from 30 - 33 %, except for a few genotypes where the means were from 33 % up to 35.7 % (for block 1 and 2 results) and to 38 % (for block 3). These limits indicated that the method we used

(firm attachment of the grain to the cob) to detect maturity in this population was effective. When plants stay green at harvest time in mild and cold conditions, experience shows that grain does not dry to below 30 % moisture in most years. Bunting and Gunn (1973), Cavalieri (1985), and Baron *et al.*(1987) stated that relative maturity ratings are based upon moisture percentage at harvest, thus percentage moisture at harvest is a trait selected for by breeders. They also stated that most of maize genotypes reach physiological maturity at 35 % moisture and, moreover that plant traits controlling the rate of grain drying are not well defined as yet.

In table E-29 we can see that most of the double crosses, S_1, and S_2 families reached physiological maturity under the conditions of this experiment. This confirms the suitability of much of the material for the generally unfavourable conditions for grain-maize growing in Northern England. Furthermore, this population represents a good source for further selection towards earliness in this environment.

Results of the Yield Components: Kernel Number, Grain Weight, and 100 kernel Weight Per Plant.

The number of kernels per plant, the grain weight per plant, and the weight of 100 kernels, for the double crosses, the S_1, and the S_2 families are given in table E-32. For all these characters and in all three generations the differences between families were highly significant (tables E-33 and E-35a). The genotypes and family x blocks interactions were mostly not significant. The exceptions were for the number of kernels in some of the S_1 and S_2 families, where there were significant family x environment interactions at the 5 % and 1 % levels for S_1 and the S_2 families respectively. This difference in the interaction for the number of kernels between the generations (from non-significant interaction for the double crosses to significant at 5 % level for S_1 and at 1 % level for S_2 generations) was not unexpected because yield

in maize is not a stable character and it will vary with the environment. It has been found in many studies (Gamble, 1961; Maryam, 1981; McConnell and Gardner; 1979b) that the dominance and the over-dominance effects were the most important contributors to the inheritance of the yield components. Cross (1977) reported, however, that maize hybrids could produce high yields almost regardless of the environmental conditions! In reality, hybrids do not perform equally well in all environments, but some tend to be closer to the ideal than others and the more stable hybrids would have a small genotype x environment interaction. Poneleit and Egli (1979) stated that yield increase, due to more kernels per unit area has been shown directly and indirectly in numerous studies of the components of yield. In maize, Funk and Anderson (1964), Rowe and Andrew (1964), and Eberhart and Russell (1969) demonstrated that heterogeneous populations tended to have a better yield stability than homogeneous populations; this would explain the significant interaction which was shown for the number of kernels per plant in the S_1 and S_2 generations where selfing will lead to more homozygosity among families.

The number of kernels ranged between 194 (25B) - 687 (19A2), 116 (4-17) - 455 (3-11B), and 127 (4-2-19A2) - 390 (1-2-9A) for the double crosses, S_1, and S_2 families respectively.

From the table of family means (E-32) it is also clear that there was a reduction in the number of kernels per plant in the S_1 generation compared with the yield of the double crosses, on occasions this reduction reaching 50 % for S_1 families. Further reduction happened between the S_1 and S_2 generation, but the fall was not as great as that which happened between S_0 and S_1. A small reduction in 100-kernel weight was observed through the S_0, S_1, and S_2 generations. This result leads to the conclusion that the decrease in the yield following selfing was mainly the result of a reduction in the number of kernels on the smaller cobs obtained with the S_1 and S_2 plants compared with the double cross hybrid plants (see Plate 4). The reduction in the yield per plant seen in S_1 and S_2 generation is a common feature in maize as it is a cross pollinated crop. Hallauer and Miranda (1988) stated that from the earliest studies

maize the effects of the inbreeding were obvious: with increasing homozygosity, vigour and productiveness were reduced and traits became fixed and differences among lines increased whereas variability within lines decreased. Effects of inbreeding were interpreted on the basis of Mendelian genetics because of fixation of alleles with increased homozygosity. They reviewed most of the studies on this feature and they conclude that, in general, inbreeding led to a reduction in all of the yield components and most of the other vegetative and agronomic characters, and increased the number of days to flowering. We also found that the S_1 and S_2 families flowered later than the double crosses. Hallauer and Miranda (1988) further argued that the degree of reduction is dependent on the percentage homozygosity reached in each generation and the number of genetic factors controlling the characters. They found that the overall reduction in the yield in terms of gm/plant ranged between -28.79 gm to -86.38 gm for 25 % to 75 % level of homozygosity. They found that selfing in Iowa Stiff Synthetic (BSSS) results in 34 % and 48 % reduction in the yield for S_1 and S_2 generations respectively.

The results of the separate ANOVA for S_1, and S_2 families derived from the same double cross (tables E-34a and E-35b) indicated that less variation was found among S_1 and S_2 families within the same double cross compared with those derived from different double crosses for the number of kernels per plant and the grain weight per plant. No significant differences were observed between these groups of families in the 100-kernel weight. Also there is no significant family x blocks interaction except for the number of kernels of the S_1 families derived from double cross 16A and S_2 families derived from 9A and 25A, and those among S_1 families of 16A and S_2 families of 9A2 for grain weight per plant.

There is no doubt that the reduction in the yield components throughout the three generation was the result of the inbreeding and the segregation. One purpose in including this trait in the evaluation of the generations under study was to investigate whether there were any effect from the selection for early germination and early maturity on the yield of these materials.

It is clear from the comparisons of the yield components with the flowering stages, maturity and cold tolerance results, that there is no negative effect on the yield. In some cases there is evidence of a positive effect of selection on the yield components. From table E-32 we can see that the best S_1 and S_2 families in the number of kernels and grain weight per plant were those families which were the fastest to mature (eg. S_1 families 4-4, 2-9A, and 3-19A2 and S_2 families 2-4-4, 1-2-9A, 10-3-19A2, 3-4-19A2, and 3-4-25A).

Several studies have reported on the relation between selection for cold tolerance and grain yield. No negative relation was reported between them. All of these studies declared that the selection for cold tolerance either increased the yield or maintained it. Mock and Bakri (1976), when they studied the effect of the recurrent selection for cold tolerance, found no change in grain yield across selection cycles and a high yield level was maintained in the population (BSSS2 (SCT)) when subjected to cold tolerance selection.

McConell and Gardener (1979a) also reported that selection for germination at cold temperatures did not have any detrimental effect on the other agronomic characters, including grain yield. Similar results were reported by Eagles and *et al.* (1983) who found no correlation between cold tolerance traits and grain yield.

Mock and McNeil (1979) showed that good seedling vigour was associated with favourable grain yield of early planted maize. Chapman (1984) found that selection of early planting genotypes was advantageous for grain yield. McConnel and Gardner (1979a) stated that the early cycles of selection for cold tolerance showed an increase in the grain yield, but reduced increases occurred in later cycles of selection. He suggested that yield can be maintained during selection for cold tolerance, if at harvest time, consideration is given to plants with good ear development. Yield can even be improved under these conditions.

In an evaluation of visual S_1 recurrent selection for early vigour in maize Hexum (1984) found that grain yield was significantly increased by selection for early vigour.

Many other studies have dealt with the selection for earliness in flowering and in maturity and reported that many agronomic traits were improved during selection for early flowering and early maturity (Troyer, 1986; Troyer and Larkins, 1985; Troyer and Brown, 1976; Troyer, 1978).

Also it can be concluded from the results of yield components that there is important variability among the double crosses, S_1, and the S_2 families for the number of the kernels and grain weight and it does appear to be sufficient for further selection in this population for yield improvement.

Table E-29 Means of plant height cm, ear height cm, and percentage of grain moisture content at harvest for the double crosses, and the S_1 and S_2 families in the two planting dates.

Double crosses				S_1 families					S_2 families				
DC	PH cm B1+B2 B3	EH cm B1+B2 B3	% H2O B1+B2 B3	F	PH cm B1+B2 B3	EH cm B1+B2 B3	% H2O B1+B2 B3	F	PH cm B1+B2 B3	EH cm B1+B2 B3	% H2O B1+B2 B3
1	151.8 170.0	64.1 83.2	32.1 35.1	2	145.1 146.6	65.1 69.2	31.8 31.5	-	- -	- -	- -
2A	156.1 169.0	60.9 80.4	31.8 33.9	1	98.9 114.4	38.8 58.8	30.6 34.8	-	- -	- -	- -
2B	152.9 158.6	58.5 70.2	32.7 33.2	2	106.8 119.8	40.1 42.2	33.0 34.2	-	- -	- -	- -
3A	142.0 149.0	69.1 76.0	32.1 34.4	3	163.5 167.6	87.7 93.2	33.8 34.8	-	- -	- -	- -
4	146.3 152.8	65.7 73.0	32.8 33.9	1	145.6 116.0	60.5 57.2	34.0 34.3	9	119.8 136.2	57.7 58.2	33.3 32.0
-	- -	- -	- -	4	123.9 127.8	60.9 60.4	33.1 34.0	2	124.7 127.6	65.4 67.6	32.0 35.4
-	- -	- -	- -	5	116.5 128.4	39.7 55.8	31.8 32.3	9	140.4 140.0	70.1 76.0	34.5 33.5
5	154.8 151.6	68.1 66.6	32.6 32.8	5	140.3 152.6	62.6 82.6	32.1 33.5	-	- -	- -	- -
6A	142.5 169.6	61.2 79.2	33.2 33.2	4	118.3 124.8	49.2 66.8	33.7 36.4	-	- -	- -	- -
6B	155.7 167.8	64.3 72.6	32.3 32.6	4	120.7 137.4	63.7 71.8	34.2 34.1	-	- -	- -	- -
7	137.0 152.2	64.1 69.6	30.9 33.2	4	105.8 114.0	44.5 50.4	32.7 32.7	-	- -	- -	- -
8	132.5 156.8	58.4 72.4	31.0 36.1	5	163.5 161.8	82.1 74.0	32.8 33.4	-	- -	- -	- -
9A2	158.6 166.4	69.2 83.4	33.2 36.0	2	161.2 170.8	78.2 83.0	34.2 34.8	1	134.2 142.4	67.8 77.4	32.8 33.8
-	- -	- -	- -	3	140.0 152.8	63.6 70.0	32.5 35.6	2	137.5 138.4	64.7 62.2	33.0 34.6
-	- -	- -	- -	5	147.5 146.0	60.5 58.4	33.9 33.1	4	109.1 93.0	49.8 37.0	32.6 34.2
10	148.5 154.6	61.3 61.4	32.5 32.8	3	137.3 147.8	62.1 72.8	33.9 35.3	-	- -	- -	- -
11A	157.4 146.2	69.3 69.0	32.7 34.7	1	128.3 164.8	48.4 68.8	32.9 32.6	5	150.1 169.8	84.1 99.5	33.1 34.5
-	- -	- -	- -	2	141.4 158.0	52.0 58.4	34.1 32.7	4	133.3 146.8	66.4 76.4	34.1 32.6
-	- -	- -	- -	3	125.4 136.8	67.8 63.0	33.7 33.9	10	114.8 135.6	58.9 76.8	33.3 30.7
-	- -	- -	- -	4	117.5 125.8	49.3 56.4	33.7 33.1	6	100.4 102.0	48.0 49.0	32.1 33.6
-	- -	- -	- -	5	149.4 153.6	53.6 68.2	33.4 34.1	1	117.8 130.0	46.3 56.8	33.6 34.7
11B	159.2 160.0	68.3 79.2	31.4 31.1	3	139.3 135.0	59.6 66.0	32.9 34.2	-	- -	- -	- -
12A	162.8 141.0	66.1 61.2	34.1 35.1	1	149.7 139.2	74.3 64.6	30.3 33.5	-	- -	- -	- -
13	139.5 154.2	57.3 63.8	32.4 34.2	2	132.4 148.6	64.9 77.4	31.9 37.6	-	- -	- -	- -
14	132.7 152.6	45.1 64.2	32.4 33.7	1	131.2 125.8	55.1 59.0	33.3 34.4	-	- -	- -	- -
15	140.8 164.8	53.9 72.4	31.7 33.8	5	130.4 143.6	51.9 64.4	34.4 34.6	-	- -	- -	- -
16A	151.6 146.8	72.8 75.8	32.3 33.3	1	128.3 159.8	62.5 89.8	34.4 38.0	4	123.2 137.4	62.2 73.0	35.7 32.6
-	- -	- -	- -	3	117.4 85.4	54.2 45.0	34.5 30.8	7	99.0 109.5	45.4 56.8	33.3 34.0
-	- -	- -	- -	5	129.3 148.8	47.8 69.0	31.5 36.5	6	102.3 110.4	36.3 49.2	33.6 34.5
16B	144.1 150.2	61.7 71.8	31.0 33.3	4	136.0 154.4	59.8 72.2	31.0 34.5	-	- -	- -	- -
17	143.3 159.6	68.3 69.6	31.7 33.1	4	130.6 157.8	70.0 74.4	31.7 34.8	-	- -	- -	- -
18	128.9 161.0	50.2 80.2	30.9 34.6	3	126.1 117.0	43.7 42.4	31.4 33.5	-	- -	- -	- -
19A	152.7 160.2	60.7 72.4	32.8 35.7	1	133.2 140.2	66.8 70.6	33.1 34.7	2	110.9 115.0	53.8 63.0	32.9 35.1
-	- -	- -	- -	2	135.2 136.4	53.3 73.2	32.7 34.7	4	107.4 109.6	49.5 48.0	35.0 36.1
-	- -	- -	- -	3	107.8 124.8	47.7 54.2	32.3 33.9	10	107.4 101.6	43.9 48.0	32.3 33.2
-	- -	- -	- -	4	115.2 117.4	47.2 56.2	32.9 33.5	7	95.2 114.4	42.5 56.2	32.1 34.4
-	- -	- -	- -	5	146.8 104.8	68.2 50.6	34.3 34.2	1	127.5 138.4	56.2 73.0	34.8 35.5
20	143.4 158.0	69.0 66.0	33.4 34.1	2	118.6 135.6	54.1 66.6	34.2 36.0	-	- -	- -	- -
21A	149.7 151.2	63.3 70.0	33.3 33.5	5	123.7 149.8	49.2 56.6	32.5 34.7	-	- -	- -	- -
21B	146.2 136.4	58.0 59.2	30.9 32.1	4	140.3 153.4	70.1 78.2	30.7 34.2	-	- -	- -	- -
22	149.4 154.4	60.1 73.8	31.3 32.7	4	118.4 125.6	52.1 59.6	31.6 32.9	-	- -	- -	- -
23	154.4 162.2	61.0 72.8	30.4 33.9	1	131.6 145.0	56.2 72.4	31.4 31.0	-	- -	- -	- -
24A	156.9 159.2	70.6 64.6	32.4 31.9	5	155.6 150.4	54.5 66.8	32.9 33.3	-	- -	- -	- -
25A	145.8 149.0	61.3 64.0	32.6 32.6	1	131.2 127.2	48.2 49.8	34.5 35.5	9	106.6 127.6	41.6 55.0	32.7 34.8
-	- -	- -	- -	3	126.3 135.0	51.7 64.6	33.4 34.1	5	124.1 160.2	45.2 71.2	32.5 34.9
-	- -	- -	- -	4	126.1 104.8	57.0 43.4	31.0 32.0	3	117.7 112.0	52.4 52.2	32.3 34.7
25B	142.3 162.8	66.2 84.8	31.3 34.0	2	110.4 120.6	48.4 63.8	32.6 34.5	-	- -	- -	- -
26A	148.7 156.8	75.9 77.0	34.3 36.0	3	116.2 125.0	50.1 47.4	29.9 33.6	-	- -	- -	- -

Table E-30. The ANOVA for plant height, ear height, and grain moisture containt at harvest for the double crosses, the S_1, and the S_2 families

Gen	Sour.of variance	Plant height Df	M.S	F	P	Ear height M.S	F	P	Grain moisture Df	M.S	F	P
DC	B1+B2+B3											
	Bet. B.	2	673.84	14.091	***	4343.9	19.974	**	2	168.893	26.119	***
	Bet. D.C.	31	594.7	1.244	N.S	220.0	1.931	**	31	10.068	1.557	*
	D.C. x B.	62	482.3	1.009	N.S	232.9	1.071	N.S	62	6.816	1.054	N.S
	Error	384	478.2			217.5			383	6.466		
	B1+B2											
	Bet. B.	1	5216.4	10.194	***	1328.4	6.076	**	1	5.585	0.856	N.S
	Bet. D.C.	31	700.0	1.368	N.S	430.2	1.968	**	31	9.070	1.391	*
	D.C. x B.	31	552.6	1.080	N.S	221.1	1.011	N.S	31	6.764	1.037	N.S
	Error	256	511.7			218.6			255	6.521		
	B3											
	Bet. D.C.	31	306.7	0.746	N.S	234.5	1.090	N.S	31	7.865	1.237	N.S
	Error	128	411.2			215.2			128	6.358		
S_1	B1+B2+B3											
	Bet. B.	2	5618.2	10.103	***	6072.4	25.677	***	2	155.887	31.999	***
	Bet. fams	47	3233.4	5.815	***	1551.9	6.656	**	4	15.917	3.267	*
	Fams x B.	94	720.7	1.296	N.S	294.9	1.247	N.S	94	6.302	1.390	N.S
	Error 569/562*		556.1			236.5			556	4.872		
	B1+B2											
	Bet. B.	1	5200.8	9.097	***	4005.3	16.065	***	1	3.240	0.737	N.S
	Bet. fams	47	2306.1	4.034	***	1184.4	4.751	***	47	15.232	3.463	**
	Fams x B.	47	677.8	1.185	N.S	274.7	1.102	N.S	47	3.764	0.856	N.S
	Error 379/372*		571.7			249.3			368	4.398		
	B3											
	Bet. fams	47	1690.9	3.222	***	682.5	3.229	***	47	10.423	1.798	**
	Error	190	524.9			211.4			188	5.798		
S_2	B1+B2+B3											
	Bet. B.	2	8089.0	8.381	***	2765.7	11.500	***	2	58.051	9.962	***
	Bet. fams	21	3685.4	6.025	***	2227.9	9.260	**	21	21.499	3.689	**
	Fams x B.	42	552.4	0.910	N.S	251.7	1.04	N.S	42	11.406	1.957	**
	Error 255/254*		607.2			240.4			243	5.827		
	B1+B2											
	Bet. B.	1	4445.9	6.709	*	630.2	2.673	N.S	1	0.260	0.045	N.S
	Bet. fams	21	2162.5	3.263	**	1408.4	5.974	**	21	10.349	1.777	*
	Fams x B.	21	670.5	1.012	N.S	239.9	1.018	N.S	21	10.173	1.747	*
	Error 169/168*		662.7			235.7			162	5.823		
	B3											
	Bet. fams	21	1930.1	3.87	**	1083.1	4.340	21	21	23.789	4.076	***
	Error	86	498.2			249.6			81	5.836		

* The first number gives the degrees of freedom for plant height, the second for ear height

Table E-31a. The ANOVA for plant height, ear height, and grain moisture containt at harvest for the S_1 families derived from the same double cross.

DC	Source of variance	Plant height Df	M.S	F	P	Ear height M.S	F	P	Grain moisture Df	M.S	F	P
4	B1+B2+B3											
	Bet. B.	2	212.5	0.219	N.S	654.5	2.628	*	2	2.718	0.442	N.S
	Bet. fams	2	916.1	0.946	N.S	1131.7	4.544	*	2	18.751	3.256	N.S
	Fams x B.	4	847.4	0.875	N.S	197.3	0.792	N.S	4	0.716	0.124	N.S
	Error	36	968.0			249.0			36	5.758		
	B1+B2											
	Bet. B.	1	213.3	0.375	N.S	1140.8	5.629	*	1	1.875	0.365	N.S
	Bet. fams	2	2287.8	4.019	*	1470.4	7.255	**	2	13.081	2.548	N.S
	Fams x B.	2	79.0	0.139	N.S	28.1	0.139	N.S	2	1.036	0.202	N.S
	Error	24	569.2			202.7			24	5.133		
	B3											
	Bet. fams	2	244	0.138	N.S	27.8	0.081	N.S	2	6.066	0.866	N.S
	Error	12	1766			341.7			12	7.007		
9A2	B1+B2+B3											
	Bet. B.	2	393.1	1.056	N.S	100.2	0.656	N.S	2	6.215	0.797	N.S
	Bet. fams	2	1789.0	4.807	*	1582.7	10.372	**	2	3.496	0.448	N.S
	Fams x B.	4	342.9	0.921	N.S	85.1	0.557	N.S	4	10.208	1.309	N.S
	Error	36	372.2			152.6			36	7.976		
	B1+B2											
	Bet. B.	1	300.8	0.741	N.S	108.3	0.621	N.S	1	2.760	0.718	N.S
	Bet. fams	2	1155.6	2.847	N.S	893.4	5.120	*	2	8.161	2.123	N.S
	Fams x B.	2	498.0	1.227	N.S	102.1	0.585	N.S	2	7.429	1.933	N.S
	Error	24	405.9			174.5			24	3.844		
	B3											
	Bet. fams	2	821.1	2.694	N.S	757.3	6.962	**	2	8.32	0.530	N.S
Error		12	304.8			108.8			12	15.70		
11A	B1+B2+B3											
	Bet. B.	2	3481.89	8.299	**	867.8	3.343	*	2	2.521	0.687	N.S
	Bet. fams	4	2402.1	5.725	**	474.8	1.809	N.S	4	2.145	0.584	N.S
	Fams x B.	8	495.3	1.180	N.S	212.9	0.811	N.S	8	3.253	0.886	N.S
	Error	60	914.5			262.5			60	3.670		
	B1+B2											
	Bet. B.	1	3010.9	7.616	**	480.5	1.804	N.S	1	3.809	1.068	N.S
	Bet. fams	4	1644.5	4.160	**	619.5	2.326	N.S	4	1.727	0.484	N.S
	Fams x B.	4	458.4	1.660	N.S	124.4	0.467	N.S	4	4.491	1.259	N.S
	Error	40	395.3			266.3			40	3.567		
	B3											
	Bet. fams	4	1289.6	2.750	N.S	156.7	0.615	N.S	4	2.433	0.628	N.S
	Error	20	468.0			254.9			20	3.877		

Continued table E-31a.

DC	Source of variance	Plant height Df	M.S	F	P	Ear height M.S	F	P	Grain moisture Df	M.S	F	P
16A	B1+B2+B3											
	Bet. B.	2	200.6	0.222	N.S	1109.0	4.422	*	2	17.066	2.269	N.S
	Bet. fams	2	4713.3	5.206	*	1782.1	7.106	**	2	28.438	4.282	*
	Fams x B.	4	2388.4	2.638	N.S	1133.4	4.519	**	4	44.488	6.698	**
	Error	32/26*	905.3			250.8			20	6.642		
	B1+B2											
	Bet. B.	1	3	0.003	N.S	502	1.570	N.S	1	7.927	1.472	N.S
	Bet. fams	2	437	0.355	N.S	545.4	1.706	N.S	2	28.676	5.323	*
	Fams x B.	2	979	0.797	N.S	990.9	3.099	N.S	2	17.670	3.280	N.S
	Error	22/16*	1229			319.7			12	5.387		
	B3											
	Bet. fams	2	8077.4	41.716	***	2511.9	17.881	***	2	69.413	8.137	*
	Error	10	193.6			140.5			8	8.530		
19A	B1+B2+B3											
	Bet. B.	2	503.7	1.053	N.S	263.7	1.680	N.S	2	11.722	4.032	N.S
	Bet. fams	4	1820.6	3.806	**	940.5	4.209	**	4	4.616	1.588	N.S
	Fams x B.	8	1146.0	2.396	*	391.5	1.752	N.S	8	1.933	0.665	N.S
	Error	60	478.3			223.5			60	2.907		
	B1+B2											
	Bet. B.	1	865.3	1.588	N.S	216.3	0.926	N.S	1	1.248	0.419	N.S
	Bet. fams	4	2508.9	4.604	**	1042.6	4.464	**	4	5.642	1.892	N.S
	Fams x B.	4	570.7	1.064	N.S	157.9	0.676	N.S	4	1.381	0.463	N.S
	Error	40	544.9			233.6			40	2.982		
	B3											
	Bet. fams	4	1033.1	2.993	*	523.0	2.574	N.S	4	1.459	0.529	N.S
	Error	20	345.1			203.2			20	2.757		
25A	B1+B2+B3											
	Bet. B.	2	238.4	0.513	N.S	215.1	1.057	N.S	2	6.379	1.561	N.S
	Bet. fams	2	5558.2	1.200	N.S	198.1	0.974	N.S	2	47.486	11.621	***
	Fams x B.	4	578.3	1.243	N.S	424.1	2.084	N.S	4	2.086	0.553	N.S
	Error	35	465.2			203.5			35	4.086		
	B1+B2											
	Bet. B.	1	171.6	0.485	N.S	429.4	2.398	N.S	1	5.146	1.023	N.S
	Bet. fams	2	83.9	0.237	N.S	198.7	1.109	N.S	2	31.899	6.342	**
	Fams x B.	2	402.1	1.137	N.S	256.5	1.432	N.S	2	4.423	0.879	N.S
	Error	23	353.6			179.1			23	5.030		
	B3											
	Bet. fams	2	1228.9	1.81	N.S	591.2	2.362	N.S	2	15.681	6.886	*
	Error	12	679.0			250.3			12	2.277		

* The first number gives the degrees of freedom for plant height, the second for ear height.

Table E-31b. The ANOVA for plant height, ear height, and grain moisture containt at harvest for the S_2 families derived from the same double cross.

DC	Source of variance	Plant height Df	M.S	F	P	Ear height M.S	F	P	Grain moisture Df	M.S	F	P
4	B1+B2+B3											
	Bet. B.	2	1072.5	1.941	N.S	153.2	0.785	N.S	2	0.963	0.239	N.S
	Bet. fams	2	1095.8	1.283	N.S	763.0	3.911	**	2	6.790	1.686	N.S
	Fams x B.	4	258.1	0.467	N.S	86.9	0.446	N.S	4	15.216	3.779	*
	Error	36	552.5			195.1			36	4.026		
	B1+B2											
	Bet. B.	1	174.80	2.762	N.S	224.1	0.885	N.S	1	0.507	0.140	N.S
	Bet. fams	2	1158.1	1.830	N.S	391.9	1.548	N.S	2	15.641	4.304	*
	Fams x B.	2	252.0	0.398	N.S	148.4	0.586	N.S	2	7.372	2.029	N.S
	Error	24	632.8			253.2			24	3.634		
	B3											
	Bet. fams	2	201.8	0.515	N.S	396.47	5.029	*	2	14.208	2.953	N.S
	Error	12	391.8			78.83			12	4.811		
9A	B1+B2+B3											
	Bet. B.	2	2234.8	3.989	*	549.5	2.740	N.S	2	11.056	1.864	N.S
	Bet. fams	2	5658.2	10.091	**	2814.6	14.033	**	2	0.909	0.153	N.S
	Fams x B.	4	582.1	1.038	N.S	494.7	2.466	N.S	4	22.244	3.749	*
	Error	32	560.7			200.6			31	5.933		
	B1+B2											
	Bet. B.	1	4415.3	7.477	*	1014.1	4.948	*	1	2.933	0.367	N.S
	Bet. fams	2	2411.9	4.085	*	927.7	4.562	*	2	0.569	0.071	N.S
	Fams x B.	2	646.0	1.094	N.S	451.4	2.202	N.S	2	44.095	5.516	*
	Error	21	590.5			205.0			20	7.914		
	B3											
	Bet. fams	2	3764.6	7.472	**	2424.9	12.618	**	2	0.761	0.348	N.S
	Error	11	503.9			192.2			11	2.185		
11A	B1+B2+B3											
	Bet. B.	2	1686.0	2.32	N.S	1414.8	4.636	*	2	0.349	0.052	N.S
	Bet. fams	4	6476.7	8.917	***	4885.9	16.019	***	4	5.942	0.886	N.S
	Fams x B.	8	231.5	0.319	N.S	93.4	0.306	N.S	8	7.155	1.067	N.S
	Error	60	726.4			305.0			60	6.703		
	B1+B2											
	Bet. B.	1	307.5	0.357	N.S	158.4	0.514	N.S	1	0.650	0.096	N.S
	Bet fams	4	3612.9	4.198	**	2851.6	9.246	***	4	5.314	0.785	N.S
	Fams x B.	4	267.1	0.310	N.S	108.1	0.350	N.S	4	1.398	0.206	N.S
	Error	40	860.7			308.4			40	6.771		
	B3											
	Bet. fams	4	3059.6	6.684	**	2112.9	7.086	***	4	13.540	2.062	N.S
	Error	20	457.7			298.2			20	6.567		

Continued table E-31b.

DC	Source of variance	Plant height Df	M.S	F	P	Ear height M.S	F	P	Grain moisture Df	M.S	F	P
16A	B1+B2+B3											
	Bet. B.	2	1200.0	1.667	N.S	709.9	2.854	N.S	2	41.490	7.730	**
	Bet. fams	2	2958.0	4.110	*	2468.9	9.927	**	2	93.777	17.471	***
	Fams x B.	4	290.6	0.404	N.S	68.5	0.275	N.S	4	21.527	4.011	*
	Error	32/31*	719.7			248.7			23	5.368		
	B1+B2											
	Bet. B.	1	1206.5	1.452	N.S	58.7	0.257	N.S	1	1.139	0.180	N.S
	Bet. fams	2	1732.1	2.085	N.S	1733.6	7.603	**	2	17.217	2.721	N.S
	Fams x B.	2	550.2	0.662	N.S	132.6	0.581	N.S	2	0.553	0.087	N.S
	Error	21/20*	830.8			228.8			17	6.327		
	B3											
	Bet. fams	2	1256.8	2.475	N.S	739.6	2.583	N.S	2	119.208	44.985	***
	Error	11	507.8			286.3			6	2.650		
19A	B1+B2+B3											
	Bet. B.	2	326.6	0.552	N.S	734.3	3.156	N.S	2	18.268	2.553	N.S
	Bet. fams	4	1993.3	3.370	*	748.9	3.218	*	4	23.950	3.347	*
	Fams x B.	8	309.0	0.522	N.S	197.6	0.849	N.S	8	11.034	1.542	N.S
	Error	59	591.5			232.7			58	7.155		
	B1+B2											
	Bet. B.	1	28.9	0.045	N.S	264.5	1.131	N.S	1	3.472	0.597	N.S
	Bet. fams	4	1347.8	2.103	N.S	358.1	1.539	N.S	4	19.538	3.360	*
	Fams x B.	4	321.7	0.502	N.S	212.7	0.914	N.S	4	20.177	3.469	*
	Error	39	641.0			232.7			38	5.816		
	B3											
	Bet. fams	4	941.8	1.902	N.S	573.5	2.465	N.S	4	6.303	0.650	N.S
	Error	20	495.0			232.7			20	9.700		
25A	B1+B2+B3											
	Bet. B.	2	3724.8	8.657	**	1144.1	5.221	*	2	29.679	7.090	**
	Bet. fams	2	2315.5	5.381	**	256.2	1.669	N.S	2	0.430	0.103	N.S
	Fams x B.	4	1011.8	2.352	N.S	441.2	2.013	N.S	4	2.653	0.634	N.S
	Error	36	430.2			219.1			35	4.186		
	B1+B2											
	Bet. B.	1	4514.1	14.382	**	580.8	4.287	*	1	4.524	1.075	N.S
	Bet. fams	2	784.0	2.494	**	302.4	2.232	N.S	2	0.478	0.114	N.S
	Fams x B.	2	530.2	1.689	N.S	310.0	2.28	N.S	2	5.186	1.232	N.S
	Error	24	313.9			153.5			23	4.209		
	B3											
	Bet. fams	2	3024.5	4.562	*	526.1	1.361	N.S	2	0.073	0.018	N.S
	Error	12	663.0			386.5			12	4.142		

* The first number gives the degrees of freedom for plant height, the second for ear height.

Table E-32 Means of grain yield gm per plant, 100 kernel weight gm, and number of kernels per plant for the double crosses, and the S_1 and S_2 families in the two planting dates.

Double crosses					S_1 families					S_2 families				
DC	Grain yield B1+B2	B3	gm/100 K. B1+B2	B3	K No./P. B1+B2	B3	F	Grain yield B1+B2	B3	gm/100 K. B1+B2	B3	K.No./P. B1+B2	B3	F	Grain yield B1+B2	B3	gm/100 K. B1+B2	B3	K.No./P. B1+B2	B3
1	71.47	70.68	17.81	17.33	396	405	2	28.51	39.08	10.02	10.61	409	408	-	-	-	-	-	-	-
2A	85.79	81.40	20.80	18.42	413	444	1	33.06	33.30	24.22	24.27	172	148	-	-	-	-	-	-	-
2B	65.99	71.83	19.84	17.59	342	410	2	42.20	48.18	18.80	19.12	226	264	-	-	-	-	-	-	-
3A	70.40	58.59	18.97	14.78	391	410	3	31.85	34.51	12.61	11.71	282	300	-	-	-	-	-	-	-
4	57.23	75.70	17.75	16.13	325	474	1	40.88	45.99	15.14	16.26	303	302	9	29.51	40.71	14.08	14.91	209	285
-	-	-	-	-	-	-	4	64.93	54.38	24.28	20.89	264	257	2	31.83	33.96	14.00	12.36	220	276
-	-	-	-	-	-	-	5	30.88	25.05	13.40	14.12	269	190	9	28.19	18.69	14.40	12.18	205	178
5	72.57	65.36	18.65	14.64	400	452	5	34.29	25.65	16.11	12.69	214	220	-	-	-	-	-	-	-
6A	64.86	88.62	17.02	15.53	387	564	4	43.96	52.63	15.95	21.09	298	257	-	-	-	-	-	-	-
6B	64.38	53.20	19.85	18.07	330	279	4	45.51	45.25	15.72	14.83	277	302	-	-	-	-	-	-	-
7	68.34	102.38	17.87	16.08	399	636	4	36.21	35.37	16.89	14.70	233	244	-	-	-	-	-	-	-
8	53.12	58.86	18.16	14.80	299	408	5	35.65	36.84	20.93	21.10	270	175	-	-	-	-	-	-	-
9A2	75.92	83.16	15.98	12.99	474	638	2	53.40	56.23	20.14	17.82	241	322	1	35.12	34.20	9.84	11.40	360	300
-	-	-	-	-	-	-	3	38.50	37.66	13.06	12.46	303	302	2	18.62	21.10	12.07	8.73	158	241
-	-	-	-	-	-	-	5	32.08	60.09	13.11	19.00	259	272	4	17.84	21.78	12.10	12.84	157	191
10	85.62	87.53	19.06	17.04	479	529	3	33.66	32.27	14.83	11.99	238	298	-	-	-	-	-	-	-
11A	57.52	38.35	18.33	13.62	355	298	1	36.87	34.88	18.82	17.37	271	220	5	25.57	20.53	15.73	15.47	172	165
-	-	-	-	-	-	-	2	35.01	51.85	12.86	15.30	316	348	4	19.18	16.19	13.95	13.39	142	124
-	-	-	-	-	-	-	3	40.52	25.13	15.78	15.81	272	158	10	19.63	17.58	14.84	14.21	141	126
-	-	-	-	-	-	-	4	24.72	33.28	14.37	12.62	196	281	6	28.47	25.51	15.37	13.90	188	140
-	-	-	-	-	-	-	5	49.55	42.93	14.95	13.17	345	339	1	24.53	24.87	15.19	15.36	193	200
11B	79.09	72.63	17.37	12.92	456	611	3	57.55	42.72	13.11	13.10	455	325	-	-	-	-	-	-	-
12A	72.31	51.46	17.89	14.33	403	370	1	48.04	44.27	15.41	14.37	343	326	-	-	-	-	-	-	-
13	61.75	71.25	14.35	15.12	421	475	2	39.47	35.28	16.76	13.47	321	294	-	-	-	-	-	-	-
14	46.15	51.77	16.53	15.50	293	324	1	34.95	27.24	16.88	11.88	195	223	-	-	-	-	-	-	-
15	72.67	124.99	20.75	25.00	352	495	5	37.94	40.09	12.60	13.82	355	309	-	-	-	-	-	-	-
16A	75.90	44.45	15.90	14.50	523	333	1	25.18	40.94	13.97	12.31	190	345	4	15.58	15.53	10.70	8.63	144	184
-	-	-	-	-	-	-	3	32.63	12.48	10.52	15.85	384	78	7	26.43	17.50	13.57	9.62	190	182
-	-	-	-	-	-	-	5	19.46	39.78	13.62	11.93	161	334	6	20.93	32.81	11.50	10.95	187	305
16B	84.65	57.78	17.04	16.35	503	357	4	48.75	28.31	17.78	13.35	260	207	-	-	-	-	-	-	-
17	73.81	66.48	14.62	15.86	500	422	4	15.35	24.05	14.18	13.98	116	187	-	-	-	-	-	-	-
18	54.22	65.98	16.32	16.59	331	359	3	36.17	25.82	14.14	13.04	257	190	-	-	-	-	-	-	-
19A	79.37	50.95	12.16	10.81	687	513	1	40.81	57.08	13.56	13.57	302	406	2	25.71	32.65	13.45	13.92	205	220
-	-	-	-	-	-	-	2	40.35	53.98	13.55	14.76	292	377	4	14.22	19.54	12.12	10.97	127	197
-	-	-	-	-	-	-	3	39.92	39.22	14.32	12.71	289	400	10	31.95	25.46	12.01	11.44	270	217
-	-	-	-	-	-	-	4	39.34	36.25	14.63	15.52	287	254	7	27.75	34.77	12.52	11.95	223	264
-	-	-	-	-	-	-	5	40.53	19.70	10.85	10.61	383	214	1	26.15	32.11	10.76	12.66	250	261
20	72.02	55.77	15.18	13.18	511	402	2	25.33	20.37	12.06	12.09	216	205	-	-	-	-	-	-	-
21A	74.86	69.45	17.46	14.48	432	442	5	48.27	43.03	14.99	13.89	312	328	-	-	-	-	-	-	-
21B	69.13	62.88	19.35	17.19	360	369	4	49.70	53.84	14.96	14.23	334	395	-	-	-	-	-	-	-
22	83.19	64.07	16.53	19.09	504	340	4	38.17	32.32	15.09	13.96	267	240	-	-	-	-	-	-	-
23	61.08	48.48	20.58	14.90	306	341	1	29.85	25.03	17.93	15.07	181	178	-	-	-	-	-	-	-
24A	95.41	72.40	19.61	23.54	507	297	5	56.69	43.39	16.62	15.00	354	305	-	-	-	-	-	-	-
25A	97.94	60.78	18.97	17.42	524	357	1	28.85	30.25	13.05	14.29	235	207	9	19.50	17.52	13.18	13.43	164	131
-	-	-	-	-	-	-	3	60.46	44.75	14.67	15.85	417	284	5	20.83	21.97	14.45	13.90	146	159
-	-	-	-	-	-	-	4	43.60	27.42	16.59	13.65	264	196	3	36.25	22.49	13.40	12.30	347	281
25B	68.76	54.79	29.63	26.99	194	196	2	30.74	19.14	16.62	12.65	193	142	-	-	-	-	-	-	-
26A	67.75	53.92	22.83	20.67	257	305	3	41.03	46.48	15.07	14.52	278	331	-	-	-	-	-	-	-

Table E-33. The ANOVA for number of kernels per plant,grain yield per plant, and 100 kernel weight for the double crosses, the S_1, and the S_2 families.

Gen	Source of variance	Df	Grain yield gm per plant M.S	F	P	100 kernels weight/ gm M.S	F	P	No of kernels per plant M.S	F	P
DC	B1+B2+B3										
	Bet. B.	2	6862.3	9.169	***	150.66	14.581	***	64581	2.010	N.S
	Bet. D.C.	31	1672.2	2.234	***	132.53	12.827	***	107951	3.360	**
	D.C. x B.	62	990.7	1.324	N.S	12.25	1.186	N.S	21285	1.285	N.S
	Error	383	865.3			10.33			32131		
	B1+B2										
	Bet. B.	1	11342.7	14.266	***	20.499	2.093	N.S	126166	3.909	*
	Bet. D.C.	31	1357.2	1.707	**	89.960	9.183	***	97012	3.005	**
	D.C. x B.	31	750.4	0.994	N.S	7.060	0.721	N.S	33874	1.049	N.S
	Error	255	795.1			9.796			32279		
	B3										
	Bet. D.C.	31	1546.0	2.358	**	60.01	5.264	***	59635	1.873	**
	Error	128	655.5			11.40			31838		
S_1	B1+B2+B3										
	Bet. B.	2	2626.6	8.316	***	30.16	1.846	N.S	172789	9.789	***
	Bet. fams	47	1199.4	3.798	***	111.16	6.806	***	68019	3.854	**
	Fams x B.	94	472.6	1.496	**	12.07	0.739	N.S	32108	1.819	**
	Error	556	315.8			16.33			17651		
	B1+B2										
	Bet. B.	1	3300.7	9.430	***	1.61	0.099	N.S	323695	16.627	***
	Bet. fams	47	1036.1	2.690	***	86.89	5.352	***	62497	3.210	***
	Fams x B.	47	419.7	1.199	N.S	6.89	0.424	N.S	33074	1.699	*
	Error	368	350.0			16.24			19468		
	B3										
	Bet. fams	47	687.1	2.760	***	41.51	2.512	***	36555	2.593	**
	Error	188	248.9			16.52			14096		
S_2	B1+B2+B3										
	Bet. B.	2	1.80	0.017	N.S	25.86	2.385	N.S	13967	2.142	***
	Bet. fams	21	476.50	4.472	***	37.69	3.475	***	42893	6.579	**
	Fams x B.	42	144.60	1.357	N.S	8.51	0.784	N.S	15650	2.400	**
	Error	243	106.5			10.85			6520		
	B1+B2										
	Bet. B.	1	3.40	0.035	N.S	15.369	1.586	N.S	22268	3.632	N.S
	Bet. fams	21	342.94	3.535	***	25.589	2.640	***	35941	5.862	**
	Fams x B.	21	124.77	1.286	N.S	10.445	1.078	N.S	20265	3.305	**
	Error	162	97.01			9.692			6131		
	B3										
	Bet. fams	21	297.9	2.371	***	18.69	1.417	N.S	17991	2.464	**
	Error	81	125.6			13.18			1301		

Table E-34a. The ANOVA for number of kernels per plant, grain yield per plant, and 100 kernel weight for the S_1 families derived from the same double cross.

DC	Source of variane	Df	Grain yield gm per plant M.S	F	P	100 kernels weight/ gm M.S	F	P	No of kernels per plant M.S	F	P
4	B1+B2+B3										
	Bet. B.	2	1147.7	3.333	*	2.06	0.085	N.S	16204	1.767	N.S
	Bet. fams	2	3988.2	11.583	***	380.69	15.677	***	1813	1.997	N.S
	Fams x B.	4	242.2	0.706	N.S	10.45	0.430	N.S	6319	0.689	N.S
	Error	36	344.3			24.28			9171		
	B1+B2										
	Bet. B.	1	2154.3	7.107	**	1.41	0.068	N.S	8300	1.079	N.S
	Bet. fams	2	3062.1	10.102	**	341.79	16.423	***	4564	0.593	N.S
	Fams x B.	2	271.5	0.896	N.S	0.05	0.002	N.S	6823	0.887	N.S
	Error	24	303.1			20.81			7693		
	B3										
	Bet. fams	2	1141.0	2.674	N.S	59.75	1.913	N.S	19565	1613	N.S
	Error	12	426.8			31.23			12128		
9A2	B1+B2+B3										
	Bet. B.	2	425.5	1.073	N.S	6.09	0.272	N.S	96660	5.076	*
	Bet. fams	2	276.6	0.698	N.S	164.43	7.337	***	104763	5.501	**
	Fams x B.	4	1320.4	3.330	*	34.27	1.529	N.S	61247	3.219	*
	Error	35	396.5			22.41			19043		
	B1+B2										
	Bet. B.	1	796.7	1.743	N.S	2.30	0.107	N.S	146580	5.680	*
	Bet. fams	2	1196.0	2.616	N.S	166.23	7.745	***	172599	6.688	**
	Fams x B.	2	27.7	0.061	N.S	5.95	0.277	N.S	48128	1.865	N.S
	Error	23	457.2			21.49			25806		
	B3										
	Bet. fams	2	1693.7	6.044	*	60.78	2.509	N.S	6530	1.184	N.S
	Error	12	280.2			24.23			5516		
11A	B1+B2+B3										
	Bet. B.	2	28.0	0.097	N.S	6.33	0.407	N.S	4201	0.238	N.S
	Bet. fams	4	856.1	2.955	*	57.17	3.679	*	62901	3.558	*
	Fams x B.	8	505.1	1.744	N.S	8.85	0.570	N.S	31002	1.754	N.S
	Error	60	289.7			18.31			17697		
	B1+B2										
	Bet. B.	1	6.6	0.018	N.S	8.46	0.462	N.S	5897	0.264	N.S
	Bet. fams	4	810.2	2.202	N.S	48.92	2.67	*	31685	1.419	N.S
	Fams x B.	4	371.4	1.009	N.S	6.84	0.373	N.S	35834	1.605	N.S
	Error	40	368.0			18.31			22332		
	B3										
	Bet. fams	4	684.7	5.146	**	19.114	1.912	N.S	57386	6.853	***
	Error	20	133.1			9.999			8374		

Continued table E-34a.

DC	Source of variane	Df	Grain yield gm per plant M.S	F	P	100 kernels weight/ gm M.S	F	P	No of kernels per plant M.S	F	P
16A	B1+B2+B3										
	Bet. B.	2	679.0	2.145	N.S	6.11	0.526	N.S	60436	3.525	*
	Bet. fams	2	103.3	0.326	N.S	5.03	0.433	N.S	5890	0.343	N.S
	Fams x B.	4	2053.6	6.488	***	29.34	2.523	N.S	249849	14.569	***
	Error	20	316.5			11.63			17149		
	B1+B2										
	Bet. B.	1	1088.9	4.804		7.61	0.447	N.S	117303	10.483	**
	Bet. fams	2	453.7	2.001	N.S	36.28	2.130	N.S	102204	9.134	**
	Fams x B.	2	2398.6	10.578	**	4.02	0.236	N.S	288321	25.767	***
	Error	12	226.8			17.03			11190		
	B3										
	Bet. fams	2	1320.4	2.926	N.S	23.119	6.583	*	112572	4.314	N.S
	Error	8	451.3			3.512			26096		
19A	B1+B2+B3										
	Bet. B.	2	387.7	1.072	N.S	2.977	0.549	N.S	47976	2.225	N.S
	Bet. fams	4	395.2	1.093	N.S	36.510	6.732	***	8453	0.392	N.S
	Fams x B.	8	492.7	1.362	N.S	3.485	0.643	N.S	38780	1.799	N.S
	Error	60	361.7			5.424			21562		
	B1+B2										
	Bet. B.	1	756.8	2.081	N.S	5.910	0.943	N.S	89549	3.582	N.S
	Bet. fams	4	3.3	0.009	N.S	22.295	3.558	*	16801	0.672	N.S
	Fams x B.	4	244.6	0.673	N.S	2.899	0.463	N.S	289500	1.156	N.S
	Error	40	363.7			6.265			24999		
	B3										
	Bet. fams	4	1132.7	3.166	*	18.285	4.889	**	40262	2.742	N.S
	Error	20	357.7			3.740			14686		
25A	B1+B2+B3										
	Bet. B.	2	547.1	1.786	N.S	0.32	0.030	N.S	34584	2.154	N.S
	Bet. fams	2	2599.5	8.485	***	18.65	1.778	N.S	98171	6.114	**
	Fams x B.	4	266.8	0.871	N.S	10.14	0.968	N.S	5822	0.363	N.S
	Error	35	306.4			10.47			16056		
	B1+B2										
	Bet. B.	1	61.0	0.164	N.S	0.34	0.030	N.S	11078	0.498	N.S
	Bet. fams	2	2502.0	6.733	**	31.29	2.715	N.S	96174	4.323	*
	Fams x B.	2	198.9	0.535	N.S	1.23	0.107	N.S	2168	0.097	N.S
	Error	23	371.6			11.52			22248		
	B3										
	Bet. fams	2	432.0	2.383	N.S	6.387	0.755	N.S	11473	2.738	N.S
	Error	12	181.3			8.463			4191		

Table E-34b. The ANOVA for number of kernels per plant, grain yield per plant, and 100 kernel weight for the S_2 families derived from the same double cross.

DC	Source of variane	Df	Grain yield gm per plant M.S	F	P	100 kernels weight/ gm M.S	F	P	No ofkernels per plant M.S	F	p
4	B1+B2+B3										
	Bet. B.	2	13.2	0.076	N.S	5.445	1.053		5028	0.522	N.S
	Bet. fams	2	311.5	1.788	N.S	3.319	0.641	N.S	9070	0.942	N.S
	Fams x B.	4	289.1	1.659	N.S	5.465	1.056	N.S	7331	0.761	N.S
	Error	36	174.2			5.174			9627		
	B1+B2										
	Bet. B.	1	10.2	0.059	N.S	0.696	0.140	N.S	8	0.001	N.S
	Bet. fams	2	34.0	0.195	N.S	0.447	0.090	N.S	532	0.074	N.S
	Fams x B.	2	219.0	1.256	N.S	2.172	0.437	N.S	2576	0.357	N.S
	Error	24	174.3			4.967			7208		
	B3										
	Bet. fams	2	636.6	3.658	N.S	11.6312082		N.S	20623	1.426	N.S
	Error	12	1740			5.582			14466		
9A2	B1+B2+B3										
	Bet. B.	2	166.32	2.088	N.S	6.590	0.703	N.S	35783	3.573	*
	Bet. fams	2	741.88	9.315	***	26.010	2.773	N.S	169237	16.899	***
	Fams x B.	4	230.67	2.896	*	20.765	2.214	N.S	66551	6.645	**
	Error	31	79.64			9.379			10015		
	B1+B2										
	Bet. B.	1	210.50	2.700	N.S	9.412	1.101	N.S	70806	6.036	***
	Bet. fams	2	472.48	6.060	**	24.955	2.920	N.S	180890	15.419	***
	Fams x B.	2	458.71	5.885	*	20.805	2.435	N.S	106919	9.080	**
	Error	20	77.97			8.545			11731		
	B3										
	Bet. fams	2	271.94	3.289	N.S	21.78	1.999	N.S	14931	2.166	N.S
	Error	11	82.69			10.89			6893		
11A	B1+B2+B3										
	Bet. B.	2	222.80	2.365	N.S	7.62	0.327	N.S	1690	0.340	N.S
	Bet. fams	4	219.69	2.332	N.S	7.55	0.324	N.S	15130	3.044	*
	Fams x B.	8	55.13	0.585	N.S	4.38	0.188	N.S	6646	1.337	N.S
	Error	60	94.20			23.32			4970		
	B1+B2										
	Bet. B.	1	102.1	1.004	N.S	4.58	0.223	N.S	899	0.223	N.S
	Bet. fams	4	159.2	1.566	N.S	4.58	0.223	N.S	6054	1.501	N.S
	Fams x B.	4	63.8	0.628	N.S	7.56	0.368	N.S	8672	2.150	N.S
	Error	40	101.7			20.52			4034		
	B3										
	Bet. fams	4	106.8	1.349	N.S	4.18	0.145	N.S	13698	2.002	N.S
	Error	20	79.20			28.93			6842		

Continued table E-34b.

DC	Source of variane	Df	Grain yield gm per plant M.S	F	P	100 kernels weight/ gm M.S	F	P	No of kernels per plant M.S	F	P
16A	B1+B2+B3										
	Bet. B.	2	9.51	0.162	N.S	25.642	6.138	**	15353	3.432	*
	Bet. fams	2	378.00	6.442	***	19.401	4.644	*	17933	4.009	*
	Fams x B.	4	197.57	3.367	*	12.578	3.011	*	7299	1.632	N.S
	Error	23	58.68			4.177			4473		
	B1+B2										
	Bet. B.	1	9.56	0.146	N.S	2.711	0.680	N.S	6193	1.357	N.S
	Bet. fams	2	294.14	4.482	*	21.931	5.513	*	6441	1.411	N.S
	Fams x B.	2	31.73	0.483	N.S	15.478	3.891	*	1275	0.297	N.S
	Error	17	65.63			3.978			4564		
	B3										
	Bet. fams	2	447.72	11.482	**	7.453	1.536	N.S	24817	5.884	*
	Error	6	38.99			4.855			4218		
19A	B1+B2+B3										
	Bet. B.	2	119.2	0.892	N.S	2.935	0.417	N.S	4094	0.738	N.S
	Bet. fams	4	521.4	3.899	**	11.201	1.592	N.S	28771	5.188	**
	Fams x B.	8	96.8	0.724	N.S	4.889	0.695	N.S	7783	1.403	N.S
	Error	58	133.7			7.034			5546		
	B1+B2										
	Bet. B.	1	4.09	0.050	N.S	5.867	1.089	N.S	751	0.162	N.S
	Bet. fams	4	434.48	5.320	***	9.397	1.744	N.S	30435	6.585	**
	Fams x B.	4	82.66	1.021	N.S	4.942	0.917	N.S	7561	1.636	N.S
	Error	38	81.67			5.389			4622		
	B3										
	Bet. fams	4	197.8	0.850	N.S	6.64	0.653	N.S	6341	0.869	N.S
	Error	20	232.7			10.16			7300		
25A	B1+B2+B3										
	Bet. B.	2	137.83	2.016	N.S	3.449	0.486	N.S	10357	1.770	N.S
	Bet. fams	2	698.07	10.212	***	6.433	0.906	N.S	4663	7.887	**
	Fams x B.	4	163.67	2.394	N.S	19.329	2.723	N.S	25081	4.285	**
	Error	35	68.35			7.098			5853		
	B1+B2										
	Bet. B.	1	38.91	0.531	N.S	4.742	0.584	N.S	4278	0.575	N.S
	Bet. fams	2	866.39	11.817	***	4.597	0.566	N.S	53470	7.190	**
	Fams x B.	2	121.61	1.659	N.S	37.119	4.574	*	39617	5.327	*
	Error	23	73.32			8.116			7440		
	B3										
	Bet. fams	2	37.42	0.636	N.S	3.375	0.656	N.S	3237	1.149	N.S
	Error	12	58.84			5.147			2818		

Table E-35a. Summary of the ANOVA results of the double crosses, S_1, and S_2 families for PH cm, EH cm, grain moisture, grain yield, number of kernels and 100 kernels weight gm.

Gen and D.C.	Source of Var.	PH cm			EH cm			% H2O			K. No./ p			Grain gm / p			gm / 100 K.		
		3*	2*	1*	3	2	1	3	2	1	3	2	1	3	2	1	3	2	1
D.C.	B	***	***	-	**	**	-	***	N.S	-	N.S	*	-	***	***	-	***	N.S	-
	F	N.S	N.S	N.S	**	**	N.S	*	*	N.S	**	**	**	***	***	**	***	***	***
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-
S_1	B	***	***	-	***	***	-	***	N.S	-	***	**	-	***	***	-	N.S	N.S	-
	F	***	***	***	**	***	***	*	**	**	**	***	***	***	***	***	***	***	***
	F x B	***	N.S	-	N.S	N.S	-	N.S	N.S	-	**	*	-	**	N.S	-	N.S	N.S	-
S_2	B	**	*	-	***	N.S	-	***	N.S	-	***	N.S	-	N.S	N.S	-	N.S	N.S	-
	F	**	**	**	**	**	**	**	**	***	**	**	***	***	***	***	***	***	N.S
	F x B	N.S	N.S	-	N.S	N.S	-	**	*	-	***	**	_	N.S	N.S	-	N.S	N.S	-

3*, 2*, and 1* are the ANOVA results for B1+B2+B3, B1+B2, and B3 respectively.

Table E-35b. Summary of the ANOVA results of S_1 and S_2 families which derived from each of the double crosses 4, 9A2, 11A, 16A, 19A2, and 25A for PH cm, EH cm, grain moisture, grain yield, number of kernels and 100 kernels weight gm.

Gen and D.C.	Source of Var.	PH cm			EH cm			% H2O			K. No./ p			Grain gm / p			gm / 100 K.
		3*	2*	1*	3	2	1	3	2	1	3	2	1	3	2	1	
4 S_1	B	N.S	N.S	-	*	*	-	N.S	N.S	-	N.S	N.S	-	*	**	-	N.S N.S -
	F	N.S	*	N.S	*	**	N.S	N.S	N.S	N.S	N.S	N.S	N.S	***	**	N.S	*** *** N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
S_2	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
	F	N.S	N.S	N.S	*	N.S	*	N.S	*	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S N.S N.S
	F x B	N.S	N.S	-	N.S	N.S	-	*	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
9A S_1	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	*	*	-	N.S	N.S	-	N.S N.S -
	F	*	N.S	N.S	**	*	**	N.S	N.S	N.S	**	**	N.S	N.S	N.S	*	*** *** N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	*	N.S	-	* N.S -
S_2	B	*	*	-	N.S	*	-	N.S	N.S	-	*	***	-	N.S	N.S	-	N.S N.S -
	F	**	*	**	**	*	**	N.S	N.S	N.S	***	***	N.S	***	**	N.S	N.S N.S N.S
	F x B	N.S	N.S	-	N.S	N.S	-	*	*	-	**	**	-	*	*	-	N.S N.S -
11A S_1	B	*	**	-	*	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
	F	**	**	N.S	N.S	N.S	N.S	N.S	N.S	N.S	*	N.S	***	*	N.S	**	* * N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
S_2	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
	F	***	**	**	***	***	***	N.S	N.S	N.S	*	N.S	N.S	N.S	N.S	N.S	N.S N.S N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
16A S_1	B	N.S	N.S	-	*	N.S	-	N.S	N.S	-	*	**	-	N.S	8	-	N.S N.S -
	F	*	N.S	***	**	N.S	**	*	*	*	N.S	**	N.S	N.S	N.S	N.S	N.S N.S *
	F x B	N.S	N.S	-	**	N.S	-	**	N.S	-	***	***	-	**	**	-	N.S N.S -
S_2	B	N.S	N.S	-	N.S	N.S	-	**	N.S	-	*	N.S	-	N.S	N.S	-	** N.S -
	F	*	N.S	N.S	**	**	N.S	***	N.S	***	*	N.S	8	**	*	**	* * N.S
	F x B	N.S	N.S	-	N.S	N.S	-	*	N.S	-	N.S	N.S	-	*	N.S	-	* * -
19A S_1	B	**	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
	F	**	**	*	**	**	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	*	*** * **
	F x B	*	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
S_2	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
	F	*	N.S	N.S	*	N.S	N.S	*	*	N.S	**	**	N.S	**	***	N.S	N.S N.S N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	*	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
25A S_1	B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
	F	N.S	N.S	N.S	N.S	N.S	N.S	***	**	*	**	*	N.S	***	**	N.S	N.S N.S N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
S_2	B	**	**	-	*	N.S	-	**	N.S	-	N.S	N.S	-	N.S	N.S	-	N.S N.S -
	F	**	**	*	N.S	N.S	N.S	N.S	N.S	N.S	**	**	N.S	***	***	N.S	N.S N.S N.S
	F x B	N.S	N.S	-	N.S	N.S	-	N.S	N.S	-	**	*	-	N.S	N.S	-	N.S N.S -

3*, 2*, and 1* are the ANOVA results for B1+B2+B3, B1+B2, and B3 respectively.

Estimates of the Genetic Components of Variance, Heritability, Selection Differentials, and Expected Gain From Selection:

Genetic Components of Variance.

Table (E-37) gives the variance component estimates for genotypic variance $\hat{\sigma}^2 F$, genotypes x environment interaction variance $\hat{\sigma}^2 F \times B$, and error variance $\hat{\sigma}^2$. All of these variance components were calculated from the mean squares obtained from the analysis of variance of block 1 and block 2 based on the results of Gilmore-Rogers heat-unit degrees required for flowering and maturity stages, as was described earlier in this chapter (method of genetic analysis). The estimated mean squares indicate that there is high genotypic variability among the S_1 and S_2 families for most traits studied in this experiment (see results of the ANOVA for all traits for the S_1 and the S_2 families), except for the number of seedlings emerging for S_1 families. Also there was no significant genotype x environment interaction for S_1 families , except for the time from silking to maturity and number of kernels. While for S_2 families there were five cases of significant family x blocks interaction; those cases were for SDW at 1 %, for 65 stage , for maturity, for grain moisture content, and for number of kernels, the last four cases being significant at the 5 % level. These significant interactions seem have no magnitude relative to the high genotypic variance for most of traits studied (table E-37). This result confirms that the differences between families were the primary source of the variability observed in this experiment, and there was also high genotypic variation among the S_1 and S_2 families. According to Hallauer and Miranda (1988 P 32) the genotypic variance among S_1 families will be equal to all the additive genetic effects plus 1/4 of the dominance effects ($\hat{\sigma}^2 f = \sigma^2 A + 1/4\, \hat{\sigma}^2 D$), and will equal all the additive genetic effects in the absence of dominance. They also demonstrated that the genetic variance among the S_2 families (after two generations of selfing)is 3/2 the additive genetic effects ($\hat{\sigma}^2 F = 3/2\, \hat{\sigma}^2 A$ in the absence of the dominance or $\hat{\sigma}^2 F = (3/2)\, \hat{\sigma}^2 A + (3/16)\, \hat{\sigma}^2 D$ (where A and D are the additive and dominance effects). As

our results showed no genotype x environment interaction, thus most of genetic variation observed would be mainly due to the additive effects for most of the traits studied. In both generations for the flowering and maturity stages and emergence rate and seedling dry weight the heritability, which will be described later, was high. While for the yield components and the moisture percentage it is expected that the additive and the dominance effects both are important, there were some important interactions (for number of kernels and seed moisture percentage; see table (E-36)) and less genotypic variance observed compared with the other characters. Gamble (1961) and Robinson and Comstock (1955) also reported dominance gene effects were important on maize yield. Maryam's study (1981) on the reference population of this material also indicated the importance of the dominance effects for the yield components. Overall it appears that the additive genetic effects still dominate the genetic variation for the important characters. Thus the S_1 and S_2 recurrent selection is an effective breeding procedure for any improvement in this population.

The low interaction component of variance also means that the evaluation under this environment was effective in distinguishing those families with the desired means for the important characters and there were no genotype x block interactions. The error variances were relatively large when compared with the genotypic variance. This point needs to be taken into consideration because it will have a slowing effect on the gain from selection although it can be reduced by evaluating the next cycle of selection in more than one location and with more replications.

There were a few negative estimates for the interaction, but all were not much smaller than zero. When compared with the other components of variance this effectively means that there was zero interaction. Although variance components are, by definition, positive, the negative values may be a result of the competition among the double crosses, the S_1, and the S_2 plants due to the differences in the vigour. Despite that, Hallauer and Miranda (1988, p 46) reported that estimates obtained by the analysis of variance can be negative. They also referred to Searle (1971) who gives some suggestions on how to overcome this anomaly. In maize, it seems, negative

estimates may be due to an inadequate model (genetic designs to estimate epistatic variance), inadequate sampling (small numbers), and inadequate experimental techniques (competition among progenies).

Heritability Estimates.

Estimates for the heritability (h^2) (narrow sense heritability) for all traits studied were calculated (table E-37) based on the genetic variance component estimates using the formulae described in this chapter (method of genetic analysis).

The heritability estimates in table E-37 indicated very high values for the S_1 families compared with the S_2 families, except for the number of seedlings emerged and the vigour scale. Here there were higher heritabilities in S_2 generation. For grain moisture there was a very low heritability estimate in the S_2 generation.

All flowering, maturity and yield components indicate a relatively consistent heritability in the two generations.

Among the cold tolerance traits, emergence rate has the highest heritability in both generations followed by the seedling dry weight. This indicated that the visual selection for both traits will be more effective for any improvement for early emergence under cold conditions. Many researchers have reported that there were high heritabilites for the emergence rate and the SDW and they stated that the visual selection of both traits was effective to improve the cold tolerance in many maize populations (Russelland Tiech, 1967; Russelland Machada, 1978; Hexum , 1984).

All flowering stages and time to maturity showed higher heritabilities compared with the other characters, with superiority of the silking and maturity stage in both generations. That also would make the selection for early silking or early maturity effective.

A smaller range of heritabilies was found for the yield components than for the flowering and maturity stages. The number of kernels per plant and the grain yield were more heritable than the other yield components characters and they were more consistent throughout the two generations.

Heritability is usually defined as the proportion of the total variance that is attributed to the average effect of genes. So the high heritability for most of the traits studied would reflect the fact that most of the variation observed among S_1 and S_2 families can be attributed to genetic variation, This also means that this population has a high breeding value for any further selection, and the best breeding value was obtained in S_1 generation.

Selection Differentials and Expected Gain from Selection.

As the bases of selection for early maturity, we chose the first ten S_1 families to mature among the 48 S_1 families used in this experiment of field evaluation (20.8 % selection intensity). The first five S_2 families to mature were selected from the 22 S_2 families used in this study (22.7 % selection intensity). All of these S_1 and S_2 families, with their means for the heat-unit degrees in Gilmore-Rogers and Ontario methods and in the calender days required to maturity are listed in table E-36.

The selection differentials for all traits studied, and for all the selected families were calculated. They are shown together with the grand means of all S_1 and S_2 families and means of the selected families in table E-39.

Selection for early maturity would mean fewer heat-unit degrees were required to achieve maturity. Thus negative selection differentials were expected for maturity and flowering stages.

From table E-39 it was found that the selection differentials for maturity was -11.62 heat-unit degrees for S_1 families and -19.79 heat-unit degrees for S_2 families. Based on these estimates the selection differentials for the other characters were estimated for the same selected families. It was found that there were slight positive effects for this selection on the cold tolerance traits (slight increase in the number of seedlings emerged and slight decrease in ER and the vigour scale), with no change in the SDW for S_1 and some increase in S_2. It was also found that selection would lead to negative selection differentials in the heat-unit degrees required to the flowering

stages (boots, 65 stage of the male flowering, and silking), but on the other hand this selection was accompanied by lengthening of the time from silking to maturity in both the S_1 and S_2 generation.

Negative differentials were also obtained for the grain moisture content and plant height, and positive differentials were found for the number of kernels and grain yield per plant (see table E-39 for the values of these differentials).

The only inconsistency between the two generations was for ear height (cm) and 100-kernel weight (gm), when both gave a negative differential in S_1 generation and positive in S_2. This result indicated that the early maturity was accompanied by improvement in all of the important characters, except for the period from silking to maturity where there was a delay in this period. This is not desirable in short season areas, but is acceptable in long season areas, and also it could give negative effect on the gain expected for maturity.

The expected gain from one cycle at this selection intensity was calculated for each character using the formula described earlier in this chapter (method of genetic analysis). The results obtained are listed in table E-37. Positive gain will mean less heat unit degrees to reach each stage. This expected gain was counted, assuming that the selected S_1 or S_2 families will be recombined (crossed) to initiate a cycle of a recurrent selection in two years. Recurrent selection has been recommended by many researchers for more benefit from S_1 and S_2 selection which capitalize the additive genetic effect for the improvement characters than Continuous inbreeding (Grogan, 1970; Mock and Eberhart, 1972; Mock and Bakri, 1976; McConnell and gardner, 1979a; Eberhart, 1970; Heard and Crosbie, 1985, Hallauer and Miranda, 1988).

From the results of the estimated gains following selection (table E-37), it was found that there should be a reduction of 5.45, and 5.03 in the heat units degrees from sowing to maturity in S_1 and S_2 generations respectively. This gain was reduced by the elongation of the stage from silking to maturity. This means that after one cycle of selection maturity should be reached 1 to 2 days earlier than in the double crosses.

The estimates was based on the grand means of the heat-unit degrees accumulated per day for the season in which this experiment was carried out.

Based on this selection for early maturity the expected gain in the other characters were calculated for the same families. There will be an expected increase in the time from silking to maturity in both generations. The combination will lead to more heterogenisity (crosses), so this change in this period was expected. In the results of this experiment that were discused earlier in the results of the yield components we noted that the time taken from silking to maturity by the double crosses was longer than that taken by the S_1 and S_2 respectively, and it was also found that, in general, the S_1 families required more time from silking to maturity than that required by the S_2 families (table E-39). Similar results were found by Hallauer and Russell(1962) when they studied the inheritance of maturity in maize. They found that S_1 and S_2 families required fewer days from silking to maturity than required by the crosses from which they were derived.This suggests that selection is unlikely to be effective for the development of lines with a shortened interval between silking to maturity from the material used in this particular programme.

The results also indicate that the time to silking, tasselling and boots will be improved by 13.73, 10.85 and 11.08 heat-unit degrees in S_1 families and by 10.99, 8.79 and 9.40 in the S_2 families respectively.

There will be also some gain in the cold tolerance traits from this selection in both generations, and in the number of kernels and grain yield per plant. There will be little change in the moisture content and the 100-kernel weight.

Some decrease in plant height is expected in both generation while ear height is expected to increase following the selection of S_1, but decrease again following selection of the S_2.

Table E-36 The means of the number of days and the HUD (Gilmore-Rogers and Ontario) required to reach maturity for the selected S_1 and S_2 families.

No	Families	days	HUD Rog	HUD Ont
S1*				
1	3-26A	149.0	698.6	2364.1
2	4-4	151.7	702.3	2386.0
3	3-18	152.6	704.2	2391.9
4	2-13	152.9	704.3	2391.9
5	2-9A2	153.5	706.1	2400.3
6	1-12A	153.8	706.9	2400.7
7	4-21B	154.6	708.7	2409.9
8	3-19A2	155.2	709.2	2412.9
9	4-19A2	155.8	710.5	2418.7
10	4-25A	156.8	712.2	2425.9
S_2*				
1	10-3-19A2	153.1	705.4	2403.6
2	2-4-4	155.5	708.3	2412.8
3	3-4-25A	155.2	710.7	2412.1
4	7-4-19A2	156.0	710.5	2420.3
5	1-2-9A2	159.0	714.8	2436.1

* Listed in rank order with the earliest family first.

Table E-37. Estimates of the genetic components of variance for genotype or families (σ^2 F),families x blocks (σ^2 F x B), and error (σ^2) for S_1 and S_2 families for all traits studied.

	S_1 families			S_2 families		
Traits	σ^2 F	σ^2 F x B	σ^2	σ^2 F	σ^2 F x B	σ^2
Cold toleranc						
Emergence	0.159	-	0.743	2.952	-	3.308
Emergence rate	0.439	-	0.103	1.050	-	0.146
Seedling dry W.	0.001	0.0002	0.004	0.001	0.0004	0.001
1-5 vigour scale	0.044	0.0020	0.5304	0.120	-0.0096	0.461
Flowering & maturity*						
Boots	380.700	-16.600	1547.000	687.700	201.200	1620.000
65 stage	312.260	-0.180	851.200	568.300	164.800	1006.000
Silking stage	526.900	12.600	1347.000	796.700	50.800	1219.000
Silking to Matturity	213.260	88.540	818.500	302.850	3.720	867.900
Maturity	83.620	-8.360	229.100	160.300	22.700	174.900
Agronomic traits						
Plant height cm	173.440	21.220	571.700	149.980	9.560	662.700
Ear height cm	93.510	5.080	249.300	117.270	0.840	235.700
Grain moisture %	1.083	-0.129	4.393	0.453	0.870	5.823
Kernels number / p	4302.900	2721.200	19468.000	2981.000	2826.800	6131.000
Grain weight gm/ p	68.610	13.940	350.002.	24.593	5.552	97.010
gm for 100 kernels	7.065	1.870	16.240	1.589	0.151	9.692

* Estimates were based on the results obtained from Gilmore and Rogers HUD.

Table E-38. Heritability estimates for all the traits studied and the expected genetic gain from the selection of the earliest 10 S_1 families to mature and from the earliest 5 S_2 families to mature.

	S_1 families		S_2 families	
Trait	exp.Gain	h^2	exp.gain	h^2
Cold tolerance				
Emergence	+0.147	29.97	+0.583	42.77
Emergence rate	-0.422	89.50	-0.420	62.23
Seedling dry W.	+0.017	66.66	+0.012	51.28
1-5 vigour scale	-0.094	44.87	-0.124	48.16
Flowering & maturity				
Boots	-11.08	71.11	-9.46	48.24
65 stage	-10.85	78.57	-8.79	50.45
Silking stage	-13.73	78.88	-10.99	56.26
Silking to maturity	+7.79	62.83	+6.49	51.57
Maturity	-5.45	78.49	-4.94	56.50
Agronomic trait				
Plant height cm	-7.52	71.90	-4.31	46.07
Ear height cm	+5.75	77.29	-4.18	55.34
Grain moisture %	-0.59	71.11	-0.16	20.54
Kernels number /p	+33.22	56.54	+17.86	39.68
Grain weight gm p	+4.39	62.20	+1.71	44.22
gm for 100 kernels	+1.61	81.30	0.42	40.22

Table E-39. Grand means of the S_1 and the S_2 families for the diffrent characters and the grand means for the earliest 10 S_1 families and the earliest 5 S_2 families to mature, with the selection differentials(D).

	S_1 fams means			S_2 fams means		
Traits	48 fams	10 fams	D	22 fams	5 fams	D
Cold tolerance						
Emergence	14.100	14.340	+0.240	12.020	13.700	+1.680
Emergence rate	12.090	11.890	-0.200	13.200	12.730	-0.470
Seedling dry W.	0.243	0.243	-0.000	0.139	0.174	+0.035
1-5 vigour scale	2.536	2.370	-0.166	3.010	2.690	-0.320
Flowering & mat.*						
Boots	328.000	309.230	-18.770	357.800	326.800	-31.000
65 stage	460.600	443.810	-16.790	492.300	460.080	-32.220
Silking stage	457.500	436.760	-20.740	490.900	453.380	-37.520
Silking to Mat.	260.600	273.260	+12.660	239.200	256.720	+17.520
Maturity**	717.920	706.300	-11.620	729.740	709.950	-19.790
Maturity days	159.940	153.590	-6.350	165.830	155.760	10.070
Agronomic traits						
Plant height cm	130.900	129.890	-1.010	118.300	115.840	-2.460
Ear height cm	57.210	59.410	+2.200	54.600	54.400	-0.200
Grain moisture %	32.830	31.770	-1.060	33.300	32.300	-1.000
Kernels number / p	264.410	278.800	+14.390	198.900	270.600	+71.700
Grain weight gm/ p	38.770	45.560	+6.790	24.490	32.580	+8.090
gm for 100 kernels	15.120	16.630	+1.510	13.180	12.350	-0.830

* Estimates were based on the results obtained from Gilmore and Rogers HUD.
** Grand means of maturity for the double crosses were 156.4 days and 711.6

PART TWO

THE USE OF THE NORTH CAROLINA MATING DESIGN FOR THE DEVELOPMENT OF COLD TOLERANCE AND EARLY MATURING MAIZE HYBRIDS FROM BRITISH AND USA INBRED LINES.

CHAPTER SIX

THE NORTH CAROLINA DESIGN: PROCEDURE FOR THE DEVELOPMENT OF THE SINGLE CROSSES AND THE STUDY OF THE GERMINATION, EMERGENCE AND SEEDLING GROWTH OF THE PARENTS AND THEIR RECIPROCAL F_1S AT LOW TEMPERATURE UNDER CONTROLLED CONDITIONS.

Experiment F.

Introduction.

In a previous study by Maryam (1981), ten inbred lines of grain maize were chosen from a collection of cold tolerant material. These were the most suitable lines for further work towards the improvement of the cold tolerance and early maturity in maize. The lines selected were GBO78, GBC100, GBC102, GBC108, and GBC233 from the Cambridge material, and HY2, Pa32, Fr43, Fr619, and A556 from the USA lines (see Chapter 2 for source of the materials).

Among the Cambridge lines, GBO78 and GBC108 were selected because both were early germinating lines although they differ in their flowering time, being early and late flowering lines respectively. The inbred lines GBC100, CBC102 and GBC233, in spite of being late germinating lines, are early flowering and have good general combining ability (GCA) for flowering time and yield. The line GBC100 and GBC233 also have good GCA for the germination trait.

Among the USA lines, Fr43, Fr619 and HY2 are all early germinating lines and although Fr43 and Fr619 are early flowering, HY2 is a late flowering. Moreover, Maryam (1981) found that the USA lines have many good agronomic qualities such as thick flexible stems, and better root systems, i.e. stronger and longer roots were observed in the USA material than in the Cambridge material. The roots of the USA material gave good anchorage to the plants. Furthermore, at the time of harvesting, the leaves were still green and so could be used for fodder. That would mean the USA material could be used both as a grain and fodder crop at one and the same time.

For these reason, the combination of these 10 lines could produce new hybrids which would combine these good vegetative characters from the USA material with the good cold tolerance and earliness of the Cambridge material on one hand and identifying promising hybrid combinations on the other hand. Maryam (1981) found that the genetic system controlling most of the important characters in the USA lines was rather complex and in most cases the additive-dominance model was not adequate. Non-allelic interaction appeared to be common and clearly there could be complications with the genetic control of the important characters following combination of the two sets of lines.

It was suggested by Maryam (1981) that diallel crosses should be made between these ten inbred lines, but this would be repeating in part, some of Maryam's work, because she had already made the diallel crosses between the Cambridge and between the USA lines. Thus to limit any repetition and to reduce the size of the experiment and the number of the single crosses which would be obtained, the North Carolina II mating design was considered. Because our main interest was a combinations between the Cambridge and the USA material this was clearly the best way to proceed.

Many other studies have suggested this method of combination. Carr and Milbourn (1976), for example, proposed the development of varieties to incorporate the ability of European flint types to grow at low temperature with the high yield potential and resistance to lodging of early American dent material.

Bunting and Gunn (1973) have mentioned that material from the Northern parts of the American Corn Belt has been found to be suitable for the production of flint x dent hybrids that will produce ripe grain in England.

This chapter is restricted to describing some of the problems experienced with the crossing programme, the crosses obtained and the result of the laboratory tests and screening of the parents, F_1s and reciprocals The tests included the cold germination test, the emergence test, and the seedling growth test in terms of seedling dry weight.

The study of the genetic variation in this population using the NC2 mating design will be introduced in the next chapter (chapter 7) when the result of the field experiments for this material will be discussed.

Materials and Methods.

Twenty five plants were grown from randomly chosen kernels from each of the ten inbred lines CBO78, GBC100, GBC102, GBC108, GBC233, HY2, Pa32, Fr43, Fr619, and A556. These plants were grown in the glasshouse in the Botanic Garden of the University of Hull in the same way as described earlier in Chapter 2. The sources of the inbred lines were the same as those obtained and used by Maryam (1981). In order to obtain flowering compatibility some of the inbred lines were sown earlier than the others. HY2 and GBC 108 were planted first followed by the other USA lines and finally by the rest of the Cambridge lines. There was a two week interval between the first and last sowings. At the time of flowering all the possible reciprocal crosses between the 5 Cambridge inbred lines and the 5 USA inbred lines were made randomly using the same technique as described in Chapter 2. Crosses were replicated where possible. At the same time two or three plants from each inbred line were selfed to make sure that all the materials obtained were of the same age.

The seeds of the parents, F_1, and the reciprocals were harvested in August 1987, except for those crosses which included inbred line HY2. These were not ready for harvest until the 9th and 22th of September. Although care was taken to reduce flowering mismatch, it was not possible to obtain seeds from all the possible crosses.

On the first of October 1987, two plants from each reciprocal F_1 were grown inside the glasshouse to obtain F_2 seeds. Unfortunately this attempt failed to give well-developed F_2 seeds because of unfavourable lighting conditions at the time of flowering of this experiment, which happened between December 1987 and January 1988. Another attempt was made sowing F_1 seeds on 14th and 21th of December 1987 respectively. The F_2 seeds were harvested in April and early May 1988.

A germination test was carried out in the growth cabinet for all the F_1s, the reciprocals and the parents simultaneously in two replications. Ten kernels were used

in each replication. The method was as described in Chapter two and was at 6 ^{0}C in the dark for 21 days. This test was started on the 12 of August 1988. A third replication of 10 kernels of each genotype was carried out under the same conditions, but at a different time (started on the 17th of October 1988) and also for 21 days.

In order to study the emergence and seedling dry weight under low temperature conditions the material used for the germination test was retained and tested as follow: Seven germinated or non-germinated kernels from each genotype were sown in 3.5" (9 cm) pots using the same compost that was used for the glasshouse experiments. The pots were placed in the growth cabinet for 35 days under conditions of 9^o C night temperature and 13^o +/- 1^o day temperature for 8 hours/night and 16 hours/day. Two replications were carried out at different times under the same conditions because of the limited space available in the growth cabinet (replication one was from materials used for replications 1 and 2 for the germination test, and replication two was from material of replication three of the germination test). Emergence was scored at 21 days from sowing and SDW (gm) was taken at 35 days from sowing.

Following both germination tests and after the kernels for the emergence tests had been removed, the remaining kernels were left in the petri-dishes on the laboratory bench at a minimum temperature of 18 ^{0} C in order to determine their ability to germinate after they had been subjected to the low temperature of 6 ^{0} C for 21 days.

The number of kernels germinated, the germination index, the number of seedling emerged, the emergence rate (ER), and the seedling dry weight (SDW, gm) after 35 days were calculated as described earlier in Chapters two and five. The ANOVA was carried out to study the variation between the genotypes. For the SDW the mean of five seedlings for each genotype was used as the base for the ANOVA. ANOVA was carried separately for the parents and for the single crosses (F_1 s and reciprocals).

To investigate any reciprocal effect, an ANOVA was carried out for each of the reciprocals separately for all traits studied.

Result and Conclusions.

1. Genetic Materials Obtained.

The NC2 mating programme produced 39 single crosses. These consisted of 22 F_1s and 17 reciprocals. Because maternal effects in these lines had been reported by Maryam (1981) it was necessary to make reciprocal crosses. Although care was taken to ensure matching of flowering time in the glasshouse and the crosses were made in more than one replication, it was not possible to obtain all of the possible crosses. That was mainly because the USA inbred line HY2 was very late flowering and to some extent inbred lines GBC108 and GBC102 from the Cambridge material were also late flowering. It was not possible to repeat this crossing programme, firstly because of the limited time for this study and secondly because we expect these crosses will also be late flowering crosses and so of little use in the selection programme. It is also clear that there are other lines that are as good or better than HY2 in the one positive attribute of the line, ie of good germination at 6^0 C, and so its exclusion is unlikely to be important. Accordingly a 4 x 4 NC2 will be used to analyse the genetic variation in the single crosses. Those crosses that included the inbred lines HY2 and GBC108 will be excluded from the full NC2 analysis in the next Chapter, but they are included in the preliminary ANOVA described below. All the inbred lines used and the single crosses obtained are listed in the table of means (F-1). F_2 seeds were also obtained from this experiment from all the F_1s.

2. Results of the Germination, the Emergence and the Seedling Dry Weight Tests.

a. The Inbred lines Result.

It is obvious from the means (table F-1) for these characters and from the ANOVA results (table F-2) that there was significant variation between the parents used in this experiment in the ability to germinate at 6^0 C constant temperature. A large number of kernels germinated from some inbred lines (Fr43, HY2, GBO78 and GBC108), while no kernels germinated from some others (GBC233 and GBC102).

Less variation was observed among the inbred lines for the germination rate (GI). This result agreed, in general, with that found by Maryam (1981). She also found that inbred lines (GBC102, GBC233, Pa32 and A556) were late germinaters.

Below is a comparison of the GI obtained in our results at 6⁰ C constant temperature for the inbred lines with those obtained by Maryam (1981) for the same inbred lines at 8⁰ C constant temperature. We can see that despite the differences in the temperatures used and in the number of kernels, the consistency of behaviour of the inbred lines in both experiments is very clear.

Inbred lines	GI at 8⁰ C from Maryam (1981)	GI at 6⁰ C from this experiment
Cambridge line		
GB078	12.70	19.45
GBC100	*	18.98
GBC102	17.00	*
GBC108	11.10	17.85
GBC233	14.33	*
USA lines		
HY2	10.00	17.72
Pa32	12.30	17.72
Fr43	10.00	18.25
Fr619	11.70	17.21
A556	14.60	18.44

* no kernel germinated.

The means and ANOVA of the emergence test of these lines in the laboratory at 9-13⁰ C (table F-1) also indicated that variability exists between the lines for the ability to emerge and for the rate of emergence (ER). Comparing the germination results with the emergence results we can conclude that some inbred lines (Fr43, Fr619, A556, GBC78 and GBC100) showed a similar behaviour for both traits, but no similarity was observed for the others. For example, HY2 was able to germinate at 6 ⁰ C, but it showed very low ability to emerge at 9-13 ⁰ C. In contrast was the behaviour of inbred lines Pa32, GBC102 and GBC233. They were the slowest lines to germinate and the latter two lines did not germinate by 21 days at 6⁰ C, but they showed good response to emerge at the higher temperatures. Indeed, Pa32 and GBC233 were the fastest lines to emerge. This conclusion would indicated that while

some of the lines were not able to germinate at 6^0 C, they were able to emerge at the relatively cool temperature (9°C - 13°C) and this ability was not affected by their previous subjection to the low temperature of 6^0 C for 21 days. In other words these lines are cold resistant and partially cold tolerant lines. Support for this conclusion was obtained from the observations on the rest of the kernels which were left in the laboratory following the 21 days of the cold test. They germinated very satisfactorily.

Highly variability was also found between the inbred lines in seedling dry weight (tables, F-1 and F-2). These tests indicated that for most of these characters useful variability existed among the inbred lines, which is necessary to create the heterozygosity between the single crosses.

b. **Result of the F_1 s and Reciprocals.**

Highly significant differences were found between the 39 double crosses (see tables F-1 and F-2) for all the characters studied, except for the number of seedling emerged. Hence there were no significant differences between the 39 single crosses, which reflects the high response of all these crosses to emerge under these temperature conditions.

Comparisons between the parents the F_1s and reciprocals for each individual cross reveal that most of the single crosses have a mean value 'better' than the mid-parental value (positive heterosis) and some showed overdominance, the mean being better than that of the better parent. Some other crosses show negative heterosis especially for the number of kernels germinated, for example, Fr43 x GBO78, Fr43 x GBC102, A556 x GBC233 and GBC100 x HY2. The least vigour was obtained for GI when most of the single-cross means did not reach the mid-parental means. Most of the single crosses showed stronger heterosis in the emergence rate and seedling dry weight than they showed in germination ability and the germination index. The low vigour of the hybrids in the rate of germination compared with their parents could mean that the temperature of 6^0 C is a critical threshold, that is, in general, there is insufficient genetical variation within these inbred lines to enable kernels to germinate below 6^0 C, even under the most favourable gene combinations. It is also

noticeable that some crosses from lines with low numbers of germinating kernels at 6^0 C (i.e. GBC233 x Pa32) showed good ability to germinate at 6 ^{0} C. On the other hand a few crosses from the faster germinating lines have considerably faster germination, for example GBC108 x Fr619 and GBC108 x HY2. This indicates that the performance of the F_1s sometimes depends on the particular parental lines used, with the actual performance of the inbred lines not being a good predictor of the F_1s.

Reciprocal Crosses.

An ANOVA of the reciprocal crosses derived from the same parents was carried out and a summary is given in table F-3 for the five characters. Overall, 19 of the 85 variance ratio tests are significant, somewhat more than is expected by chance. There does not appear to be any clear pattern here although GBO78 is involved in nine significant reciprocal crosses. For the number of kernels germinated, six reciprocal crosses showed significant differences; six reciprocals crosses showed reciprocal differences in the germination rate. Only two pairs of reciprocal crosses were significantly different for both traits.

No important reciprocal differences were found for the number of seedlings emerged. Three cases of reciprocal differences were found for each of ER and SDW traits, one of each was for the same reciprocal. These means that fewer reciprocal differences were found for the emergence and SDW traits than found for germination. These reciprocal effects can only be attributed to maternal effects. Similar important maternal effects in maize germination were found by Maryam (1981) when she tested a different set of crosses obtained from different combinations (diallel crosses) between two set of inbred lines, some of which are included in the experiment described above.

Maternal effects for germination and emergence in maize have been reported by many researchers (Pinnell, 1949; Tatum, 1954; Pesev, 1970; Eagles and Hardacer, 1979a; Faranets, 1981). In contract, no maternal effect was found by McConnell and Gardner (1979b) when they investigated possible maternal differences for the

percentage of emergence and this agrees with our results for the number of seedlings emerged, where no significant reciprocal effect was found.

From table F-1 it can be seen that in most of the reciprocal crosses showing important differences, the better cross was the one in which the Cambridge line was as the used as female parent. Even where there were no significant reciprocal differences the better means were obtained when the Cambridge lines were used as females. This result suggests that the British lines have a positive effect on the characters studied and back-crossing to the Cambridge lines could be effective in further improvement of these characters for cold tolerance.

From the results of this experiment we can conclude that there is good genetic variation among the single crosses which were developed by the NC2 mating design. Most of the genotypes showed a good response to germinate and to emerge under low temperature conditions. There were also strong indications that some maternal effects exist among the reciprocals for the different characters studied. The study of the maternal effects indicated that the Cambridge lines are good parents for any back crossing for cold tolerance improvement. It is appears also from these results that more investigations need to be carried on this material in the field to get a better understanding of the behaviour of the major characters of interest (flowering and maturity stages) as well as the other agronomic characters. The nature of the genetic variation and the genetic effects of importance need also to be determined. These objectives are the subject of the next chapter in which some field experiments over two seasons will be described.

Table F-1. Inbred lines and F_1s and reciprocals (F_1"s)used number of kernelsgerminated (KG) from 30 kernels used, means of GI, number of seedling emerged of kernels sown, means of ER and means of SDW.

	Parents & F_1 s	Germination			Emergence	SDW
No	Genotype	KG	GI	SE	ER	
	Inbred lines					
	1. USA lines					
1	HY2	17	17.72	4	17.08	0.017
2	Pa32	7	18.72	14	13.07	0.056
3	Fr43	23	18.25	14	11.28	0.037
4	A556	11	18.44	14	15.57	0.046
5	Fr619	13	17.21	12	17.35	0.037
	2. UK lines					
1	GBO78	16	19.45	13	15.20	0.030
2	GBC100	13	18.98	10	17.16	0.040
3	GBC102	0	-	13	17.10	0.039
4	GBC108	18	17.85	9	17.83	0.032
5	GBC233	0	-	12	14.91	0.032
	F_1s & F_1"s					
1	Fr43 x GBO78	11	19.58	14	10.71	0.077
2	GBO78 x Fr43	23	15.98	14	11.07	0.050
3	Fr43 x GBC102	9	19.27	14	11.49	0.060
4	Fr43 x GBC233	7	19.72	14	13.14	0.054
5	GBC233 x Fr43	22	18.49	12	13.32	0.055
6	Fr43 x GBC100	12	19.78	14	13.71	0.066
7	GBC100 x Fr43	9	18.46	12	13.28	0.080
8	Fr619 x GBC108	28	17.08	13	13.37	0.090
9	GBC108 x Fr619	30	14.08	14	11.13	0.070
10	Fr619 x GBC100	28	18.30	14	14.06	0.058
11	GBC100 x Fr619	29	17.20	14	14.92	0.059
12	Fr619 x GBC102	25	18.01	13	13.72	0.080
13	Fr619 x GBC233	15	18.96	14	13.78	0.071
14	GBC233 x Fr619	13	18.06	14	11.92	0.050
15	Fr619 x GBO78	10	19.38	14	17.35	0.030
16	GBO78 x Fr619	15	16.94	11	12.42	0.069
17	A556 x GBC233	2	21.00	14	12.35	0.050
18	GBC233 x A556	8	19.16	14	14.99	0.066
19	A556 x GBC100	17	18.15	11	16.53	0.048
20	GBC100 x A556	18	17.25	14	12.85	0.045
21	A556 x GBC108	14	19.02	14	13.99	0.073
22	GBC108 x A556	12	19.58	13	13.50	0.075
23	A556 x GBO78	16	18.88	12	12.08	0.065
24	GBO78 x A556	17	16.65	14	12.78	0.063
25	A556 x GBC102	0	-	13	15.10	0.057
26	GBC102 x A556	22	19.12	14	11.78	0.054
27	Pa32 x GBC108	24	18.77	11	13.95	0.054
28	GBC108 x Pa32	25	18.42	10	13.00	0.054
29	Pa32 x GBC100	23	18.58	13	15.17	0.039
30	GBC100 x Pa32	27	17.89	14	11.49	0.054
31	Pa32 x GBO78	25	17.73	14	12.06	0.086
32	GBO78 x Pa32	20	16.56	13	11.05	0.063
33	Pa32 x GBC233	17	18.91	14	12.71	0.081
34	GBC233 x Pa32	24	18.32	14	12.85	0.049
35	Pa32 x GBC102	23	19.75	13	11.66	0.069
36	GBC102 x Pa32	10	19.02	12	11.28	0.066
37	GBC233 x HY2	11	20.00	14	12.60	0.075
38	GBC100 x HY2	7	20.30	11	13.96	0.049
39	GBC108 x HY2	27	17.15	13	14.72	0.049

Table F-2. The ANOVA for germination, emergence and seedling dry weight for the parents and their F_1 s and reciprocals (F_1"s) obtained by NC2 crossing.

Character	G.	Source of variance	DF	M.S.	VR	P
Kernels germinated	Parents	Bet. parents	7	7.881	6.101	***
		Error	16	1.292		
	F_1 & F_1"	Bet. crosses	37	19.797	15.782	***
		Error	76	1.254		
Germination index	Parents	Bet. parents	7	1.5906	2.271	N.S
		Error	16	0.7004		
	F_1 & F_1"	Bet. crosses	37	5.3871	5.981	***
		Error	76	0.9007		
Seedlings emerged	Parents	Bet. parents	9	4.133	4.133	*
		Error	10	1.000		
	F_1 & F_1"	Bet. crosses	38	0.6545	1.418	N.S
		Error	39	0.4615		
Emergence rate	Parents	Bet. parents	9	9.0145	9.281	***
		Error	10	0.9713		
	F_1 & F_1"	Bet. crosses	38	4.4796	6.003	***
		Error	39	0.7462		
Seedling dry weight	Parents	Bet. Blocks	1	128×10^{-7}	0.419	N.S
		Bet. parents	9	215×10^{-6}	6.922	***
		Error	9	306×10^{-7}		
	F_1 & F_1"	Bet. blocks	1	738×10^{-6}	15.71	**
		Bet. F_1 s	38	371×10^{-6}	7.877	***
		Error	38	47×10^{-6}		

Table F-3. Summary of the separated ANOVA for the 17 reciprocals for the germination , emergence and SDW.

No.	Reciprocals	K.G	GI	S.E.	ER	SDW
1	Fr43 x GBO78 GBO78 x Fr43	***	***	N.S	N.S	*
2	Fr43 x GBC233 GBC233 x Fr43	***	N.S	N.S	N.S	N.S
3	Fr43 x GBC100 GBC100 x Fr43	N.S	N.S	N.S	N.S	N.S
4	Fr619 x GBC108 GBC108 x Fr619	N.S	*	N.S	N.S	N.S
5	Fr619 x GBC100 GBC100 x Fr619	N.S	N.S	N.S	N.S	N.S
6	Fr619 x GBC233 GBC233 x Fr619	N.S	N.S	N.S	N.S	N.S
7	Fr619 x GBO78 GBO78 x Fr619	N.S	*	N.S	*	***
8	A556 x GBC233 GBC233 x A556	N.S	*	N.S	N.S	N.S
9	A556 x GBC100 GBC100 x A556	N.S	N.S	N.S	***	N.S
10	A556 x GBC108 GBC108 x A556	N.S	N.S	N.S	N.S	N.S
11	A556 x GBO78 GBO78 x A556	N.S	*	N.S	N.S	N.S
12	A556 x GBC102 GBC102 x A556	***	***	N.S	*	N.S
13	Pa32 x GBC108 GBC108 x Pa32	N.S	N.S	N.S	N.S	N.S
14	Pa32 x GBC100 GBC100 x Pa32	N.S	N.S	N.S	*	N.S
15	Pa32 x GBO78 GBO78 x Pa32	**	N.S	N.S	N.S	*
16	Pa32 x GBC233 GBC233 x Pa32	*	N.S	N.S	N.S	N.S
17	Pa32 x GBC102 GBC102 x Pa32	***	N.S	N.S	N.S	N.S

CHAPTER SEVEN

THE NORTH CAROLINA MATING DESIGN 2 (NC2) AS A METHOD FOR TESTING THE COMBINING ABILITY OF TWO DIFFERENT SETS OF SELECTED INBRED LINES OF GRAIN MAIZE FOR COLD TOLERANCE AND EARLINESS IN A FIELD TRIAL OVER TWO SEASONS.

Experiment G.

Introduction.

In this chapter all the crosses and their reciprocals obtained from the NC2 mating explained earlier in Chapter 6 were utilised. These crosses and their F_2s were evaluated in two experiments in the field over two seasons in 1988 and 1989. The main objectives of this experiments were: 1) to obtain information on the nature of the genotypic and the phenotypic variation in these hybrids by using the analysis of the North Carolina design 2 as described by Comstock and Robinson (1948), and 2) to obtain a clear understanding of the performance of these hybrids originally obtained by mating two different cold-tolerant sets of inbred lines obtained from USA material and from British material (see Chapter 2 and Chapter 6 for the source of material).

Both Mather and Jinks (1982) and Cockerham (1963) stated that the best understanding will be obtained when true inbred lines are included in the mating. Without them, the maximum coefficient in the covariance of non-inbred relatives, is 1/2 for additive and 1/4 for dominance variation, whereas with them, these coefficients can be increased to one. Furthermore, the coefficients of all components of genetic variance will be unity, so permitting the estimation of the total genetic variance, an obviously desirable feature.

Experience has shown that unrelated inbred lines (derived from different open pollinated varieties) will generally combine to produce higher-yielding single crosses than inbred lines derived from related parental materials, which might have more of the same genes in common for any quantitative character (Poehlman, 1959).

Material, Methods and Experimental Techniques.

Two experiments were carried out in the field at the Botanic Garden of the University of Hull in 1988 and in 1989 respectively. The materials used in 1988 consisted of all the inbred lines, the 39 single crosses listed in table F-1(Chapter 6) and their F_2s. These genotypes were tested in 1988 in the field in a randomized complete block design of two blocks. Five plants were grown from each entry in each block. Block one was sown on the 18th of May 1988, while block two was sown on the 24th of May 1988.

In 1989 the experiment consisted of two sowing times, each of two blocks, and was carried out in the same location. The first sowing was on the 27th of April 1989, and the second was on the 4th of May 1989. The material used in this experiment was only the F_1s obtained from the mating of 4 x 4 inbred lines. Four USA lines were used as females; Pa32, Fr43, A556, and Fr619. Four of the Cambridge inbred lines were used as males; GBO78, GBC100, GBC102, and GBC233. Thus 16 single crosses were tested.

The remaining kernels from the 10 inbred lines and from the 39 single crosses used in experiment F (chapter 6) were used in these experiments. All kernels were of the same age and had been stored under the same conditions. The 39 F_2s of the 39 F_1s were also of the same age and had been stored under the same conditions together with the F_1s. Storage conditions were as described in Chapter 4 (experiment D). Throughout the discussion of the results of these experiments the genotypes will be referred to by their real names.

The experimental design, techniques used, traits measured and the methods of measurement were exactly as described for experiment E (Chapter 5). Because of the similarity of the results obtained by using calender day and the heat-unit degrees methods in Chapter five, the evaluation and study of the flowering and the maturity stages was carried out using only the Gilmore-Rogers heat-unit degrees method (see Chapter 5 for details). The number of days required for maturity are given merely for comparison.

Methods of the Statistical and Genetic Analysis.

Theory of the NC2 Design Analysis.

The diallel mating design and the North Carolina mating design 2, have been used in maize breeding programmes. The former, in which the crosses are made in pairs for n number of parents, has been used and abused more extensively than the NC2 in maize and other plant species. Design 2, in which crosses are made between two different sets of parents, has not been used nearly as extensively in maize as the diallel, but it seems to merit further consideration (Hallauer and Miranda 1988). The mechanics of making crosses when the parents are inbred lines are no different from those for diallel design.

The designs, however, are very different. In the diallel, the same set of parents is used both as males and as females, while in the NC2 one set of parents is used as males and the other set as females. As the number of parents used increases, the number of crosses in both designs increases, but there are considerably fewer crosses made in producing a NC2.

As the number of parents increases from 1 to n, the ratio of crosses (NC2 / diallel) decreases from 0.67 to 0.50 (Hallauer and Miranda, 1988). For the same number of crosses, twice as many parents can be evaluated in the NC2. This is a major advantage of the NC2 design, especially when estimates of the genetic parameters of a population are desired. For both designs a greater number of parents can be evaluated by subdividing the parents into sets, but the NC2 still has the advantage of being able to evaluate twice as many parents per set. The intial assumptions presented for both designs are similar. As stated later several assumptions presented for the NC2 are not necessary and, when removed, the two sets of assumptions are identical.

Comstock and Robinson's (1948, 1952) design II (NC2 mating design) was outlined as a factorial mating design (Cockerham 1963), where different sets of

parents were used as males and females and crosses made between the two sets. The sources of variance commonly used in the literature for NC2 design are the males, females and males x females (Comstock and Robinson, 1948, 1952; Cockerham, 1963; Gardner, 1963; Mather and Jinks, 1982; Hallauer and Miranda, 1988). The expectations of the means squares corresponding to the source of variation presented by Comstock and Robinson (1948, 1952), which were expressed as linear functions of the components of genetic variance (Cockerham, 1954; Comstock, 1955; Kempthorne, 1973) are as follows:

COV paternal HS ($COVHS_m$) = $(1+f/4)\ \sigma^2 A + (1+f/4)^2\ \sigma^2 AA$ +..;

COV maternal HS ($COVHS_f$) = $(1+f/4)\ \sigma^2 A + (1+f/4)^2\ \sigma^2 AA$ +. ; and

COVFS = $(1+f/2)\ \sigma^2 A + (1+f/2)^2\ \sigma^2 D + (1+f/2)^2\ \sigma^2 AA + (1+f/2)^3\ \sigma^2 AD + (1+f/2)^4\ \sigma^2 DD$.

Therefore, as demonstrated by Comstock and Robinson (1948, 1952):

$\sigma^2 M = (1+f/4)\ \sigma^2 A + (1+f/4)^2\ \sigma^2 AA$ +..;

$\sigma^2 F = (1+f/4)\ \sigma^2 A + (1+f/4)^2\ \sigma^2 AA$ +..;

$\sigma^2 FM = (1+f/2)\ \sigma^2 A + (1+f/2)^2\ \sigma^2 D + (1+f/2)^2\ \sigma^2 AA + (1+f/2)^3\ \sigma^2 AD + (1+f/2)^4\ \sigma^2 DD$.

where M, F, FM, A, D , and f are males, females, males x females, additive genetic effects, dominance genetic effects, and inbreeding coefficient respectively. The value of f is 1 for inbred lines and 1/2 for the other sources (Cockerham, 1954; Hallauer and Miranda, 1988).

It can be seen that the NC2 design provides the researcher with two unique estimates of the $\sigma^2 A$ and an estimate of the $\sigma^2 D$.

Comstock and Robinson (1948, 1952) listed and discussed many assumptions which are necessary to permit unbiased estimation of the variance components from their mating design. These assumptions were: a) random choice of the individuals mated; b) random distribution of the genotype relative to variation in the environment; c) no non-genetic maternal effects; d) regular diploid behaviour at meiosis; e) gene frequencies of 0.5; f) no multiple allelism; g) no linkage.

This was the original list of assumptions suggested by them. However, e, f have been found to be unnecessary (Kempthorne, 1973; Jacquard, 1974; and Cockerham, 1983). Regardless of the number and frequency of alleles per locus, the following is true:

$COVHS = (1+f/4)\,\sigma^2 A + (1+f/4)^2\,\sigma^2 AA + ..;$

$COVFS = (1+f/2)\,\sigma^2 A + (1+f/2)^2\,\sigma^2 D + (1+f/2)^2\,\sigma^2 AA + (1+f/2)^3\,\sigma^2 AD + (1+f/2)^4\,\sigma^2 DD.$

Hallauer and Miranda (1988) discused the other assumptions and they reported that the proper use of the experimental design and randomization will ensure no correlation of environmental effects with relatives, and maternal effects in maize are normally not important. They also stated that maize normally exhibits regular diploid inheritance. Thus assumptions b, c, and d are also unnecessary.

The other assumptions are similar to those required to obtain unbiased estimates from the diallel and, as with the diallel, the failure to meet these assumptions would result in biased estimates. Despite that, the non-genetic maternal effects can be examined experimentally with the inclusion of reciprocal crosses and by the male and female sources in the NC2 design.

However, if one is interested in the estimating of the components of variance, Cowen, (1985) and Hallauer and Miranda (1988) stated the NC2 design seems to have many advantages over the diallel design. For example, more parents can be included, two independent estimates of σ^2 A are available, and an estimate of σ^2 D can be determined directly from the mean squares. If only a few selected parents are included, design two has no advantages over the diallel for estimating genetic effects of parents (general combining ability(GCA)) and their crosses (specific combining ability (SCA)); the same information can be obtained from both designs.

It appears, therefore, that the genetic information obtained from the diallel and the NC2 are very similar (Cockerham, 1956; 1963; 1980; and Hallauer and Miranda, 1988). The variance for the GCA obtained from the diallel analysis is equivalent to

the male or female variance in the NC2 analysis, and the variance for the SCA is equivalent to the male x female interaction variance.

σ^2 GCA = σ^2 M = σ^2 F = COVHS and

σ^2 SCA = σ^2 F x M = COVFS - 2(COVHS) - COVFS - $COVHS_m$ - $COVHS_f$.

Poehlman (1959) stated that the ability of an inbred line to transmit desirable performance to its hybrid progenies is referred to as its combining ability. The average performance of particular inbred line in a series of hybrids combination is known as its general combining ability (GCA). Specific combining ability refers to the performance of a combination of two specific inbred lines in a particular cross. Specific combining ability is judged by relation of the performance of inbred lines in a particular cross to the average performance of the inbred lines in a series of crosses.

The North Carolina Design 2 and the Fixed Model.

The mechanics of making crosses between two sets of inbred lines are usually not too difficult with maize, when the proper allowance is made for the differential flowering of the male and female inflorescences. The kernels from a NC2 mating design are grown in replicated tests, with appropriate randomization, to determine the relative merits of the parents of the crosses. If fewer than 12 parents are included in the mating a randomized complete block design should be considered (10 inbred lines were used in the mating in this experiment) (Hayman, 1960).

There is, however, an important question to be answered at this stage: are the parents the reference genotypes or are the parents random genotypes from some reference population ? The answer to this question has great importance for the interpretations made from the analyses of the NC2 mating design. Frequently, the assumptions made about the parents, and not how the experiment was conducted and analysed, causes the the greatest difficulties in the interpretation of the estimated parameters.

Grifing (1956b) and Cockerham (1963) have discussed the diallel analysis in detail as well as the analysis of variance for both models and they stated that when the parents are the reference genotypes the fixed model (model 1) is appropriate, and estimates apply only to the genotypes included and cannot be extended to some hypothetical reference population. When the parents are random genotypes from some reference population the random model (model II) is appropriate, and the estimates are interpreted relative to some reference population from which the genotypes included are an unselected sample. Both models can be applied to the NC2 design and the genetic information obtained is also similar (Cockerham, 1980; and Hallauer and Miranda, 1988). Consequently, in both models we will have sources of variation for males, females, and the interaction of males x females. The expectations of mean squares of males and females for design 2 are equivalent to the GCA variance, and the males x females variance is equivalent to SCA, as in the diallel analysis. Because we have two sets of parents in the NC2 design, we have two independent estimates of the GCA. Appropriate F tests can be made to test for the differeces among males and among females and for males x females interaction. Because the parents are the population for model 1, the estimation of components of variance is not appropriate (Cockerham 1963; 1980), but estimation of the effects of the inbred lines in specific crosses (SCA) and in a series of crosses (GCA) is appropriate and valid. Sprague and Tatum (1942) were the first who used the expression of GCA and SCA. They found that GCA was relatively more important than SCA for unselected inbred lines, whereas SCA was more important than GCA for previously selected lines. They also interpreted GCA as an indication of genes having largely additive genetic effects, while SCA us indication of genes having dominance and epistatic effects.

Cockerham (1963; 1980) and Hallauer and Miranda (1988) confirmed that the GCA and SCA effects are more informative than components of variance for the model 1 analysis. Also, estimated effects are applicable only for the parents included and would be different if the parents were tested with a different group of parents.

They also stated that the model 1 analysis, therefore, yields considerable information about the fixed set of parents and this type of information is quite useful to maize breeders, particularly if the selected sets of parents represent an elite group of inbred lines that are possible candidates as parent seed stock for the production of single hybrids, while, for the random model analysis, estimation of the components of variance is of prime interest.

If F tests for the preliminary ANOVA in model 1 show that differences may exist between crosses, partition of the main effect (between crosses) to the male (GCA_m), female (GCA_f) and male x female interaction (SCA) effects will show the relative magnitude and sign of the effect for each parent and each cross. The general model for the ANOVA is:

$$X_{ijk} = U + r_k + g_i + g_j + s_{ij} + p_{ijk}$$

Where U is the mean, r_k is the replication effects, g_i and g_j are the GCA effects for the males and for the females parents, s_{ij} is the SCA effect, and p_{ijk} is the experimental error for the X_{ijk} observation ($_k$=1,2,...,r; $_i = _j$ = 1,2, ,n).

Further extensive discussions are given by Cockerham (1956; 1963; 1981) for the interpretation of results obtained from mating of a fixed set of inbred lines. He stated that when these sets of inbred lines, their crosses, and possibly selfs or their back crosses are used, many estimates and tests of hypotheses concerning effects of lines, heterosis, and so on are available. All of these are phrased in terms of effects or comparisons of means, as is appropriate for the interpretation of a fixed group of treatments or genotypes. He mentioned that the additive and dominance genetic components of variance can be limited only to additive (for GCA) and dominance (for SCA) effects of genes with model 1. He stated that in this case it does not seems wise, then, to attempt to estimate components of genetic variance from a specific set of inbred lines, their crosses and with or without selfs of the crosses, and back crosses. He, and also Hayman (1960), stressed that considerably more accuracy is obtained when estimates of variances are used, but these variances apply strictly to the set of genetic material in the sample. Hayman (1960) noted that even with random model as many as ten parents are required to supply useful estimate of genetic

variances when the parents are considered to be random sample. Despite that Cockerham (1981) stated that when the breeder has selected sets of materials such as screened inbred lines or varieties and, consequently, he tends to view his collection as a fixed set, various designs of fixed entries can be explored for the estimation of genetic effects such as generations means, parents crosses, hybrid combinations from factorial mating design. He also stated that if one still want to estimate genetic variances in advanced generations from a fixed sets of parents, then the features involved will be the same as for the experiment for random sets.

The form of the analysis of variance when M males are crossed with F females and evaluated in replications is shown in table (G-1) below.

Table G-1 model of the ANOVA for the NC2 design with a fixed effect (Model 1).

Source	DF	Expected value of mean square
Bet. Blocks	r-1	$\sigma^2 + nmf \Sigma B^2 /(r-1)$
Bet. males	$m-1$	$\sigma^2 + nrf \Sigma M^2 /(m-1)$
Bet. females	$f-1$	$\sigma^2 + nrm \Sigma F^2/(f-1)$
Blocks x M	$(r-1)(m-1)$	$\sigma^2 + nf \Sigma (BM)^2 /(r-1)(m-1)$
Blocks x F	$(r-1)(f-1)$	$\sigma^2 + nm \Sigma (BF)^2 /(r-1)(f-1)$
M x F	$(m-1)(f-1)$	$\sigma^2 + nr \Sigma (MF)^2 /(m-1)(f-1)$
B x M x F	$(r-1)(m-1)(f-1)$	$\sigma^2 + n \Sigma (BMF)^2 /(r-1)(m-1)(f-1)$
Error	$rmf(n-1)$	σ^2

Where B, M and F are blocks, males and females respectively and r, m, f, n in italics are the number of blocks, number of males, number of females and number of observations (plants) per block respectively.

Methods of Analysis.

Model one was considered to be appropriate for the ANOVA of this experiment, because both sets of inbred lines used to generate the F_1s and the F_2s were selected inbred lines. The blocks and sowings were also considered to be fixed.

On the basis of the fixed model for the North Carolina design , a preliminary ANOVA was conducted in a way similar to that described in chapter 5 (experiment E table E-3), where all of the main effects were tested against the experimental error.

When the preliminary ANOVA shows significant differences between the single crosses, the North Carolina design 2 ANOVA was calculated. For the 1989 season, the block and sowing date effects were included (the model for the NC2 ANOVA is shown in table G-1 for an experiment with many replications). In this case, when the F test shows that significant differences exist for the male or female or their interaction effects , the genetic effects, the GCA (for the males and for the females parents) and the SCA (M x F effects) will be discussed later in this Chapter.

The NC2 ANOVA was calculated for the F_1s obtained from the matings of 4 of the USA inbred lines as females (Pa32, Fr43, A556, and Fr619) with 4 of the Cambridge inbred lines (GBO78, GBC100, GBC102, and GBC233) as males. The NC2 ANOVA was also carried out for the reciprocal set of crosses obtained from the same inbred lines separately. Two reciprocal crosses were not available (GBC102 x Fr43 and GBC102 x Fr619) and these were replaced by their F_1s (Fr43 x GBC102 and Fr619 x GBC102) because no reciprocal differences were found in any of their combinations with the other inbred lines.

The terms 'bet. males', 'bet. females' and 'M x F' were used in the NC2 ANOVA tables of results, and they are equivalent to the GCA for males, GCA for females and SCA for M x F interaction respectively. Means for the GCA and the SCA for males and females are listed in the tables for all traits studied (Tables G-8 and G-10). The GCA and the SCA effects were estimated using the formula explained earlier in page 190 and only for F_1 in both season and results are shown in tables G-8a and G-10a.

Results and Conclusions

Results for the 1988-Season Experiment.

The Preliminary ANOVA Results.

A preliminary ANOVA was carried out for the inbred lines, the F_1s and their reciprocal crosses and for the F_2s separately. The data in the two blocks were pooled when there was no significant difference between them, otherwise a separate ANOVA was carried out for each block. Analysis of the number of seedlings emerging and the emergence rate was based on one set of observations for each genotype per block.

Results for the Inbred Lines.

The means of the different characters for the inbred lines and the ANOVA results (tables G-2 and G-3) indicated no significant differences between the two blocks, except for seedling dry weight, the heat-unit degrees required form silking to maturity, and for the maturity stage. As a result a separate ANOVA was conducted for each block for these traits.

Highly significant differences were found for all traits between the inbred lines. There were no significant block x inbred lines interactions for most of the traits studied. Exceptions were the boots and 65 stages of flowering. These results indicate that these inbred lines contains sufficient variability to obtain crosses with a good range of variation for the characters of interest. During the analysis it appeared that the USA line HY2 emerged late and gave the lowest seedling dry weight. This line was late flowering and did not reach the silking stage. This result parallels the one obtained in experiment F under controlled conditions. Inbred line Fr619 (USA) also did not reach the maturity stage. Among the Cambridge lines GBC108 was found to be late emerging, but it did reach the flowering and maturity stages.

ANOVA Results for the Single Crosses (F_1s and Reciprocals).

The preliminary ANOVA showed that there were significant differences between blocks for all the traits studied except for plant height and ear height. Thus separate ANOVAs for each block were calculated for the other traits.

The ANOVA results for F_1s are shown in table G-3 and the means are presented in tables G-8 for all traits studied. The means for the single crosses, which were not included in the 4 x 4 NC2 ANOVA (discussed later), were excluded, although they are included in the preliminary ANOVA.

The results indicated that there were highly significant differences between the 39 single crosses included in the ANOVA for all the traits studied in the two blocks. An ANOVA was also carried out (results are not shown here) for each pair of the 17 reciprocal crosses tested, (similar to that for experiment F (Chapter 6)) to investigate any reciprocal differences. These tests clearly indicated there are no important reciprocal differences. Of 336 ANOVAs calculated only 20 statistically significant reciprocal differences were found. Most of them were significant at the 5% level of probability. In no case did reciprocal differences occur in both blocks at the same time. Thus the small number of reciprocal differences can be attributed to chance effects.

Because there were significant differences between the single crosses in this preliminary ANOVA for the traits studied, a further subdivision of the mean source of variation in males and females and their interaction was carried out by the NC2 ANOVA and will be discussed later.

ANOVA Results for the F_2s of the 39 Single Crosses.

The preliminary ANOVA of the F_2s showed no significant differences between the blocks for six of the traits studied (boots, 65 stage, silking, maturity, PH, and EH), but significant differences between blocks were found for the rest of the characters.

Highly significant differences were found between progenies of the F_2s generation for all the traits studied (see tables G-5 and G-6 for the means and ANOVA results respectively)

This experiment was conducted mainly to study the variation between the F_1s and the combining ability of the inbred lines. The F_2 progenies were included in the first year (1988 season) experiment to monitor and obtain more understanding about these selected materials.

The F_2 results indicated that most of them were able to grow and to reach maturity stage under these conditions and their means were mostly superior to the inbred lines used to made the F_1s from which they were derived. On comparing the F_2 means with the F_1 means , some delay in the emergence, decrease in the SDW, delay in the flowering and maturity time, decrease in the PH and EH, and decrease in the number of kernels is obse rved These probably result from inbreeding. From the F_2 results, it is also seen that most of the F_2s derived from the early maturing F_1s also mature earliear than the other F_2s, for example, the F_2s derived from Pa32 x GBO78 and A556 x GBO78 and their reciprocals (see tables G-5 and G-8 for the heat-unit degrees required to maturity).

Results of the NC2 Analysis for the F_1s and their Reciprocals in the 1988 Season.

All the traits will be discussed here except for those traits that did not show significant differences between the single crosses in the preliminary ANOVA. These characters covered all the growth, flowering and the maturity stages as explained in Chapter 5. Because the fixed model is appropriate for these materials no estimation will be made of the genetic components of variance. Evaluation of these traits will be discussed here in terms of the gene effects, GCA, and SCA means as described earlier in this Chapter.

Results for Emergence Rate (ER) and Seedling Dry Weight (SDW).

The NC2 ANOVA (table G-7) the means for F_1 (table G-8) and the GCA effect of each inbred line from the two sets and SCA (in each particular cross) (table G-8a) for both traits indicated that, for the ER, there are significant differences between the UK Lines for GCA at the 5% level of probability both in the analyses of the F_1 (as males) set and also in the NC2 ANOVA of the reciprocals (where they were the females). For the USA inbred lines, significant differences among them were obtained for GCA at the 5% level only for the F_1s(where they used as females). No important differences appeared in the SCA (male x female interaction) for any of the cases examined. This result means that the additive gene effects are more important for this trait and are mainly contributed by the Cambridge lines. The means of the GCA revealed higher differences for GCA among the Cambridge lines than among the USA lines. The means for ER (table G-8) also showed that among the Cambridge lines the inbred line GBO78 has the best GCA with the USA lines and it has also the best SCA with inbred line Pa32. The separate NC2 ANOVA for the F_1s and for their reciprocals confirmed the absence of reciprocal or maternal effects. For the USA lines it is not clear that any one of them has better GCA for ER and SDW with the Cambridge lines than any other, even though both Pa32 and Fr34 lines do better than the others, and there is no doubt that both lines have the best SGA with the Cambridge line GBO78. In other words, hybrids Pa32 x GBO78 and Fr43 X GBO78 and their reciprocals were the earliest crosses to emerge in both blocks.

The NC2 ANOVA results and means for the SDW in tables G-7 and G-8 respectively, indicated that there are no important differences either in the GCA for the Cambridge lines or for the USA lines. There was, however, a significant difference at the 5 % level of probability for the results of the F_1s in block 1, but this was absent in block 2 and in the NC2 ANOVA of the reciprocal set. It is also appears that there is no strong evidence for an important M x F interaction. This interaction was not significant for the F_1s nor for their reciprocals in block one, although it was significant in block two. From these results it is not possible to conclude which

effects are more important for seedling dry weight in these specific combinations. Apparently GBO78 showed good GCA for this trait compared with the other Cambridge lines and among the USA lines Pa32, and Fr43 appear to be better than the other USA lines. Repeating this experiment in 1989, with more replications and observations, should make it clearer whether additive or dominance gene effects, or both, are important for this trait in these single crosses.

Results of the NC2 ANOVA for the Flowering and Maturity Stages in the 1988 Season.

The NC2 ANOVA results for these traits are shown in table G-7 and the means of the heat-unit degrees required from sowing to reach each particular stage (boots, 65 stage, silking, silking to maturity, and for maturity stage) are shown in tables G-8. Estimated effects for GCA and SCA are shown in table G-8a. From the results of the F_1s (USA lines as females) it has been found that the main effects male, female and the interaction males x females all show significant differences, except for the boots stage where the significant differences appeared only between the males (UK lines) and, for the interaction, only in block 2. The results of the ANOVA for the reciprocals, when the Cambridge lines were used as females and the USA lines used as males, indicated that for all characters both items of male and males x females were not significant except for the maturity stage where all the variances were significant. It appears that some maternal effects are present for the flowering and the maturity stages in the USA inbred lines. Support for this conclusion can be obtained from the comparison of the mean squares for the male and female sources in both sets of F_1s and their reciprocals. This comparison also indicates that, in both cases, the effect of the variation in the GCA for the UK lines is greater (see table G-7 for the F_1s and for their reciprocals for flowering and maturity stages mean squares), suggesting no differences between the paternal and the maternal effects for the UK lines. It also indicates that most of the additive gene effects were contributed by the Cambridge lines. The higher variances generally

observed for the GCA compared with the SCA in the F_1s also means that the additive gene effects are more important for these characters, but non-additive effects also exist. With the reciprocal crosses, it seems that for most characters (except for maturity) the interaction of males x females (SCA) was not important, and this suggests the absence of non-additive gene effects for the flowering and maturity traits in these reciprocals. The best SCA in the F_1s for flowering and maturity stages was observed when the USA inbred lines were used as females (see table G-7 and G-8 for flowering and maturity stages). From these results there is evidence of the importance of additive gene effects for both sets of F_1s and their reciprocals in both dates of sowing, but it still in doubt whether the non-additive genetic effects are of importance or not, except for the maturity stage where both effects were significant for the F_1s and for their reciprocals. Another conclusion to be drawn from this result is that the best specific combinations for these traits appeared in the F_1 set when the USA lines were females and the UK lines were males (eg crosses Pa32 x GBO78 and A556 x GBO78). Reciprocals of these crosses were also the earliest to mature. Thus those good specific combinations (crosses) need to be tested in adequate replications and in different environments. This was one of the reasons behind the repeating of the F_1 experiment in 1989.

The results indicated that the inbred line GBO78 has the best GCA among the other inbred lines for the different traits. It is also has the best SCA with Pa32 followed by Fr43 and A556. Except for the time from silking to maturity, where GBC102 gave the best GCA among the Cambridge lines with the USA lines. GBC102 also has the best SCA with Fr43 and A556 where the lowest heat-unit degrees were obtained for this period.

Taking into consideration our interest in early flowering and early maturity, the good SCA for GBO78 with Pa32, and then with A556 for maturity in the two sowings (blocks) and in both the F_1s and their reciprocals would confirm that crosses Pa32 x GBO78, A556 x GBO78 are superior to the other crosses in the ability to mature earlier. The progenies of cross Pa32 x GBO78 matured even earlier (they

required 148 days; equivalent to 690.8 heat-unit degrees in Gilmore-Rogers method, see table G-8) than the fastest double cross to mature (21B, required 151 day equivalent to 701.7 heat-unit degrees in Gilmore-Rogers method, see table E-15). There were also equal to the fastest S_1 family to mature even though these latter had been selected (3-26A, required 149 days; equivalent to 698.6 Gilmore-Rogers heat-unit degrees to mature, see tables E-15 or E-36) in experiment E (Chapter 5). Both experiments were carried out in the same season in the same location and therefore these direct comparisons are legitimate. The double crosses and the S_1 families derived from them were sown earlier (on the 8th of May 1988) than the single crosses of this experiment (18th May).

Results of the NC2 ANOVA for the Other Agronomic Characters in the 1988 Season.

The characters included were plant height (cm), ear height (cm), grain moisture content (%), and the number of matured kernels per plant.

The NC2 design ANOVA results (in tables G-7) for these traits and the means (in tables G-8 and G-8a) showed that there are a few cases where the differences between the inbred lines in the GCA (M and F items) or in the SCA (M x F interaction) were important. An exception is the GCA of the UK lines for the number of kernels per plant. The Cambridge inbred lines GBC233, GBC100, and GBO78, gave the best GCA with the USA for the number of kernels per plant. However, the differences between these best crosses were not large. From the results of the 1988 season for these traits , it appears that selection for early maturity can be effective and would not cause important changes in the other agronomic characters, although the test for these agronomic chatacters in this season was not sufficient to give a clear idea of their behavior. Thus more tests for these characters will be introduced in 1989 results.

Table G-2. The means for all traits for the original USA and the Cambridge inbred lines. The results are for the 1988 season.

	ER day		SDW gm/plant		HUDs in Gilmore-Rogers method to Boots		65 stage		Silking	
Inbred lines	B1*	B2*	B1	B2	B1	B2	B1	B2	B1	B2
USA lines										
HY2	16.1	11.9	0.037	0.123	562.0	562.3	-	-	-	-
Pa32	12.3	9.3	0.346	0.716	355.4	379.3	468.5	492.0	444.3	464.9
Fr43	13.6	10.3	0.298	0.476	401.4	416.3	561.7	571.0	555.5	553.0
A556	12.9	9.7	0.216	0.442	397.4	412.2	515.3	543.8	500.1	521.8
Fr619	13.8	10.7	0.230	0.486	496.2	445.5	598.5	584.4	594.9	585.2
UK lines										
GBO78	13.2	10.7	0.198	0.340	388.8	399.3	493.2	505.6	472.9	486.3
GBC100	13.3	10.9	0.270	0.572	359.7	387.8	482.1	505.3	472.3	503.9
GBC102	16.0	11.6	0.120	0.430	382.2	395.2	512.6	506.9	502.7	491.0
GBC108	18.5	12.2	0.064	0.170	478.2	449.1	596.5	551.2	577.7	555.1
GBC233	17.4	11.4	0.076	0.326	453.1	423.2	533.5	538.2	567.1	492.6

	HUDs in Gilmore-Rog. to Silk-Mat		Maturity		% H20		K/plant		PH (cm)		EH (cm)	
Inbred lines	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
USA Lines												
HY2	-	-	-	-	-	-	-	-	34.2	59.0	- -	-
Pa32	276.5	249.9	720.8	714.8	35.5	34.8	192	205	139.7	155.8	63.0	68.4
Fr43	205.1	178.1	730.0	718.5	37.1	36.5	154	59	151.8	161.0	62.4	72.6
A556	214.3	191.0	724.8	717.2	34.5	37.5	231	267	150.8	141.0	70.4	68.6
Fr619	-	-	-	-	-	-	-	-	104.0	106.0	41.2	37.8
UK lines												
GBO78	252.0	228.6	724.8	714.8	34.4	35.2	174	72	98.4	105.0	46.0	53.0
GBC100	345.7	212.4	723.4	716.2	32.8	32.6	140	113	117.0	102.0	66.2	46.8
GBC102	228.5	223.0	725.2	714.8	34.47	34.9	232	196	155.2	158.2	66.0	64.2
GBC108	176.3	183.5	730.0	720.4	42.5	43.6	51	44	109.0	112.2	58.3	51.7
GBC233	153.1	222.6	729.0	715.1	35.4	34.5	93	114	92.4	126.0	46.0	58.4

* Means for block 1 and block 2 respectively.

Table G-3. The ANOVA for the inbred lines for all characters scored during the 1988 season.

Source of variation	Emergence Rate Df	MS	F	P	Boots Stage DF	MS	F	P
Bet. Blocks	1	73.0001	73.939	***	1	0	0.000	N.S
Bet. Inbreds	9	4.4996	4.558	*	9	34906	31.821	***
B x Inbreds	-	-	-	-	8	1998	1.822	N.S
Error	9	0.9873	-	-	64	'1097	-	-
Traits	65 Stage of anthesis				Silking Stage			
Bet. Blocks	1	357.5	0.659	N.S	1	313.9	0.362	N.S
Bet. Inbreds	8	15207.6	28.024	***	8	19839.8	22.878	***
B x Inbreds	8	1341.1	2.471	*	8	2578.1	2.973	**
Error	57	542.7	-	-	60	867.2	-	-
Traits	Grain Moisture Content				Number of Kernels / plant			
Bet. Blocks	1	2.564	0.403	N.S	1	12183	1.008	N.S
Bet. Inbreds	7	94.60	14.861	***	7	45826	3.798	**
B x Inbreds	7	4.313	0.678	N.S	7	6644	0.550	N.S
Error	42	6.366	-	-	42	12088	-	-
Traits	Plant Height (cm)				Ear Height (cm)			
Bet. Blocks	1	1358.9	3.280	N.S	1	1.0	0.007	N.S
Bet. Inbreds	9	11518.9	27.800	***	8	987.7	6.442	**
B x Inbreds	9	536.7	1.295	N.S	8	242.3	1.581	N.S
Error	72	414.4	-	-	66	153.3	-	-
Traits	Seedling dry Weight*				Silking to Maturity Stage*			
B1								
Bet. Inbreds	9	0.056428	21.982	***	7	4665.8	7.658	***
Error	39	0.002567	-	-	20	609.3	-	-
B2								
Bet. Inbreds	9	0.15756	12.471	***	7	3130.3	5.031	***
Error	39	0.01263	-	-	22	622.3	-	-
Traits	Maturity Stage*							
B1								
Bet. Inbreds	7	58.063	9.212	***				
Error	20	6.303	-	-				
B2								
Bet. Inbreds	7	21.405	9.319	***				
Error	22	2.297	-	-				

* The blocks were analysed separately because significant differences between blocks were found for these traits.

Table G-4. The ANOVA results for the F_1s for all characters scored during the 1988 season.

Source of variation	Seedling dry weight				Boots stage			
	Df	MS	F	P	DF	MS	F	P
B1								
Bet. F_1s	38	0.014592	2.574	***	38	3616.0	2.155	***
Error	153	0.005670	-	-	156	1678.0	-	-
B2								
Bet. F_1s	38	0.07604	1.999	***	38	2288.8	3.050	***
Error	149	0.03805	-	-	153	750.5	-	-
Traits	65 Stage of anthesis				Silking Stage			
B1								
Bet. F_1s	38	2359.3	6.223	***	38	2738.6	4.699	***
Error	155	379.1	-	-	141	582.8	-	-
B2								
Bet. F_1s	38	3504.7	7.869	***	38	3713.6	7.746	***
Error	150	445.4	-	-	153	479.4	-	-
Traits	Silking to Maturity				Maturity Stage			
B1								
Bet. F_1s	38	1834.1	4.681	**	38	386.88	14.683	***
Error	151	397.2	-	-	151	26.35	-	-
B2								
Bet. F_1s	38	3203.8	7.743	***	38	99.34	5.179	***
Error	151	413.8	-	-	151	19.18	-	-
Traits	Plant Height (cm)				Number of Kernels / plant			
B1								
Bet. F_1s	38	533.4	1.628	**	38	51675	1.868	***
Error	156	327.6	-	-	151	27664	-	-
B2								
Bet. F_1s	38	556.0	2.016	***	38	36207	2.673	***
Error	156	275.7	-	-	151	13544	-	-
Traits	Emergence Rate				Grain Moisture Content %			
Bet. Blocks	1	222.6068	1022.06	***	1	0.39	0.024	N.S
Bet. f_1s	38	0.5202	2.38	**	38	30.48	1.912	***
B x F_1s	-	-	-	-	38	28.06	1.761	**
Error	38	0.2178	-	-	302	15.94	-	-
Traits	Ear Height (cm)							
Bet. Blocks	1	19.0	0.121	***				
Bet. F_1s	38	702.7	4.469	***				
B x F_1s	38	208.2	1.324	N.S				
Error	311	157.2	-	-				

Continued table G-5.
The means for the F_2s progenies for all characters scored during the season 1988.

No	Genotypes of the F_2s	HUDs in Gilmore-Rogers required to Silking		silk-Mat		Maturity		% H2O	
		B1	B2	B1	B2	B1	B2	B1	B2
1	Fr43 x GBO78	523.5	546.2	212.9	187.9	727.3	717.7	35.4	36.6
2	GBO78 x Fr43	506.3	503.0	219.9	214.3	726.2	713.9	37.8	35.7
3	Fr43 x GBC102	544.1	517.2	199.4	219.8	729.1	718.6	35.0	33.1
4	Fr43 x GBC233	481.0	480.6	40.7	229.4	721.6	710.0	34.4	36.8
5	GBC233 x Fr43	454.5	474.2	270.6	236.9	720.2	711.1	35.3	36.5
6	Fr43 x GBC100	47.6	502.5	252.1	201.7	724.6	704.2	35.5	33.2
7	GBC100 x Fr43	492.1	492.3	234.2	224.5	726.2	715.9	37.2	37.8
8	Fr619 x GBC108	532.6	504.1	189.6	209.1	727.7	716.7	35.9	39.6
9	GBC108 x Fr619	484.4	510.2	239.8	208.7	724.2	718.9	35.6	38.1
10	Fr619 x GBC100	483.7	494.6	246.4	223.1	725.2	717.7	34.5	37.0
11	GBC100 x Fr619	549.5	531.1	197.7	228.8	726.7	717.9	35.7	37.7
12	Fr619 x GBC102	485.5	503.0	234.1	216.4	719.7	719.3	35.3	39.9
13	Fr619 x GBC233	519.6	513.6	222.9	211.3	724.8	717.5	31.5	37.7
14	GBC233 x Fr619	531.8	491.1	235.5	231.7	726.2	712.8	39.1	36.1
15	Fr619 x GBO78	512.1	496.3	244.3	220.7	727.5	717.1	34.7	36.4
16	GBO78 x Fr619	509.7	499.3	218.5	217.8	728.2	717.1	35.53	36.1
17	A556 x GBC233	531.1	538.7	218.9	195.5	724.8	711.1	31.0	32.5
18	GBC233 x A556	501.7	442.9	217.1	266.1	718.8	714.8	35.5	34.3
19	A556 x GBC100	521.8	549.1	205.1	188.2	736.3	718.6	35.5	39.8
20	GBC100 x A556	505.7	501.0	211.2	216.6	724.8	716.5	33.9	35.0
21	A556 x GBC108	498.2	516.7	230.5	218.9	724.8	714.9	35.1	35.5
22	GBC108 x A556	514.6	478.8	212.7	234.3	727.4	713.0	35.5	36.2
23	A556 x GBO78	469.8	485.5	252.1	230.5	721.9	716.0	32.3	34.1
24	GBO78 x A556	473.3	445.5	244.5	263.6	717.8	709.1	37.4	36.8
25	A556 x GBC102	549.0	541.0	191.6	190.8	728.6	716.7	36.5	35.4
26	GBC102 x A556	509.7	506.3	213.4	196.1	723.1	718.6	35.9	35.8
27	Pa32 x GBC108	496.7	510.2	226.6	205.8	726.7	717.5	39.0	36.3
28	GBC108 x Pa32	498.4	511.1	230.7	207.9	729.1	718.9	37.4	37.5
29	Pa32 x GBC100	483.3	492.0	240.4	229.5	723.7	715.6	33.7	34.7
30	GBC100 x Pa32	520.8	527.7	213.0	190.5	724.8	718.2	38.3	38.1
31	Pa32 x GBO78	467.5	467.6	248.5	243.6	716.0	711.2	36.3	35.0
32	GBO78 x Pa32	489.3	469.7	237.4	248.5	723.2	712.2	34.6	36.0
33	Pa32 x GBC233	463.0	474.6	259.7	246.8	722.7	714.8	33.6	35.0
34	GBC233 x Pa32	499.6	477.1	245.1	238.0	724.2	715.1	38.5	34.8
35	Pa32 x GBC102	506.7	499.9	221.3	234.1	726.2	716.2	35.4	34.4
36	GBC102 x Pa32	459.0	489.3	270.7	227.4	724.8	716.7	31.2	33.0
37	GBC233 x HY2	598.7	557.1	172.5	162.0	724.1	719.1	37.5	38.2
38	GBC100 x HY2	571.2	539.8	175.6	184.5	730.5	717.9	43.1	40.2
39	GBC108 x HY2	585.0	584.0	163.9	145.5	730.4	720.5	37.0	43.8

Continued table G-5.
The means for the F_2s progenies for all characters scored during the season 1988.

No	Genotypes of the F_2s	HUDs in Gilmore-Rogers required to Silking B1	Silking B2	silk-Mat B1	silk-Mat B2	Maturity B1	Maturity B2	% H2O B1	% H2O B2
1	Fr43 x GBO78	523.5	546.2	212.9	187.9	727.3	717.7	35.4	36.6
2	GBO78 x Fr43	506.3	503.0	219.9	214.3	726.2	713.9	37.8	35.7
3	Fr43 x GBC102	544.1	517.2	199.4	219.8	729.1	718.6	35.0	33.1
4	Fr43 x GBC233	481.0	480.6	40.7	229.4	721.6	710.0	34.4	36.8
5	GBC233 x Fr43	454.5	474.2	270.6	236.9	720.2	711.1	35.3	36.5
6	Fr43 x GBC100	47.6	502.5	252.1	201.7	724.6	704.2	35.5	33.2
7	GBC100 x Fr43	492.1	492.3	234.2	224.5	726.2	715.9	37.2	37.8
8	Fr619 x GBC108	532.6	504.1	189.6	209.1	727.7	716.7	35.9	39.6
9	GBC108 x Fr619	484.4	510.2	239.8	208.7	724.2	718.9	35.6	38.1
10	Fr619 x GBC100	483.7	494.6	246.4	223.1	725.2	717.7	34.5	37.0
11	GBC100 x Fr619	549.5	531.1	197.7	228.8	726.7	717.9	35.7	37.7
12	Fr619 x GBC102	485.5	503.0	234.1	216.4	719.7	719.3	35.3	39.9
13	Fr619 x GBC233	519.6	513.6	222.9	211.3	724.8	717.5	31.5	37.7
14	GBC233 x Fr619	531.8	491.1	235.5	231.7	726.2	712.8	39.1	36.1
15	Fr619 x GBO78	512.1	496.3	244.3	220.7	727.5	717.1	34.7	36.4
16	GBO78 x Fr619	509.7	499.3	218.5	217.8	728.2	717.1	35.53	36.1
17	A556 x GBC233	531.1	538.7	218.9	195.5	724.8	711.1	31.0	32.5
18	GBC233 x A556	501.7	442.9	217.1	266.1	718.8	714.8	35.5	34.3
19	A556 x GBC100	521.8	549.1	205.1	188.2	736.3	718.6	35.5	39.8
20	GBC100 x A556	505.7	501.0	211.2	216.6	724.8	716.5	33.9	35.0
21	A556 x GBC108	498.2	516.7	230.5	218.9	724.8	714.9	35.1	35.5
22	GBC108 x A556	514.6	478.8	212.7	234.3	727.4	713.0	35.5	36.2
23	A556 x GBO78	469.8	485.5	252.1	230.5	721.9	716.0	32.3	34.1
24	GBO78 x A556	473.3	445.5	244.5	263.6	717.8	709.1	37.4	36.8
25	A556 x GBC102	549.0	541.0	191.6	190.8	728.6	716.7	36.5	35.4
26	GBC102 x A556	509.7	506.3	213.4	196.1	723.1	718.6	35.9	35.8
27	Pa32 x GBC108	496.7	510.2	226.6	205.8	726.7	717.5	39.0	36.3
28	GBC108 x Pa32	498.4	511.1	230.7	207.9	729.1	718.9	37.4	37.5
29	Pa32 x GBC100	483.3	492.0	240.4	229.5	723.7	715.6	33.7	34.7
30	GBC100 x Pa32	520.8	527.7	213.0	190.5	724.8	718.2	38.3	38.1
31	Pa32 x GBO78	467.5	467.6	248.5	243.6	716.0	711.2	36.3	35.0
32	GBO78 x Pa32	489.3	469.7	237.4	248.5	723.2	712.2	34.6	36.0
33	Pa32 x GBC233	463.0	474.6	259.7	246.8	722.7	714.8	33.6	35.0
34	GBC233 x Pa32	499.6	477.1	245.1	238.0	724.2	715.1	38.5	34.8
35	Pa32 x GBC102	506.7	499.9	221.3	234.1	726.2	716.2	35.4	34.4
36	GBC102 x Pa32	459.0	489.3	270.7	227.4	724.8	716.7	31.2	33.0
37	GBC233 x HY2	598.7	557.1	172.5	162.0	724.1	719.1	37.5	38.2
38	GBC100 x HY2	571.2	539.8	175.6	184.5	730.5	717.9	43.1	40.2
39	GBC108 x HY2	585.0	584.0	163.9	145.5	730.4	720.5	37.0	43.8

Table G-6. The ANOVA results for the F_2s for all characters scored during the 1988 season.

Source of variation	Emergence Rate Df	MS	F	P	Boots Stage DF	MS	F	P
Bet. Blocks	1	371.1230	544.168	***	1	1015	0.885	N.S
Bet. f_2s	38	1.8371	2.694	***	38	7832	6.828	***
B x F_2s	-	-	-	-	38	1431	1.247	N.S
Error	38	0.6820	-	-	295	1147	-	-
Traits	65 Stage of flowering				silking Stage			
Bet. Blocks	1	392.9	0.416	N.S	1	1077	0.977	N.S
Bet. f_2s	38	5359.4	5.678	***	38	8669	7.864	***
B x F_2s	38	1406.4	1.490	*	38	1220	1.106	N.S
Error	271	944.0	-	-	285	1102	-	-
Traits	Maturity Stage				Plant Height			
Bet. Blocks	1	2505	1.685	N.S	1	667.6	1.060	N.S
Bet. f_2s	38	1691	1.138	N.S	38	2059.0	3.269	***
B x F_2s	37	1814	1.221	N.S	38	730.3	1.159	N.S
Error	220	1486	-	-	310	629.9	-	-
Traits	Ear height (cm)							
Bet. Blocks	1	17.8	0.079	N.S				
Bet. f_2s	38	805.9	3.586	***				
B x F_2s	38	306.7	1.365	N.s				
Error	300	224.7	-	-				
Traits*	Seedling Dry weight				Silking to Maturity stage			
B1								
Bet. F_2s	38	0.011854	2.493	***	37	3982.5	5.044	***
Error	152	0.004756	-	-	107	789.6	-	-
B2								
Bet. F_2s	38	0.08724	3.344	***	38	3760.7	6.326	***
Error	156	0.02609	-	-	113	594.5	-	-
Traits*	Grain Moisture Content %				Number of Kernel / plant			
B1								
Bet. F_2s	37	26.57	2.387	***	37	21052	2.296	***
Error	107	11.13	-	-	107	9168	-	-
B2								
Bet. F_2s	38	25.85	1.962	***	38	22225	2.017	***
Error	116	13.17	-	-	116	11017	-	-

* Initial ANOVA indicated significant differences among blocks for these traits (B1 and B2 were sown in different dates).

Table G-7. The North Carolina 2 (NC2) ANOVA for the F_1s crosses and for their reciprocals; results of the 1988 season for the different traits studied.

Source of Varia and Traits	F_1s (USA lines (F)				Reciprocals (UK lines (F)			
	Df	MS	F	P	DF	MS	F	P
Emergence R								
Blocks	1	99.7225	290.900	***	1	93.2978	-	***
Bet. Males	3	0.8779	5.772	**	3	0.1925	0.779	N.S
Bet. Females	3	0.6901	4.534	*	3	1.2419	5.025	*
M x F	9	0.3665	2.409	N.S	9	0.4238	1.715	N.S
Error	15	0.1521	-	-	15	0.2472	-	-
Seedling DW.								
B1*								
Bet. Males	3	0.017188	2.891	*	3	0.017641	2.580	*
Bet. Females	3	0.017790	2.993	*	3	0.007364	1.077	N.S
M x F	9	0.006053	1.018	N.S	9	0.008151	1.192	N.S
Error	62	0.005944	-	-	62	0.006837	-	-
B2*								
Bet. Males	3	0.01222	0.402	N.S	3	0.08285	2.592	N.S
Bet. Females	3	0.03017	0.990	N.S	3	0.01306	0.409	N.S
M x F	9	0.10749	3.534	**	9	0.08043	2.516	*
Error	62	0.03041	-	-	60	0.03196	-	-
Boots								
B1								
Bet. Males	3	6715	2.011	N.S	3	439.9	0.831	N.S
Bet. Females	3	522	0.156	N.S	3	2585.1	4.881	***
M x F	9	4705	1.409	N.S	9	1781.0	3.363	***
Error	64	3338	-	-	62	529.6	-	-
B2								
Bet. Males	3	4989.0	10.511	***	3	432	0.351	N.S
Bet. Females	3	1062.5	2.239	N.S	3	3703	3.012	*
M x F	9	1747.6	3.678	***	9	1392	1.132	N.S
Error	64	474.6	-	-	62	1230	-	-
65 Stage								
B1								
Bet. Males	3	2936.1	9.849	***	3	928.9	1.923	N.S
Bet. Females	3	1375.0	4.613	**	3	3288.9	6.809	***
M x F	9	1022.9	3.431	**	9	843.6	1.747	N.S
Error	63	298.1	-	-	61	483.0	-	-
B2								
Bet. Males	3	9121.4	24.600	***	3	678.2	1.157	N.S
Bet. Females	3	2545.8	6.866	***	3	4183.6	7.136	***
M x F	9	2258.3	6.090	***	9	1061.0	1.810	N.S
Error	63	370.8	-	-	61	586.3	-	-

* Preliminary ANOVA indicated significant differences among blocks for these traits (B1 and B2 were sown in different dates).

Continued Table G-7. The North Carolina 2 (NC2) ANOVA for the F_1s crosses and for their reciprocals; result of the 1988 season for the different traits studied.

Source of Varia and Traits	F_1s (USA lines (F)				Reciprocals (UK lines (F)			
	Df	MS	F	P	DF	MS	F	P
Silking								
B1								
Bet. Males	3	4512.9	7.008	***	3	873.9	1.405	N.S
Bet. Females	3	2661.1	4.132	*	3	5808.5	9.335	***
M x F	9	1477.6	2.294	*	9	886.2	1.424	N.S
Error	62	644.0	-	-	63	622.2	-	-
B2								
Bet. Males	3	11572.5	33.651	***	3	334.1	0.481	N.S
Bet. Females	3	2315.0	6.732	***	3	7980.2	11.497	***
M x F	9	1867.8	5.431	***	9	391.6	0.564	N.S
Error	62	343.9	-	-	63	694.1	-	-
Silk.- Mat.								
B1								
Bet. Males	3	3614.3	13.535	***	3	325.7	0.614	N.S
Bet. Females	3	1241.9	4.651	*	3	3072.4	5.794	**
M x F	9	836.8	3.134	***	9	686.1	1.294	N.S
Error	58	267.0	-	-	61	530.3	-	-
B2								
Bet. Males	3	9722.8	31.538	***	3	183.0	0.330	N.S
Bet. Females	3	2278.4	7.391	***	3	7113.4	12.822	***
M x F	9	1990.9	6.458	***	9	391.0	0.705	N.S
Error	58	308.3	-	-	61	554.8	-	-
Maturity								
B1								
Bet. Males	3	762.54	17.530	***	3	310.97	17.187	***
Bet. Females	3	431.68	9.924	***	3	1259.26	69.597	***
M x F	9	294.15	6.762	***	9	312.38	17.264	***
Error	58	43.50	-	-	61	18.09	-	-
B2								
Bet. Males	3	405.65	22.177	***	3	70.61	2.766	*
Bet. Females	3	99.21	5.424	**	3	414.98	8.421	***
M x F	9	50.61	2.767	*	9	67.50	2.644	*
Error	58	18.29	-	-	61	25.53	-	-
PH (cm)								
B1								
Bet. Males	3	201.7	0.710	N.S	3	200.5	0.879	N.S
Bet. Females	3	271.2	0.955	N.S	3	313.7	1.375	N.S
M x F	9	234.0	0.824	N.S	9	411.8	1.806	N.S
Error	59	284.0	-	-	61	228.1	-	-
B2								
Bet. Males	3	512.5	2.765	*	3	155.3	0.652	N.S
Bet. Females	3	174.8	0.943	N.S	3	439.1	1.769	N.S
M x F	9	565.9	3.053	**	9	471.0	1.896	N.S
Error	59	185.3	-	-	61	248.3	-	-

Continued Table G-7. The North Carolina 2 (NC2) ANOVA for the F_1s crosses and for their reciprocals; result of the 1988 season for the different traits studied.

Source of Varia and Traits	F_1s (USA lines ♀ F)				Reciprocals (UK lines ♀ F)			
	Df	MS	F	P	DF	MS	F	P
EH (cm)								
B1								
Bet. Males	3	749.4	4.532	**	3	196.0	1.237	N.S
Bet. Females	3	224.4	1.357	N.S	3	1022.8	6.458	***
M x F	9	388.4	2.349	*	9	202.4	1.278	N.S
Error	59	165.4	-	-	61	158.4	-	-
B2								
Bet. Males	3	105.7	0.631	N.S	3	455	2.337	N.S
Bet. Females	3	238.7	1.424	N.S	3	362.3	1.858	N.S
M x F	9	212.9	1.270	N.S	9	181.5	0.931	N.S
Error	59	167.6	-	-	61	194.9	-	-
% H2O								
B1								
Bet. Males	3	55.86	1.011	N.S	3	4.775	0.990	N.S
Bet. Females	3	46.72	0.846	N.S	3	0.767	0.159	N.S
M x F	9	74.31	1.345	N.S	9	5.865	1.216	N.S
Error	59	55.24	-	-	61	4.822	-	-
B2								
Bet. Males	3	22.245	4.008	*	3	36.046	4.012	*
Bet. Females	3	2.363	0.426	N.S	3	24.147	2.688	N.S
M x F	9	11.981	2.159	N.S	9	22.697	2.256	*
Error	59	5.550	-	-	61	8.984	-	-
Kernels no.								
B1								
Bet. Males	3	147009	4.588	***	3	12279	0.525	N.S
Bet. Females	3	5325	0.166	N.S	3	195043	8.345	***
M x F	9	58449	1.824	N.S	9	50272	2.151	N.S
Error	59	32039	-	-	61	23371	-	-
B2								
Bet. Males	3	140915	11.574	***	3	66108	5.612	**
Bet. Females	3	8558	0.703	N.S	3	102790	8.726	***
M x F	9	17151	1.403	N.S	9	45480	3.861	***
Error	59	12175	-	-	61	11779	-	-

Table 6.8 Means obtained from the NC2 mating of the USA and the British grain maize inbred lines for the F_1s and their reciprocals (F_1R) for all traits studied in the experiment of 1988.

Emergence rate. (45 kernels sown in each block)

Inbred lines		Single crosses means									
	USA	PA32		Fr43		A556		Fr619		Mean	
UK	Blk	F_1*	F_1R*	F_1	F_1R	F_1	F_1R	F_1	F_1R	F_1	F_1R
GBO78	B1	12.13	12.60	12.06	13.00	12.60	13.40	14.10	12.30	12.72	12.82
	B2	9.35	8.53	9.53	9.50	9.40	9.66	10.40	9.85	9.67	9.38
GBC100	B1	13.86	14.33	13.60	13.66	13.85	13.73	14.86	13.80	14.04	13.88
	B2	9.86	10.80	9.70	10.29	9.46	9.53	10.53	10.13	9.89	10.18
GBC102	B1	13.46	13.54	13.15	13.15	14.00	13.10	13.28	13.28	13.47	13.26
	B2	9.85	9.75	9.93	9.93	10.46	9.71	10.06	9.93	10.07	9.86
GBC233	B1	14.20	13.20	13.06	14.20	13.33	13.20	13.46	13.06	13.52	12.91
	B2	9.93	9.73	10.13	9.73	9.92	9.71	10.00	10.00	9.99	9.75
Means	B1	13.41	12.92	12.97	13.50	13.44	13.36	13.92	13.11	13.43	13.21
	B2	9.75	9.70	9.82	9.86	9.81	9.66	10.24	10.01	9.90	9.64

In F_1s the USA lines were used as females and the Cambridge lines as males. F_1R is the reciprocal crosses of F_1.

Seedling dry weight (gm per plant) (SDW)

Inbred lines		Single crosses means									
	USA	PA32		Fr43		A556		Fr619		Mean	
UK	Blk	F_1*	F_1R*	F_1	F_1R	F_1	F_1R	F_1	F_1R	F_1	F_1R
GBO78	B1	0.40	0.35	0.42	0.39	0.30	0.36	0.41	0.38	0.38	0.37
	B2	0.95	0.88	0.88	0.69	0.79	0.65	0.66	0.82	0.82	0.76
GBC100	B1	0.28	0.39	0.33	0.43	0.30	0.33	0.38	0.32	0.32	0.36
	B2	0.77	0.59	0.70	0.91	0.92	0.94	0.69	0.80	0.77	0.81
GBC102	B1	0.35	0.38	0.31	0.31	0.25	0.26	0.36	0.36	0.32	0.33
	B2	0.82	0.57	0.87	0.87	0.48	0.78	0.90	0.90	0.77	0.78
GBC233	B1	0.35	0.39	0.33	0.41	0.33	0.34	0.33	0.31	0.33	0.36
	B2	0.81	0.71	0.69	0.85	0.77	0.74	0.89	0.72	0.79	0.75
Mean	B1	0.34	0.38	0.35	0.38	0.29	0.32	0.37	0.34	0.34	0.36
	B2	0.84	0.69	0.79	0.83	0.74	0.78	0.78	0.81	0.79	0.78

In F_1s the USA lines were used as females and the Cambridge lines as males. F_1R is the reciprocal crosses of F_1.

Continued Table G-8.

Mean of heat-unit degrees required to the boot stage of tasselling.

Inbred lines		Single crosses means								Mean	
		PA32		Fr43		A556		Fr619			
UK	Blk	F_1*	F_1R*	F_1	F_1R	F_1	F_1R	F_1	F_1R	F_1	F_1R
GBO78	B1	304.3	329.7	339.7	341.2	340.1	324.5	356.8	350.7	335.2	336.5
.	B2	331.9	334.7	345.2	348.7	327.7	348.7	351.5	374.7	341.6	351.7
GBC100	B1	340.3	364.3	344.0	343.2	340.0	378.0	359.7	369.7	346.0	363.8
.	B2	379.1	377.0	357.2	352.8	370.7	357.1	381.4	385.8	370.6	368.2
GBC102	B1	439.4	339.3	388.3	388.3	355.9	339.9	328.8	327.9	377.9	348.9
.	B2	347.9	399.8	385.8	385.8	416.7	381.0	357.1	357.1	376.9	380.9
GBC233	B1	336.7	338.8	355.3	340.5	350.3	343.9	347.5	358.0	347.5	345.3
.	B2	350.3	344.7	363.7	348.1	355.4	361.2	353.5	361.9	355.7	354.0
.Mean	B1	355.2	343.0	356.8	353.3	346.6	346.6	348.0	351.6	351.6	348.6
.	B2	352.3	364.1	361.5	358.8	370.1	362.0	360.9	369.9	361.2	363.7

In F_1s the USA lines were used as females and the Cambridge lines as males. F_1R is the reciprocal crosses of F_1.

Mean of heat-unit degrees required to half way anthesis (65 stage).

Inbred lines		Single crosses means								Mean	
		PA32		Fr43		A556		Fr619			
UK	Blk	F_1*	F_1R*	F_1	F_1R	F_1	F_1R	F_1	F_1R	F_1	F_1R
GBO78	B1	453.3	457.2	467.3	474.2	477.4	455.8	489.9	469.4	471.9	464.2
.	B2	461.6	462.0	481.3	474.7	468.3	477.9	464.7	486.8	469.0	475.9
GBC100	B1	470.3	482.1	465.6	473.3	476.3	493.6	478.7	482.4	472.8	482.9
.	B2	489.1	501.7	467.7	458.4	494.6	482.6	507.3	498.6	489.7	485.3
GBC102	B1	479.8	480.2	524.4	524.4	503.6	490.6	475.4	475.4	495.8	492.7
.	B2	484.0	492.3	517.2	517.2	569.9	514.2	494.6	434.6	516.4	504.6
GBC233	B1	457.8	460.3	470.1	473.8	471.0	469.0	482.2	476.9	470.4	472.0
.	B2	465.8	460.3	482.9	470.8	476.4	474.5	470.9	483.4	474.0	472.3
.Mean	B1	465.3	431.8	481.8	486.5	482.2	477.3	481.5	476.0	477.7	477.4
.	B2	475.1	477.1	487.3	480.3	502.3	487.3	484.4	491.4	487.3	484.9

In F_1s the USA lines were used as females and the Cambridge lines as males. F_1R is the reciprocal crosses of F_1.

Continued Table G-8.

Mean of heat-unit degrees required to silking stage.

Inbred lines		Single crosses means									
	USA	PA32		Fr43		A556		Fr619		Mean	
UK	Blk	F_1*	F_1R*	F_1	F_1R	F_1	F_1R	F_1	F_1R	F_1	F_1R
GBO78	B1	411.9	432.0	446.4	449.2	448.7	432.9	465.7	453.1	443.2	439.6
	B2	436.1	433.2	461.5	451.3	442.2	439.8	440.6	462.3	445.1	447.7
GBC100	B1	447.8	458.1	445.7	454.5	447.9	467.5	463.5	472.1	451.2	463.0
	B2	456.5	468.1	451.7	449.5	468.2	452.3	477.7	467.6	463.5	459.4
GBC102	B1	458.9	465.2	505.4	505.4	485.5	488.0	463.2	463.2	479.4	480.4
	B2	462.5	482.1	499.2	499.2	547.2	490.5	486.9	486.9	499.0	489.7
GBC233	B1	445.8	449.0	443.4	455.2	485.7	450.5	460.8	463.9	458.9	456.6
	B2	446.1	443.5	461.4	443.5	446.0	451.2	452.1	449.9	451.4	447.0
Mean	B1	441.1	451.1	460.2	466.1	467.0	457.5	463.3	463.1	457.9	459.4
	B2	450.3	452.7	468.5	460.9	475.9	458.5	464.3	466.7	464.7	460.9

In F_1s the USA lines were used as females and the Cambridge lines as males. F_1R is the reciprocal crosses of F_1.

Mean of heat-unit degrees required for the period from silking to maturity..

Inbred lines		Single crosses means									
	USA	PA32		Fr43		A556		Fr619		Mean	
UK	Blk	F_1*	F_1R*	F_1	F_1R	F_1	F_1R	F_1	F_1R	F_1	F_1R
GBO78	B1	278.9	264.4	276.2	273.3	258.4	268.8	268.6	267.1	270.5	268.4
	B2	263.8	269.6	250.1	260.3	261.3	263.9	275.9	252.3	262.8	261.5
GBC100	B1	272.4	265.1	283.3	261.1	271.7	257.4	261.3	250.3	272.2	258.5
	B2	255.0	246.8	262.3	269.2	246.6	262.3	238.9	249.5	250.7	257.0
GBC102	B1	265.9	256.5	220.9	220.9	229.2	230.9	261.6	261.6	244.4	242.5
	B2	252.3	233.9	218.6	218.6	165.3	216.6	230.5	230.5	216.7	224.9
GBC233	B1	277.5	274.3	275.5	268.1	258.8	272.7	272.2	261.0	271.0	269.0
	B2	268.8	271.3	251.8	271.3	267.2	259.6	267.8	264.9	263.9	266.8
Mean	B1	273.7	265.1	264.0	255.9	254.5	257.5	265.9	260.0	264.5	259.6
	B2	260.0	255.4	245.7	254.9	235.1	250.7	253.3	249.3	248.5	252.6

In F_1s the USA lines were used as females and the Cambridge lines as males. F_1R is the reciprocal crosses of F_1.

Continued Table G-8.

Mean of heat-unit degrees required from sowing to maturity stage.

Inbred lines		Single crosses means									
	USA	PA32		Fr43		A556		Fr619		Mean	
UK	Blk	F_1*	F_1R*	F_1	F_1R	F_1	F_1R	F_1	F_1R	F_1	F_1R
GBO78	B1	690.8	696.4	722.6	722.6	707.2	692.7	722.2	720.2	710.7	708.1
.	B2	699.9	706.7	711.64	711.6	703.4	703.6	712.8	714.84	706.9	709.4
GBC100	B1	720.2	723.2	722.0	721.9	719.5	724.8	724.8	722.4	721.7	723.1
.	B2	711.5	714.8	714.8	705.8	714.8	714.8	716.6	717.1	714.4	713.1
GBC102	B1	724.8	721.6	726.3	726.3	724.8	726.2	724.8	724.8	725.2	7245.7
.	B2	714.8	715.9	717.8	717.8	720.4	717.6	717.4	717.4	717.6	717.4
GBC233	B1	723.2	723.2	718.9	723.2	712.6	723.2	724.8	724.8	719.9	723.6
.	B2	714.8	714.8	713.2	714.8	713.2	710.8	714.8	714.8	714.0	713.8
Mean	B1	714.8		716.1	722.4	723.5	716.0	716.7	724.2	723.1	719.4
.	B2	710.3	713.1	714.4	712.5	712.9	711.7	715.4	716.0	713.3	713.3

In F_1s the USA lines were used as females and the Cambridge lines as males. F_1R is the reciprocal crosses of F_1.

Mean of number of day required from sowing to maturity stage.

Inbred lines		Single crosses means									
	USA	PA32		Fr43		A556		Fr619		Mean	
UK	Blk	F_1*	F_1R*	F_1	F_1R	F_1	F_1R	F_1	F_1R	F_1	F_1R
GBO78	B1	148.4	150.4	162.2	162.2	156.0	149.6	162.7	161.2	157.3	155.8
.	B2	150.0	153.4	157.4	157.2	151.4	151.8	155.7	161.0	153.6	155.8
GBC100	B1	163.4	164.6	163.5	165.7	162.5	165.4	162.4	164.4	164.4	165.0
.	B2	156.8	159.8	158.7	153.2	159.8	159.2	169.2	167.2	161.1	159.8
GBC102	B1	168.2	163.4	174.8	174.8	173.9	168.2	169.0	169.0	171.4	168.8
.	B2	163.0	165.2	170.8	170.8	173.9	168.5	169.0	169.0	169.2	168.3
GBC233	B1	163.4	163.0	163.4	162.8	159.4	162.4	164.2	170.8	162.6	164.7
.	B2	158.0	157.2	161.0	158.4	156.2	156.0	161.5	160.8	159.1	158.1
Mean	B1	160.8	160.3	165.4	166.3	162.9	161.4	164.5	166.3	163.9	163.6
.	B2	156.9	158.9	161.9	159.9	160.3	158.8	163.3	164.5	160.7	160.5

In F_1s the USA lines were used as females and the Cambridge lines as males. F_1R is the reciprocal crosses of F_1.

Continued Table G-8.

Mean of number of kernels per plant.

Inbred lines		Single crosses means									
	USA	PA32		Fr43		A556		Fr619		Mean	
UK	Blk	F_1*	F_1R*	F_1	F_1R	F_1	F_1R	F_1	F_1R	F_1	F_1R
GBO78	B1	378	311	391	517	308	498	408	419	373	437
.	B2	358	383	367	405	342	454	399	363	366	401
GBC100	B1	386	392	458	297	347	247	512	279	426	304
.	B2	384	387	300	497	274	295	385	206	336	346
GBC102	B1	394	218	138	138	308	250	304	304	286	228
.	B2	300	314	200	200	146	250	191	191	209	239
GBC233	B1	425	455	655	376	523	306	352	336	489	418
.	B2	393	292	384	585	448	343	418	389	411	402
Mean	B1	398	344	411	382	372	325	394	335	394	347
.	B2	334	319	313	422	302	336	349	287	330	347

In F_1s the USA lines were used as females and the Cambridge lines as males. F_1R is the reciprocal crosses of F_1.

Mean of plant height (cm).

Inbred lines		Single crosses means									
	USA	PA32		Fr43		A556		Fr619		Mean	
UK	Blk	F_1*	F_1R*	F_1	F_1R	F_1	F_1R	F_1	F_1R	F_1	F_1R
.GBO78	B1	155.6	153.0	172.4	177.0	162.6	168.8	177.0	161.2	166.9	165.0
.	B2	154.4	161.6	168.0	147.2	153.4	159.2	155.7	160.8	157.9	157.2
GBC100	B1	161.0	177.0	157.2	156.5	155.6	167.2	165.0	169.0	159.7	167.0
.	B2	164.4	178.6	137.7	153.7	163.4	158.2	147.6	169.0	153.3	164.9
GBC102	B1	162.4	152.4	174.8	174.8	161.7	155.0	156.2	156.2	163.8	159.6
.	B2	155.8	156.4	173.2	173.2	157.7	146.2	153.4	153.4	160.0	157.3
GBC233	B1	154.8	158.0	163.0	160.4	166.0	162.4	160.5	157.4	161.1	159.5
.	B2	156.6	148.4	136.0	154.6	153.2	156.2	148.7	156.0	148.6	153.8
.Mean	B1	158.4	160.1	166.9	167.2	161.5	163.3	164.7	161.0	162.9	162.9
.	B2	157.8	161.2	153.7	157.2	156.9	155.0	151.4	159.8	155.0	158.3

In F_1s the USA lines were used as females and the Cambridge lines as males. F_1R is the reciprocal crosses of F_1.

Continued Table G-8.

Mean of ear height (cm).

Inbred lines		Single crosses means									
	USA	PA32		Fr43		A556		Fr619		Mean	
UK	Blk	F_1*	F_1R*	F_1	F_1R	F_1	F_1R	F_1	F_1R	F_1	F_1R
GBO78	B1	74.8	69.0	79.9	83.4	59.0	78.0	79.5	72.5	73.3	75.5
.	B2	69.8	86.2	74.6	74.6	63.6	79.2	63.3	65.7	67.8	76.4
GBC100	B1	67.0	81.8	75.7	67.7	64.4	76.0	67.4	68.8	68.6	73.8
.	B2	82.8	86.6	66.2	68.0	71.8	71.2	61.0	66.4	70.5	73.0
GBC102	B1	59.8	63.0	64.4	64.4	56.7	55.0	56.4	56.4	59.3	59.7
.	B2	66.6	66.6	72.0	72.0	73.0	65.0	62.4	62.4	68.5	66.5
GBC233	B1	62.4	62.6	72.0	72.6	87.4	79.4	61.7	64.8	70.9	69.8
.	B2	64.8	66.2	57.2	75.2	71.4	73.0	66.2	65.2	64.9	69.9
Mean	B1	66.0	69.1	68.0	72.3	66.9	72.1	66.3	65.6	68.0	69.8
.	B2	71.0	76.4	67.5	72.4	69.9	72.1	63.2	64.9	67.9	71.5

In F_1s the USA lines were used as females and the Cambridge lines as males. F_1R is the reciprocal crosses of F_1.

Mean of grain moisture content (% H2O).

Inbred lines		Single crosses means									
	USA	PA32		Fr43		A556		Fr619		Mean	
UK	Blk	F_1*	F_1R*	F_1	F_1R	F_1	F_1R	F_1	F_1R	F_1	F_1R
GBO78	B1	35.48	33.46	33.72	33.40	45.90	36.16	35.77	33.47	37.72	34.12
.	B2	32.98	33.50	35.04	33.64	32.32	35.24	33.87	36.57	33.55	35.24
GBC100	B1	34.02	33.08	34.75	35.70	34.30	33.00	33.60	34.92	34.17	34.17
.	B2	35.64	34.48	34.87	32.60	34.76	31.90	36.10	36.58	35.34	33.89
GBC102	B1	33.56	33.14	34.90	34.90	34.61	33.32	33.60	33.96	34.26	33.83
.	B2	33.86	34.56	36.35	36.32	38.86	36.17	34.84	34.84	35.97	35.47
GBC233	B1	33.66	33.84	34.02	34.24	33.34	33.88	33.45	33.22	35.87	33.79
.	B2	35.52	33.14	35.02	36.38	33.10	27.94	34.17	35.22	34.45	33.17
Mean	B1	34.18	33.83	36.60	34.56	37.04	34.09	34.20	33.89	35.50	33.98
.	B2	34.50	33.92	35.31	35.23	34.76	32.81	34.76	35.80	34.83	34.44

In F_1s the USA lines were used as females and the Cambridge lines as males. F_1R is the reciprocal crosses of F_1.

Table G-8a. Estimate of male (g_i) and female (g_j) parents GCA and their SCA (S_{ij}) effects for the F_1 generation obtained from the NC2 mating between the USA and the British inbred lines of grain maize for all the traits studied in the experiment of 1988. (results were obtained from the means in table G-8 by using the formula in page 190). All symbols have the same meaning as in table G-8.

Estimate of the GCA and SCA effects for emergence time rate (days) (ER).

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	B1	-0.57	-0.20	-0.13	0.89	-0.71
	B2	-0.17	-0.06	-0.18	0.39	-0.23
GBC100	B1	-0.16	0.02	-0.20	0.33	0.61
	B2	0.12	-0.11	-.34	0.30	-0.01
GBC102	B1	0.01	0.14	0.52	-0.68	0.04
	B2	-0.07	-0.06	0.48	-0.38	0.17
GBC233	B1	0.71	0.00	-0.20	-0.55	0.09
	B2	0.09	0.22	0.02	-0.33	0.09
GCA (g_j)	B1	-0.02	-0.46	0.01	0.49	-
	B2	-0.15	-0.08	-0.09	0.34	-

Estimate of the GCA and SCA effects for seedling dry weight (gm per seedling).

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	B1	0.02	0.03	-0.03	0.00	0.04
	B2	0.08	0.06	-0.08	-0.15	0.03
GBC100	B1	-0.04	0.00	0.03	0.03	-0.02
	B2	-0.05	-0.07	0.20	-0.07	-0.02
GBC102	B1	0.03	-0.02	-0.02	0.01	-0.02
	B2	0.00	0.10	-0.24	0.14	-0.02
GBC233	B1	0.02	-0.01	-0.01	-0.03	-0.01
	B2	-0.03	-0.10	0.03	0.11	0.00
GCA (g_j)	B1	0.00	0.01	-0.05	0.03	-
	B2	0.05	0.00	-0.05	-0.01	-

Estimate of the GCA and SCA effects for boots stage of tasselling (HUD Rog.) for the F_1.

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	B1	-34.5	-0.7	9.9	25.2	-16.4
	B2	-0.8	3.3	-12.8	10.2	-19.6
GBC100	B1	-9.3	-7.2	-1.0	17.3	-5.6
	B2	17.4	-13.7	-8.8	11.1	9.4
GBC102	B1	57.9	5.2	-17.0	-46.3	26.3
	B2	-20.1	8.6	20.3	-19.5	15.7
GBC233	B1	-14.4	4.1	7.8	3.6	-4.1
	B2	3.5	7.7	-9.2	-1.9	-5.5
GCA (g_i)	B1	3.6	5.2	-5.0	-3.6	0.2
	B2	-8.9	0.3	8.9	-0.3	0.0

Estimate of the GCA and SCA effects for 65 stage of male flowering (HUD Rog.) for the F_1.

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	B1	-6.2	-8.7	1	14.2	-5.8
	B2	4.8	12.3	-15.7	-1.4	-18.3
GBC100	B1	9.9	-11.3	-1.0	2.1	-4.9
	B2	11.6	-22.0	-10.1	20.5	2.4
GBC102	B1	-3.6	24.5	3.3	-24.2	18.1
	B2	-20.2	0.8	38.5	-18.9	29.1
GBC233	B1	-0.2	-4.4	-3.9	8.0	-7.3
	B2	4.0	8.9	-12.6	0.2	-13.3
GCA (g_i)	B1	-12.4	4.1	4.5	3.8	-
	B2	-12.2	0.0	15.0	-2.9	-

Estimate of the GCA and SCA effects for silking stage (HUD Rog.) for the F_1.

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	B1	-14.8	0.9	-3.6	17.1	-14.7
	B2	5.4	12.6	-14.1	-4.1	-19.6
GBC100	B1	13.1	-7.8	-12.4	9.0	-6.7
	B2	7.4	-15.6	-6.5	-22.5	-1.2
GBC102	B1	-2.9	24.8	-1.9	-20.5	20.4
	B2	-22.1	-3.6	37.0	-11.7	34.3
GBC233	B1	3.4	-17.8	17.7	-3.5	1.0
	B2	9.4	6.2	-16.6	1.1	-13.3
GCA (g_j)	B1	-16.5	2.3	9.1	5.4	-
	B2	-14.4	3.8	11.2	-0.4	-

Estimate of the GCA and SCA effects for the period from silking to maturity (HUD Rog.) for the F_1.

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	B1	-0.8	6.2	-2.1	-3.3	6.0
	B2	-2.2	-9.9	11.9	8.3	14.3
GBC100	B1	-9.2	11.6	9.5	-12.3	7.7
	B2	-7.2	14.4	9.3	-16.6	2.2
GBC102	B1	12.3	-23.0	-5.2	15.8	-20.1
	B2	24.1	4.7	-38.0	9.0	-31.8
GBC233	B1	-2.7	5.0	-2.2	-0.2	6.5
	B2	-6.6	-9.3	16.7	-0.9	15.4
GCA (g_j)	B1	9.2	-0.5	-10.0	1.4	-
	B2	11.5	-2.8	-13.4	4.8	-

Estimate of the GCA and SCA effects for maturity stage (HUD Rog.) for the F_1.

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	B1	-15.3	8.9	-0.1	6.6	-8.7
	B2	-4.0	3.6	-3.1	3.8	-6.4
GBC100	B1	3.1	-2.7	1.2	-1.7	2.3
	B2	-2.9	-0.7	0.8	0.1	1.1
GBC102	B1	4.2	-1.9	3.0	-5.2	5.8
	B2	-2.8	-0.9	3.2	-2.3	4.3
GBC233	B1	7.9	2.0	-3.9	0.1	0.5
	B2	0.8	-1.9	-0.4	-1.3	0.7
GCA (g_j)	B1	-4.6	3.0	-3.4	4.8	-
	B2	-3.0	1.1	-0.4	2.1	-

Estimate of the GCA and SCA effects for the number of days from sowing to maturity (HUD Rog.) for the F_1.

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	B1	-5.8	2.9	-0.3	4.8	-6.6
	B2	-7.4	2.1	-1.8	-1.0	-7.1
GBC100	B1	2.1	-2.9	-0.9	-2.6	0.5
	B2	-0.5	-3.6	-0.9	5.0	0.4
GBC102	B1	-0.1	1.4	3.5	-3.0	7.5
	B2	-2.4	0.4	5.1	-3.3	8.5
GBC233	B1	3.9	-1.2	-2.2	1.0	-1.3
	B2	2.7	0.7	-2.5	-0.7	-1.6
GCA (g_j)	B1	-3.1	2.0	-1	0.6	-
	B2	-3.8	1.2	-0.4	3.1	-

Estimate of the GCA and SCA effects for the number of kernels per plant for the F_1.

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	B1	3	1	-43	35	-21
	B2	-37	27	4	14	36
GBC100	B1	-42	15	-57	86	32
	B2	19	-19	-34	30	6
GBC102	B1	106	-165	44	18	-108
	B2	62	8	-35	-37	-121
GBC233	B1	-66	149	56	-137	95
	B2	-47	-10	65	-12	81
GCA (g_j)	B1	2	17	-22	0	-
	B2	29	-17	-28	19	-

Estimate of the GCA and SCA effects for plant height (cm) for the F_1.

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	B1	-6.8	1.5	-2.9	8.3	4.0
	B2	-6.3	11.4	-3.1	1.6	2.9
GBC100	B1	5.8	-6.5	-2.7	3.5	-3.2
	B2	9.8	-14.3	8.2	-1.9	-1.7
GBC102	B1	3.1	7.0	-0.7	-9.4	0.9
	B2	-7.0	14.5	-4.2	-2.8	5.0
GBC233	B1	-1.8	-2.1	6.3	-2.4	-1.8
	B2	5.2	-11.3	2.7	3.9	-6.4
GCA (g_j)	B1	-4.5	4.0	-1.4	1.8	-
	B2	2.8	-1.3	1.9	-3.8	-

Estimate of the GCA and SCA effects for ear height (cm) for the F_1.

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	B1	3.5	1.6	-13.2	7.9	5.3
	B2	-1.1	7.2	-6.2	0.2	-0.1
GBC100	B1	0.4	2.1	-3.1	0.5	0.6
	B2	9.2	-3.9	-0.7	-4.8	2.6
GBC102	B1	2.5	0.1	-1.5	-1.2	-8.7
	B2	-5.0	3.1	2.5	-1.4	0.6
GBC233	B1	-6.5	-3.9	17.6	-7.5	2.9
	B2	-3.2	-7.3	4.5	6.0	-3.0
GCA	B1	-2.0	5.0	-1.1	-1.7	-
(g_j)	B2	3.1	-0.4	2.0	-4.7	-

Estimate of the GCA and SCA effects for grain moisture content (% H2O) for the F_1.

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	B1	-0.92	-5.10	6.64	-0.65	2.22
	B2	-0.24	1.01	-1.16	0.39	-1.28
GBC100	B1	1.17	-0.52	-1.41	0.73	-1.33
	B2	0.63	-0.95	-0.65	0.83	0.51
GBC102	B1	0.62	-0.46	-1.19	0.64	-1.24
	B2	0.60	-0.10	2.96	1.06	1.14
GBC233	B1	-0.89	-2.95	-4.07	-1.12	0.37
	B2	1.40	0.09	-1.33	-0.21	-0.38
GCA	B1	-1.32	1.10	1.54	-1.3	-
(g_j)	B2	-0.33	0.48	-0.07	-0.07	-

Rsults of the 1989 for the NC2 Experiment.

The Preliminary ANOVA Results.

It was explained earlier that the 1989 experiment was carried out at two sowing times. The experimental material used consisted only of the F_1 crosses of the 4 x 4 NC2 mating (four USA lines used as females and 4 from the Cambridge lines as males).

The results of the preliminary ANOVAs for all the characters previously studied in the 1988 season will be found in table G-9. Two additional yield components were also measured in this season; grain yield per plant (gm) and 100-kernel weight (gm).

The ANOVA results show that of the fourteen traits studied significant differences between the sowing dates were found for 5 of them. Those are for the seedling dry weight, HUD required from silking to maturity, HUD required to maturity, plant height and ear height. There were highly significant differences between the 16 crosses for all characters, except for the emergence rate where the differences between the single crosses were not significant. The relatively high temperatures at both times of sowing in 1989 could account for the lack of differences in the emergence obtained in this season, (see appendix 1 for the temperature records). The summer of 1989 in the UK was exceptional by all previous records. No significant blocks x crosses nor dates x crosses interactions were found for any of the characters. Because of the highly significant differences between the crosses it is necessary to partition the main genotypic effects between the males, females, males x females and the dates and blocks interaction by using the NC2 analysis.

Results of the NC2 ANOVA for the 1989 Season.

The preliminary ANOVA results indicated that there were no significant differences between the crosses for emergence rates because of the high temperature at the time of sowing. Therefore this character was excluded from the NC2 analysis,

because apparently no detectable differences were contributed by the parents to their offspring (Hallauer and Miranda, 1988).

The NC2 ANOVA was carried out for the other characters. According to the results obtained from the preliminary ANOVA, both dates of sowing were combined in the NC2 ANOVA if the differences between dates were not significant and separated where they differed significantly. The NC2 ANOVAs are presented for each character in table G-11. It includes the items dates, blocks, males, females, and all the interactions between these items: (D x M, D x F, D x M x F, B x M , B x F, B x M x F).

For all characters significant effects were found for the items: males, females, and males x females. No significant differences were found for any of the interactions between these items nor for dates or blocks, which indicates the absence of the genotype x environment interaction. Thus our discussion will concentrate on the GCA for males and females and the SCA (M x F) for all traits.

Results for the Number of Seedlings Emerged and SDW in 1989 Season

The significant differences observed in the NC2 ANOVA for the number of seedlings emerged (table G-9, and G-11) were mainly the result of the low number of seedlings that emerged from the single cross Fr619 x GBO78 and the single cross A556 x GBC100 (see table G-10). If we exclude those two crosses no important differences between the other hybrids are observed. In addition, this trait was evaluated on the basis of the total number of seedlings that emerged from each entry in each block. Thus no clear differences in the GCA or the SCA can be detected for this trait.(table G-8a).

The means and the NC2 ANOVA result for seedling dry weight in tables G-10 and G-11 respectively for sowing 1 and sowing 2, indicate that there are significant differences between the females (USA lines) in their GCA. The inbred lines Pa32 and Fr43 showed the best GCA with the UK lines. On the other hand, there are no significant differences between the Cambridge lines, they having similar means for

the GCA. Highly significant differences were found for the M x F interaction (SCA). A good SCA was found for the mating of the inbred line Pa32 with GBO78 in both sowings (see tables G-10 and G-10a). This result is similar to the one obtained during 1988 season. It was also found that there were significant differences among the USA lines for this trait in sowing 1 (block 1, 1988; see table G-7 and G-11 for comparison). It also seems that, as in the 1988 season, both the additive and the non additive genetic effects were important for this trait in these genotypes.

Results for Flowering and Maturity Stages (1989 season).

Both sets of inbred lines showed significant differences in the GCA in both seasons (see tables G-10, and G-10a for the means and the GCA and SCA effect, and tables G-11 for the NC2 ANOVA results). Highly significant differences were also found in the M x F (SCA). No important male or female interactions with sowing date or with blocks were detected. The results obtained here in 1989 for the F_1s were similar to those obtained for these characters in 1988 (see tables G-7, and G-11 for comparison). This could indicate that most of the variation found was due to genetic differences arising both from additive and non additive gene effects, because only effects due to GCA and SCA were important. As was found in 1988, of the UK lines GBO78 has the best GCA with the USA lines. Inbred line GBC233 also showed good GCA . Among the USA lines Pa32 has the best GCA (fewer heat-unit degrees required to the particular stage) with the UK lines. Comparison of the SCA for each pair of inbred lines showed that the crosses Pa32 x GBO78 and Pa32 x 233 have the best SCA followed by crosses A556 x Pa32, A556 x Pa233. These crosses were also the earliest to flower and to mature in 1988 (see tables G-10 and G-10a).

The ANOVA and the means for maturity for 1989 are presented in terms of calender days in addition to the heat-unit degrees according the Gilmore-Rogers method, so that comparisons with the 1988 results are possible. Similar results in the NC2 ANOVA were obtained by using the calender days or the heat-unit degrees as a base for the ANOVA as was found in experiment E in Chapter 5. The variation in the

means of number of calendar days required to maturity between the two sowings was higher than the variation in the heat-units degrees, confirming what we observed in Chapter 5; ie that the heat-unit method is more accurate for classifying maize hybrids for 'time' to maturity.

Because the SCA is not the same in the two sowings and the GCA is highly variable, the means of the heat units required from silking to maturity (table G-10) indicate that the length of this period depends on the hybrid itself. Both male and females showed significant differences in their GCA in sowing 1. But no significant differences between the males (UK lines) and less variability between the females were observed in sowing 2. The important differences in the SCA that appeared in sowing 2 were absent in sowing 1. The inconsistency of the time from silking to maturity observed in these crosses is similar to that found for the double crosses, S_1, and S_2 in Chapter 5.

Results for the Other Agronomic Characters.

The characters scored were yield per plant (gm), number of kernels per plant, 100-kernel weight, grain moisture content (%), plant height (cm), and the ear height (cm). Important differences were observed between inbred lines in their GCA and the SCA for these traits (see table G-10 and G-10a G-11). These differences were absent in the 1988 season except for the number of kernels. For all of these agronomic characters the M x F item was significant which means that there are some combinations between the inbred lines which perform significantly better than other combinations. It is also seems that both additive and non-additive gene effects are important for these traits in this material.

In the 1988 season, yield was measured only on the basis of the number of the matured kernels obtained per plant. The results for this component were found to be similar in the 1989 season. In both years it can be seen that inbred lines GBC233 and GBC100 were similar in that they have the best GCA for the number of kernels per

plant.. It was also found that crosses that were superior in the number of kernels in 1988 were also superior in the 1989 season.

The study of the other yield components (grain weight/plant and 100-kernel weight) also indicated that there are significant differences in the GCA and the SCA of the two sets of inbred lines. GBC102 has the best GCA for both traits compared with the other UK lines, followed by GBC233. Among the USA lines, both Pa32 and Fr619 have good GCA with the UK lines for both traits. Combinations of the UK line GBC102 with the USA lines Pa32 and Fr43 was found to give the best SCA for the grain yield per plant (gm) and 100-kernel weight. As was found for the other traits, no important male or female times environment interaction was found for these traits. It is well known that both the number of kernels per plant and the 100-kernel weight are the main contributors to the grain yield (gm) per plant. Evidence was found from the results of the yield components for these crosses that high 100-kernel weight appears to be more associated with high grain yield per plant than the number of kernels per plant. Support for this conclusion is found in table G-10 (the yield components means). For example, combinations of inbred line GBC102 with the USA lines gave the highest grain yield per plant, although they did not have the highest number of kernels, but it is obvious that they have the highest 100-kernel weight. Thus in any selection aimed to maintain high yielding ability some consideration must be given to these yield components.

The means of the GCA and the SCA for plant height and ear height were less variable in 1989 although neither the males nor the females were consistent in their behaviour in the two seasons. From the results of both the 1988 and 1989 seasons it seems that PH and EH are greatly influenced by the environment. However, the variation in the two characters was not so high that it would be ineffective to include these characters in any selection programme for early flowering or early maturity.

Some differences in the GCA and the SCA of the inbred lines were observed in the 1989 season for grain moisture content, but again the results in table G-10a show that this variation was not sufficient for this character to be included in a breeding

programme. If we compare the 1988 means for grain-moisture content with the 1989 means, there is some reduction in the grain moisture content in 1989. This reduction is not too high to be considered, specially for the early matured hybrids (Pa32 x GBO78 and A556 x GBO78 and their reciprocals) in both years. There is no important decrease in the grain moisture content in 1989, despite a good weather conditions and earlier maturity (during September) compared with late maturity (during late October) in 1988 season under cold and wait weather conditions. This result indicates that the post-maturity drying of the grain is slow and variation for this character is very low in these crosses. This agrees with Bunting and Guun (1973) in their survey of maize research in Britain since 1950; they stated that there is no evidence yet to suggest that varietal differences in rate of post-maturity drying are significant in Britain.

Final Conclusions from Both Years' Results of the NC2 Mating.

The experiments in this chapter used selected sets of inbred lines with fixed main effects in the ANOVA. Thus it is not possible to estimate the genetic components of variance or any further parameters such as heritability (Cockerham, 1963; 1980; and Hallauer and Miranda, 1988). It has been easy, however, to distinguish the superior combinations (hybrids) and those lines with good GCA or SCA for the following reasons: 1) the information obtained from the NC2 ANOVA (for model 1) in both seasons, 2) the study of the GCA and the SCA for the two sets of inbred lines, 3) the repetition of the experiment, with more replications, in the 1989 season.

Overall, the USA line Pa32 and the Cambridge line GBO78 have the best CGA and also they gave the best SCA. For example, the reciprocal crosses Pa32 x GBO78 gave early maturing progeny in both years. It was also found that there were some other early maturing crosses such as A556 x GBO78 and A556 x GBC233 and their reciprocals. These three pairs of reciprocals were the fastest in both years. The single cross Pa32 x GBO78 required fewer heat-unit degrees and number of days to

maturity than the best double crosses or S_1 found in experiment E (Chapter 5) (see table E-15 and G-10 for comparison). The superiority of these hybrids in both years, despite the great differences in weather conditions between the years (1989 was an exceptional season with high temperature records in Britain), could mean that an even greater response could be expected in more favourable environmental conditions. These hybrids required 148-159 days in 1988 to reach maturity, but they required only 126-132 days to mature in 1989. Comparisons between the performance of these hybrids with hybrids that have been grown both in the USA and England are instructive. ASE 101, an early ripening American hybrid which requires 80 days from sowing to maturity in northern Minnesota, needs 180 days to ripen grain in England (Bunting and Gunn, 1973). Andrew *et al.* (1956) reported that the very early American hybrids W240 and W255 matured in 80-85 days, according to the Wisconsin maturity rating, but required an average of 155 and 160 days respectively to mature in some experiments carried out over a period of 5 years in the Netherlands.

Bunting and Gunn (1973) emphasise the importance of the uniformity of grain ripening within the crop. Gunn (1974) found that plant to plant variation ranged from 13-18 and 34-47 days for the spread of silking and maturity among hybrids. We checked this feature for each individual plant for the crosses that matured early. We found that there is a good uniformity in date of maturity of these crosses. The most uniform was cross Pa32 x GBO78 where there was a spread of 11 days between the first and last of the ten plants grown in 1988 to reach maturity. While only six days spanned the maturing of 20 plants of this cross in 1989. The maturing of cross A556 x GBO78 spread over 14 days and 11 days for the 10 plants in 1988 and the 20 plants in 1989 respectively. F_2 progenies derived from these crosses were also among the earliest F_2s to mature (see table G-5).

Overall the results gave a strong indication that most of the hybrids showed high positive heterosis for the desired characters. The unseasonably high temperatures at the time of the sowing both in 1988 and in 1989 (despite sowing in late April in 1989) did not permit the expression of variability for cold tolerance to

any extent greater than that found in the laboratory experiments (Chapter 6). Even though we did not expected high variation for cold tolerance, a good response of most of the genotypes to cold weather is expected because of the previous screening of the inbred lines for cold tolerance. We expected that good progress towards shortening the life cycle would be achieved by selection for early flowering and for early maturity, the purpose being that the plants would mature before the low autumn temperatures in Britain and before the high summer temperatures in Iraq. Bunting and Gunn (1973) stated that a major concern in the early attempts to improve cold tolerance in maize was centred on the development of varieties able to respond favourably to early sowing. In their survey in 1973 they concluded that, although a wide range of material was tested, no significant differences in the rate of field emergence were detected. They recommended that the major thrust should be the selection for early flowering and early maturity. The early hybrids to mature among these single crosses obtained in our experiments seem to be of importance for many reasons: a) these crosses have been developed by mating USA and British cold tolerant lines (the latter lines had been developed in the Plant Breeding Institute in Cambridge). This type of mating was suggested by Bunting (1978) and Carr and Milbourn (1976) as being the most likly to improve the grain maize genotypes in Britain, b) they were tested further north in England than most of the earlier studies, in a region where the temperatures are usually lower and the weather conditions less favourable than in the south of England, and c) despite the relatively unfavourable conditions in 1988 they reached 32-35% grain moisture content, which was considered by Bunting and Gunn (1973) as the best that could be achieved to obtain well matured grain. They also expressed the opinion that the earliest grain maize hybrids could reach this limit only when conditions during ripening are favourable.

Table G-9. The preliminary ANOVA for all the characters studied on the F_1 progeny of a 4 x 4 NC2 mating (1989 season).

Source of variation	Seedling Emerged Df	MS	F	P	Emergence rate DF	MS	F	P
Bet. Dates	1	1.000	0.672	N.S	1	0.8281	2.760	N.S
Bet. Blocks	3	1.333	0.896	N.S	3	0.2302	0.767	N.S
Bet. f_1s	15	19.550	13.133	***	15	0.5178	1.726	N.S
Error	44	1.489	-	-	44	0.3570	-	-
Traits	Seedling dry weight Date 1				Date 2			
Bet. Blocks	1	0.004082	0.544	N.S	1	0.075711	10.857	***
Bet. f_1s	14	0.017901	2.386	**	14	0.030214	4.333	***
B x F_1s	14	0.008156	1.087	N.S	14	0.007236	1.038	N.S
Error	166	0.007503	-	-	112	0.006974	-	-
Traits	Boots stage				65 stage			
Bet. Dates	1	2035	1.594	N.S	1	194.1	0.238	N.S
Bet. Blocks	3	1001	0.784	N.S	3	1058.4	1.298	N.S
Bet. f_1s	15	9502	7.445	***	15	9758.4	11.966	***
D x F_1s	15	1852	1.451	N.S	15	1249.3	1.532	N.S
B x F_1s	45	620	0.486	N.S	45	356.4	0.437	N.S
Error	239	1276	-	-	239	815.5	-	-
Traits	Silking stage							
Bet. Dates	1	671.4	0.946	N.S				
Bet. Blocks	3	1824.2	2.571	N.S				
Bet. f_1s	15	11555.8	16.289	***				
D x F_1s	15	1062.4	1.498	N.S				
B x F_1s	45	707.0	0.997	N.S				
Error	240	1246.1	-	-				
Traits	Silking to Maturity stage Date 1				Date 2			
Bet. Blocks	1	1.2	0.002	N.S	1	106.4	0.237	N.S
Bet. f_1s	15	1249.3	2.002	*	15	987.7	2.538	**
B x F_1s	15	364.4	0.584	N.S	15	560.1	1.439	N.S
Error	123	624.1	-	-	127	389.2	-	-

Continued table G-9
The preliminary ANOVA for all the characters studied on the F_1 progeny of a 4 x 4 NC2 mating (1989 season).

Traits / Source of variation	Maturity stage Date 1 Df	MS	F	P	Date 2 DF	MS	F	P
Days								
Bet. Blocks	1	148.22	10.701	**	1	12.38	1.080	N.S
Bet. f_1s	15	231.04	16.679	***	15	168.28	14.684	***
B x F_1s	15	21.11	1.524	N.S	15	14.62	1.276	N.S
Error	123	13.85	-	-	127	11.46	-	-
Rogers HUD								
Bet. Blocks	1	3572.2	9.970	**	1	115.8	0.383	N.S
Bet. f_1s	15	5755.0	16.062	***	15	3927.0	12.996	***
B x F_1s	15	518.0	1.446	N.S	15	405.0	1.340	N.S
Error	123	358.3	-	-	127	302.2	1.340	N.S
Traits	Plant height Date 1				Date 2			
Bet. Blocks	1	562.5	1.794	N.S	1	752.6	3.179	N.S
Bet. f_1s	15	690.3	2.201	**	15	720.1	3.042	***
B x F_1s	15	376.5	1.201	N.S	15	146.8	0.620	N.S
Error	128	313.6	-	-	128	236.7	-	-
Traits	Ear height Date 1				Date 2			
Bet. Blocks	1	127.8	0.708	N.S	1	955.5	6.694	*
Bet. f_1s	15	409.0	2.266	**	15	506.3	3.547	**
B x F_1s	15	133.9	0.742	N.S	15	160.4	1.124	N.S
Error	128	180.5	-	-	128	142.7	-	-
Traits	Grain moisture content %				Number of kernels / plant			
Bet. Dates	1	1.832	0.516	N.S	1	17847	1.618	N.S
Bet. Blocks	3	15.566	4.414	**	3	6781	0.615	N.S
Bet. f_1s	15	30.565	8.618	***	15	36781	3.334	***
D x F_1s	15	3.187	0.899	N.S	15	15495	1.405	N.S
B x F_1s	45	3.120	0.880	N.S	45	6659	0.604	N.S
Error	235	3.547	-	-	235	11031	-	-
Traits	Grain yield per plant				100 kernels weight			
Bet. Dates	1	299.7	0.719	N.S	1	12.20	0.963	N.S
Bet. Blocks	3	143.4	0.344	N.S	3	18.00	1.421	N.S
Bet. f_1s	15	3634.6	8.721	***	15	226.71	17.901	***
D x F_1s	15	1010.9	2.425	**	15	17.00	1.350	N.S
B x F_1s	45	373.4	0.896	N.S	45	9.83	0.776	N.S
Error	235	416.8	-	-	235	12.66	-	-

Table G-10. Means for the F_1s obtained from the NC2 mating between the USA and the British inbred lines of grain maize for all the traits studied in the experiment of 1989.

Means of number of seedling emerged (SE) and emergence time rate (ER).

Inbred lines		Single Crosses means				
UK	USA	PA32	Fr43	A556	Fr619	Mean
GBO78	SE	14.25	13.75	14.75	7.00	12.44
	ER	13.24	13.59	13.22	13.28	13.34
GBC100	SE	13.50	14.25	9.00	15.00	12.94
	ER	13.62	13.41	13.89	14.35	13.81
GBC102	SE	14.50	14.75	14.75	13.75	14.44
	ER	12.96	13.08	13.49	13.77	13.33
GBC233	SE	13.75	13.25	14.50	14.25	13.94
	ER	13.94	13.71	13.23	13.67	13.63
Mean	SE	14.00	14.00	13.25	12.50	13.44
	ER	13.44	13.44	13.45	13.76	13.52

Means of seedling dry weight (gm / plant).

Inbred lines		Single Crosses means				
UK	USA	PA32	Fr43	A556	Fr619	Mean
GBO78	D1*	0.388	0.265	0.263	0.132	0.262
	D2*	0.469	0.406	0.353	0.175	0.351
GBC100	D1	0.256	0.285	0.281	0.282	0.276
	D2	0.324	0.346	0.362	0.403	0.359
GBC102	D1	0.304	0.284	0.192	0.261	0.260
	D2	0.403	0.401	0.225	0.413	0.360
GBC233	D1	0.297	0.232	0.287	0.316	0.278
	D2	0.336	0.394	0.373	0.395	0.374
Mean	D1	0.307	0.266	0.256	0.248	0.269
	D2	0.383	0.387	0.328	0.346	0.361

D1 - Sowing 1 April 27th 1989.
D2 - Sowing 2 May 4th 1989.

Continued Table G-10.

Means of heat-units degrees required for the boots stage.

Inbred lines UK		Single Crosses means USA	PA32	Fr43	A556	Fr619	Mean
GBO78	D1*	299.1	326.7	307.5	349.3	320.6
	D2*	290.2	336.5	319.1	375.9	330.4
GBC100	D1	354.0	320.2	353.2	327.3	338.7
	D2	319.4	322.0	321.2	353.3	329.0
GBC102	D1	298.9	355.4	378.1	336.4	342.2
	D2	326.6	352.5	375.7	331.3	346.5
GBC233	D1	292.6	324.2	319.3	314.7	312.7
	D2	298.8	334.9	339.4	340.6	328.4
Mean	D1	311.2	331.6	339.5	331.9	328.5
	D2	308.8	336.5	338.9	350.3	333.6

Means of heat-units degrees required for the 65 stage

Inbred lines UK		Single Crosses means USA	PA32	Fr43	A556	Fr619	Mean
GBO78	D1*	441.9	478.2	453.2	514.0	471.8
	D2*	444.1	479.9	475.5	515.7	478.8
GBC100	D1	478.5	461.7	497.5	466.3	476.0
	D2	469.3	471.9	474.3	477.4	473.2
GBC102	D1	466.8	515.7	527.6	490.3	500.1
	D2	482.5	484.7	521.4	479.0	491.9
GBC233	D1	443.4	469.8	453.0	449.9	454.1
	D2	449.1	461.4	474.2	472.5	464.3
Mean	D1	457.6	481.4	482.9	480.1	475.5
	D2	461.2	474.5	486.4	486.1	477.1

D1 - Sowing 1 April 27th 1989.
D2 - Sowing 2 May 4th 1989.

Continued table G-10.

Means of heat-units degrees required for silking

Inbred lines UK		Single Crosses means USA	PA32	Fr43	A556	Fr619	Mean
GBO78	D1*	429.9	465.2	444.5	506.7	461.6
	D2*	434.5	466.4	450.5	506.5	464.5
GBC100	D1	473.3	460.3	504.6	458.8	474.2
	D2	473.7	467.6	473.7	477.5	473.1
GBC102	D1	463.3	512.8	519.3	485.9	495.4
	D2	468.1	492.6	525.5	469.5	488.9
GBC233	D1	442.3	465.7	441.7	443.4	448.3
	D2	451.6	478.0	462.5	465.8	464.5
Mean	D1	452.2	476.0	477.5	473.7	469.9
	D2	457.1	476.1	478.0	479.9	472.8

Means of heat-units degrees required for the period from silking to maturity

Inbred lines UK		Single Crosses means USA	PA32	Fr43	A556	Fr619	Mean
GBO78	D1*	317.8	313.0	307.1	304.6	310.6
	D2*	312.7	298.2	310.9	298.1	305.0
GBC100	D1	317.4	329.3	304.2	328.7	319.9
	D2	295.2	310.8	305.5	309.6	305.3
GBC102	D1	331.2	317.3	303.3	330.8	320.7
	D2	315.7	308.7	295.3	325.1	311.2
GBC233	D1	327.4	321.8	317.9	340.3	326.9
	D2	313.2	304.4	288.9	321.3	307.0
Mean	D1	323.5	320.4	308.1	326.1	319.5
	D2	309.2	305.6	300.1	313.5	307.1

D1 - Sowing 1 April 27th 1989.
D2 - Sowing 2 May 4th 1989.

Continued table G-10.

Means of number of days required from sowing to maturity.

Inbred lines		Single Crosses means				
UK	USA	PA32	Fr43	A556	Fr619	Mean
GBO78	D1*	130.0	136.0	131.0	141.0	134.6
	D2*	126.6	130.0	129.4	138.2	131.0
GBC100	D1	138.6	136.9	141.8	137.9	138.8
	D2	130.7	133.3	133.5	135.3	133.2
GBC102	D1	139.5	146.5	144.7	143.7	143.6
	D2	134.6	137.7	141.3	136.9	137.6
GBC233	D1	134.2	137.2	132.2	137.1	135.1
	D2	130.1	134.1	127.3	134.6	131.5
Mean	D1	135.5	139.1	137.4	140.0	138.0
	D2	130.5	133.7	132.8	136.2	133.3

Means of heat-units degrees required from sowing to maturity.

Inbred lines		Single Crosses means				
UK	USA	PA32	Fr43	A556	Fr619	Mean
GBO78	D1*	747.8	778.2	751.5	804.8	770.6
	D2*	747.2	764.7	761.4	804.6	769.5
GBC100	D1	790.7	783.9	808.8	787.5	792.7
	D2	768.9	778.3	779.2	787.2	778.4
GBC102	D1	794.5	830.1	822.7	813.8	815.3
	D2	783.8	801.3	820.8	794.6	800.1
GBC233	D1	769.8	784.1	759.6	783.6	774.3
	D2	764.8	782.5	751.4	787.1	771.5
Mean	D1	775.7	794.1	785.7	797.4	788.2
	D2	766.2	781.7	778.2	793.4	779.7

D1 - Sowing 1 April 27th 1989.
D2 - Sowing 2 May 4th 1989.

Continued table G-10.

Means of the grain moisture content %.

Inbred lines UK		Single Crosses means				
	USA	PA32	Fr43	A556	Fr619	Mean
GBO78	D1*	33.07	34.86	34.85	35.83	34.65
	D2*	34.71	35.25	34.05	34.52	34.63
GBC100	D1	33.69	35.49	34.34	32.91	34.11
	D2	33.70	34.73	33.91	33.26	33.90
GBC102	D1	31.24	33.56	33.72	31.90	32.60
	D2	30.74	33.35	34.34	31.63	32.51
GBC233	D1	33.90	34.69	34.04	32.17	33.70
	D2	32.49	35.53	33.40	32.22	33.41
Mean	D1	32.97	34.65	34.24	33.20	33.77
	D2	32.91	34.72	33.92	32.91	33.62

Means of number of kernels per plant.

Inbred lines UK		Single Crosses means				
	USA	PA32	Fr43	A556	Fr619	Mean
GBO78	D1*	372.0	383.3	409.6	350.3	378.8
	D2*	357.0	467.7	392.5	364.4	395.4
GBC100	D1	317.8	401.1	313.5	450.1	370.6
	D2	401.6	423.7	440.5	469.8	433.9
GBC102	D1	373.2	415.7	319.8	368.0	369.2
	D2	394.5	407.4	324.3	459.9	396.5
GBC233	D1	391.3	496.4	454.4	490.5	458.1
	D2	345.0	448.5	415.7	433.5	410.7
Mean	D1	363.6	424.1	374.3	414.7	394.2
	D2	374.5	436.3	393.2	431.9	409.1

D1 - Sowing 1 April 27th 1989.
D2 - Sowing 2 May 4th 1989.

Continued table G-10.

Means of grain yield per plant (gm).

Inbred lines UK	USA	Single Crosses means PA32	Fr43	A556	Fr619	Mean
GBO78	D1*	94.0	71.6	77.3	67.3	77.6
	D2*	82.1	81.9	73.8	68.8	76.6
GBC100	D1	72.5	70.1	62.4	99.1	76.0
	D2	81.7	68.4	92.7	99.2	85.5
GBC102	D1	107.5	90.2	73.1	90.8	90.4
	D2	114.8	105.5	63.5	118.7	100.6
GBC233	D1	76.4	85.2	79.8	93.2	83.6
	D2	74.7	75.3	65.9	74.1	72.5
Mean	D1	87.6	79.2	73.1	87.6	81.9
	D2	88.3	82.8	74.0	90.2	83.8

Means of 100 kernel weight (gm).

Inbred lines UK	USA	Single Crosses means PA32	Fr43	A556	Fr619	Mean
GBO78	D1*	25.29	18.98	19.57	19.44	20.82
	D2*	23.59	17.86	19.62	18.97	20.00
GBC100	D1	23.33	16.82	19.83	22.32	20.58
	D2	20.37	16.31	20.98	21.19	19.71
GBC102	D1	28.97	22.00	23.59	24.65	24.80
	D2	29.13	25.83	20.13	25.77	25.22
GBC233	D1	19.66	17.40	17.99	19.85	18.73
	D2	21.79	17.05	15.96	18.93	18.43
Mean	D1	24.31	18.80	20.25	21.56	21.23
	D2	23.73	19.25	19.17	21.22	20.84

D1 - Sowing 1 April 27th 1989.
D2 - Sowing 2 May 4th 1989.

Continued table G-10.

Means of plant height (cm).

Inbred lines UK		Single Crosses means				
	USA	PA32	Fr43	A556	Fr619	Mean
GBO78	D1*	157.7	175.2	145.9	163.6	160.6
	D2*	162.8	179.9	158.4	166.7	166.9
GBC100	D1	154.3	143.4	163.9	160.9	155.6
	D2	164.5	157.3	165.0	173.5	165.0
GBC102	D1	147.2	154.4	159.3	148.9	152.4
	D2	166.3	170.1	147.3	162.4	161.5
GBC233	D1	148.9	155.2	148.6	150.6	150.8
	D2	153.20	159.4	154.7	151.2	154.6
Mean	D1	152.0	157.0	154.4	156.0	154.8
	D2	161.7	166.6	156.3	163.4	162.0

Means of ear hieght (cm).

Inbred lines UK		Single Crosses means				
	USA	PA32	Fr43	A556	Fr619	Mean
GBO78	D1*	59.9	67.0	55.8	59.2	60.4
	D2*	63.1	69.8	54.6	65.6	63.2
GBC100	D1	60.2	43.8	56.8	47.7	52.1
	D2	63.5	57.5	62.0	54.8	59.5
GBC102	D1	48.0	55.6	54.3	46.3	51.0
	D2	63.7	71.2	47.2	51.7	58.4
GBC233	D1	49.1	60.2	49.4	51.2	52.47
	D2	58.2	62.0	59.2	47.0	56.6
Mean	D1	54.3	56.6	54.0	51.1	54.0
	D2	62.1	65.1	55.7	54.7	59.4

D1 - Sowing 1 April 27th 1989.
D2 - Sowing 2 May 4th 1989.

Table G-10a. Estimate of male (g_i) and female (g_j) parents GCA and their SCA (S_{ij}) effects for the F_1 generation obtained from the NC2 mating between the USA and the British inbred lines of grain maize for all the traits studied in the experiment of 1989. (results obtained from the means in table G-10 by using the formula in page 190). All symbols have the same meaning as in table G-10.

Estimate of the GCA and SCA effects for the number of seedling emerged (SE) and rate of time to emergence (days) (ER) for the F_1.

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	SE	1.25	0.75	2.50	-4.50	-0.10
	ER	-0.09	0.26	-0.12	-0.37	-0.11
GBC100	ES	0.00	0.75	-3.75	3.0	-0.50
	ER	-0.11	-0.32	0.15	0.3	0.29
GBC102	SE	-0.50	-0.25	0.50	0.25	1.00
	ER	-0.29	-0.17	0.23	0.20	-0.19
GBC233	SE	-0.75	-1.25	0.75	1.25	0.50
	ER	0.61	0.65	-0.11	0.02	-0.11
GCA (g_j)	SE	0.56	0.56	-0.19	-0.94	-
	ER	-0.08	-0.08	-0.07	0.24	-

Estimate of the GCA and SCA effects for seedling dry weight (gm per seedling) for the F_1 (1989 season).

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	D1*	-0.081	-0.001	0.007	-0.116	0.00
	D2*	0.140	0.029	0.035	-0.161	-0.01
GBC100	D1	-0.058	0.012	0.018	0.027	0.007
	D2	-0.057	-0.039	0.038	0.059	-0.002
GBC102	D1	0.006	0.027	-0.005	0.022	-0.009
	D2	0.021	0.015	-0.102	0.068	-0.001
GBC233	D1	-0.019	-0.043	-0.001	-0.009	0.009
	D2	0.060	-0.006	-0.013	-0.013	0.013
GCA (g_j)	D1	0.038	-0.003	-0.013	-0.021	-
	D2	0.022	0.026	-0.033	-0.015	-

Estimate of the GCA and SCA effects for boots stage of tasselling (HUD Rog.) for the F_1 (1989 season).

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	D1	-4.2	3.0	-24.1	25.3	-7.9
	D2	-15.5	3.2	-16.7	28.8	-3.2
GBC100	D1	32.6	-21.6	3.5	14.8	10.2
	D2	20.3	-9.9	-13.1	7.6	-4.6
GBC102	D1	-26.0	10.1	24.9	-9.2	13.7
	D2	4.9	3.1	23.9	-31.9	12.9
GBC233	D1	-2.8	8.4	-4.4	-1.4	-15.8
	D2	-4.8	3.6	5.7	-4.5	-5.2
GCA (g_j)	D1	-17.3	3.1	11.0	3.4	-
	D2	-24.8	2.9	5.3	11.7	-

Estimate of the GCA and SCA effects for the 65 stage (HUD Rog.) for the F_1 (1989 season).

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	D1	-12.0	0.5	-26.0	37.6	-3.7
	D2	-18.8	3.7	-12.5	27.9	1.7
GBC100	D1	20.4	-20.2	14.1	-14.3	0.5
	D2	12.0	1.3	-8.1	-4.8	-3.9
GBC102	D1	-15.4	9.7	20.1	-14.4	24.6
	D2	6.5	-4.6	20.3	-21.9	14.8
GBC233	D1	7.2	9.8	-8.5	-8.8	-21.4
	D2	0.7	-0.3	0.7	-0.8	-12.8
GCA (g_j)	D1	-17.9	5.9	7.4	4.6	-
	D2	-15.9	-2.6	9.2	9.0	-

Estimate of the GCA and SCA effects for silking stage (HUD Rog.) for the F_1 (1989 season)..

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	D1	-14.0	-2.5	-24.7	41.3	-8.3
	D2	-14.3	-1.2	-19.2	34.9	-8.3
GBC100	D1	16.8	-20.0	22.8	-19.2	4.3
	D2	16.3	-8.6	-4.6	-2.7	0.3
GBC102	D1	-14.4	11.3	16.3	-13.3	25.5
	D2	-5.1	0.6	31.4	-26.5	16.1
GBC233	D1	11.7	11.3	-14.2	-8.7	-12.6
	D2	2.8	10.4	-7.2	-5.8	-8.3
GCA (g_j)	D1	-17.7	6.1	7.6	3.8	-
	D2	-15.7	3.1	5.2	7.1	-

Estimate of the GCA and SCA effects for the period from silking to maturity (HUD Rog.) for the F_1 (1989 season).

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	D1	3.2	1.5	7.9	-12.6	-8.9
	D2	5.6	-5.3	12.9	-13.3	-2.1
GBC100	D1	-6.5	8.5	-4.3	2.2	0.4
	D2	-14.4	7.0	7.2	-2.1	-1.8
GBC102	D1	6.5	-4.3	-6.0	3.5	1.2
	D2	2.4	1.0	-8.9	7.5	4.1
GBC233	D1	-3.5	-6.0	2.4	6.8	7.4
	D2	4.1	-1.1	-11.1	7.9	-0.1
GCA (g_j)	D1	4.0	0.9	-11.4	6.6	-
	D2	2.1	-1.5	-7.0	6.4	-

Estimate of the GCA and SCA effects for number of days from sowing to maturity for F_1 (1989 season).

Inbred lines UK	SCA (S_{ij})					GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	D1	-2.1	0.3	-3.0	4.4	-3.4
	D2	-1.6	-1.4	-1.1	4.3	-2.3
GBC100	D1	2.3	-3.0	3.6	-2.9	0.8
	D2	0.3	-0.3	0.8	-0.8	-0.1
GBC102	D1	-1.6	1.8	1.7	-1.9	5.6
	D2	-0.2	-0.3	4.2	-3.6	4.3
GBC233	D1	1.6	1.0	-2.3	0.0	-2.9
	D2	1.4	2.2	-3.7	0.2	-1.8
GCA	D1	-2.5	1.1	-0.6	2.0	-
(g_j)	D2	-2.8	0.4	-0.5	2.9	-

Estimate of the GCA and SCA effects for time from sowing to maturity (HUD Rog.) for F_1 (1989 season).

Inbred lines UK	SCA (S_{ij})					GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	D1	-10.3	1.7	-16.6	25.0	-17.6
	D2	-8.8	-6.8	-6.6	21.4	-10.2
GBC100	D1	10.5	-14.7	18.6	-14.4	4.5
	D2	4.0	-2.1	2.3	-4.9	-1.3
GBC102	D1	-8.3	8.9	9.9	-10.7	27.1
	D2	-2.8	-0.8	22.2	-19.2	20.4
GBC233	D1	8.0	3.9	-12.2	0.1	-13.9
	D2	6.8	9.0	-18.6	1.9	-8.2
GCA	D1	-12.5	5.9	-2.5	9.2	-
(g_j)	D2	-13.5	2.0	-1.5	13.7	-

Estimate of the GCA and SCA effects for grain moisture content (% H2O) for the F_1 (1989 season).

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	D1	-0.78	-0.67	-0.27	1.75	0.88
	D2	0.78	-0.48	-0.88	0.6	1.01
GBC100	D1	0.38	0.50	-0.24	-0.63	0.34
	D2	0.50	-0.27	-0.29	0.07	0.28
GBC102	D1	-0.56	0.08	0.65	-0.13	-1.17
	D2	-1.07	-0.26	0.09	-0.17	-1.11
GBC233	D1	0.86	-0.03	-0.13	-0.96	-0.07
	D2	-0.22	1.02	-0.31	-0.48	-0.21
GCA (g_j)	D1	-0.80	0.88	0.47	-0.57	-
	D2	-0.70	1.10	0.30	-0.71	-

Estimate of the GCA and SCA effects for number of kernels per plant for the F_1 (1989 season).

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	D1	23.8	-25.4	50.7	-49.0	-15.4
	D2	-3.8	45.1	13.0	-53.8	-13.7
GBC100	D1	-22.2	0.6	-37.2	59.0	-23.6
	D2	2.3	-37.4	22.5	13.1	24.8
GBC102	D1	34.6	16.6	-29.5	-21.7	-25.0
	D2	47.5	-16.3	-56.3	40.6	-12.6
GBC233	D1	-36.2	8.4	16.2	11.9	63.9
	D2	-27.9	10.6	20.9	0.0	1.6
GCA (g_j)	D1	-30.6	29.9	-19.9	20.5	-
	D2	-34.6	27.2	-15.9	22.8	-

Estimate of the GCA and SCA effects for grain yield per plant for the F_1 (1989 season).

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	D1	10.7	-3.3	8.5	-16.0	-4.3
	D2	0.9	6.2	7.0	-14.2	-7.2
GBC100	D1	-9.2	-3.2	-4.8	17.4	-15.9
	D2	-8.3	-16.1	17.0	7.3	1.3
GBC102	D1	11.4	2.5	-8.5	-5.3	8.5
	D2	9.7	5.9	-27.3	11.7	16.8
GBC233	D1	-12.9	4.3	5.0	3.9	1.7
	D2	-2.3	3.8	3.2	-4.8	-11.3
GCA (g_j)	D1	5.7	-2.7	-8.8	5.7	-
	D2	4.5	-1.0	-9.8	6.4	-

Estimate of the GCA and SCA effects for 100 kernels weight (gm) for the F_1 (1989 season).

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	D1	1.39	0.59	-0.27	-1.71	-0.41
	D2	0.31	-0.55	1.29	-1.41	-0.84
GBC100	D1	-0.33	-1.33	0.23	1.41	-0.65
	D2	-2.23	-1.81	2.94	1.10	-1.13
GBC102	D1	1.09	-0.37	-0.23	0.52	3.57
	D2	1.02	2.20	-3.42	0.17	4.38
GBC233	D1	-2.15	2.10	0.24	0.79	-2.50
	D2	0.43	0.18	-0.80	0.12	-2.41
GCA (g_j)	D1	3.08	-2.43	-0.98	0.33	-
	D2	2.89	-1.59	-1.67	0.38	-

Estimate of the GCA and SCA effects for plant height (cm) for the F_1 (1989 season).

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	D1	-0.1	12.4	-14.3	1.8	5.8
	D2	-3.8	8.4	-2.8	-1.4	4.9
GBC100	D1	1.5	-14.4	8.7	4.1	0.8
	D2	-0.2	-5.7	5.7	7.1	3.0
GBC102	D1	-2.4	0.2	6.5	-4.7	-2.4
	D2	5.1	4.0	-8.5	-0.5	-0.5
GBC233	D1	0.9	2.2	-1.8	-1.4	-4.0
	D2	-1.1	0.2	5.8	-4.8	7.4
GCA (g_j)	D1	-2.8	2.2	-0.4	1.2	-
	D2	-0.3	4.6	-5.7	1.4	-

Estimate of the GCA and SCA effects for ear height (cm) for F_1 (1989 season).

Inbred lines UK		SCA (S_{ij})				GCA
	USA	PA32	Fr43	A556	Fr619	(g_i)
GBO78	D1	-0.8	4.0	-4.6	1.7	6.4
	D2	-2.8	0.9	-4.9	7.1	3.8
GBC100	D1	7.8	-10.9	4.7	-1.5	-1.9
	D2	1.3	-7.7	6.2	0.0	0.1
GBC102	D1	-3.3	2.0	3.3	-1.8	-3.0
	D2	2.6	7.1	-7.5	-2.0	-1.0
GBC233	D1	-3.3	5.2	-3.0	1.7	-1.6
	D2	-1.1	-0.3	6.3	-4.9	-2.8
GCA (g_j)	D1	0.3	2.6	0.0	-2.9	-
	D2	2.7	5.7	-3.7	-4.7	-

Table G-11 The ANOVA of the NC2 crosses for all the characters studied for F_1s (1989 season).

Source of variation	Seedling Emerged Df	MS	F	P	Emergence rate DF	MS	F	P
Bet. Dates	1	1.000	0.672	N.S	1	0.8281	2.760	N.S
Bet. Blocks	3	1.667	1.145	N.S	3	0.5062	1.725	N.S
Bet. males	3	13.333	9.160	***	3	0.9014	3.072	*
Bet. females	3	8.250	5.668	***	3	0.4081	1.391	N.S
M x F	9	25.389	17.445	***	9	0.4265	1.454	N.S
Error	44	1.456	-	-	44	0.2934	-	-
Traits	Seedling dry weight Date 1				Date 2			
Bet. Blocks	1	0.003393	0.452	N.S	1	0.088061	12.624	***
Bet. Males	3	0.003622	0.483	N.S	3	0.003986	0.571	N.S
Bet. Females	3	0.027338	3.300	*	3	0.032489	4.697	**
B x. M	3	0.002253	0.300	N.S	3	0.018063	2.589	N.S
B x F	3	0.004224	0.563	N.S	3	0.002772	0.397	N.S
M x F	9	0.039832	5.308	***	9	0.075988	10.893	***
B x M x F	8	0.011956	1.595	N.S	9	0.004576	0.656	N.S
Error	116	0.007503	-	-	116	0.006976	-	-
Traits	Boots stage				65 stage			
Bet. Dates	1	2035	1.594	***	1	194.1	0.238	N.S
Bet. Blocks	3	1001	0.784	N.S	3	1058.4	1.298	N.S
Bet. Males	3	8678	6.799	***	3	18244.6	22.373	***
Bet. Females	3	16576	12.987	***	3	10729.0	13.156	***
D x M	3	2367	1.855	N.S	3	1457.3	1.787	N.S
B x M	9	226	0.177	N.S	9	84.0	0.103	N.S
D x F	3	1768	1.385	N.S	3	658.6	0.808	N.S
B x F	9	431	0.338	N.S	9	346.5	0.425	N.S
M x F	9	7419	5.812	***	9	6606.0	8.101	***
D x M x F	9	1708	1.338	N.S	9	1376.9	1.688	N.S
B x M x F	27	814	0.638	N.S	27	450.5	0.552	N.S
Error	239	1276	-	-	239	815.5	-	-
Traits	Silking stage							
Bet. Dates	1	671.4	0.946	N.S				
Bet. Blocks	3	1824.2	2.571	N.S				
Bet. Males	3	19495.4	27.481	***				
Bet. Females	3	9967.7	14.051	***				
D x M	3	1861.1	2.623	N.S				
B x M	9	656.7	0.926	N.S				
D x F	3	184.6	0.260	N.S				
B x F	9	573.3	0.808	N.S				
M x F	9	9438.6	13.305	***				
D x M x F	9	1088.8	1.535	N.S				
B x M x F	27	768.4	1.083	N.S				
Error	240	709.4	-	-				

D, B, M, F are the dates, blocks, males, and females effects respectively.

Continued table G-11
The ANOVA of the NC2 crosses for all the characters studied for F_1s (1989 season).

Source of variation	Silking to Maturity stage Date 1 Df	MS	F	P	Date 2 DF	MS	F	P
Bet. Blocks	1	1.2	0.002	N.S	1	106.4	0.273	N.S
Bet. Males	3	1795.5	2.877	*	3	326.9	0.842	N.S
Bet. Females	3	2517.6	4.034	**	3	1281.3	3.292	*
B x M	3	747.7	1.198	N.S	3	585.9	1.505	N.S
B x F	3	90.8	0.146	N.S	3	41.8	0.107	N.S
M x F	9	644.5	1.033	N.S	9	1110.1	2.852	**
B x M x F	9	327.8	0.525	N.S	9	724.3	1.861	N.S
Error	127	624.1	-	-	127	389.2	-	-
Traits	Maturity stage Date 1				Date 2			
Days								
Bet. Blocks	1	148.22	10.701	**	1	12.38	1.080	N.S
Bet. Males	3	689.31	49.762	***	3	358.31	31.267	***
Bet. Females	3	156.94	11.330	***	3	225.99	19.720	***
B x M	3	8.01	0.578	N.S	3	13.08	1.142	N.S
B x F	3	22.40	1.617	N.S	3	37.40	3.264	*
M x F	9	102.99	7.435	***	9	85.70	7.478	***
B x M x F	9	25.04	1.808	N.S	9	7.54	0.658	N.S
Error	127	13.85	-	-	127	11.46	-	-
Rogers								
Bet. Blocks	1	3572.2	9.970	**	1	115.8	0.383	N.S
Bet. Males	3	16754.1	46.760	***	3	7877.1	26.069	***
Bet. Females	3	3771.3	10.525	***	3	5010.3	16.581	***
B x M	3	242.3	0.676	N.S	3	457.4	1.514	N.S
B x F	3	572.5	1.598	N.S	3	961.8	3.183	*
M x F	9	2749.9	7.675	***	9	2249.2	7.444	***
B x M x F	9	591.7	1.651	N.S	9	201.8	0.668	N.S
Error	127	358.3	-	-	127	302.2	-	-
Traits	Number of kernels /plant				Grain yield / plant			
Bet. Dates	1	17847	1.618	N.S	1	299.7	0.719	N.S
Bet. Blocks	3	6781	0.615	N.S	3	143.4	0.344	N.S
Bet. Males	3	43688	3.960	**	3	5873.1	14.092	***
Bet. Females	3	71513	6.498	***	3	4068.1	9.761	***
D x M	3	42594	3.861	**	3	2037.1	4.888	**
B x M	9	10960	0.994	N.S	9	485.3	1.164	N.S
D x F	3	278	0.025	N.S	3	39.1	0.094	N.S
B x F	9	5061	0.459	N.S	9	327.4	0.785	N.S
M x F	9	22901	2.076	*	9	2744.0	6.584	***
D x M x F	9	11535	1.046	N.S	9	992.7	2.382	*
B x M x F	27	5758	0.522	N.S	27	351.5	0.843	N.S
Error	235	11031	-	-	235	416.7	-	-

D, B, M, F are the dates, blocks, males, and females effects respectively.

Continued table G-11
The ANOVA of the NC2 crosses for all the characters studied for F_1s (1989 season).

Source of variation	100 kernels weight				Grain moisture content %			
	Df	MS	F	P	DF	MS	F	P
Bet. Dates	1	12.20	0.963	N.S	1	1.830	0.516	N.S
Bet. Blocks	3	18.00	1.421	N.S	3	15.655	4.414	**
Bet. Males	3	613.91	48.471	***	3	61.357	17.301	***
Bet. Females	3	395.20	31.206	***	3	55.987	15.787	***
D x M	3	7.15	0.564	N.S	3	0.282	0.080	N.S
B x M	9	12.26	0.968	N.S	9	1.622	0.457	N.S
D x F	3	8.11	0.640	N.S	3	0.675	0.190	N.S
B x F	9	16.20	1.279	N.S	9	1.868	0.527	N.S
M x F	9	41.48	3.275	***	9	11.827	3.335	***
D x M x F	9	23.40	1.848	N.S	9	4.993	1.408	N.S
B x M x F	27	6.90	0.544	N.S	27	0.037	1.138	N.S
Error	235	12.66	-	-	235	3.547	-	-
Traits	Plant height							
	Date 1				Date 2			
Bet. Blocks	1	562.5	1.794	N.S	1	752.6	3.180	N.S
Bet. Males	3	741.6	2.365	N.S	3	1180.9	4.989	***
Bet. Females	3	190.9	0:609	N.S	3	746.2	3.153	*
B x M	3	56.1	0.179	N.S	3	32.8	0.139	N.S
B x F	3	896.7	2.859	*	3	103.3	0.436	N.S
M x F	9	839.6	2.677	**	9	557.8	2.357	*
B x M x F	9	309.9	0.988	N.S	9	199.4	0.842	N.S
Error	128	313.6	-	-	128	236.7	-	-
Traits	Ear height							
	Date 1				Date 2			
Bet. Blocks	1	127.8	0.708	N.S	1	955.5	6.694	*
Bet. Males	3	752.9	4.171	**	3	316.7	2.219	N.S
Bet. Females	3	207.0	1.147	N.S	3	998.8	6.997	***
B x M	3	77.9	0.431	N.S	3	47.8	0.335	N.S
B x F	3	241.0	1.335	N.S	3	234.8	1.645	N.S
M x F	9	361.7	2.004	*	9	405.4	2.840	**
B x M x F	9	116.9	0.648	N.S	9	173.1	1.213	N.S
Error	128	180.5	-	-	128	142.7	-	-

LD, B, M, F are the dates, blocks, males, and females effects respectively.

CHAPTER EIGHT

GENERAL DISCUSSION AND CONCLUSIONS

Progress in plant breeding depends upon the existence of genetic variation, the recombination of the variation and the selection of the improved genotypes. Procedures and details vary according to whether the species is self or cross pollinated and the method of propagation. However, irrespective of the breeding system of the plant, the principles of breeding are to some extent similar. When a species is capable both of easy self-fertilization and of easy crossing (eg maize) and true breeding parental lines are available, and also where self-mating, crossing and back crossing can be practiced, a great multiplicity of statistics are available for estimating the genetic and environment components and variances (Mather and Jinks, 1982). Any breeding programme should include three stages: assembly or creation of a pool of variable germplasim; selection of superior individuals to create a superior variety; estimates of genetic variance and the other genetic parameters such as heritability, so that predictions for further improvement can be made. Early detection of the type of genetic control of the characters of interest is of particular importance before deciding on the best method of selection to be followed to achieve the objectives of the breeding programme, although estimation of genetic parameters can be of value in all three stages (Dudley and Moll, 1969). When the genetic information is available, the breeder has to consider whether any response to selection is likely and how the desirable characteristics can be added to the genetic properties of the population. Falconer (1989) suggested two actions; the first being the choice of individuals to be used as parents, i.e. selection, and the second being the choice of control of the way in which the parents are mated, i.e. the experimental design.

In other words, selection as defined by Falconer (1989) means breeding from the 'best' individuals, whatever 'best' may be in the ways by which the theory of

quantitative genetics can help; firstly by showing how to choose individuals with the best breeding value (the additive genetic effects), and secondly by predicting the outcome so that different breeding schemes can be used.

My study dealt with cold tolerance of grain-maize genotypes that had been developed and screened by Maryam (1981). The first part of my study was an evaluation of the 32 double crosses followed by a few generations of selection within and among them for early germination and early maturity (see Chapter 2 for details).

In part two, the best of the USA and of the Cambridge lines, as determined by Maryam, were combined using the NC2 mating design.

Thus I carried out series of experiments from October 1986 to October 1989 under the controlled conditions of the growth chamber, partly controlled conditions in the glasshouse and in the experimental field. The results obtained were described and discussed separately for each experiment in the earlier chapters and conclusions were drawn. This Chapter consists of a general discussion of the results and conclusions of the work reported in this study. As mentioned above the work was divided into two parts:

Part One: The Studies on the 32 Double Crosses, their S_1 and S_2 Families. (Chapters 3, 4, and 5).

In experiments A, B, C and D (Chapters 3 and 4), we evaluated some characteristics of the 32 double crosses and of the selected and unselected S_1 and S_2 families. Experiment A confirmed that useful variation for both germinability and the rate of germination exists among and within the double crosses and, in general, a good response during the germination test has been shown by the double crosses. This result was discussed in detail and comparisons made in Chapter 3 (experiment A). At this early stage of evaluation, selection was for the fastest seeds to germinate (five seeds from each double cross). This enabled us **a)** to limit the size of the experiment in the next evaluation, **b)** to represent the whole population in the next test, **c)** to increase the range of the genetic diversity within the selected population

and **d)** to insure that we included the best individuals from each double cross and so reducing the possibility of losing the good genotypes to the minimum. Thus, in experiment A, 25 % of the seeds used from the 32 double crosses (20 kernels per double cross) were selected. This type of selection was found to be effective for improving the low temperature germinability for the whole population, because additive genetic effects were of importance for this trait. McConnel and Gardner (1979) used laboratory and field selection for cold tolerance based on the selection of the first seeds to germinate at 7.2^0 C, in the laboratory. After four cycles of selection they found that cold germination under laboratory conditions (7.2^0 C) improved by 8.8 and 9.9 % per cycle in Pioneer Cold Tolerance Synthetic (CTCG) and Iowa Stiff Stalk Synthetic (SSCG), respectively. They also found that this kind of selection did not have any detrimental effects on other agronomic traits measured in the population. Cold test of germination have been used frequently in maize breeding for cold tolerance (for example; Isely, 1950; Andrew, 1954; Eagles and Hardacre 1979; Maryam and Jones, 1983a; Galeev and Kiyashko, 1985; Martin *et al.* 1988). The latter have found that the cold test was highly correlated with field emergence (r = 0.74). Galeev and Kiyashko (1985), in the Netherlands, have constructed an index of cold resistance based upon the analysis of the capacity of seeds of maize lines to germinate at low temperature. They found that the field evaluation of seedlings at the 5-6 leaf stage (sown in three ecological zones) largely coincided with the grouping of lines according to their laboratory data.

The effectiveness of the selection for early germination at 6^0 C in experiment A was clear in the results of the germination test carried out on S_1 and S_2 families in Chapter 4 (experiment D). Most of S_1 and S_2 families maintain the good germination at low temperatures shown by the double crosses in experiments A. Most of the S_1 or S_2 families required a similar number of days or fewer than those required by the double crosses from which they were derived (details are given in chapter 4 and table D-5).

Table D-5 also indicates that most of the S_1 and the S_2 families selected from double crosses 4, 9A2, 11A, 16A, 19A2, 25A (except few families) were as good as the double crosses or better (required fewer days to germinate at 6^0 C). This was very clear for families of 9A2 and 11A. Thus either the heterosis for early germination is now fixed in some lines or selection and inbreeding has been effective in improving this character in other lines, although no selection for germinability was carried out between the S_1 and S_2 generations. Selection at that stage was only for early maturity. (The only selection for germinability was from S_0 seeds.) The consistency of the germination ability in the S_1 and S_2 generations leads to the conclusion that the independent selection for early flowering or early maturity did not alter the ability to germinate at low temperatures in this population. This agrees with Zemetra (1983) who found that response to early germination and emergence was not affected by selection for the silking or maturity duration. Similarly, Mock and Skrdla (1978) found no association between cold tolerance response and maturity in the collection they tested.

In experiments B, and C (Chapter 3), the S_0 plants grown from the early germinated seeds were evaluated. The accumulated heat unit degrees (Gilmore and Rogers method, 1958) was used to assess the flowering and maturity stages. Selection among the double crosses for early maturity was based on the mean of the heat-unit degrees required to reach maturity, both for five plants and for each plant. Experiment B indicated that a population with a wide range of variability for flowering and maturity was obtained by this method. The range was 114 HUDs between the double crosses and 250 HUDs among the S_0 plants for silking. The range for maturity was 207 and 338 HUDs between the double crosses and among the S_0 plants, respectively. This variation enabled us to select among and within the double crosses. A good range of variability was included in the selected families to allow us to evaluate the effectiveness of this method for distinguishing the desired genotypes (see table B-3, Chapter 3 for silking and maturity stages). Because the seeds grown were not all sown on the same day (see methods of experiment A and B), the daily

accumulated heat-unit degrees method was the most suitable method for studying the variation among the S_0 plants.

The results of experiment C (tables C-2 and C-3) confirmed that the HUDS method was more effective for classifying S_0 plants of the double crosses for their flowering time and maturity time. Support for this conclusion can be obtained from the comparison of the HUDS required for silking and maturity stages by S_0 plants and S_1 families (table B-3 and table C-2), for those double crosses tested in experiment C. A summary is given in table 8-1 below, and reader is referred to the comparisons and conclusions shown in Chapter 3 (experiment C).

Table 8-1. Accumulated heat-unit degrees (by the Gilmore-Rogers method) required for silking and maturity by S_0 plants (experiment B) and their S_1 progenies (experiment C).

Double	fam	HUDs to silking		HUDs to maturity	
cross		S_0 exp. B	S_1 exp C	S_0 exp B	S_1 exp C
4	1	826.25	775.60	1503.50	1152.00
	4	730.25	704.90	1283.00	1071.00
	5	835.25	756.40	1427.00	1200.00
9A2	2	720.75	765.70	1319.25	1178.00
	3	855.75	800.00	1332.25	1234.00
	5	895.50	883.90	1510.50	1292.00
11A	1	826.25	763.60	1405.25	1106.00
	2	765.50	761.80	1319.25	1134.00
	3	826.25	790.00	1447.75	1190.00
	4	820.75	789.30	1616.00	1290.00
	5	924.0	772.50	1601.00	1193.00
16A	1	871.25	875.00	1405.25	1289.00
	3	825.75	862.00	1272.50	1240.00
	5	971.50	923.00	1576.75	1311.00
19A2	1	811.25	820.00	1319.25	1216.00
	2	795.50	702.40	1319.25	1112.00
	3	855.75	710.80	1288.50	1121.00
	4	765.50	787.10	1364.75	1051.00
	5	895.50	870.20	1384.75	1277.00
25A	1	901.00	800.00	1503.50	1206.00
	3	815.75	713.00	1308.75	1078.00
	4	815.75	711.00	1394.75	1100.00

These comparisons confirmed that differences between the means of most of S_1 progenies paralleled those of the S_0 plants from which they were derived. Most of the earlier S_0 plants gave earlier S_1 progenies for silking or for maturation. Despite that, the inconsistency of the time from silking to maturity, which we noted in Chapter 3, alters the rank order of some families within each double cross in the S_1 progenies test (experiment C). Thus changes in this interval should be taken into account in any selection for early maturity.

The importance of the heat-unit degrees method in the classifying of maize genotypes for flowering or maturity time was discussed at the end of Chapter 3.

Thus the procedures used in experiments, A, B, and C gave clear evidence about the degree of the genetic variability for germination at low temperature and for flowering characters and the maturity. This variability appeared to be high. Also by this procedure a good genetic diversity was maintained for traits of importance in this material. Generally, in most plant breeding programmes, improvement is accompanied by a decrease in the genetic diversity, particularly in the materials that reach commercial production. This then reduces the potential variability available to the breeder for selection (Stuber, 1985). At the other extreme we have been able to distinguish the most promising double crosses or S_1 families. In addition to that, two generation of inbreeding was obtained (S_1 and S_2) from the double crosses. These experiments required not more than one year to be carried out under controlled conditions in the glasshouse in the North of England, provided that there is enough space in the glasshouse. It was not possible to start experiment C in July 1987 because of there was another experiment of the North Carolina Mating Design performed in the same glasshouse in the Summer of the 1987.

The use of glasshouse conditions to produce well matured S_1 and S_2 seeds was considered advisable at this stage because the field conditions may not be consistent enough over years for the development of seeds with low moisture content to occur every year. This has been refered by Bunting and Gunn (1973), as one of the important practical considerations. They stated that 'in Britain few maize genotypes

produce good quality seeds from field sowing. Thus it is necessary to grow breeding material under glass to obtain seed of consistency good quality, and the high capital cost of glasshouses suitable for seed production is a major factor limiting the scale of maize breeding programme in Britain'. One bonus of the work in the field at Hull was to show that Bunting and Gunn were being unduly pessimistic.

Both germination and seedling vigour at low temperatures were used as criteria for cold tolerance and their potential for early planting. Subsequently selection for earliness was based on early flowering and early maturity. Time has been saved in two ways; firstly by using controlled environments, and secondly by carrying out the evaluation and the selection at the same time. The evaluation was essential for obtaining the necessary information and understanding of the nature both in degree and kind, of the existing genetic variability for the important traits. The selection was applied to plants grown in controlled environments in the growth chamber and the glasshouse, using a procedure combining selection for early germination and early maturity. Priority was given to those individuals or families that combined early germination with early flowering and early maturity. Selfing with testing of S_1 and S_2 families in replicated experiments were used to evaluate and maintain selected and desired individuals and families.

The Field Evaluation of the Double Crosses, the Selected and Unselected S_1 and S_2 Families.

This test included all the 32 double crosses, 48 S_1 families and 22 S_2 families (Experiment E, Chapter 5). The results, confirmed that the genetic variability for all the traits studied is similar to that observed in the glasshouse. The generalized randomized block design, with equal block size, as described by Addalman (1969) and referred to by Steel and Torrie (1980, p 215), was used for these experiment. The authors stated that it is the most suitable design to follow when all factors are fixed effects and the block x genotypes interaction is important.

The traits studied in Chapter 5 were divided into three groups.

1. Seedling Emergence and Seedling Vigour Traits.

The results for the number of seedling emerged, emergence rate, seedling dry weight, and for seedling vigour scale have been discussed in detail in Chapter 5. Comparisons of the results with other studies was also made. The environmental conditions of relatively high temperatures especially at the time of the planting of block 1 and block 2 on the 8th of May in 1988 did not allow the genotypic differences to be expressed (table E-4), particularly for the number of seedlings emerged and for the emergence rate. Despite that, superior genotypes among the S_1 and S_2 families were determined. McConnell and Gardner (1979b) and Cowen (1985) reported the importance of adequate cold stress conditions during evaluation to allow differentiation among the genotypes to be revealed. In a study for selection for cold tolerance, Hoard and Crosbie (1986) found that direct gain from selection for percentage emergence was greater in cooler environments than in warmer environments. In their survey of maize breeding in Britain, Bunting and Gunn (1973) stated that further significant differences in the rate of early emergence of grain maize were not expected and greater success has followed selection for early maturity, thus aimed at shortening the life cycle at the end rather than at the beginning.

The results also show the correspondence between the germination test in the laboratory (experiment A and D) and the emergence in the field for these genotypes. The early germinating families were found to emerge earlier in both situations (see Chapter 4 table D-5 and table E-4 Chapter 5 for comparison). Families which were consistent in the laboratory and in the field tests were listed in Chapter 5.

The results for seedling dry weight and the 1-5 vigour scale were also found to be similar. Variation for both traits was high compared with that for emergence (see table E-4, E-5, E-6a, E-6b, E-7, E-8, E-9a and E-9b). The positive correlation between the emergence traits and SDW was highly significant (see table E-10). This association was found to be consistent over the three generations (S_0, S_1 and S_2). This result suggests that seedling emergence rate or SDW could be used to select for improved cold tolerance in these genotypes. The absence of G x E interaction for the

SDW, in general, could mean that selection for this trait can be done in one environment. It is also an indication of the importance of the additive gene effects for seedling growth. In the source material used to obtain the double crosses, Maryam (1981) found that germination at low temperature was mainly controlled by additive genetic factors. Thus we can argue that the same type of genetic system could control both the emergence and seedling growth in these genotypes.

The results for all the seedling-emergence and seedling-growth traits included in this study indicated that the variation between families selected from different double crosses is greater than that within each double cross (see tables E-5, E-8). Despite that variation among families derived from the same double cross was significant for some double crosses (eg 4, 19A2) especially for the SDW. This suggests that selection for cold tolerance based on SDW is more effective than on ER if the environmental conditions are similar to the conditions experienced in this experiment, i.e. when the temperature at sowing time was relatively high (Appendix 1). This result agrees with the finding of Hoard and Crosbie (1986). They emphasized that direct gain from selection for cold tolerance was greatest in warmer environments for seedling dry weight. It is clear that the results for these traits (Chapter 5) enabled us to distinguish those genotypes with the most desirable characteristics. Since 1965, when Pendleton declared that cold tolerance in maize is not only the ability to germinate, but also to grow and develop good seedlings under cool condition, most studies have reported the use of tests for germination, emergence, and SDW and vigour scale in the breeding for cold tolerance in maize. Cowen(1985) reviewed most of studies of this kind and concluded that cold tolerance is a quantitative trait, and sufficient genetic variability exists within adapted and exotic material to enable cold tolerance to be increased within the examined material. Mock and Bakri (1976) reported some progress for cold tolerance by S_1 selection. The percentage emergence and seedling dry weight increased by 8.4 % and 0.6 % kg per cycle, respectively, in the American maize population BSSS13CSCT. But no important progress was obtained in the population BSSS2(SCT).

Correlation among cold tolerance components wasn't highly significant. Genotype x environment interaction effects were not clear for the emergence traits (because they cannot be examined, see chapter 5, for reasons). The G x E interaction seems to be absent for seedling dry weight and the seedling vigour scale. Some G x E interaction appeared when families derived from each double cross were analysed separately, e.g. for families of double cross 19A2 (see tables, E-9a and E-9b) for the SDW. As a result, it seems that inheritance of cold tolerance is not complex in these genotypes. Selection of the desired families for cold tolerance is possible. The most encouraging S_1 and S_2 families were listed in Chapter five.

Marshall (1982) has described many studies on cold tolerance in many other crops; wheat, barley, oats, cotton and alfalfa. He confirmed that both controlled and uncontrolled environments were used. The progeny test was also used in the selection for cold tolerance and winter hardiness in these crops. He stated that winter hardiness generally appears to be under polygenic control, with the major component of variance attributable to additive effects, with some effects of the environmental conditions. In barley, winter hardiness may be either dominant or recessive, depending on the test, location and conditions. He also reported that in these crops the GCA and SCA for cold tolerance were also studied. Differences between lines, maternal and reciprocal effects were also investigated. Unremarkably, he stated that the prospects of improving of the cold tolerance of the major crop plants are dependent on the availability of exploitable genetic diversity.

2. Flowering and Maturity Stages.

The assessing of the flowering and maturity stages (boots, 65 , silking, silking to maturity and maturity stages) was based on the heat unit degrees (Gilmore and Rogers (1958), and the Ontario (Brown, 1975) methods) and the calender day.

Comparison of the heat-unit methods (Chapter 5) indicated the validity of both methods for the evaluation of all stages. Furthermore, either of the heat-unit degrees methods can be used without any important differences. Both methods were more

accurate than the calender day to evaluate the maturity stage (see table E-27 for the coefficient of variation for the three methods). This conclusion agrees with the findings of Mederiski *et al.* (1973) and Aspiaza and Shaw (1972) and many other researchers. There is no evidence that the Ontario method is more accurate than the Gilmore-Rogers method in this experiment for classifying the maize genotypes for flowering and maturity under the experimental conditions the plants experienced. This result is in contrast to those reported by Mederiski *et al.* (1973) and by Bunting (1976).

The results for the flowering and maturity stages (discussed in Chapter 5) also indicated that there is high genetic variation for these traits (boots, 65, silking, silking to maturity and maturity stages) between the double crosses , the S_1 and the S_2 families over the two dates of planting. Variation among the S_1 families was higher than that between the hybrids because the S_1 progenies included selected and non selected families. Less variability was observed among families derived from the same double cross both in the S_1 and the S_2 families results.

The results for these traits (tables E-11 through table E-26b) clearly confirmed that the procedure we used to select for flowering and maturity under controlled conditions, i.e. based on fewer heat-unit degrees to reach each stage, was effective to distinguish the families earlier to flower or to mature. Most of families known to be faster from the glasshouse experiments B and C were found to be faster in the field. Thus this method of selection seems to be effective with these genotypes. This agreement between the results obtained in the field test and in the glasshouse was also observed by Maryam (1981) when she tested the source material of the genotypes used in this study. This results, supported by the absence of G x E interactions (table E-16 to E-26a), stresses the importance of the additive genetic effect in the controlling of these traits, a situation that was also observed by Maryam (1981).

Measurement of the period from silking to maturity gave incosistient results and so, reduced the response to selection for early maturity. Support for this is found in table E-28 (chapter 5) where the families are listed in order, from the earliest to the

latest for each stage. Although most of the earliest families to reach maturity were among the earliest families to reach the 65 and silking stages, they were not necessarily among those families that required the shortest time from silking to maturity (see tables E-14 and E-15), although the orders were altered only slightly. As we have mentioned before, the time from silking to maturity is not constant and it depends on the genotypes (hybrids or families) themselves. This has been demonstrate several times previously (for example Mederski *et al*, 1973; Aspiazu and Shaw, 1972; Troyer, 1978). Thus the earliest families to flower and to mature may have a relatively long period from silking to maturity compared with other families. This feature (long 'filling' period) is desirable in maize (Troyer and Karkins, 1985; Troyer and Brown, 1978; Troyer, 1976; 1972; Mutisya, 1986) because it allows enough time for the grain to develop under the most suitable conditions. This lengthening of the period between flowering and maturity should not cause any decrease in the yield nor any increase in the moisture content at maturity; on the contrary in table E-28 there is some evidence in favour of using selection for early silking as a predictor for early maturity. It seems that the initiation of silking is the trait best associated with maturity, when the material is tested under unfavourable conditions. This conclusion is supported by evidence in Bunting and Gunn (1973), Gunn (1974), Troyer (1978), Troyer and Karkins (1985).

Bunting (1972a) in a study on early and late flowering plants found that one day's advance in time of flowering would advance harvest by approximately two days. He explained the differences in ripening period in terms of declining temperatures during the Autumn. Early flowering plants ripen under higher average temperatures than the later flowering ones. Thus early flowering hybrids should ripen earlier than late flowering hybrids and should exhibit less plant to plant variation in the date of maturity.

From the Maize Unit at Wye College, University of London, Hill (1977) stated that in the immediate future the continuance of grain maize production in Britain will depend upon a succession of favourable seasons enabling the full

potential of the crop to be realized. In the longer term the production of earlier maturing hybrids, which would reduce the vulnerability of the crop to adverse weather, will considerably enhance the prospects for sowing an increased area of grain maize in England.

Overall these studies of flowering and maturity showed that selection for S_1 and S_2 progeny was effective to distinguish the best families for earliness in this material.

3. Other Agronomic Characters.

The traits studied were plant height (cm), ear height (cm), grain moisture content, number of kernels per plant, grain yield per plant and 100-kernels weight. The results for these traits have been discussed in Chapter 5. Although some variation was observable, among the S_1 and S_2 families, compared with no important variation within the double crosses, this variation did not effect the plant height and ear height in the families of importance. Despite that, neither trait should be ignored during any selection programme.

It was also found that variability for grain moisture content at harvest was not too high although some variation was observed between the double crosses, the S_1 and the S_2 families. Most families gave kernels with less than 35 % moisture content at maturity, but these did not dry to the 30 % moisture content, which is reported to be the target for breeding programmes in Northern Europe (Baron *et al.*, 1987). The early maturing families had a lower moisture content than the others. This trait cannot be ignored in any breeding programme on the developing grain maize genotypes for the colder regions of the world, but it seems less important for those regions when temperatures at maturity times are high, such as in the Spring season in Iraq.

Yield is the most important trait determining the ultimate success or otherwise of any breeding programme, irrespective of the main objectives of a short-term programme. Clearly the breeder must maintain an acceptable yielding ability in his

material. Thus the yield components (grain yield (gm/plant), 100 kernels weight and number of kernels per plant) were studied and discussed extensively in Chapter 5. Reduction in the yield was observed in the S_1 generation compared with S_0 plants and further reduction also found in the S_2 generation. An interpretation was given for this reduction, which would not be unexpected as a result of the inbreeding. However, it was found that the early maturing families were among the high yielding families. In some cases they out yielded the others. This would confirm that the selection applied did not have a negative effect on the yielding ability. A review of the literature indicates that most studies agree with this finding (Bakri and Mock 1976; McConell and Gardner, 1979; Eagles *et al.*,1983; Hexum, 1984). The relevant details from these works were given in Chapter 5.

The Study of the Variance Components, Heritability, Selection Deferential and the Expected Gain from Selection.

The important genetic parameters were presented and discussed in Chapter 5. I estimated the variance components for the S_1 and S_2 families, including the variance due the genotypes, the G x E variance and the error variance (see table E-37). The genotypic variance between families was found to be high (for S_1 or S_2 families) compared with the G x E variance. It was concluded that the additive genetic effects were more important than non-additive effects for all flowering and maturity stages and most of the other characters.

Estimates of the 'narrow sense' heritability for the S_1 and S_2 families indicated that it was relatively high for most of the importance characters such as ER, SDW, silking and maturity for both S_1 and S_2 generations. Both additive and dominance effects seem to be of importance for the yield component. The 'narrow-sense' heritability measures the proportion of the variation due to the additive genetic effects. The higher the h^2, the higher the breeding value (Falconer, 1989), and good gain from selection is expected.

Based on selecting the best 10 S_1 families and the best 5 S_2 families for early maturity, calculations of the selection differentials and expected gain from selection (tables E-38 and E-39) indicated that there are selection differentials of -11.6 and -19.7 heat-unit degrees for maturity in the selected S_1 and S_2 families respectively. These differentials were also accompanied by positive (to the desired direction) improvement in most of the other traits studied. It was also found that this selection will lead to an expected gain in the time to maturity and early flowering and positive gain in many other agronomic traits (see the discussion in Chapter 5). The inconsistency of the time from silking to maturity was found to have a slowing effect on the expected gain from selection to early maturity.

These results confirmed the effectiveness of the S_1 and S_2 progeny selection. S_1 progeny testing has been one of the most promising methods to increase the frequency of alleles with favourable additive effects (Sprague and Eberhart, 1977; Hallauer and Miranda, 1988). Selection based on early maturity was accompanied by improvement for most of the 15 characters included. These results were discussed in detail in the estimation of h^2 in Chapter 5 and examples were given.

Hallauer and Miranda (1988) reviewed numerous works in which S_1 or S_2 progeny selection programmes were used. They concluded that many traits such as yield, resistance to maize diseases and resistance to lodging were improved. In contrast they also reported some cases when selection based on inbred family means (S_1 or S_2 lines) was less effective than expected. They argued that, theoretically, this method is more effective for changing frequencies of genes having additive effects than is the test cross method.

Williams *et al.* (1968) found that selection for high yield, based on the performance of S_1 testcross progenies, was superior to full-sib selection for characters with low heritability. The expected gain was found to be greater for selection based on S_1 testcrosses. Horner *et al.* (1969) also reported that S_2 progenies produced the highest yielding selfed population in selection for higher grain yield in maize compared with the topcross method.

We can conclude from the results of experiment E that; **a)** there is good breeding potential for early maturity and cold tolerance in this population, **b)** some understanding of the degree of variability for each character was established and the kind of gene action most likely to be important for each trait was also detected, **c)** selection for early maturity did not affect the cold tolerance trait and most of the other agronomic characters, and in some cases actually improved some of the other traits, **d)** following selection among and within the double crosses some superior S_1 and S_2 families were detected (table E-37), and **e)** as a result of selfing the very early flowering (silking) plants in the field, 25 S_1, 13 S_2 and 2 S_3 early maturing families were obtained. These families were selected from a total of 1530 plants grown in Experiment E. These families represent a good source for further breeding to compare selection under field conditions with that under controlled conditions.

For further work it is obvious, due to the importance of the additive genetic effects for most characters, that the next step in this breeding is intercrossing the best S_1 families (those families listed in table E-36) to create a new population for another cycle of S_1 recurrent selection. Continued selfing is also possible as another method to develop new inbred lines. I believe that recurrent selection' by mean' of S_1 families will be the more effective. In this way concentrating the favourable alleles can be improved. Selection of the best plants can be based mainly on early maturity using early flowering (silking) as an initial predictor. Priority should be given to early emergence or high SDW and genotypes of good yielding ability. S_2 recurrent selection also can be applied. This method seems more powerful than continuing selecting and selfing (S_1, S_2, S_3...etc) to develop inbred lines, although the latter is still a valid method to proceed this breeding programme.

Allard (1960) explained that random fixation could be limited by recurrent selection particularly when the number of the selected lines is small. If most of the genetic variability of a population were due to additive gene action, improvement theoretically should continue until all desirable alleles have been fixed in the population. The rate at which selection leads to fixation, and hence to exhaustion of

the genetic variability depends both on gene frequencies and numbers. When we deal with a polygenic characters, it is unacceptable to obtain all the favourable alleles within the base population in one selected plant. Under this circumstance alleles are disparate among number of plants. The probability of including all the plants with desirable genes will de pened on the selection intensity. As the relationship is negative one, a very large number of experimental plants would be needed to achieve maximum improvement in the desired character when the selection intensity is strong. This is clearly impracticable and thus the complete exploitation of the source material is possible only by the use of recurrent selection methods. In these methods, the selection of the best plants or lines in the early generations (S_1 or S_2), followed by intercrossing them, will reduce the rate of losing the variability , because of random fixation, to a minimum and the frequency of the desirable genes will be increased. The higher the frequency of desirable gene combinations, the greater the expectation of finding plants with high performance. Allard (1960) also reported that the evidence available suggested that selection in a selfing series 'is not likely to be profitable compared with other procedures for plant improvement.'

S_1 and S_2 recurrent selection has been successfully applied to maize (Mutisya, 1986; Gardner, 1978; Sprague and Eberhart, 1977). It used to improve cold tolerance in maize by Mock and Eberhart, (1972) and flowering time by Troyer (1978; 1985). Mutisya (1986) argued that S_1 recurrent selection for multitraits prior to flowering may offer a rapid and relatively inexpensive approach to improving early maturing populations and thereby promote their commercial breeding and maintain an expected level of productivity.

Part Two: The Evaluation of Single Crosses Between two Selected Sets of Inbred Lines Obtained from Sources in the UK and the USA: The North Carolina Mating Design (NC2) (Chapters, 6 and 7).

The results of the laboratory and two seasons of field experiments were presented in Chapters 6 and 7. The inbred lines and the hybrids were tested for cold tolerance in the laboratory . All genotypes, including the F_2s, were evaluated in the field in the 1988 season. The evaluation of the F_1s was repeated during the 1989 season. In both seasons the NC2 ANOVA was used to study the variation (using the GCA and SCA) in the F_1s and the reciprocals.

Griffing (1956) discussed methods for the analysis of GCA and SCA with random and fixed models, and stated that, in most combining-ability analyses in which a chosen set of lines is used, the interest centres on the performance of the F_1s. Therefore, the parental lines need not be included.

In Chapter 6 and Chapter 7 it was explained that there is a highly variability for the GCA and SCA of the inbred lines for most of the traits studied. In the cold test of this material both germination and seedling dry weight were investigated under controlled conditions (experiment F, Chapter 6) and the cold test was extended to include the rate of emergence. Kernels tested for germination were subsequently tested for their rate of emergence and ability to develop vigorous seedlings at 10-13° C. The results of this test (tables F-1, F-2, F-3), clearly indicated the importance of the study of the number of seeds germinated , germination index, the number of seedlings emerged, emergence rate, and seedling dry weight to establish a basic understanding about the cold tolerance and cold resistance. It was found that some good germinating lines were not able to emerge and develop vigorous seedlings (eg inbred line HY2). In contrast, other lines such as Pa32, GBC102 and GBC233, although they were the slowest lines to germinate, emerged well and grew well at 10-13° C after they been subjected for 21 days in the cold test. The results of experiment F (table F-1) also indicated that, in general, all the USA lines, except for (HY2), were

more vigorous in their seedling growth and produced higher weights per seedling than the Cambridge lines. Hybrid vigour also existed for the emergence and SDW and was more marked than for the number of seeds germinating and the germination index. Some maternal effects were also detected for these traits, except for the SDW. It is important to note that most of the genotypes subjected to the cold test developed normal seedlings when they transferred to optimum temperatures.

In experiment G (Chapter 7), two seasons of field testing were carried out. The results in tables (G-2 and G-3) for the 1988 season indicated high variability between the inbred lines similar to that obtained under controlled conditions (experiment F).

The preliminary ANOVA of the F_1s and the F_2s and their means for the different traits (1988 season tables, G-3, G-5, G-6, and G-8) indicated good variability among the single crosses and positive heterosis (hybrid vigour) was found for most of the traits. These results also indicated that the faster hybrids to mature were the same in both the F_1 and F_2 generations.

The results for the GCA and SCA of the inbred lines for emergence and seedling vigour in both seasons (1988, 1989) were inconsistent (see table G-7, G-8, G-10, G-10a). In 1988 when temperatures were less favourable, variation was found for the emergence rates. No important variation found for these traits in 1989. In 1989 higher variation was found in GCA for SDW. The NC2 ANOVA (tables G-7, G-11) showed that, in both seasons, variability for the GCA of the Cambridge lines for ER was evident and some important M x F interaction (SCA) was also found for this trait. For SDW differences, the GCA of the USA lines was stronger in both seasons with high M x F interaction, especially in 1989. These results were similar to those found under controlled conditions (experiment F, Chapter 6). Thus we can conclude that both additive and non-additive genetic effects are important for this trait. It is clear that most of the additive effects for ER were contributed by the Cambridge lines, whereas variability for SDW was higher among the USA lines. It was concluded that any selection for these traits, in these crosses, needs to be based

on selection for the best emergence and the best SDW together. This selection must be based on both GCA and SCA.

The results from the study of the CGA and the SCA for the flowering and maturity stages for the F_1s crosses in both 1988 and, 1989 were very similar (table G-7,8,8a,10,10a, G-11). There was variation in the GCA in both of the Cambridge and the USA lines and there was also variation in the SCA. The similarity of the results over the two years confirmed that both additive and non-additive genetic effects were of importance for these traits. From the set of reciprocal crosses it was found from the 1988 results that in the UK lines only the GCA was important, and this was true for all the traits, except for the maturity stage. No important M x F interaction was observed for any trait, again except for maturity. That suggested the existence of maternal effects for the USA lines for these traits. It is also means that the UK lines were more consistent in the F_1s and in their reciprocals. Maryam (1981) also mentioned similar behaviour in the genetic variation for the USA lines for these traits. Result of both seasons clearly indicated that the best SCA (promising single crosses for earliness) were obtained from the F_1s when the USA lines were used as females and the UK lines as males. The fastest hybrids to mature were the same in both seasons (see the results in Chapter 7, and tables G-8 and G-10 for more discussion and the names of the superior hybrids). The high temperatures in 1989 resulted in a reduction of 22-28 days in the time required to reach maturity by the same hybrids in the same area of land. This suggests that an even greater response should be expected in a more suitable environment. It was also found that these early maturing hybrids show good uniformity for the date of maturity (i.e. little spread of maturity,). The range of spread of maturity has previosly been found to be high in grain maize in England (Bunting and Gunn, 1973). Gunn (1973) concluded that the average ratio of spread of silking to spread of maturity was 1:2.6 (13-18; 34-47 days).

Hallauer (1975) pointed out that, in general, a suitable test should be simple to use and provide information that correctly classifies the relative merit of lines and also maximizes genetic gain. Hallauer and Miranda (1988) reviewed most of the

works centred on the use of the GCA and the SCA. Based on either a narrow base (inbred line tester), or broad base tester (non inbred line tester). They concluded that both selection for general or specific combining ability will lead to an improvement of the additive gene action in the crosses. They also concluded that although present evidence seems to show that the GCA (or additive gene effects) is more important, tests to identify that unique combination of inbred lines for high productivity, i.e. SCA, should be used although the GCA was probably more important in identifying the lines for the unique combinations. Non-additive gene effects seem to be small, on the average, but they may be important for that one unique combination. It seems that using the UK lines as males will provide the best discrimination among the USA lines.

Horner *et al.* (1976) used selection based on the SCA to improve grain yield, lodging resistance and low ear height. Seven cycles of selection resulted in 18% more grain yield, 9% lower ear height, and 35% less lodging. They suggested that gain for all traits resulted from increasing the frequency of genes with additive effects. They also concluded from these results, and others previously reported for inbred testers, that narrow base testers are effective for improving general as well specific combining ability.

No important variation was found for most of the other agronomic characters (PH (cm), EH (cm), grain moisture content, and yield components) especially in the 1988 season. Relatively important variation was evident in the 1989 season for yield and yield components (number of kernels per plant, 100 kernels weight (gm), and grain weight (gm) per plant). Both the GCA and the SCA effects were important, showing that both additive and dominance genetic effects had an influence on yield.

Overall, the results in this part of the thesis (Chapters 6 and 7) lead to the following conclusions:

1. The production of new genotypes combining together the characteristic of the Cambridge and the USA inbred lines is worthwhile and very promising for the

establishment of grain maize as a new and satisfactory crop in the UK and for the spring season in Iraq. The material used in this study also has excellent potential for the early spring season in Iraq conditions. In general the weather conditions in the Spring season in Iraq are more favourable than those in Britain (more details on the weather conditions in Iraq are given in Chapter 1).

2. Both the laboratory and the field tests indicated that there were some promising hybrids between these lines both for earliness and uniform maturity (see Chapter 7 for the genotypes of these hybrids).

3. Any evaluation of these genotypes for cold tolerance should include the germination rate emergence rate, and seedling dry weight.

4. Using the NC2 mating design and its analysis led to a good understanding of the nature of the genetic variation in these hybrids, and certainly for those characters of importance. The highest variation obtained was for flowering and the maturity stages. The results have met the most important objective, to establish hybrids which combine the early maturing characteristics of the Cambridge lines with the good agronomic traits of the USA lines. Visual observation of these hybrids indicated that they were more vigorous for vegetative growth. They were also characterised by an ability to remain green after maturity, which makes them also suitable for green forage production, whereas the double cross material lacked this character. Because both sets of experiments were planted side by side in the same location and season in 1988 a direct comparison can be made between the double crosses and the single crosses, (see plate 3).

5. This study also enables us to distinguish those superior lines among each set of the UK and the USA inbred lines. It was found that the best combinations (crosses) obtained were from those lines with good GCA such as GBO78 and Pa32.

6. Finally, it has been shown that when combining two different sets of inbred lines with different patterns of gene action for the characters to be selected, NC2 mating is a very satisfactory mating system to be followed to study the genetic variation in the resulting hybrids.

It can be concluded that, for further work, the single hybrid crosses Pa32 x GBO78, A556 x GBO78, and A556 x GBC233 and their reciprocals are of great importance for any further breeding. Comparison tests of these combinations with the recommended hybrids or varieties is now required to see how far the response of these crosses is from the desired response. That would allow us to decide on the best way of proceeding with selection or breeding, i.e. back crossing to the parents or to the better parent, selecting among the F_2s, or creating new inbred lines.

Plate 1. General view of the field experiments in the 1988 season.

The photograph shows the greater part of the field experiments in the 1988 season. Numbers 1 to 6 are as follows:

1, 2, and 3 indicate block 1, block 2 (sown on 8th of May) and block 3 (sown on 15th of May), for the double crosses, S_1 and S_2 families in experiment E.

4 and 5 indicate block 1 (sown on 18th of May) and block 2 (sown on 24th of May) of Experiment G, for the NC2 mating experiment.

6 indicates the Stevenson Screen containing the thermograph and the thermometer for the temperature records.

Plate 2. Thirty day old seedlings of S_0, S_1 and S_2 families.

The photograph was taken the day before the hills were thinned to one plant per hill. Three kernels were sown in each hill. The plants labelled 27 are the double cross plants (S_0 plants). Numbers 45, 76 and 79 are plants of S_1 families, and 97 are S_2 family plants.

Plate 3. Comparison of the vegetative growth of the double crosses and their S_1 and S_2 families plants with the NC2 single crosses at flowering time.

The photograph shows that the single crosses obtained from the mating of the USA inbred lines with the Cambridge inbred lines on the left seem more vigorous in their vegetative growth (more greenish and more leaf area) than the double crosses and their S_1 and S_2 families on the right

Plate 4. Collections of maize cobs at maturity , from S_0, S_1 and S_2 plants.

The photograph shows the reduction in the cob size as a result of the inbreeding (selfing).

Appendix (1) The daily minimum and maximum air temperatures in degrees Celsius from the date of sowing to harvest for the 1988 and 1989 seasons. Temperature records from 20th of April till the end of May for 1986 and 1987 seasons are included. The daily mean of the soil temperature are also shown for the relevant 45 days at and post sowing. All records were taken in the experimental field in the Botanic Garden of the University of Hull.

Month	Day	1986		1987		1988		1989	
		min	max	min	max	min	max	min	max
April									
	20	5.0	10.5	10.0	12.0	10.0	18.0	2.0	10.0
	21	3.5	9.0	8.5	15.0	6.0	17.0	6.0	11.5
	22	4.0	10.5	9.0	15.0	1.5	8.0	3.0	10.0
	23	5.5	11.5	4.0	18.0	1.5	10.0	0.0	5.0
	24	5.5	11.5	4.0	18.0	1.5	10.0	0.0	5.0
	25	1.5	13.0	5.0	14.0	7.0	13.0	-2.0	8.5
	26	2.5	14.0	4.0	15.5	5.0	9.0	0.0	12.0
	27	3.0	10.0	4.0	18.0	5.0	8.8	1.5	11.0
	28	4.0	7.5	4.0	19.0	3.0	10.0	3.5	9.0
	29	5.5	12.5	6.0	21.0	2.5	11.0	9.0	15.0
	30	7.0	18.5	9.0	18.0	6.0	11.0	9.0	15.5
May									
	1	4.0	15.0	5.0	11.0	6.0	14.0	6.0	21.0
	2	7.0	17.0	5.0	9.0	7.0	15.0	5.0	20.0
	3	6.0	13.5	3.0	10.0	8.0	14.5	6.0	21.0
	4	9.0	11.0	3.0	11.0	10.5	14.2	10.0	22.0
	5	8.0	11.0	9.0	15.0	8.5	14.0	1.0	17.0
	6	6.0	14.5	4.0	14.0	6.2	15.2	2.0	14.0
	7	7.0	13.5	4.0	17.0	6.0	15.0	8.0	22.0
	8	7.0	13.0	8.5	22.0	10.0	13.0	10.0	22.0
	9	5.5	13.0	8.5	18.0	11.0	13.0	4.0	17.5
	10	11.5	17.0	6.0	12.0	7.0	14.0	7.5	13.0
	11	10.5	14.0	7.5	15.5	8.5	12.2	3.5	12.0
	12	9.0	17.0	8.0	11.5	9.0	16.0	4.0	12.0
	13	10.5	15.0	4.0	13.0	8.0	18.0	3.0	15.5
	14	5.5	14.0	6.5	8.5	9.0	15.5	8.5	18.0
	15	5.0	12.0	4.0	10.0	9.0	15.5	8.5	18.0
	16	5.0	15.0	3.0	12.0	9.0	17.5	3.0	18.5
	17	6.5	13.0	3.5	11.0	6.0	10.5	10.0	21.5
	18	11.0	16.5	7.0	10.0	5.0	9.0	10.0	20.0
	19	8.0	19.0	3.0	13.0	5.0	10.0	9.2	20.0
	20	9.0	15.0	4.5	11.5	4.5	12.0	6.5	18.0
	21	9.0	13.0	8.0	10.5	3.7	13.0	6.5	20.0
	22	7.0	15.0	6.5	11.5	7.0	14.0	6.5	20.0
	23	10.0	16.0	8.0	12.0	7.0	15.0	9.0	23.0
	24	8.0	15.0	7.0	11.5	11.5	14.5	11.0	22.0
	25	11.0	16.5	7.0	14.0	11.2	13.0	8.0	15.0
	26	13.0	16.0	7.0	14.0	11.0	14.0	4.0	15.0
	27	12.0	16.0	4.5	14.0	7.0	17.5	8.0	17.0
	28	11.0	15.0	9.0	10.0	6.5	17.0	9.5	16.0
	29	6.0	13.0	7.5	15.0	11.5	15.0	7.0	23.0
	30	9.0	13.0	11.0	17.5	12.0	15.0	4.0	13.0
	31	9.0	13.0	7.5	20.5	11.5	15.5	5.0	14.0

Continued Appendix (1) (records here are only for the 1988 and 1989 seasons.

Month	1988		1989		month	1988		1989	
June	min	max	min	max	July	min	max	min	max
1	11.5	16.0	2.0	14.0	1	16.5	21.0	9.0	20.0
2	12.0	16.0	6.5	15.0	2	11.5	19.0	8.0	20.0
3	11.0	15.0	3.5	14.0	3	11.0	18.0	9.5	21.0
4	11.5	14.5	2.0	15.0	4	14.0	18.0	9.0	22.0
5	12.0	13.0	6.0	17.0	5	12.0	18.3	10.0	23.0
6	7.0	16.0	7.0	14.5	6	11.2	19.0	13.0	22.0
7	6.0	13.0	5.0	15.5	7	13.0	17.5	15.0	20.0
8	13.0	16.2	5.6	15.0	8	12.0	17.5	14.0	16.5
9	12.0	13.0	10.0	16.0	9	12.5	18.5	11.0	16.0
10	12.0	16.0	7.0	21.0	10	15.0	19.0	12.0	21.0
11	10.5	15.0	13.0	24.0	11	12.0	18.5	14.0	25.0
12	9.5	17.0	13.0	23.0	12	13.0	18.0	13.0	24.0
13	9.0	19.0	13.0	24.0	13	13.0	18.5	11.0	20.0
14	7.0	17.0	11.0	23.5	14	13.0	17.0	12.0	21.5
15	12.0	17.0	9.0	21.5	15	15.0	18.5	11.0	24.0
16	11.5	14.0	10.5	24.0	16	12.0	18.0	14.0	21.0
17	12.5	16.0	9.0	26.0	17	15.0	16.0	13.0	27.0
18	9.5	19.5	11.5	24.0	18	13.0	18.2	8.5	19.5
19	9.5	21.0	11.0	24.0	19	14.0	18.5	12.0	27.0
20	13.0	21.0	10.5	30.0	20	16.0	19.0	12.0	29.0
21	17.5	20.0	12.0	20.0	21	15.0	19.5	16.0	25.5
22	13.5	18.5	8.0	20.0	22	17.0	21.0	15.0	28.5
23	12.5	18.5	12.0	20.0	23	16.5	21.5	12.5	27.0
24	10.0	21.0	9.0	20.	24	13.0	17.0	14.5	26.0
25	13.5	23.0	12.0	27.0	25	14.0	19.0	16.0	27.0
26	16.0	18.0	14.0	21.0	26	14.7	18.5	11.0	23.0
27	15.0	16.0	7.0	17.5	27	12.0	16.5	14.0	23.0
28	14.0	15.0	8.0	16.0	28	12.0	16.5	15.0	22.0
29	9.0	21.0	5.0	19.0	29	12.0	15.5	13.0	23.0
30	14.5	22.7	11.5	11.5	30	12.0	16.0	11.0	18.0
					31	13.5	16.5	9.0	18.0

Continued Appendix 1 .

	August				September				October*	
	1988		1989		1988		1989		1988	
Day	min	max	min	max	min	max	min	max	min	max
1	12.0	17.0	7.0	21.0	14.0	16.5	7.5	20.0	2.5	14.0
2	7.5	17.0	14.0	22.0	12.7	15.0	6.0	15.0	7.5	16.5
3	9.3	17.3	9.0	25.0	10.0	17.0	6.5	18.0	4.5	16.0
4	14.5	19.0	8.5	22.0	11.0	17.0	10.5	19.5	6.0	14.0
5	17.0	22.5	9.5	25.0	12.0	17.5	11.0	22.0	12.0	15.5
6	11.5	24.5	14.0	25.0	12.0	17.5	10.0	26.0	10.5	12.5
7	11.0	24.5	12.0	25.0	12.0	22.5	12.0	21.0	8.7	10.0
8	15.0	17.0	15.0	25.0	13.5	22.0	12.0	16.0	9.5	12.5
9	17.0	21.5	14.0	23.0	14.0	21.0	12.0	16.0	.0.0	12.5
10	11.0	21.7	12.0	18.0	10.0	15.0	13.0	16.0	9.0	13.0
11	13.0	18.7	13.0	21.0	12.0	17.5	14.0	12.5	2.0	13.0
12	14.1	17.5	13.0	22.0	11.5	16.0	13.0	16.0	12.0	13.5
13	13.5	19.5	12.0	22.0	10.5	14.5	9.5	19.5	9.0	12.0
14	16.0	21.5	14.0	23.0	11.0	13.7	7.5	16.5	5.0	13.0
15	14.5	20.0	13.0	23.0	11.0	16.5	11.5	19.5	7.0	12.0
16	12.5	20.0	11.0	22.0	7.7	18.0	10.5	18.0	12.0	12.0
17	9.5	23.2	10.0	20.0	14.7	18.0	10.5	19.0	11.5	12.0
18	16.0	21.0	6.5	22.0	9.0	18.5	10.0	20.0	12.0	14.0
19	16.0	21.0	12.5	24.5	7.5	18.0	10.5	22.5	13.0	14.0
20	14.5	18.0	12.0	27.0	7.5	12.5	11.5	19.5	12.0	12.0
21	14.0	16.0	10.0	24.0	10.0	13.5	12.0	22.0	.2.0	14.4
22	11.5	17.5	9.5	22.0	13.0	15.5	12.0	25.0	7.0	15.5
23	13.5	17.7	15.0	22.0	9.0	12.0	11.0	20.0	10.0	13.5
24	16.0	18.5	13.0	18.5	10.0	14.5	9.0	21.0	10.0	15.0
25	11.0	15.0	12.0	15.0	5.0	16.5	9.5	22.0	7.0	12.5
26	10.5	18.0	11.0	17.0	15.0	16.0	9.5	21.0	13.0	14.0
27	16.0	21.0	9.0	17.0	12.7	17.5	9.0	19.0	11.5	15.0
28	13.0	17.5	7.0	19.0	13.5	14.5	8.0	20.0	4.0	9.5
29	11.0	17.5	12.0	20.0	8.0	14.5	10.0	21.0	2.0	7.5
30	12.5	17.5	9.5	25.0	3.0	14.0	12.0	17.0	2.0	8.0
31	15.0	18.0	9.0	19.0					0.0	10.0

* All plants were harvested before October in the 1989 season.

Continued Appendix (1). The daily mean of the soil temperatures at the surface about 3 (cm) depth for four seasons (1986, 1987, 1988 and 1989) which covered the period from 20th of April to the end of May.

Month	Day	1986	1987	1988	1989
April	20	6.6	11.1	10.0	6.3
	21	7.7	11.3	11.1	9.9
	22	8.1	11.9	9.1	9.2
	23	8.6	12.3	9.0	8.9
	24	9.3	12.3	10.9	6.9
	25	10.7	12.5	10.7	6.1
	26	9.2	12.3	9.0	7.7
	27	10.4	12.7	10.3	7.7
	28	9.9	13.1	9.8	8.3
	29	9.5	13.3	9.1	8.3
	30	12.4	14.4	10.6	8.9
May	1	13.3	13.2	10.5	10.8
	2	13.9	10.7	11.8	14.4
	3	12.2	9.9	13.0	15.9
	4	11.3	10.2	13.5	15.3
	5	11.0	12.0	14.2	12.6
	6	11.1	13.2	14.0	14.0
	7	11.1	14.8	12.8	15.4
	8	10.3	15.5	12.3	16.3
	9	13.7	13.8	13.3	13.7
	10	13.1	12.5	13.0	11.7
	11	12.5	12.0	14.9	10.3
	12	12.9	10.7	14.7	11.9
	13	11.7	10.4	15.7	12.7
	14	1.6	10.2	16.3	13.0
	15	12.7	10.2	11.0	14.6
	16	11.3	10.2	11.0	15.0
	17	13.6	10.5	12.9	17.7
	18	15.3	10.8	13.6	18.4
	19	13.6	10.1	16.1	18.4
	20	12.2	11.2	15.6	18.5
	22	12.0	11.6	15.7	18.0
	23	14.3	13.5	14.2	18.8
	24	14.9	14.9	15.8	16.2
	25	16.9	15.1	17.0	16.1
	26	11.9	14.4	15.1	16.4
	27	14.8	12.6	15.4	17.9
	29	14.6	14.8	16.3	15.5
	30	13.4	16.1	17.0	14.2
	31	14.9	16.4	15.9	14.2

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