INHERITANCE OF NITROGEN USE EFFICIENCY COMPONENTS IN MAIZE

BY

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DEDICATION

"I dedicate this dissertation to my late father Ntate Lefu and my lovely mother M'e 'Makhothatso, for raising and instilling in me the character quality of discipline, hope and perseverance.

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LIST OF ABBREVIATIONS

% = Percentage
ARD = Agricultural Research Department
av. = Average
Ca = Calcium
CIMMYT = Centro Internacional de Meiz y Trigo
cm = Centimeter
CML = CIMMYT Maize Line
df = Degrees of freedom
DNA = Deoxy ribonucleic acid
E = East
EC = Exchangeable cations
FAO = Food and Agriculture Organization
g = Grams
G.D.P. = Gross domestic product
g/100seed = Grams per 100 seed
GCA = General combining ability
GLS = Grey leaf spot
GNU = Grain nitrogen uptake
GY = Grain yield
ha = Hectare
K = Potassium
KCl = potassium chloride
kg = Kilogram
Kg/ha = Kilogram per hacter
L.A.N. = Limestone Ammonium Nitrate
LSD = Least significant difference
masl = meters above sea level
Max = Maximum
Mg = Magnesium
Mg/kg = Milligrams per kilogram
Min = Minimum
ml = millilitres
MSV = Maize streak virus
N = Nitrogen
NPK = Nitrogen Phosphorus Potassium
$N0_3$ = Nitrate
Na = Sodium
NH4 = Ammonium
NHI = Nitrogen harvest index
NRf = Nitrogen recovery in fertilized plot
NRo = Nitrogen recovery in unfertilised plot
NUE = Nitrogen use efficiency
^{o}C = Degrees centigrade

P(Bra -1) = Method that extracts more soluble phosphorus
ppm = parts per million
PE = Physiological efficiency
pH = Measure of soil acidity or alkalinity
PLTHT = Plant height
RE = Recovery efficiency
RSA = Republic of South Africa
S = South
SADC = Southern Africa Development Countries
SCA = Specific combining ability
SDN = Seed number
SDW = Seed weight
SNU = Stover nitrogen uptake
Temp. = Temperature
TNU = Total nitrogen uptake
ton = Tones
YE = Yield efficiency
Yf = Yield of fertilized plot
Yo = Yield of unfertilised plot
Zn = Zinc

CHAPTER 1

INTRODUCTION

1.1 *Importance of maize*

Maize (*Zea mays Linneaus*) is one of the major important crops of the world and it is the most staple food crop in southern and eastern Africa. Among the world's cereals crops, maize ranks third after rice and wheat in worldwide production (Dowswell *et al.*, 1996; FAO, 1992; Kling and Edmeades, 1997). With adequate rainfall, it is one of the most important crops in many temperate, subtropical and tropical regions, with a yield potential higher than most other cereals. It is grown under a wider range of climatic conditions than either wheat or rice.

Sixty-four percent of the world's maize area is found in developing countries (Kling and Edmeades, 1997). The area planted by maize in these countries has increased by 41 percent between 1961 and 1993. This expansion exceeds that of other crops like rice or wheat (Hess, 1997). Nearly 40 percent of the total world production of maize is produced in the United States, where the average yield is 7.5 tons/ha. In general the difference of yields between industrialised and developing countries is striking. The average yield for industrialised countries is 6.2 t/ha compared with only 2.5 t/ha for developing countries. In West and Central Africa, the average yield is about 1 t/ha, and between 1.5 - 2 t/ha in East Africa (Kling and Edmeades, 1997).

Maize is the most widely grown and consumed food crop by small farmers in Africa and forms an important part of the transformation of smallholder agricultural systems that has taken place during the last century (Blackie, 1994; Paterniani, 1990). Therefore, it has the greatest potential for alleviating hunger in the African continent. The crop is increasing in its importance as a source of food (Paterniani, 1990). Per capita consumption of maize in some countries exceeds 100 kg per year (Paterniani, 1990; Pandey and Gardner, 1995), and the crop is probably the most widely distributed of any in the world.

1.2 *End use of maize*

Maize is used primarily as a food for humans in Africa, in contrast to the United States where about 85 percent of the crop is used as a feed grain for livestock (Jugenheimer, 1976; Poehlman, 1987; Inglett, 1970). Maize is the staple food in the SADC region (Zambezi and Mwambula, 1996), and it contributes on average 40 percent of the calories consumed in people's diet. According to Mangelsdorf (1974) maize supplies carbohydrates, small amounts of protein and fat.

Perry (1970), states that wherever it can be grown successfully, maize yields more energy per acre than any other crop grown routinely for livestock feeding, and it is the highest in both energy and palatability when compared with the common feed grains for all classes of livestock. As nutrient for humans and animals, maize serves as a basic raw material for the production of starch, oil, protein, alcoholic beverages, food sweeteners and more recently fuel (Dowswell *et al.,* 1996; FAO, 1992; Morrison, 1951). As a feed the grain of maize is of most importance; and so are stalks, leaves and immature ears, which are also used as fodder in some areas (Miracle 1966). Maize ranks high as a forage crop. According to Morrison (1951), silage made from the entire maize plant gives a higher average yield of dry matter and digestible nutrients per acre than any other forage crop.

In tropical Africa and parts of the South America, beer is frequently made from maize (Miracle, 1966). In the United States, Western Europe and other temperate areas, the industrial use of maize is into whisky and acetone (Miracle, 1966; Jugenheimer, 1976). The dry process millers utilise large quantities of maize. The principal food outlets of the dry miller are maize meal, flour, oil, and breakfast cereals.

1.3 Maize production in Lesotho

Agriculture is the largest production sector in Lesotho; it provides an important source of income for about 85 percent of the population, and contributes 41.1 percent of the G.D.P. Maize and sorghum are principal food crops grown on 60 percent and 30 percent respectively of the cultivated land. Maize is the most important cereal crop in Lesotho with the planted area ranging from 91,928 ha to 189,900 ha for the last ten years and the corresponding production ranging from 48,918 mt to 171,576 mt respectively for the same period (Lesotho Bureau of Statistics, 1996). The low maize production is a result of low average yields (0.3 to 1.2 ton per ha) and crop failure that may be as high as 55 percent in the mountain region and 45 percent in the southern region (Lesotho Bureau of Statistics, 1996).

1.4 Major maize production problems in Lesotho

Maize production per hectare has declined over the years in Lesotho. Maize yields are very low ranging from 0.3 to 1.2 tons/ha. This production decline is due to several factors among which are low temperatures and unreliable rainfall. Above all maize production is mostly constrained by declining soil fertility. Lesotho soils have been characterised as being low in organic matter and are frequently low in N and very frequently low in P (Lesotho Farming Systems Research Project 1979-1986). When both are encountered, P is usually more deficient than N. Yield responses to fertiliser are very common in Lesotho, especially to N and P. Nitrogen responses are more frequent, and are usually greater than P (Lesotho Farming Systems Research Project 1979-1986). The application of fertiliser and organic amendments can generally correct nutrient limitation of maize yields in Lesotho though these are often not available. Most farmers recognise the need for fertilisers.

Resource-poor resource farmers rarely use inorganic fertilisers. Due to high-energy cost, chemical fertilisers have become very expensive and they are often not available at the appropriate time. Inorganic fertilisers play an important role in maintaining and increasing soil fertility, but many small-scale farmers either do not obtain the necessary returns from fertiliser use to justify the costs or cannot afford to use inorganic fertilisers. The government used to subsidize fertilisers to farmers but this does no longer prevail.

Small-scale farmers often use less than half the recommended N-rate. As a result of this the gap between the yields of farmers in the fields varies between 0.3 and 1.2 tons/ha, while the yields in research experiments varies between 4 and 6 tons/ha. Due to inadequate cash, these farmers have to choose between spending more money on hybrid maize seed and applying very little N, or rather use unimproved seed in order to spend more money on N-fertilisers. Therefore, to enhance maize yields and to reduce the impact of N-deficiency on maize production in Lesotho, breeders should improve the N-use efficient of maize genotypes grown in Lesotho.

1.5 The objectives of this study are;

1) To study the genetic variability for nitrogen use efficiency (NUE) components.
2) To identify suitable inbred parental lines with out-standing combining ability for nitrogen use efficiency components.
3) To calculate the inheritance of nitrogen use efficiency (NUE) components and
4) To develop a strategy for the development of nitrogen use efficient maize hybrids.

CHAPTER 2

LITERATURE REVIEW

2.1 Origin of maize

There are a number of theories regarding the origin of maize. Mangelsdorf (1947) and Mangelsdorf and Smith (1949), have done extensive studies on the origin of maize and their conclusions have been generally accepted, although others have different viewpoints regarding certain points. No wild plant is known from which maize could readily have been derived. This might be accounted for by an assumption that the wild maize plant has become extinct (Kiesselbach, 1980). Teosinte is usually regarded as very closely related to, not only because of its morphological resemblance, but also because it can be hybridised readily with maize, the progeny being fertile (Mangelsdorf and Reeves, 1939).

Any satisfactory explanation of the origin of maize must also account for its close relationship to teosinte. Collins (1919), suggested that maize arose from a cross of teosinte with a grass belonging to the Andropogoneae (sorghum tribe). This, however, seems doubtful as it neither has been shown that teosinte can be crossed with any member of Andropogoneae nor that if such a cross were made, the result would be maize. Following extensive studies of crosses between maize and gama grass, Mangelsdorf and Reeves (1939), suggested that teosinte arose as a natural cross between maize a species of gama grass. This would explain the close relationship of teosinte and maize, and would eliminate teosinte as an ancestor of maize, but does not account for the origin of corn. Also Wellhausen *et al.* (1951), observed over 2000 introductions and discussed the origin of twenty-five races of maize in Mexico. They concluded that the most ancient corn of Mexico was both a pod and pod corn.

The conclusion reached by Montgomery (1906), and by Weatherwax (1916), that both maize and gama grass have arisen from an unknown common ancestor by independent lines of descent, is accepted. This, together with the Mangelsdorf and Reeves (1939), theory of the origin of teosinte by natural hybridisation of maize and gama grass, would account for the origin of all three genera of maize.

Based on the evidence of comparative morphology, it is concluded that modern naked maize has arisen from an assumed primitive ancestor bearing glume-enclosed seeds on the brittle rachis of a terminal, perfect-flowered inflorescence (Kiesselbach, 1980). The geographic point or origin is generally conceded to be somewhere in the tropics (Kuwada, 1911; Mangelsdorf and Reeves, 1939) of Central or South America, with the latter seeming most probable. This belief is based upon archeologic and ethnologic evidence and upon the theory that the birthplace of a new species is likely to be found in the region of its greatest variability (Collins, 1919 and Vavilov, 1926). As there has been a wide divergence of opinion about the botanical characteristics of maize's ancestor, there have also been differences of opinion about its geographic origin. However, Mangelsdorf (1974), suggested that corn had not one origin but several in both Mexico and South America.

2.2 Types of maize

Maize may be divided into various groups in character of the seeds (Sturtevant, 1899, as cited by Jungenheimer, 1976). These types are dent, flint, sweet, flour, popcorn, waxy and podcorn.

I) Dent maize (*Zea mays indentata);* It is the most widely grown type of maize in the United States. It is characterised by a depression or "dent" in the crown of the seed. The sides of the seed have a corneous starch, while the soft starch extends to the summit of seed. Rapid drying and shrinkage of the soft starch results in the characteristic denting.

II) Flint maize (*Zea mays amylacea);* The kernel is hard and smooth and contains little soft starch. The relative amounts of soft and corneous starch vary in different varieties. In temperate zones flint maize often is earlier in maturity, germinates better, has earlier plant vigour and has more tiller than the dent strains. Columbus and his followers landed in countries where flint strains were widely grown (Jungenheimer, 1976). Consequently, flint maize probably was the type first seen by the Europeans.

III) Sweet corn (*Zea mays saccharata);* It is characterised by a translucent, horny appearance when immature and a wrinkled condition when dry. The ears are picked green and used for canning and fresh use. Sweet corn differs from dent by only one recessive gene (*su*), which prevents the conversion of some of the sugar into starch.

VI) Flour corn (*Zea mays indurata);* The kernels are compared largely of soft starch and have little or no dent. Flour corn has been widely grown in the drier sections of the United States. It is one of the oldest types of corn, and it is frequently found in graves of the ancient Aztecs and Incas. Americans Indians ground the kernels for flour because of their softness.

V) Popcorn *(Zea mays everta);* It is an extreme form of flint with the endosperm containing only a small proportion of soft starch. Popcorn is a relatively minor crop compared with dent corn. The crop is used primarily for human consumption as freshly popped corn and is the basis of popcorn confections. The ability to pop seems to be conditioned by the relative proportion of horny endosperm (Jungenheimer, 1976), where the starch grains are embedded in a tough, elastic colloidal material that confines and resists the steam pressure upon heating until it reaches explosive force.

VII) Waxy (wx) corns *(Zea mays ceratina);* It is so named because of the somewhat waxy appearance of kernels. Waxy starch is composed entirely of the branched molecular form, amylopectin, whereas common corn starch is approximately 78 percent amylopectin and 22 percent amylose, the starch chain form. China was the original source of the waxy gene, but waxy mutations have since occurred in American dent strains.

VIII) Pod corn (*Zea mays tunicata);* It is an unusual type of maize, each kernel of which is enclosed in a pad or husk. The ear is also enclosed in husks, as are the other types of corn. Homozygous podcorn usually is highly self-sterile, and the ordinary type of podcorn is heterozygous. Podcorn is not being grown commercially, but is of considerable interest in studies of the origin of maize.

2.3 Cytogenetics of maize

Immediately following the discovery of Mendel's law in 1900, the maize plant became a favoured subject for genetical investigation. Among its desirable features is the separation of the male and female inflorescence, which makes unnecessary the tedious emasculating required for controlled pollination in many other species (Rhoades, 1955).

2.3.1 Chromosome morphology

2.3.1.1 Meiotic chromosomes

Maize has 10 chromosomes, which were first characterised by McClintock (1929). She reported that the 10 chromosomes could be recognised by relative lengths, arm ratios, and knob positions at the prophase of the first microspore division. McClintock (1930, 1931, 1933), later found that much better morphological detail was available in the pachytene stage of meiosis. Longley (1938, 1939), and Rhoades (1950, 1955), described the pachytene chromosomes and found that they are distinguished from each other on the basis of overall length, centromere position (arm ratio), and appearance of the centromeric, heterochromatin, characteristic chromomeres, and the possession of knobs at specific chromosomal sites. The basic features of pachytene chromosomes in maize are relatively constant throughout the species. Surveys of maize have shown little evidence for naturally occurring translocations (Cooper and Brink, 1937), or inversions (Rhoades and Dempsey, 1953). Variant centromere positions have been found for chromosomes 2 and 4 (McClintock, 1933). However, in a review of large-scale studies of maize in South America, McClintock (1978) reported that chromosome lengths and centromere positions were constant among races examined.

2.3.1.2 Mitotic chromosome

The morphological detail available in mitotic chromosomes is considerably reduced from that found in pachynema. Mitotic prophase chromosomes show differential staining of heterochromatin and euchromatin just as is found in meiotic prophase. However, the condensed nature of chromosomes in mitosis makes the distinction between heterochromatin and euchromatin much more difficult to determine. Only large prominent heterochromatic regions are easily identified by conventional staining (Carlson, 1970). In mitotic metaphase, the loss of morphological detail is even greater since, the whole chromosome is densely stained. Also the reduced size of mitotic chromosomes makes accurate determinations of overall length or centromere position more difficult than that with parchytene chromosomes.

2.3.2 Meiosis in maize

The most significant event in meiosis is chromosomal pairing. Although pairing occurs during the first meiotic division, preparations for it may begin in the prior mitotic divisions. The prophase chromosomes of premeiotic cells are longer and thinner than those in somatic cells (Carlson, 1988). Rhoades (1955), suggested that they are being made ready for the onset of meiosis. Maguire (1983), studied the last premeiotic mitosis and proposed that some association or pairing of homologues occurs in this division.

Synapsis occurs during early substages of the first meiotic prophase. The chromosomes at this time are extremely long and attenuated compared to either somatic or premeiotic chromosomes (Palmer, 1971). The earliest substage of prophase is leptonema, during which the chromosomes are unpaired and appear extremely thin (Carlson, 1988 and Rhoades, 1950). The next substage, zygonema, is the time of chromosomal pairing. Pachynema begins when pairing has been completed, this is the time when paired chromosomes emerge from the zygotone knot and spread throughout the nucleus (Carlson, 1988). Three kinds of chromosomal association are seen during pachynema; homologous pairing, which is usually complete along the length of each bivalent; nonhomologous pairing, which is found with chromosomes that lack pairing partners; and thirdly is the formation of centromeric fusions and heterochromatic fusions (Carlson, 1988). Pachynema is the most useful meiotic stage for cytogenetic work.

2.3.3 Crossing-over in maize

Rhoades and McClintock (1935), define “crossing-over” as the placing of genes in linkage groups and locating them on the chromosomes, and it is used to denote the exchange of pieces or segments between homologous chromosomes.

2.3.3.1 Nonhomologous crossing over

Synapsis in maize, as in other organisms, is usually completely homologous. However, nonhomologous synapsis can occur when a denation from the normal chromosomal constitution is present (Carlson, 1988). Most evidence suggests that crossing over is not possible between nonhomologous sites. In structural heterozygotes, imprecise (nonhomologous) synapsis is associated with a reduction in crossing over (Burnham, 1934 and Rhoades, 1968). Nevertheless, crossing over between nonhonologous chromosomes is occasionally found in haploids (Carlson, 1988).

2.3.3.2 Comparisons of crossing over in male and female flowers

Crossing over in maize occurs during micro and megasporogenesis (Rhoades, 1978). Carlson (1988), had drawn few general conclusions from the work of many investigators tabulated by Robertson (1984), that many chromosomal regions have similar rates of crossing over in male and female gametes. When rates of crossing over differ between the sexes, it is usually higher in the male gametes, and finally differences in rates of recombination between male and female flowers may appear in one genetic environment or chromosomal arrangement but not another.

Origin of sex differences in crossing over has been made. Rhoades (1941), proposed that one cause might be an effect of centromeric heterochromatin on proximal regions of maize chromosomes. He suggested that the heterochromatin might be more loosely coiled in microsporocytes than in megesporocytes, and therefore, subject to more crossing over. Rhoades (1978), also showed that another type of heterochromatin could induce differences in male versus female crossover rates.

2.3.4 Synapsis in maize

Chromosome pairing during meiosis serves two basic functions. It sets the stage for a reduction in chromosome number also allows for crossing over between homologues. Synapsis of the chromosomes begins in zygonema both at distal and intercalary sites on maize chromosomes (Carlson, 1988), and proceeds to completion through formation of secondary contact sites and by extension from regions already paired. Synapsis is initiated and completed during zygonema. Pachynema is the time during which the chromosomes are completely paired along their lengths. Anderson *et al.* (1985), studied the relationship between the pachytene bivalent and its synaptonemal complex in 10 higher plants, including maize. They found that a constant amount of DNA is associated with a unit length of synaptonemal complex. The conclusion was that a similar chromosomal organisation is present during pachynema in all species examined.

2.4 *Importance of nitrogen in the maize plant*

Nitrogen plays a central role in plant productivity because it is a major component of amino acids, proteins, nucleic acids and chlorophyll. Organic N commonly constitutes 1.5 to 5 percent of the dry weight of plants, although there is some variation with age, species and plant organ (Haynes, 1986). Haynes and Goh (1978) reported that ammonium and nitrate are the only major ionic forms of N actively absorbed by maize plants in both fertilised and unfertilised soils.

Variation in nitrogen supply affect growth and development of plants (Girardin *et al.* 1987; Muchow (1988a); Muchow and Davis (1988) and McCullough *et al.* (1994). Muchow (1988a), reported that N-shortage reduces leaf expansion more than leaf emergence rate, whereas McCullough *et al.* (1994), found a greater effect of N-deprivation on leaf emergence rate. Uhart and Andrade (1995), reported that N-supply had a much larger effect on the area of individual leaves thus he found significant differences among N-levels in the area of upper leaves with reduction as much as 60 percent for the N- stress treatments. His results agree with those presented by Muchow (1988a), and do not agree with those showed by McCullough *et* *al.* (1994) who reported a larger effect of N-availability on leaf emergence rate than on expansion rate.

2.5 *Nitrogen efficiency and the problems it causes*

Meisinger *et al.* (1992), reported that efficient N-management is essential for profitable corn production because (a) corn requires large quantities of N., (b) N is the major limiting nutrient in most agricultural soils. Nitrogen is intrically woven into the complex soil N-cycle processes of mineralisation, immobilisation, leaching, and denitrification. Excess NO_3 is vulnerable to leaching which can contribute to NO_3 contamination of groundwater. The importance of efficient N-management has generated renewed scientific efforts to improve methods for predicting N-fertiliser needs for corn.

Soil fertility decline, particularly nitrogen is probably second in importance to drought. and related to low maize yields in smallholder farmers' fields (Zambezi and Mwambula, 1996). Nitrogen is the major limiting soil nutrient to normal plant growth (Balko and Russell, 1980), and for maize production (Kihinda *et al.,* 1996; Rhoades and Bennett, 1990; and Heuberger *et al.,* 1994). This element is the primary constituent of maize fertilisers for smallholder farmers in Lesotho. In Africa, farmers' yields average less than one ton/ha, whereas researches may obtain 10 tons/ha or more (Zambezi and Mwambula, 1996). Low soil nitrogen supply is one of the principal causes for the large differences observed between maize yields on experimental stations and yields in farmers' fields (Lafitte and Banziger, 1994). Maize production in Africa must increase to meet demands. However, low maize grain prices and high cost of N-fertiliser discourages production (De Datter and Broadbent, 1990). Pixley *et al.* (1995) states that smallholder farmers and those farming marginally productive fields are often limited in their option for providing supplemental N to their maize crops.

A considerable proportion of maize in the tropics and in less developed countries is produced under low N-conditions (Banziger and Lafitte, 1997). Soils are very low in organic matter, and N is readily leached out of the rooting zone. Although fertiliser use in these areas is currently growing at a rate of about 8 percent per year (CIMMYT, 1992), nitrogen will probably continue to be an important factor that limits yield in farmers' fields (Banziger and Lafitte, 1997). There are many factors responsible for smallholder farmers using low rates of N-fertiliser to maize crops.

Cost of N-fertiliser has increased beyond most farmers purchasing capacity (Sibale and Smith, 1996) and some farmers may fail to purchase N-fertiliser for the lack of cash or access to credit (Pixley *et al.*, 1995). Therefore, promoting genotypes, which have high potential only on N-environments and perform poorly in low N-environments will not help resource-poor smallholder farmers (Sibale and Smith, 1996). As a result there is a need to identify genotypes that can perform better under very low nitrogen levels.

2.6 *Genetic variability for nitrogen use efficiency in maize*

Genetic variability of N-use efficiency has been recognised for many years (Smith, 1934). Pollmer *et al.* (1979); Chevalier and Schrader (1977); Moll *et al.* (1982) and Muruli and Paulsen (1981), reported that the genetic variation for N-use efficiency may be partitioned into differences in uptake and in utilisation of N. Moll *et al.* (1982) quantified the genetic variance of N-use efficiency in corn (*Zea mays L.*) and demonstrated that selection for increased efficiency was possible. Van Sanford and MacKown (1986), Dhugga and Waines (1989), reported that the presence of genotypic variation for traits related to N-accumulation and use has also been demonstrated in wheat. Thus the potential for developing superior N-efficient cultivars does exist in some crops (Sission *et al.*, 1991).

The potential for breeding for efficient use of N in crop plants is dependent on the genetic variability present in the species for the trait(s) that determine efficient N-utilisation, and the development of procedures to accurately measure parameters that reflect N-use in the plant (Sherrard *et al.*, 1984). In one study, conducted by Muruli and Paulsen (1981), a single cycle of selection among tropically adapted half-sib families for yield under low N resulted in a population that performed well under N-stress, but which did not respond to high N.

According to Lafitte and Edmeades (1994), this study confirmed the feasibility of using genetic variability to improve maize performance at sub-optimal N-levels, but indicates there may be a cost in terms of yield potential.

Genetic differences have been observed among maize inbred lines in their performance under low N-conditions (Lafitte and Edmeades, 1995), whether measured as yield or as response to applied fertiliser (Balko and Russell, 1980). Also considerably genetic variation exists for performance under low N-conditions and within maize populations (Lafitte and Edmeades, 1994a). Thiraporn *et al.* (1987), reported significant yield differences among improved tropical cultivars at low soil N-levels, though this may have been due to variation in maturity among the cultivars examined.

Muruli and Paulsen (1981), conducted one cycle of selection under high and low nitrogen fertility, and found significant differences between the products for nitrogen efficiency traits and yield under nitrogen limiting conditions. Lafitte and Edmeades (1991), conducted two cycles of selection for high yield under both low and high nitrogen availability, and found improvements for both nitrogen regimes, but greater improvements under the low nitrogen conditions.

Short (1991), selected divergently for good performance in both high and low nitrogen regimes ("nitrogen efficiency") vs. good performance under high nitrogen and poor performance under low nitrogen ("nitrogen inefficiency"). The "nitrogen efficient" selection was higher yielding under both optimal and low nitrogen regimes than the "nitrogen inefficient" selection. These studies all indicate that useful genetic variation exists for performance under low nitrogen conditions (Smith *et al.*, 1995). Significant interactions of commercial varieties with nitrogen availability levels provide additional evidence of genetic variation affecting maize performance under nitrogen limiting conditions (J. van Beem, T.C. Barker, M. E. Smith, unpublished data as cited by Smith *et al.*, 1995; Smith, 1934; Stringfield and Salter, 1934).

Beauchamp *et al.* (1976) studied the genotypic variation among selected inbreds for N-accumulation and translocation to determine if differences were expressed in their hybrids. Genotypic differences were observed for N-accumulation and translocation from leaf tissue to the developing grain after silking. Studies have suggested that increasing the sink strength through prolificacy (Moll *et al.*, 1987), or altered endosperm composition (Tsai and Tsai, 1990), can increase nitrogen use efficiency in maize (grain yield per unit of N-applied). Ta and Wieland (1992), reported that genotypic differences in maize performance under low N have also been related to differences in N and biomass partitioning within the plant, especially in terms of the amount of N-remobilisation from vegetative tissues.

There are clear indications that genotypic differences in nitrate-N absorption, N accumulation, and utilisation of N taken up for yield (Beauchamp *et al.*, 1976; Chevalier and Schrader, 1977; Moll and Kamprath, 1977; Pollmer *et al.*, 1979; Reed *et al.*, 1980; Jackson *et al.*, 1986 and Mollaretti *et al.*, 1987). These genotypic differences suggest the possibility for developing superior N-efficient hybrids. Accordingly, the N-response of maize genotypes was found to be altered by selection for yield (Fakorede and Mock, 1978; Muruli and Paulsen, 1981 and Kamprath *et al.*, 1982). Teyker *et al.* (1989) reported evidence that selection could also be effective in modifying the uptake of nitrate-N of seedlings in certain maize populations; however, the response of N as measured by yield and other N-use parameters was not correlated with selection based on seedling nitrate uptake.

2.7 Combining ability

Combining ability has been defined as the performance of a line in hybrid combinations (Kambal and Webster, 1965). Assessment of the combining ability could be useful to define the contribution of a variety to the performance of its progeny. Sprague and Tatum (1942) and Rojas and Sprague (1952) divided gene action involved in combining ability into two categories, as general combining ability (GCA) and specific combining ability (SCA). They defined GCA as the average performance of lines in a number of hybrid combinations and that of SCA as deviations of certain crosses from expectations on the basis of the average performance of lines involved. General combining ability is largely due to additive gene effects and higher order additive gene interactions. SCA is largely a function of non-additive dominance gene effects and other types of epistasis (inter-allelic gene interactions) as well as genotypes x environment interactions (intra-allelic gene interactions) Cukadar-Olmedo *et al.* (1997), and Griffing (1956). Thus, significant values of SCA could be interpreted as indications of the predominance of non-additive gene effects caused by dominance and epistasis (Kambal and Webster, 1965).

General and specific combining ability are important in cross-pollinated crops, particularly corn. Rojas and Sprague (1952) reported that general combining ability in corn is relatively more stable over location and years than specific combining ability. Shehata and Dhawan (1975); El-Hosary (1989); Galal *et al.* (1990) and Beck *et al.* (1991) studied GCA and SCA x years/locations interactions. Stuber and Moll (1977); Nawar *et al.* (1986); Salem *et al.* (1986); Nawar *et al.* (1988) and Sedhom (1992) studied interactions of both GCA and SCA with certain factors of productivity in maize, i.e. planting date, plant densities and nitrogen fertilisation levels. Their results indicated, in general, that performance of genotypes and the magnitude of most types of gene action varied from one environment to another and the GCA appeared to be more important than SCA in the inheritance of grain yield and other related-yield contribution.

Mohamed (1993), studied the mean performance, combining ability and their interactions with four nitrogen fertilisation levels. Their results showed that the main effects of nitrogen levels were significant for grain yield per plant, number of ears, ear length, ear diameter, number of kernels per row and 100-kernel weight, indicating overall differences between the four N-levels. Significant variances obtained for interactions of GCA and SCA with environments for all traits, indicated the sensitivity of both kinds of genetic effects to the variation in nitrogen levels. Sensitivity of GCA was higher than of SCA for grain yield per plant, number of ears per plant, ear diameter and 100-kernel weight. In general, results revealed the importance of evaluating genotypes under various environments in order to get a thorough evaluation for genotypes performance and to recognise the favourable conditions for exploiting both types of gene action in maize breeding programs.

2.8 *Heritability*

Heritability is a measure of the correspondence between breeding values and phenotypic values (Jones, 1986; Falconer and Mackay, 1996). Allard (1960) used the term heritability to specify the genetic portion of the total variability. There are two distinctly different meanings of heritability, according to whether they refer to genotypic values or breeding values (Fehr, 1987). Heritability can be expressed in a broad-sense or a narrow-sense. Broad-sense heritability (h^2_b) is ratio of the total genotypic variance including additive dominance and epistatic variance to the phenotypic variance ($\sigma^2 g/\sigma^2 ph = (\sigma^2_A + \sigma^2_D + \sigma^2_A) / \sigma^2 ph$, it expresses the extent to which individuals' phenotypes are determined by the genotypes. Narrow-sense heritability is a ratio of the additive genetic variance to the phenotypic variance ($\sigma^2_A / \sigma^2 ph$), it expresses the extent to which phenotypes are determined by the genes transmitted from the parents. Heritability in the narrow-sense determines the degree of resemblance between relatives (Falconer and Mackay, 1996), and measures the relative importance of additive portion of the genetic variance that can be transmitted to the next generation of offspring. Therefore, it is of greatest importance in breeding programmes as it is used to predict gain expected from selection for a character (Falconer and Mackay, 1996; and Fehr, 1987).

The heritability of a character is not a constant value. Decisions made by the breeder can influence the magnitude of heritability and the amount of genetic improvement obtained from selection. Heritability estimates provide an indication of the expected response to selection in segregating population; as such they are useful tools in designing an effective breeding program (Burton and DeVane, 1953). In theory, both h^2_b and h^2_n can vary from 0 to 1. A high estimate, estimates how well evaluation of the parents will predict what the progenies will be like with a particular combination of breeding material and techniques of evaluation (Jones, 1986). Characters with high h^2_n values can be improved more rapidly with less intensive evaluation than those with low values and hence h^2_n is useful in making selection progress estimates. The h^2_b overestimates the response to selection as it includes non-additive effects (Dudley and Moll, 1969).

Heritability estimates are dependent on the method used to estimate them, the populations from which the estimates are derived, the unit of measurement and the environmental conditions encountered during the test (Sidwell *et al.*, 1976; Jones, 1986).

2.9 Inheritance of nitrogen use efficiency components and other characteristics

CIMMYT evaluated three eight-parent diallels under low and high N (Lafitte and Edmeades, 1995), and more recently a larger diallel of 17 lines (Beck and Betran, 1997). Inbred lines failed to predict hybrids performance in any of the diallels, and non-additive effects seemed to be as important as additive effects in determining hybrid yields under low N-level. Lafitte and Edmeades (1995), also observed that significant correlations between line and hybrid performance under low N existed only for maturity, plant height, ear height and hundred kernel weight, but not for grain yield. All diallels indicated a significant interaction between combining abilities measured under low and high N confirming that a good combiner or hybrid under high N is not necessarily a good combiner or hybrid under low N-level (Banziger and Lafitte, 1997), and that hybrid performance needs to be determined under low N if low N characterises the target environment.

Rizzi *et al.* (1991), measured the inheritance of nitrate-N concentration, total N concentration, and the nitrate-N/total N ratio in the lower stalk internodes in an eight-line diallel cross experiment and in an experiment involving segregation generations. He found that the parameters examined particularly nitrate-N concentration, are genetically controlled and that maize genotypes differ in this respect. Moreover the magnitude of the general combining ability effects in relation to the size of specific combining ability obtained from the dialled analysis and the mean squares of the analysis of variance of generation means indicated additive heritability of nitrate-N concentration and other N related traits in maize stalks.

2.10 Relationship between nitrogen efficiency and other agronomic characteristics

Low nitrogen has been shown to influence both the number of florets per ear and the fraction of those florets, which form kernels (Jacobs and Pearson, 1991). Reed and Singletary (1989), found that a greater biomass per floret is associated with reduced abortion of fertilised florets. and Lemcoff and Loomis (1986), reported that low N-supply tends to reduce the biomass per floret, resulting in the low number of grains per ear which is typical of N-stress. Patterns of N-uptake and partitioning before flowering have also been shown to be critical to maintaining grain number in N limited environments (Pearson and Jacobs, 1987).

Freier *et al.* (1983) reported that greater synchrony of grain within an ear has been associated with reduced tip grain abortion and more grains per row, but experimental tests of this hypothesis are inconclusive (Frey, 1981). The abortion of tip kernels after pollination has been associated with a slower growth rate of those kernels (Reed and Singletary, 1989), and the lower sink strength and growth rate of kernels in apical positions have been related to kernel volume at the onset of the linear grain-filling phase (Tollenaar and Daynard, 1978).

Muchow (1988a,b); Muchow and Davis (1988), reported that the morphological and physiological responses of maize to continuous N-stress include reduced plant size, reduced radiation use efficiency, accelerated senescence, increased mobilisation of vegetative N to the grain, and reduced plant N-concentration. The effects on crop growth of several of these can be easily evaluated in the field among progenies, allowing the identification of families on the basis of minimal direct effects of N-stress as well as on the basis of grain yield.

Lafitte and Banziger (1994) evaluated potential selection criteria for improving the tolerance of maize cultivars to the low soil N-supply. They examined the relationships among primary (grain yield) and secondary traits at two levels among full-sib families forming part of two selection cycles (C_0 and C_2) of a recurrent selection scheme in the tropical maize population Across 8328 BN. They found weak phenotypic correlations (r_p) between grain yields at +N and -N, among full-sib progenies (r_p = 0.11 to 0.85, with 224 to 251 df), though the genetic correlation (r_g) was stronger ($r_g = 0.51$). Significant values of rp between grain yield under low N and ear-leaf chlorophyll concentration, ear-leaf are, plant height, the anthesis-silking interval and senescence rate were detected under low soil N (-N). These associations were less strong when traits were measured under high soil N (+N).

2.11 *Response of maize under low nitrogen conditions*

The results of selection programs for performance under low N have been conflicting (Lafitte and Edmeades, 1994). Muruli and Paulsen (1981), reported that nitrogen use efficiency of maize can be improved by selection, but that nitrogen use efficiency at low soil N-levels might not be compatible with responsiveness to high soil N-levels. In another study using a temperate maize, a fraction selected for increased efficiency of nitrogen use improved grain yield per unit of N-applied and prolifically yielded well at higher N-levels, but could not be distinguished from the unselected population at low N (Moll *et al.*, 1987).

Lafitte and Banziger (1994), reported that if a large sink is established, it seems that selection for improved performance under low N may result in increased potential for grain yield under fertile conditions. In an associated study of divergent selection of full-sib families within a tropical maize population, Lafitte and Edmeades (1994a), concluded that an ideotype of a maize plant with good performance under low N would be characterised by increased total biomass production under low N and plant height, leaf area and chlorophyll concentration that were little affected by deficiency. Furthermore, they suggested that biomass and N should be efficiently partitioned to a large grain sink, and delaying leaf senescence under low N would ensure that grain is well filled.

Banziger *et al.* (1997), assessed the value of low N vs. high N-selection environments for improving lowland tropical maize for low N-target environments, and found generally positive genetic correlations between grain yields under low and high N-levels. They decreased with increasing relative yield reduction under low N indicating that specific adaptation to either low or high N became more important the more low N and high N experiments differed in grain yield. Also they reported that selection under high N for performance under low N was predicted significantly less efficient than selection under low N when relative yield reduction due to N-stress exceeded 43 percent. Banziger and Lafitte (1997), reported that a consideration of various secondary traits could improve selection efficiency under stress condition.

Other studies reporting results of selection in maize under high and low N availability (Smith *et al.*, 1995) show significant alterations in plant N uptake, utilisation and yield of the resulting populations. Muruli and Paulsen (1981), conducted one cycle of selection under high and low N fertility, and found significant differences between the products for N efficiency traits and yield under N limiting conditions. Lafitte and Edmeades (1991), conducted two cycles of selection for high yield under both low and high N availability, and found improvements for both nitrogen regimes, but greater improvements under low N conditions.

2.12 Response of maize to nitrogen use efficiency components

The problems in the use of N fertilisers are those that lead to inefficiency and any effort to increase N fertiliser efficiency is of paramount importance (Simonis, 1988). The efficiency of N fertiliser is expressed in several ways (Parish *et al.*, 1980; Novoa and Loomis, 1981; and Bock, 1984), but the term "nitrogen use efficiency" has usually referred to the relationships between yield and N-rate (yield efficiency or agronomic efficiency), between N-recovered and N-rate (recovery efficiency), or between yield and N-recovered (physiological efficiency) Bock (1984). From the agronomic point of view the effect of fertiliser N is described according to Bock (1984), as the yield increase per unit N-applied. This according to Dilz (1988), can be defined as yield efficiency, which is the product of N-recovery, i.e. the amount of N-taken up by the crop as a fraction of the amount applied, and utilisation.

Both physiological and agronomical efficiency are based on grain yield rather than total dry matter yields, and the apparent nitrogen recovery reflects the efficiency of the crop in obtaining fertiliser nitrogen from the soil, while the physiological efficiency can be viewed as the efficiency with which crops utilise nitrogen in the plant for the synthesis of grain yield (Craswell and Godwin, 1984).

The poor efficiency with which crops utilise fertiliser N has been emphasised by Allison (1955, 1966), who suggested that the average recovery of fertiliser N in the above-ground parts of crops is about 50 percent, whereas the average value for rice may be 30-40 percent (Mitsui, 1954; Craswell and Vlek, 1979). In a field and greenhouse studies conducted to determine the effect of different levels of N-application on N use efficiency in maize, Simons (1988), calculated N use efficiency components: Yield efficiency (YE), recovery efficiency (RE) and physiological efficiency (PE) by the difference and regression methods. He reported that grain yield and N-recovered in dry matter of maize increased significantly with an increase in N-application rate. Nitrogen use efficiency (NUE)-values generally decreased with increasing applied N. In all experiments, the average YE-values ranged from 13 to 35 kg grain/kg N for maize, while the average RE-values ranged from 27 to 87 percent.

CHAPTER 3

MATERIALS AND METHODS

3.1 Parental material

A total of seven white maize inbred lines comprised of one from the CIMMYT highland program in Mexico, namely CML-351; four from the CIMMYT mid-altitude program in Zimbabwe, namely CML-202, CML-216, AC8342 and CML-394; and two lines from the Summer Grain Research Centre, Potchefstroom in South Africa, namely K64R and M162W, are used as parental inbreds in this study. Details regarding the source and pedigree of the genotypes were listed in Table 3.1. These inbred lines were chosen according to their unique characteristics, heterotic grouping and their maturity as stipulated in Tables 3.2 and Table 3.3 respectively. Materials from CIMMYT Harare and Summer Grain Research Centre were not tested prior for N-behaviour, while CML-351 was found to be high yielding under low N.

Table 3.1 - The pedigrees and country of origin of parental inbred lines used in the crossing block to develop F_1 hybrids.

No.	*Material*	*Pedigree*	*Country*
1	CML-351	B.P.V.C.BA90 163-4-1-1-1TL-1-1TL-B-#-#	CIMMYT. Mexico
2	CML-202	ZSR923S4BULK-5-1-B-B	CIMMYT, Harare
3	CML-216	[MSR:131]-3-3-3-5-B-B	CIMMYT, Harare
4	AC8342/IKENNE	[AC8342/IKENNE{1}8149SR//PL9A]C1F1-500-4-X-1-1-BB-1-BB	CIMMYT. Harare
5	CML-394	[PL31/POOL16SR//PL9A]C1F2-124-2-B*7	CIMMYT. Harare
6	K64R	Pride of Saline	Kansas. USA
7	M162W	K64R.B1138T	South Africa

Table 3.2 - Heterotic groups and disease resistance of seven parental maize inbred lines (as obtained from Pixley).

Entry No.	*Inbred Lines*	*Heterotic group*	*Disease Resistance*		
			GLS	MSV	Turcicum
1	CML-351 (Tester)	A	I	S	I
2	CML-202 (Tester)	B	R	R	R
3	CML-216 (Tester)	B or A	I	R	I
4	AC8342/IKENNE (Line)	A	I	I	I
5	CML-394 (Line)	B	R	R/I	R/I
6	K64R (Line)	C (S.A. Standard)	I	S	I
7	M162W (Line)	D (S.A. Standard)	I	S	I

GLS = Grey leaf spot, MSV = Maize streak virus, I = Intermediate; R = Resistant; S = Susceptable.

3.1.1 Characteristics of inbred lines (lines and testers)

The characteristics of three testers and four lines are briefly discussed below.

3.1.1.1 Testers

CML-351- This line is classified into a heterotic group 'A'. It is a highland line from CIMMYT Mexico maize program, and is reported to flower in approximately 80 to 84 days at El Batan, Mexico, latitude 17N, elevation 2200 masl. Therefore it can be regarded as early maturing. It is a high yielding line under low N conditions. It is the best tester line for CIMMYT highland maize program and it is tolerant to low N-conditions.

CML-202 - It is classified into heterotic group 'B'. The line is very good for resistance to turcicum and grey leaf spot (GLS), with excellent maize streak virus (MSV) resistance.

CML-216 - This is classified into the 'B' heterotic group, but it can go either way as it has excellent combining ability. It shows resistance for maize streak virus (MSV), moderate resistance for grey leaf spot (GLS) and turcicum.

3.1.1.2 Lines

AC8342/IKENNE - It is classified into the 'A' heterotic group. It has moderate resistance for grey leaf spot (GLS), turcicum and maize streak virus (MSV), and is a late maturing line.

CML-394 - Classified into heterotic group 'B' but can be used both ways as 'A or B'. It has good grey leaf spot (GLS) resistance, with moderate resistance against maize streak virus (MSV) and turcicum. It has an intermediate maturity.

K64R - It is classified into the 'C' heterotic group, South African standard and has moderate resistance against most of these diseases. In comparison with the CIMMYT lines it can be classified as an early line.

M162W - It is classified into the 'D' heterotic group, South African standard. It has moderate resistance against most of the diseases and is an early maturing line compared to CIMMYT lines.

3.2 Crossing block and development of F_1 hybrids

The parental inbred lines were planted in pots in the greenhouse at the University of the Free State, in Bloemfontein in October 1998. At planting, N.P.K fertilizer of 3:2:0 (25) + Zn was mixed with soil to enhance the growth development of the plants. To synchronise pollination the planting was replicated three times with a one-week interval. Three plants per plot were planted and thinned out to one plant after eight weeks. The temperature in the glasshouse was maintained at 25^0C during the day and 18^0C at night.

Plants were watered regularly. Aphids and red spider mites infestation was controlled by spraying the plants with Metasystox R250 EC, and Kelthane AP respectively. To prevent pollen contamination ear shoots were covered with small ear-shoot bags prior to the emergence of the silks. The tassels were also covered with large tassel bags prior to the day of pollination. Pollination was done by transferring the pollen from male plants to silks of female plants by hand. The pollinated ear-shoots were then covered with a pollination bag to prevent unnecessary pollination from other plants.

Table 3.3 - Crossing block of three testers by four lines used to develop F_1 hybrids.

Entry No.	*Testers*	*Lines*	*Crosses*
1	CML-351	AC8342	CML-351 x AC8342
2		CML-394	CML-351 x CML-394
3		K64R	CML-351 x K64R
4		M162W	CML-351 x M162W
5	CML-202	AC8342	CML-202 x AC8342
6		CML-394	CML-202 x CML-394
7		K64R	CML-202 x K64R
8		M162W	CML-202 x M162W
9	CML-216	AC8342	CML-216 x AC8342
10		CML-394	CML-216 x CML-394
11		K64R	CML-216 x K64R
12		M162W	CML-216 x M162W

All four lines (AC8342/I KENNE, CML-394, K64R, and M162W) were individually crossed to each tester (CML-351, CML-202, and CML-216) to produce F_1 hybrid seed (Table 3.3). After maturity the F_1 hybrid seeds of each individual cross were harvested and threshed separately. Sufficient F_1 seeds were generated to plant two trials, each one consisted of two different nitrogen levels.

3.3 Soil sampling, preparation and nitrogen analysis

Prior to planting some soil samples were taken from two locations namely Bethlehem Research farm and Doornpan farm at Bainsvlei near Bloemfontein. Soil samples were taken at the depth of 20 cm. Six soil samples per location were taken and mixed thoroughly to form one sample. Soil samples were then taken to The Small Grain Institute soil laboratory in

Bethlehem. Soil samples were oven-dried at a maximum temperature of 40^{0}C. When dry soil samples were crushed using a suitable mortar and pestle and screened through a 2mm sieve, then mixed thoroughly (Hand Book of Standard Soil Testing Methods for Advisory Purposes. 1990).

Soils were analysed for nitrogen (NO_3-N and NH_4-N contents) and other soil nutrients. The following soil analyses methods were used: (1) Cations: Ammonium acetate (1 Mol. dm^{-3}, pH 7): to determine extractable cations Ca^{2+}, Mg^{2+}, K^+ and Na^+ in soils reflecting the nutrient status. (2) Phosphate: Bray-1 extraction solution: to extract the more soluble phosphorus and (3) pH and nitrate and ammonium: 1 Molar Potassium chloride for pH, Nitrate and Ammonium (Chapman 1965; Bray and Kurtz, 1945). Details of the soil analysis of the experimental plots at these two locations are presented in Table 3.4.

Table 3.4 - Soil analyses results for Bloemfontein (Doornpan) and Bethlehem in 1999/2000.

No	**Lab No**	**pH**	**P Bray-1**	**K**	**Ca**	**Mg**	**Na**	**NH_4**	**NO_3**
		(KCI)	(mg/kg)					(p.p.m)	
				Doornpan trial					
1	3635	5.1	12.76	228.9	639.5	188.34	36.72	3.768	4.806
				Bethlehem trial					
1	3597	4.8	53.5	193.2	439.0	170.3	4.1	4.06	8.92

3.4 *Trials and procedures*

3.4.1 Nitrogen treatments

In order to calculate the nitrogen use efficiency components, two levels of nitrogen were needed at each location. To achieve a high nitrogen application level of 50 kg N and 25 kg P ha^{-1} that was needed at the Bethlehem trial, it was recommended that a total amount of 50 kg ha^{-1} of NPK [2:3:0: (25) + Zn] plus 150 kg ha^{-1} of L.A.N (28) (Limestone Ammonium Nitrate) be applied at planting. At Bloemfontein (Doornpan trial) the nitrogen application level of 200 kg of NPK 2.3.0 (25) + Zn was applied in order to achieve a high nitrogen application level of 30 kg N and 20 kg P ha^{-1}. No additional fertilizer was applied for the low N- levels at both these locations.

3.4.2 Field experiments

Two trials were planted at two separate locations namely Bethlehem trial in Bethlehem (28^0 12' S, 28^0 52' E, 1686 masl., Avalon soil type), and Doornpan trial (29^0 06' S, 26^0 18' E, 1351 masl., Kimberly soil type) in Bainsvlei near Bloemfontein, on the 28 October 1999 and on the 2 December 1999 respectively. The F_1 hybrid material was planted according to a factorial design with three replications and two N-levels per block per location. Each field experiment was divided into two N-environments, low N (no N applied) and high N (N applied) blocks sown adjacent to each other on the same date per location. Nitrogen fertility treatments served as the whole plots with the twelve genotypes randomly assigned as subplots. The previous crop at Bethlehem trial and at Doornpan trial was maize and wheat respectively. Fertilizer was side-dressed prior to planting on a plot size of a single 4-meter ridge. The plants were individually spaced at 25 cm within and 1.5 meter between ridges. Plants were sown at a density of 20000 plants per ha in field plots. To ensure the population density and even distribution of plants in the plot, double sowing and thinning out at the 3-5-leaf stage were done. Two border rows were planted around the trial and between the N-levels.

Plants were hand weeded at both locations, and Bulldock 050 EC was sprayed at Bethlehem trial at the rate of 100 ml/ha mixed with 250 ml water/ha for cutworm control. Trials were irrigated after planting to boost germination. Weather conditions during each trial season were obtained from the closest weather stations. Rain delayed planting at Doornpan trial in 1999 and precipitation was below normal (Table 3.5) for most of the growing season for both locations causing the field trials to be stressed.

The average minimum and maximum temperature and average rainfall data per month received at Bloemfontein (Doornpan) and Bethlehem trials for 1999/2000 growing season are presented in Table 3.5.

Table 3.5 - Climatological data for the average minimum and maximum temperatures and rainfall (mm) for Bloemfontein (Doornpan) and Bethlehem in 1999/2000 growing season.

	Oct 1999	**Nov 1999**	**Dec 1999**	**Jan 2000**	**Feb 2000**	**Mar 2000**	**April 2000**	**May 2000**
Climate					**Doornpan trial**			
Av. Min. Temperature (^{0}C)	12.50	13.00	17.60	15.20	16.10	15.30	15.30	6.70
Av. Max.Temperature (^{0}C)	24.10	30.90	27.80	25.20	28.60	26.20	22.00	20.1
Av. Rainfall (mm)	23.00	45.10	21.30	30.10	16.70	21.00	25.00	50.1
					Bethlehem trial			
Av. Min. Temperature (^{0}C)	8.00	11.60	13.60	12.20	14.10	13.50	8.10	3.40
Av. Max.Temperature (^{0}C)	22.20	27.90	23.70	22.90	24.40	23.50	19.80	16.9
Av. Rainfall (mm)	13.32	3.45	12.60	19.42	13.78	12.42	10.73	7.47

At physiological maturity all plants were hand harvested very closely to the ground surface and weighed to determine the aboveground biomass yield, and then sun dried. At Doornpan all plants in a single plot were harvested, whereas at Bethlehem the number of plants per plot varied due to damage by a porcupine. Therefore, the characteristics measured were adjusted according to the number of plants harvested in each plot. A random sample of three plants per plot was taken to the Agricultural Research Station at Maseru, oven-dried at 26^0 C and ground with a 'Thomas-Wiley Laboratory Mill Model 4' machine to pass through a 0.05 mm sieve. Cobs per plot were oven-dried at a maximum temperature of 26^0 C for three days and adjusted to a standard moisture content of 12.5 percent. Cobs per plot were then taken to ARD Maseru, threshed and weighed to determine grain yield per plot. A random sample of grain per plot was taken to Lesotho Flour Mills ground to pass a 0.05 sieve using a 'Falling Number Laboratory type 120'machine. Samples of 5grams per plot of both ground maize and stovers were sent to Summer Grain Research Centre, Potchefstroom for grain N and plant N analysis. Nitrogen was determined by Kjeldahl digestion and distillation procedure from 0.1g ground sub-samples digested overnight in sulphuric acid in the presence of hydrogen peroxide.

3.5 Characters measured

The following characteristics were measured.

3.5.1 Yield characteristics

Plant height (PLHT)

Plant height was measured as an average of five randomly sampled competitive plants per plot, the distance measured (cm) from the ground level to the tip of tassels, at physiological maturity and their means were calculated to estimate the average plant height per plot.

Grain yield (GY)

This was measured as the mean weight (kg/ha) of shelled ears harvested from 20 plants per plot and adjusted to 12.5% moisture percentage.

Seed weight (SDW)

Seed weight was calculated as the mean weight (g) of 100 randomly counted kernels per plot after harvesting. (g/100 seed).

Seed number (SDN)

This was calculated as grain yield per plot divided by the seed weight per plot {grain yield/(seed weight/100)} x 100.

Harvest Index (HI)

Harvest Index was calculated as grain yield (seed yield) divided by total dry matter (seed yield + residue) and expressed as percentage.

Selection Index (SI)

The selection index for each entry was calculated according to the formula described by Fischer *et al.*, (1983).

$$\text{Low N index}_a = \frac{\text{Yield}_a\text{(-N)}}{\text{Yield}_a\text{(+N)}} \times \frac{\text{Site mean Yield (-N)}}{\text{Site mean Yield (+N)}} \qquad (1)$$

Where:

Yield_a(-N) = mean grain yield of genotype A under low N.

Yield_a(+N) = mean grain yield of genotype A under high N.

Site mean Yield (-N) = mean grain yield of all genotypes under low N.

Site mean Yield (+N) = mean grain yield of all genotypes under high N.

Selection for high grain yield under high or low nitrogen conditions may lead to genotypes adapted to those specific conditions. Hence, simultaneous selection under both conditions should be made using this selection index. A low N index > 1.0 indicates relatively low N tolerance, whereas an index < 1.0 indicates a relatively low N susceptibility.

3.5.2 Nitrogen use efficiency (NUE) components

The nitrogen use efficiency components were calculated for each entry following the terminology of Bock (1984):

3.5.2.1 Yield (agronomic) efficiency (YE)

Yield or agronomy efficiency is the average yield increase per unit of applied N calculated as the yield of fertilized plots (Yf) of each treatment minus the yield of unfertilized plots divided by the amount or rate of N applied.

$$\text{YE} = \frac{\text{Yf} - \text{Yo}}{\text{N}} \qquad (2)$$

3.5.2.2 Recovery efficiency (RE)

Recovery efficiency was calculated as the total N recovered in each of the fertilized plots (NRf) minus the N recovered in each of the corresponding unfertilised plots (NRo) divided by the supplied rate of N applied and expressed as a percentage.

$$RE = \frac{NRf - NRo}{N} \times 100 \qquad (3)$$

3.5.2.3 Physiological efficiency (PE)

Physiological efficiency was calculated as the yield of fertilized plots (Yf) minus the yield of unfertilized plots (Yo) divided by the recovered N in fertilized plots (NRf) minus the recovered N in unfertilized plots (NRo).

$$PE = \frac{Yf - Yo}{NRf - NRo} \qquad (4)$$

3.5.2.4 Nitrogen Harvest Index (NHI)

Nitrogen harvest index was calculated as N-content of the grain (GNC) divided by the total N-content of the grain and residue (SNC).

$$NHI = \frac{GNC}{SNC} \qquad (5)$$

The percentage N content was determined for grain and stover samples from each plot. Grain N-uptake (GNU) and stover N-uptake (SNU) values were calculated by multiplying grain and stover yields by the respective N-contents. Total N-uptake (TNU) was calculated as the sum of grain and straw N-uptake.

3.6 Statistical analyses

A range of statistical analyses using the statistical software computer programme, *MSTAT-*C^{TM}, EXCELL and AGROBASE 20 were conducted on the data. The test of Bartlett (1947) was used to test if the error variances were homogenous for the characters analysed. Since the value of α was between ($\alpha = 0.01$) and ($\alpha = 0.001$) no consideration was given to the transformation of the data.

3.6.1 Combined ANOVA

A combined analysis of variance was performed on the data obtained from both environments using *MSTAT-C*^{TM} micro software computer program. A fixed model was used. The programme calculated the means, mean squares, LSD and coefficient of errors variation (CV).

3.6.2 Simple ANOVA

The data obtained from each location was analysed separately using a simple analysis of variance. The *MSTAT-C*^{TM} micro software computer program was used. Differences among treatment means were tested using least significant differences (LSD) at $P \leq 0.05$.

3.6.3 Least significant differences (LSD)

For each character measured at both N levels, LSD (0.05) procedure was used to compare the entry means obtained from the analysis of variance at each location. The means were in the histogram charts. The charts were drawn using the Microsoft EXCEL computer program.

3.6.4 Line x tester analysis (L x T)

Variance components were calculated using a line x tester analysis. Line x tester analysis was conducted separately on the data obtained from each N-level at both locations. The components of variance of the ANOVA were interpreted genetically by translating them into covariance of relatives (Table 3.7) based on the factorial model (Singh and Chaudhary, 1979; Wricke and Weber, 1986). The assumed mathematical model is by the following equation:

$$\mathbf{Y}_{hijk} - \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \mathbf{R}_h + \varepsilon_{hijk}$$

Where: $\mathbf{Y}_{hijk}$ = the observation of the k-th full sib progeny in a plot in h-th replication of the I-th paternal plant and the j-th maternal plant. Mμ (μ) is common to all observations, α_i is the effect of the I-th paternal plant, β_j is the effect of the j-th maternal plant, $(\alpha\beta)_{ij}$ is the interaction of the paternal and maternal plants; $\mathbf{R}_h$ is the effect of the h-th replication, and ε_{hijk} is the environmental effect and reminder of the genetic effect between full sibs on the sample plot. All effects are random (except for replication), normal, independent with exceptions equal to zero, (Becker 1984).

Table 3.6. Analysis of variance and expected mean squares (EMS) from a factorial design (one set) Wricke and Weber (1986).

Source	*Df*	*MS*	*EMS*	*Variance components*
Lines (L)	l-1	M1	$\sigma^2_e + r\sigma^2_{lt} + rt\,\sigma^2_l$	$\sigma^2_l = C(HSl)$
Testers (T)	t-1	M2	$\sigma^2_e + r\sigma^2_{lt} + rl\,\sigma^2_t$	$\sigma^2_l = C(HSt)$
L x T	(l-1)(t-1)	M3	$\sigma^2_e + r\sigma^2_{lt}$	$\sigma^2_{lt} = C(FS) - C(HSl) - C(HSt)$
Blocks	r-1	M5	-	-
Error	(lt-1)(r-1)	M4	σ^2_e	$\sigma^2_e \approx \sigma^2$

Translation of model variance components to causal components as applied for non-inbred parents follows Wricke and Weber (1986):

$\sigma^2_A = 4\,\sigma^2_l = 4.M1\text{-}M3/rt$ and $\sigma^2_A = 4\,\sigma^2_f = 4.M2\text{-}M3/rl$

$\sigma^2_D = 4\,\sigma^2_{lt} = 4.M3\text{-}M4/rt$ and $\sigma^2 = M4$

$\sigma^2_e = (\sigma^2_G - C(FS) + \sigma^2)/n$

Where σ^2_A and σ^2_D are the variances due to additive and dominance genetic effects respectively. The analysis of variance consisted of two variance components, which estimate the covariance between half sibs, one from sample of lines, and one from the samples of testers. These estimates might differ due to maternal effects (Wricke and Weber 1986).

3.6.4.1 General and specific combining ability (GCA and SCA) effects

The general and specific combining abilities of lines and testers were calculated from the L x T analysis using the AGROBASE computer program. The general combining ability value of a genotype determines its crossing value. Estimates of general combining ability (GCA) and specific combining ability (SCA) were calculated using the formula by Singh and Chaudhary (1979).

3.6.4.1.1 General combining ability (GCA) effects

The GCA effects for the lines for lines and testers were calculated for all characteristics to identify the best combiners under low and high nitrogen levels at both locations. The GCA estimates for the lines (g_i) and testers (gt) was calculated as follows:

a) **Lines: (gi):**

$$gi = \frac{xi...}{tr} - \frac{x..}{ltr}$$

Where:
l = no. of lines
t = no. of testers
r = no. of replications

Standard error (SE) for gi effects

$$S.E.\ (\text{gca for lines}) = (Me/r \times t)^{1/2}$$

Where: Me is error mean square

b) **Testers:**

$$\textbf{gca (teter)} = gt = \frac{x.j.}{lr} - \frac{x...}{ltr}$$

Standard error for gt effects

$$S.E.\ (\text{gca for tester}) = (Me/r \times l)^{1/2}$$

The LSD between GCA was calculated as:

$$LSD = q\alpha;\ t,f.\ S^2\sqrt{E/r} \qquad (t= 0.5)$$

$q\alpha$; t, f = α value at t treatment's degree of freedom and error's degree of freedom

3.6.4.1.2 Specific combining ability (SCA) effects

The SCA effects were calculated for the F_1 hybrids to identify the best specific hybrid combinations under low and high N-levels at both locations. The SCA effects estimation (S_{ij}) for crosses was calculated as follows:

SCA effects (Sij):

$$Sij = \frac{xij}{r} - \frac{xi..}{tr} - \frac{x.j.}{lr} + \frac{x...}{ltr}$$

Standard error for Sij effects

$$S.E.\ (\text{sca effects}) = Me/r)^{1/2}$$

The LSD between SCA effects was calculated as:

$$LSD = q\alpha;t,f.\ \ S^2\sqrt{E/r} \qquad (t = 0.5)$$

$q\alpha;t,f = \alpha$ value at t treatment's degree of freedom and error's degree of freedom

Significance of GCA and SCA effects.

The two tailed t-tests were used to test for significance differences between the GCA and SCA effects where: $t = GCA/S.E_{GCA}$ or $SCA/S.E_{SCA}$, respectively (Cox and Frey, 1984).

3.6.4.2 GCA: SCA ratios

The GCA:SCA ratio was calculated for each characteristic to study the importance of additive and non-additive gene effects. It was done for both low and high nitrogen levels. The ratio indicates whether a character is mainly controlled by additive or non-additive gene action (Singh *et. al.,* 1986). The GCA:SCA ratio was computed from the estimates of genetic components of the line x tester analysis of variance, as the ratio of sum of additive genetic variances to the dominance genetic variance ($\sigma^2_A:\sigma^2_D$). A high ratio indicates additive gene action, while a low ratio indicates specific gene action.

3.6.4.3 Phenotypic correlation coefficients

Phenotypic correlation (r_p) is the ratio of the covariance to the product of the two standard deviations (Falconer and Mackay, 1996). Phenotypic correlations were calculated between the characteristics measured at both low and high nitrogen levels at the two localities. The following equation was used:

$$r_p = Covxy.\sqrt{(\sigma^2_X\,\sigma^2_Y)}$$

Where: Covxy = covariance between characteristics x and y.

σ^2_X = phenotypic variance of characteristic x.

σ^2_Y = phenotypic variance of characteristic y.

The phenotypic correlation coefficients were calculated on the mean values of the F_1 hybrids at both low and high nitrogen levels. The AGROBASE 20 computer program, sub-menu statistic command correlation were used to calculate the correlation coefficients. The analysis provides both positive and negative correlation coefficient estimates together with their probabilities, such that a probability near zero indicates significant correlation, and near 1.00 indicates no correlation (AGROBASE 20). Phenotypic correlation coefficients were also calculated between the nitrogen use efficiency components and the yield at the low and high nitrogen levels.

3.6.4.4 Genetic correlation coefficients

The genetic correlation coefficients (r_A) were calculated using the breeding values (GCA) effects of the inbred lines. It was done for both low and high nitrogen levels. The formula described by Falconer and Mackay (1996) was used.

$$r_A = COVxy.\sqrt{(Var_x \, Var_y)}$$

Where: COVxy = covariance of the characteristic x and y.
Var_x = variance of character x
Var_y = variance of character y

The AGROBASE 20 sub-menu statistic corr. command was used to calculate the genetic correlations. The analysis provides both positive and negative correlation coefficient estimates together with their probabilities, such that a probability near zero indicates significant correlation, and near 1.00 indicates no correlation (AGROBASE 20).

3.6.4.5 Heritability

Heritability is defined as the ratio of the genotypic variance (σ^2_g) to the phenotypic variance (σ^2_{ph}) Wricke and Weber 1986, and Fehr, 1987), thus the genotypic variance is the variation by genetic differences among individuals. Heritability can be expressed in a broad-sense or a narrow-sense. Heritabilities were computed from the variance components obtained by the analysis. The AGROBASE 20 computer program was used. Heritabilities were calculated for all characteristics measured at both the low and high nitrogen levels.

Broad-sense heritability was calculated from the formula:

$$h^2 = \sigma^2_A + \sigma^2_D / \sigma^2_A + \sigma^2_D + \text{MSEgca}$$

Narrow-sense heritability was calculated from the formula:

$$h^2 = \sigma^2_A / \sigma^2_A + \sigma^2_D + \text{MSEgca}$$

Where: σ^2_A = Additive genetic variance

σ^2_D = Dominance genetic variance

MSEgca = Mean square error

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Analyses of variance (ANOVA'S)

4.1.1 Combined ANOVA

A combined analysis of variance was computed on the data obtained from the two locations. The mean squares for each of the characters measured were listed in Table 4.1. The results showed significant differences between locations ($P<0.01$) for all characters measured. indicating large environmental differences between the two locations.

The nitrogen levels were highly significant for PLHT and GNC, which indicate that these characters were significantly affected by the different N-levels. The location x nitrogen interactions was significantly different ($P<0.01$) for PLHT, GY, SDN and HI. The mean squares for entries (F_1 hybrids) showed highly significant differences for PLHT, GY, SDW, SDN and GNC, indicating that there was high genetic variability among F_1 hybrids for these characters. No significant variability existed among the F_1 hybrids for HI.

The locations x entries' interactions were significantly different for PLHT, GY. SDW, SDN and HI. These results indicated that the F_1 hybrids reacted differently in each environment. The nitrogen level x entry interactions, and location x nitrogen level x entry interactions were not significant for the characters measured. These results indicated that the different nitrogen levels did not cause a significant change in the rankings of the F_1 hybrids.

Table 4.1. - Mean squares from the combined analysis of variance over two locations for plant height (PLHT), grain yield (GY), seed weight (SDW), seed number (SDN).harvest index (HI), grain N-content (GNC) and stover N-content (SNC) in 1999/2000.

		Mean Squares						
Source of Variation	***df***	***PLHT (cm)***	***GY ($t\ h^{-1}$)***	***SDW (g/100)***	***SDN (10^9) (no/ha)***	***HI (%)***	***GNC (%)***	***SNC (%)***
Total	143	75218.938	594.948	7724.222	871.803	1.753	7.371	2.444
Location (L)	1	13205.840**	359.709***	5980.44**	3585.925***	1.088***	0.649***	0.101*
Nitrogen (N)	1	3610.007***	2.361ns	0.111§	17.405§	0.006ns	0.125*	0.014§
L x N	1	2407.562***	13.256***	9.000ns	203.585**	0.017*	0.024§	0.001§
Entries (E)	11	3398.108***	6.213***	57.035***	125.409***	0.006ns	0.197***	0.028ns
L x E	11	517.734***	2.182**	16.278*	68.998***	0.009*	0.020§	0.008§
N x E	11	59.931§	0.542§	2.975§	17.679§	0.004§	0.028ns	0.009§
L x N x E	11	122.547ns	0.888ns	6.318§	23.143ns	0.004§	0.024§	0.010§
Error	92	105.820	0.798	8.228	20.448	0.004	0.028	0.016
Mean		167.313	3.428	40.611	0.0000483	0.275	1.409	0.492
C.V. %		6.15	26.06	7.06	0.0000000266	23.22	11.80	26.07

ns = non -significant, *,**,*** = significantly different from zero at 0.05, 0.01 and 0.001 levels of probability respectively, §= F-value smaller than one.

4.1.2 Simple ANOVA'S

A simple analysis of variance was done separately for each location. The mean squares for the two locations (Doornpan and Bethlehem) are presented in Table 4.2 and Table 4.3 respectively.

Doornpan trial

There were significant differences ($P<0.01$) between nitrogen levels for PLHT and GY at Doornpan trial (Table 4.2), which indicates a significant effect of nitrogen on these characters. Highly significant differences exist among entries for all characters measured indicating sufficient genetic variability between F_1 hybrids at both N-levels. No significant differences were found for nitrogen x entry (F_1 hybrids) interactions, which indicates that the F_1 hybrids did not react differently to the different N-levels.

Bethlehem trial

The mean squares for nitrogen levels at Bethlehem trial (Table 4.3) showed no significant differences for the characters measured. Significant differences were found among entries (F_1 hybrids) for PLHT, GY, SDW, SDN and GNC, indicating large variability among the F_1 hybrids at both N-levels. Nitrogen level x entry interactions were not significant for all characters measured at Bethlehem indicating that F_1 hybrids did not react differently to the different N-levels.

The results obtained from the analysis of variance at the two locations indicated that sufficient phenotypic variability existed among the F_1 hybrids at both nitrogen levels for PLHT, GY, SDW, SDN, HI, GNC and SNC at Doornpan and for PLHT, GY, SDW, SDN and GNC at Bethlehem. However the nitrogen x entry interaction showed no significant change in the rankings of the F_1 hybrids due to the two nitrogen levels.

Table 4.2. - Mean squares from analysis of variance for plant height (PLHT) grain yield (GY), seed weight (SDW), seed number (SDN), harvest index (HI), grain N-content (GNC), and stover N-content (SNC) at Bloemfontein (Doornpan) in 1999/2000.

		Mean Squares						
Source of Variation	***df***	***PLHT (cm)***	***GY ($t\ h^{-1}$)***	***SDW (g/100)***	***SDN (10^9) (no/ha)***	***HI (%)***	***GNC (%)***	***SNC (%)***
Total	71	44621.11	125.928	997.778	1957.255	0.145	2.573	0.803
Replication	2	258.514ns	15.384**	31.347ns	214.078*	0.004ns	0.352*	0.050ns
Nitrogen (N)	1	5547.556**	13.402**	3.556§	170.021**	0.002ns	0.130ns	0.005
Entries (E)	11	3051.040***	3.986***	41.859***	65.115***	0.006***	0.069***	0.019*
N x E	11	79.949§	0.284§	5.010§	4.774§	0.002ns	0.018ns	0.008ns
Error	44	90.533	0.780	8.578	12.820	0.001	0.017	0.008
Mean		176.889	5.008	47.056	0.00064	0.362	1.342	0.465
C.V. %		5.38	17.64	6.22	0.000000018	9.145	9.71	19.64

ns =non-significant, *, **, *** = significantly differently from zero at 0.05, 0.01 and 0 .001 levels of probability respectively, § = F-value smaller than one.

Table 4.3. - Mean squares from analysis of variance for plant height (PLHT) grain yield (GY), seed weight (SDW), seed number (SDN), harvest index (HI), grain N-content (GNC) and stover N-content (SNC) at Bethlehem in 1999/2000.

		Mean Squares						
Source of Variation	*Df*	*PLHT (cm)*	*GY ($t\ h^{-1}$)*	*SDW (g/100)*	*SDN (10^9) (no/ha)*	*HI (%)*	*GNC (%)*	*SNC (%)*
Total	71	17391.986	109.311	746.000	3428.62	0.521	4.148	1.540
Replication	2	510.764ns	3.672ns	3.167ns	134.00ns	0.004ns	0.183ns	0.056ns
Nitrogen (N)	1	110.014§	2.214ns	5.556ns	50.96	0.022ns	0.020§	0.010ns
Entries (E)	11	864.802**	4.408***	31.455***	129.29***	0.009ns	0.148***	0.017ns
N x E	11	102.529§	1.145ns	4.283§	36.04ns	0.006§	0.034§	0.011§
Error	44	5382.612	0.790	7.679	26.87	0.007	0.037	0.025
Mean		157.736	1.847	34.167	0.00033	0.188	1.476	0.518
C.V. %		7.01	48.10	8.11	0.000000051	45.46	13.07	30.50

ns = non-significant, *, **, *** = significant differently from zero at 0.05, 0.01 and 0.001 levels of probability respectively, § = F-value smaller than one.

Discussion

The fact that the nitrogen level x entry interaction was not significant implies that breeders can select at both low and high N-levels as there was no different response of entries to N- levels. Therefore selection at low N-levels would help those resource-poor farmers in less developed countries who often cannot afford the use of fertiliser. With the escalating price of chemical fertilizer and other inputs, there is a need for N-use efficient genotypes, which have high yield per se at both low and high N-levels (Mduruma and Ngowi 1996).

4.2 Nitrogen use efficiency components

4.2.1 Combined ANOVA

A combined analysis of variance was computed on the data obtained from the two locations for the nitrogen use efficiency components. This was done to determine the environmental effects on the F_1 hybrids. The mean squares are shown in Table 4.4. Locations were significantly different for yield efficiency and recovery efficiency showing a large environmental difference between the locations for these components. Significant differences were observed between entries (F_1 hybrids), for all nitrogen use efficiencies except for nitrogen harvest index, and between locations x entries interaction for recovery efficiency only, indicating no variability among the F_1 hybrids for other components.

Table 4.4. - Mean squares from the combined analysis of variance for nitrogen use efficiency components in 1999/2000.

		Mean Squares			
		Nitrogen use efficiency components			
Source of Variation	df	Yield efficiency (YE)	Recovery efficiency (RE)	Physiological efficiency (PE)	Nitrogen harvest index (NHI)
		kg grain/kg N	%	kg grain/kg N	%
Total	71	116.696	2.923	244.749	0.221
Location (L.)	1	86.631**	2.537***	16.558ns	0.006 §
Entries (E)	11	1.213***	0.010**	10.169***	0.002§
L. x E	11	0.298ns	0.009**	2.482ns	0.004ns
Error	44	0.199	0.003	1.373	0.003
Mean		2.076	0.395	5.028	0.621
C.V. %		21.520	14.800	23.30	8.140

ns = non - significant, *,**,*** = significantly different from zero at 0.05, 0.01 and 0.001levels of probability. §= F-value smaller than one.

4.2.2 *Simple ANOVA'S*

Analysis of variance for yield efficiency, recovery efficiency, physiological efficiency and nitrogen harvest index was also performed separately for each location. The mean results are shown in Table 4.5 and Table 4.6 for Doornpan and Bethlehem respectively.

Doornpan trial

The results at Doornpan trial showed significant differences between replications for yield efficiency and physiological efficiency. Entries were significantly different for yield, recovery and physiological efficiencies at Doornpan, indicating variability for these nitrogen efficiency components between the F_1 hybrids.

Bethlehem trial

In the Bethlehem trial replications were significantly different for physiological efficiency only. Significant differences between entries for yield and physiological efficiencies were observed. Yield efficiency and recovery efficiency were generally low at both environments, whereas physiological efficiency was higher at both environments with the large magnitude at Doornpan.

Table 4.5. - Mean squares from analysis of variance for nitrogen use efficiency components at Bloemfontein (Doornpan) in 1999/2000.

		Mean Squares			
		Nitrogen use efficiency components			
Source of variation	df	Yield efficiency (YE)	Recovery efficiency (RE)	Physiological efficiency (PE)	Nitrogen harvest index (NHI)
		kg grain/kg N	%	kg grain/kg N	%
Total	35	16.892	0.253	53.031	0.096
Replications	2	2.088***	0.007ns	4.122**	0.005ns
Entries	11	0.728**	0.014*	2.434**	0.003ns
Error	22	0.214	0.004	0.819	0.003
Mean		3.173	0.583	5.508	0.612
C.V. %		14.580	10.700	16.430	8.260

ns = non - significant *,**,*** = significantly different from zero at 0.05, 0.01 and 0.001levels of probability.

Table 4.6. Mean squares from analysis of variance for nitrogen use efficiency components at Bethlehem in 1999/2000.

		Mean Squares			
		Nitrogen use efficiency components			
Source of Variation	df	Yield Efficiency (YE)	Recovery efficiency (RE)	Physiological efficiency (PE)	Nitrogen harvest index (NHI)
		kg grain/kg N	%	kg grain/kg N	%
Total	35	13.073	0.133	175.160	0.120
Replications	2	0.196ns	0.004ns	6.215*	0.014*
Entries	11	0.783**	0.005ns	10.938***	0.003ns
Error	22	0.185	0.003	1.98	0.003
Mean		0.979	0.208	4.549	0.630
C.V. %		43.930	26.200	30.520	8.020

ns = non - significant, *, **,*** = significantly different from zero at 0.05, 0.01 and 0.001levels of probability.

Discussion

Nutrient use efficiency is generally greatest where yield response to applied nutrient is the highest (Clarke *et al.,* 1990; Sieling *et al.,* 1998). Under favourable conditions, increased application of N generally increases the concentration of N nutrient in cereal grain (Ponce *et al.,* 1993), and total nutrient uptake due to increased grain yield above-ground biomass (Vig and Singh 1983; Gauer *et al.,* 1992). An increase in the rate of N fertilizer application, however, decreases yield, physiological and recovery efficiency in cereals (Sieling *et al*; Simonis, 1988; Harmsen, 1984; Ponce *et al.,* 1993). This trend, however vary considerably with the yield potential of the crop varieties tested (Harmsen, 1984; Gauer et al, 1992) cropping history of the site (Raun and Johnson, 1992), moisture availability (Clarke *et al.,* 1990; Gauer *et al.,* 1992; Vig and Singh, 1982), and nutrient status and retention capacity of the soil (Mooleki and Foster, 1993; Baligar and Bennett, 1986).

4.3 Low nitrogen selection index

According to the low N-index of Fischer et al., (1983), selection for high grain yield under high or low N-conditions may lead to genotypes adapted to those specific condition. A low N-index value of above one indicates tolerance to low nitrogen conditions while an index smaller than one indicates susceptibility to low nitrogen conditions. The low N-indices were calculated for each entry using the procedures described by Fischer et al., (1983), and are given in Table 4.7.

Doornpan trial

The selection indices for plant height were less than one and it varies in a range between 0.871 and 0.755. The results indicate very little variability for plant height as far as the selection index values are concern.

The selection indices of the crosses for grain yield were less than one. The three crosses with the best selection indices were CML351 x K64R (0.824), CML202 x M162W (0.798) and CML216 x K64R (0.780). The results indicate that according to the selection indices these three hybrids will use nitrogen the most effectively. The F_1-hybrid combinations that use nitrogen very ineffectively was CML202 x CML394 (0.616) and CML216 x CML394 (0.608). The selection indices for seed weight were on average much higher than the indices for grain yield. The relative high indices accentuate the importance of large seed size under low N-conditions. The crosses with indices that exceed the value of one were CML351 x AC8342 (1.052), CML351 x CML394 (1.038) and CML216 x CML394 (1.023). Both the inbred lines CML351 and CML394 were involved in these three crosses.

The index values for seed number are relatively low and none of the indices exceed the value of one. The crosses with the highest indices for seed number were CML351 x K64R (0.839), CML202 x M162W (0.832), and CML216 x K64R (0.850).

The indices for harvest index were relatively high in comparison with the other characteristics. The indices of five of the crosses exceed the value of one. They were CML351 x K64R (1.021), CML202 x AC8342 (1.025), CML202 x CML394 (1.007), CML202 x K64R (1.028) and CML216 x K64R (1.067).

Bethlehem trial

In the Bethlehem trial the selection indices for plant height had a value less than the value one for most of the crosses. It varies from 0.988 to 0.894. The only crosses with selection indices that exceed the value of one were CML351 x AC8342 (1.021), CML202 x CML394 (1.022) and CML216 x M162W (1.081). The result indicates that there was sufficient variability with regard to plant height for the low N-index values.

The indices for grain yield exceed the value of one in ten of the twelve crosses tested. The cross CML202 x CML394 had the highest selection index value (3.411). The crosses with the second and third highest indices were CML216 x M162W (2.349) and CML351 x AC8342 (2.054) respectively. The results indicate that according to the low N index of Fischer (1986) these three crosses will use N more effectively than the rest of the crosses.

The selection indices for seed weight exceed the value of one for most of the crosses. The relative large indices for the nine crosses accentuate the importance of seed size under low N-conditions. The crosses with the indices that exceed the value of one were CML351 x AC8342 (1.016), CML351 x K64R (1.085), CML351 x M163W (1.027), CML202 x AC8342 (1.037). CML202 x K64R (1.103), CML202 x M163W (1.016), CML216 x AC8342 (1.063), CML216 x K64R (1.057) and CML216 x M163W (1.109). The inbred lines CML351, CML202, CML216, AC8342, K64R and M162W were involved in nine of these crosses.

The indices for seed number were relatively high in most of the crosses. The cross with the highest low N index was CML202 x CML394 (3.529). The crosses with the second and third highest indices were CML216 x M162W (2.069) and CML351 x AC8342 (2.003) respectively. These three crosses had also the highest indices for grain yield. The results indicate an association between grain yield and seed number. The rest of the crosses had indices that exceed the value of one except for the crosses CML351 x M162W (0.949), CML202 x AC8342 (0.971) and CML216 x AC8342 (0.759).

The indices for harvest index were relatively high. The indices for all twelve crosses exceed the value of one. The cross CML351 x CML394 had the highest index value (2.546). The indices for the rest of the crosses ranged between 1.802 and 1.024.

Table 4.7. - Low nitrogen selection indices of the different crosses for plant height (PLHT). grain yield (GY), seed weight (SDW), seed number (SDN), and harvest index (HI), at Bloemfontein (Doornpan) and Bethlehem locations in 1999/2000.

	Doornpan trial					***Bethlehem trial***				
CROSSES	**PLHT (cm)**	**GY (t/ha)**	**SDW (g/100)**	**SDN (no/ha)**	**HI (%)**	**PLHT (cm)**	**GY (t/ha)**	**SDW (g/100**	**SDN (no/ha)**	**HI (%)**
CML351 x AC8342	0.871	0.662	1.052	0.641	0.785	1.021	2.054	1.016	2.003	1.431
CML351x CML394	0.842	0.715	1.038	0.689	0.978	0.978	1.033	0.998	1.010	2.546
CML351 x K64R	0.770	0.824	0.991	0.839	1.021	0.953	1.315	1.085	1.199	1.691
CML351 x M162W	0.804	0.755	0.983	0.779	0.982	0.894	0.954	1.027	0.949	1.087
CML202 x AC8342	0.826	0.701	0.955	0.754	1.025	0.896	1.018	1.037	0.971	1.146
CML202x CML394	0.809	0.616	0.945	0.652	1.007	1.022	3.411	0.943	3.529	1.802
CML202 x K64R	0.840	0.677	0.955	0.720	1.028	0.966	1.110	1.103	1.010	1.024
CML202 x M162W	0.821	0.798	0.962	0.832	0.925	0.974	1.126	1.016	1.096	1.150
CML216 x AC8342	0.847	0.687	0.977	0.715	0.89 7	0.952	0.822	1.063	0.759	1.182
CML216x CML394	0.834	0.608	1.023	0.625	0.772	0.922	1.946	0.965	1.985	1.517
CML216 x K64R	0.819	0.780	0.928	0.850	1.067	0.988	1.789	1.057	1.662	1.415
CML216 x M162W	0.755	0.678	0.958	0.713	0.923	1.081	2.349	1.109	2.069	1.492

Discussion

According to the selection index described by Fischer et al., (1983), used to aid selection we conclude that all crosses were susceptible to low N at Doornpan environment. for all characteristics with the exception of HI, this could be due to the low initial nitrogen level in the soil. At Bethlehem environment a number of crosses (ten) were tolerant to the low N. The results showed that these ten hybrids were adapted to this specific environment. Selection for high grain yield under high or low nitrogen conditions may lead to genotypes adapted to those specific conditions (Chantachume *et al.,*1996). The low nitrogen index values at Doornpan trial where the initial nitrogen level in the soil was much lower than at Bethlehem trial, were lower than one. It indicates that very low nitrogen levels reduce the low nitrogen index values. Most of the low nitrogen index values for seed weight were above one. According to the values it seems that the low nitrogen index for seed weight might have a slight advantage above the index for grain yield as a selection parameter for high yields at low nitrogen conditions. This will only be true if there is a high correlation between the indices for seed weight and the real yield under low nitrogen.

4.4 Mean performance of F_1 hybrids at two different N-levels at Bloemfontein (Doornpan)

Plant height (PLHT)

The effects of the two nitrogen levels on plant height at Doornpan are illustrated in Figure 1. The two nitrogen levels affected the F_1 hybrids differently, although the N x E interaction were insignificant (Tables 4.1, 4.2, and 4.3), the t-distribution showed some significance between the two N-levels for some of the hybrids. The high N-level caused a significant enhancement in plant height in seven of the twelve hybrids namely; CML351 x K64R, CML351 x M162W, CML 202 x AC8342, CML202 x CML394, CML216 x CML394, CML216 x K64R and CML216 x M162W. The higher nitrogen levels did not significantly affect the plant height of five of the F_1 hybrids. They were CML216 x AC8342, CML216 x CML394, CML216 x K64R and CML216 x M162W. The rankings of the F_1 hybrids at the low and high N-levels followed the same pattern, which is an indication that interactions between plant height and N-levels were insignificant. Significant differences existed between the F_1 hybrids at both the low and the high N-levels. The hybrids CML216 x AC8342,

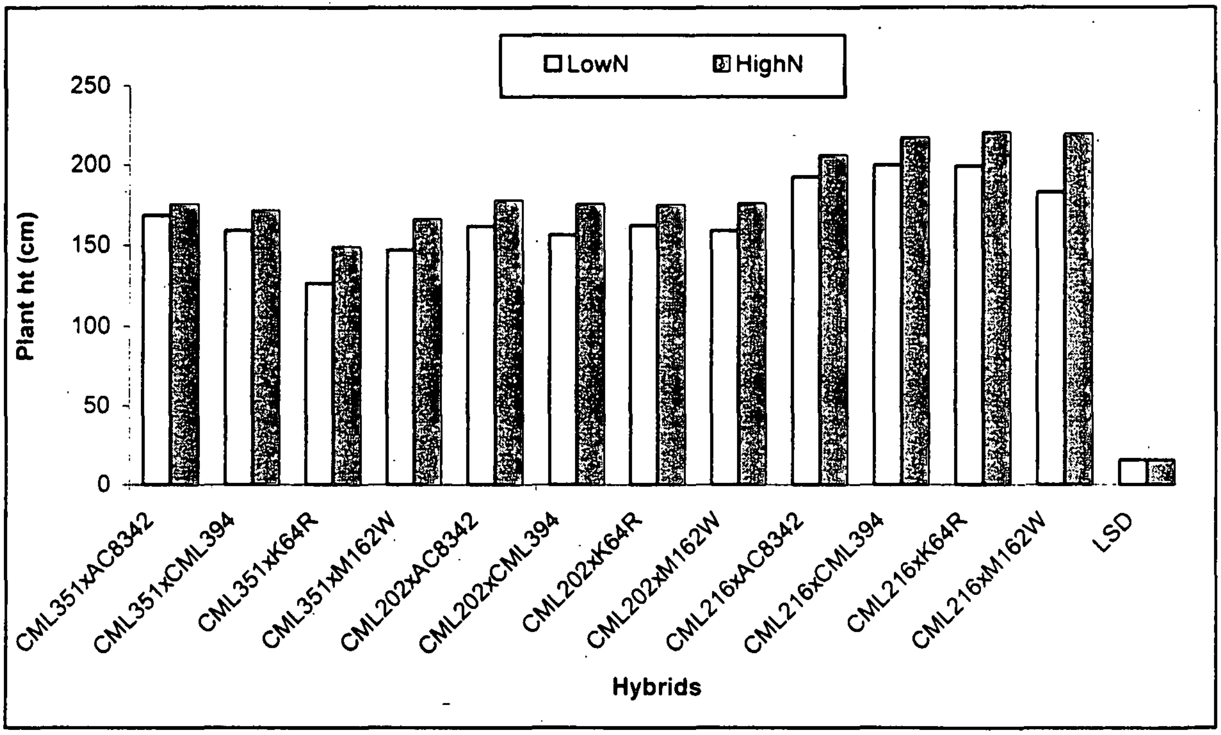

Figure 1. Mean plant height of the F_1 hybrids at two N-levels at Bloemfontein (Doornpan trial)

CML216 x CML394, CML216 x K64R and CML216 x M162W were significantly taller than the rest of the hybrids at both the low and the high N-levels. CML351 x AC8342, CML351 x CML394, CML202 x AC8342, CML202 x CML394, CML202 x K64R and CML2202 x CML202 x M162W were significantly different from CML351 x K64R and CML351 x M162W at the high N-level. At the low N-level highly significant differences were observed from CML216 x AC8342, CML216 x K64R and CML216 x CML394. The following hybrids; CML394 x AC8342 and CML351 x AC8342, were significantly different from CML351 x CML394, CML202 x AC8342, CML202 x M162W and CML202 x K64R which were significantly different from CML202 x CML394, CML351 x M162W and CML351 x K64R.

Grain yield (GY)

The mean yields of the F_1 hybrids at the two nitrogen levels are illustrated in figure 2. The

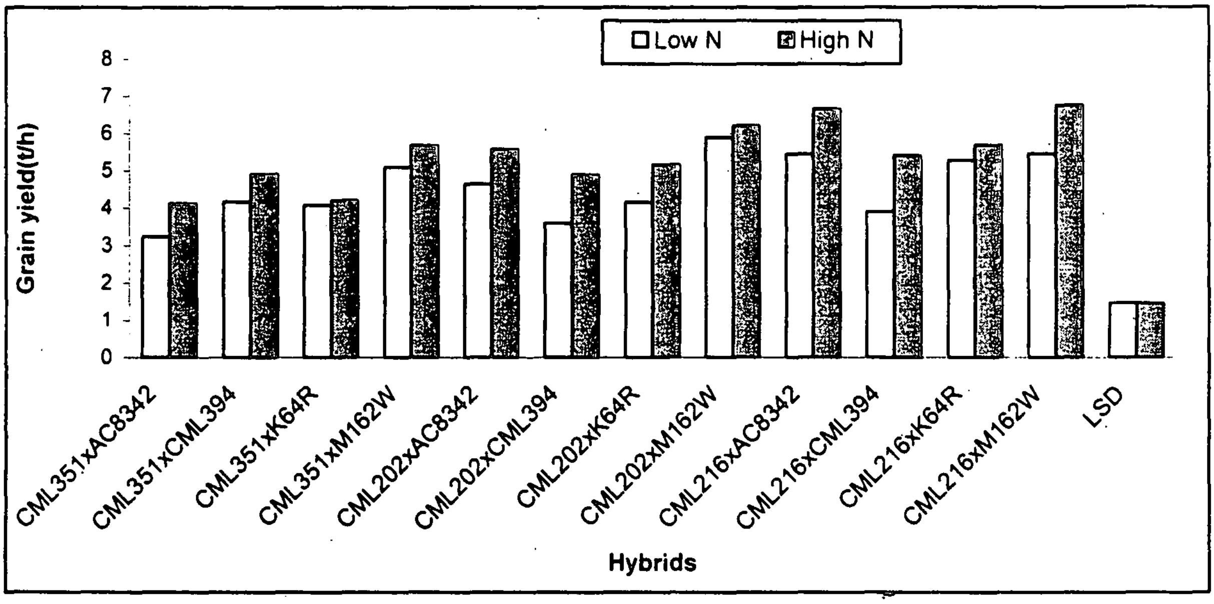

Figure 2. Mean grain yield of the F_1 hybrids at two N-levels at Bloemfontein (Doornpan trial)

yield of six of the hybrids were significantly higher at the high N-level. These were CML202 x AC8342, CML202 x CML394, CML202 x K64R, CML216 x AC8342, CML216 x CML394 and CML216 x M162W. The yield of six of the hybrids did not improve significantly by the higher N-level. They were; CML351 x AC8342, CML351 x CML394, CML351 x K64R, CML351 x M162W, CML202 x M162W and CML216 x K64R. The rankings between the F_1

hybrids at the low and the high N-levels followed the same trend, which is an indication that the interaction between genotype and N-level is insignificant. The F_1 hybrids differed significantly from one another at both the low and the high N-levels. Significant difference for grain yield at the high N-level were observed between the following hybrids; CML202 x M162W, CML216 x AC8342, and CML216 x M162W, and also from CML202 x AC8342 and CML351 x M162W. At the low N-level, CML351 x M162W, CML202 x M162W, CML216 x AC8342, CML216 x K64R and CML216 x M162W were significantly different from the rest of the F_1 hybrids.

Seed weight (SDW)

The effects of the two different N-levels on seed weight are illustrated in figure 3. There were no significant differences between the two N-levels for the various hybrids. Therefore, the

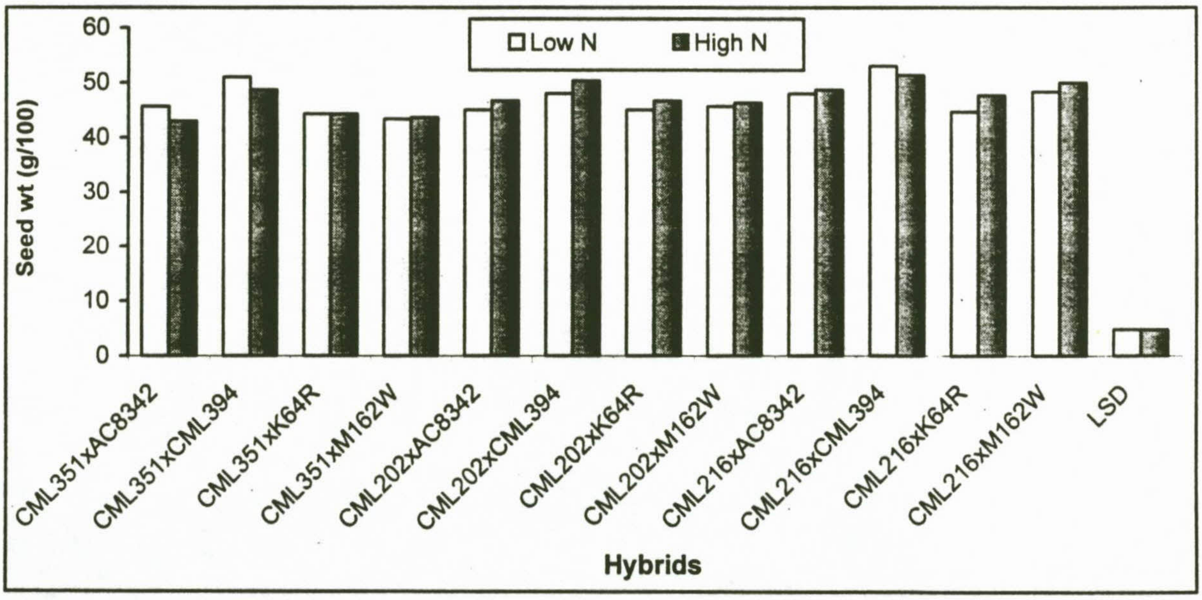

Figure 3. Mean seed weight of the F_1 hybrids at two N-levels at Bloemfontein (Doornpan trial)

higher nitrogen level did not significantly affect seed weight. The rankings of the F_1 hybrids remained the same at the two N-levels. This is an indication that there was no significant genotype x N-level interaction for seed weight. The F_1 hybrids differed significantly for seed weight at both nitrogen levels, indicating significant variability at both N-levels. The hybrids CML351 x CML394, CML202 x CML394, CML216 x CML394 and CML216 x M162W differed significantly from the rest of F_1 hybrids at the high N-level. The hybrid combinations with the highest seed weight at both the low and the high N-levels were CML216 x CML394, CML202 x CML394, CML351 x CML394 and CML216 x AC8342.

Seed number (SDN)

The differences between the two nitrogen levels for seed number are illustrated in figure 4. The seed number for nine of the F_1 hybrids were significantly higher at the high N-level. These were CML351 x AC8342, CML351 x CML394, CML351 x M162W, CML202 x AC8342, CML202 x CML394, CML202 x K64R, CML216 x AC8342, CML216 x CML394, and CML216 x M162W. Three of the F_1 hybrids (CML351 x K64R, CML202 x M162W and CML216 x K64R) did not respond to the higher N-level. With the exception of the two of the F_1 hybrids there were no significant differences between the rankings of the hybrids at the low and high N-levels. Significant variability existed between the F_1 hybrids at both N-levels for seed number.

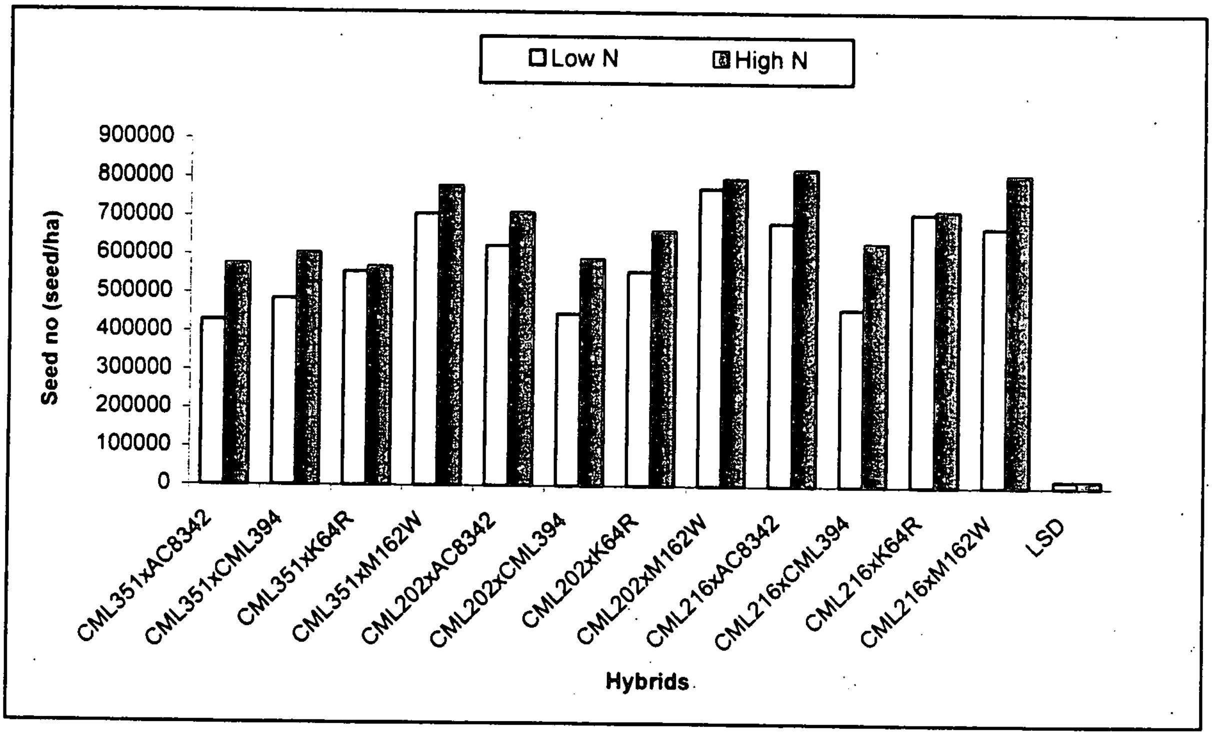

Figure 4. Mean seed number of the F_1 hybrids at two N-levels at Bloemfontein (Doornpan)

Harvest index (HI)

The effects of the two N-levels on the harvest indices of the F_1 hybrids are illustrated in figure 5. In two hybrids (CML351 x AC8342 and CML216 x CML394) the harvest indices at the low N-level were lower than at the high N-level. Although the harvest index was not affected by the higher N-level, significant differences were found between the F_1 hybrids at both N-levels.

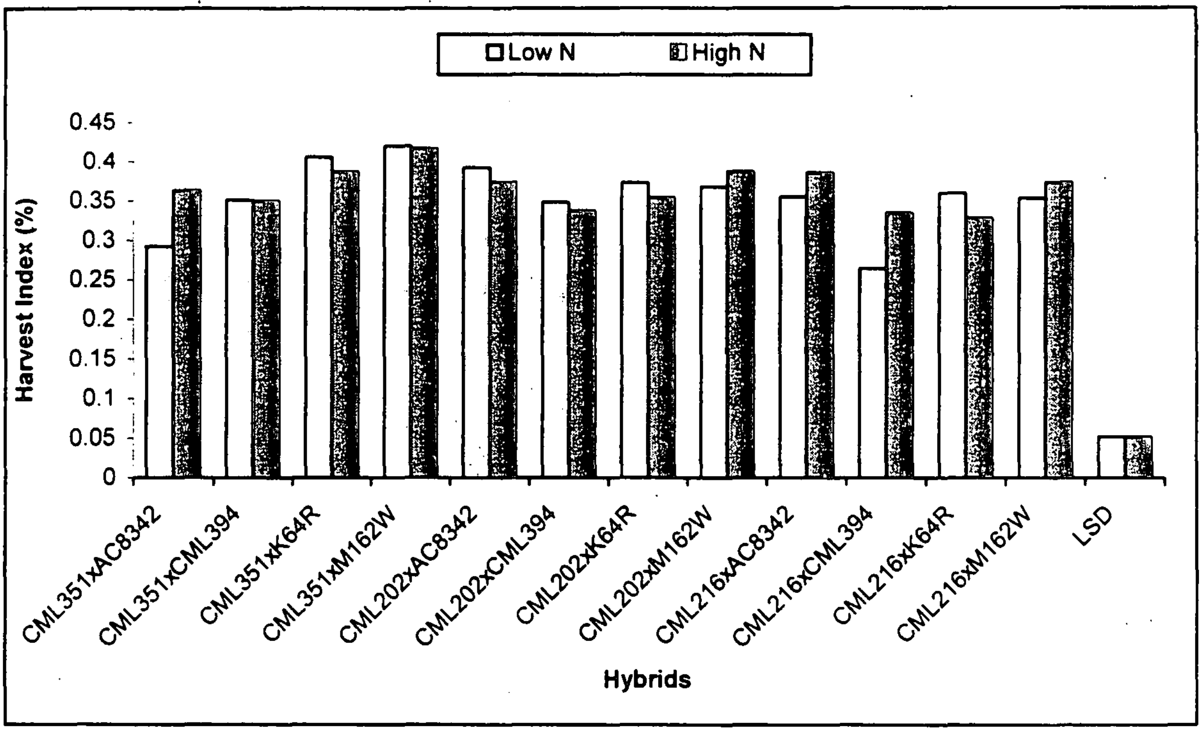

Figure 5. Mean harvest index of the F_1 hybrids at two N-levels at Bloemfontein (Doornpan)

Grain N-content (GNC)

The effects of the two N-levels on the grain N-content of the F_1 hybrids were illustrated in figure 6. The grain N-content in six of the hybrids namely; CML351 x AC8342, CML351 x K64R, CML202 x AC8342, CML202 x CML394, CML216 x CML394 and, CML216 x

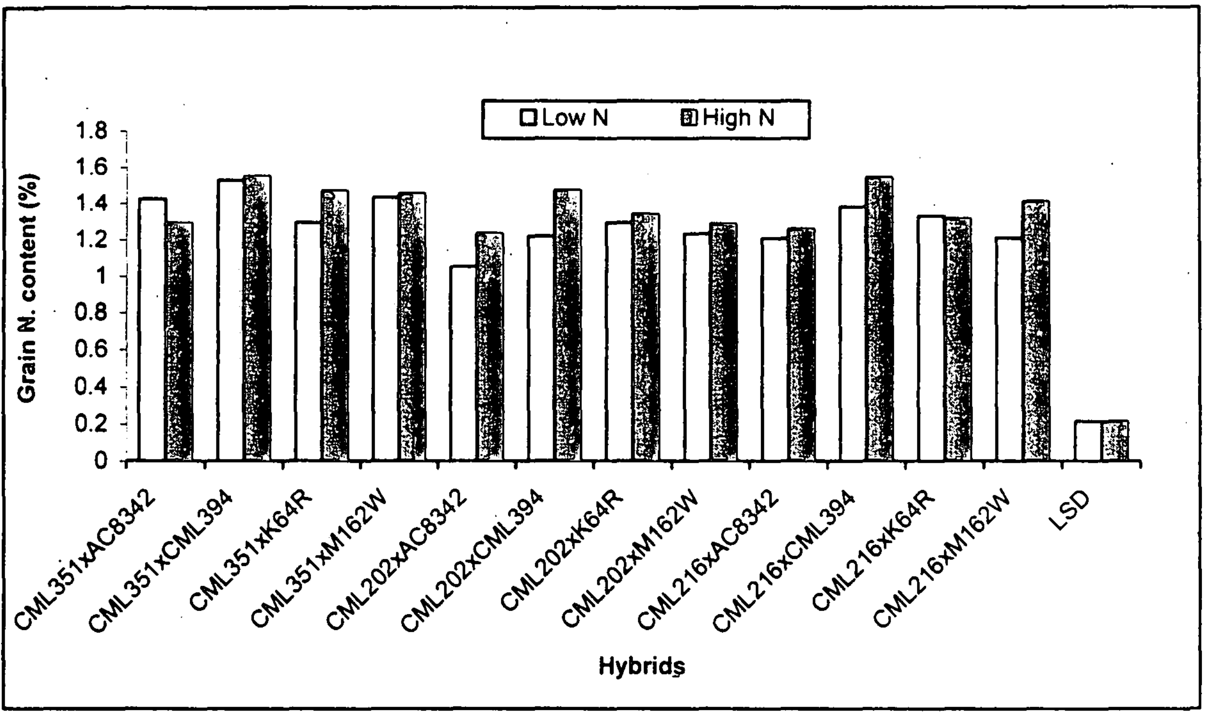

Figure 6. Mean grain N-content of the F_1 hybrids at two N-levels at Bloemfontein (Doornpan)

M162W was significantly affected by the two nitrogen levels. In these hybrids with an exception of CML351 x AC8342, the grain N-content at the high N-level was significantly higher than at the low N-level. The results showed significant variability in the rankings of the F_1 hybrids at both N-levels.

Stover N-content (SNC)

The stover N-content of the F_1 hybrids at the two N-levels was illustrated in figure 7. The two N-levels had no significant effect on the stover N-content of the F_1 hybrids. No significant variability was observed between the F_1 hybrids for stover N-content at both the low and the high N-levels. The two N-levēls did not influence any change in the rankings of the F_1 hybrids.

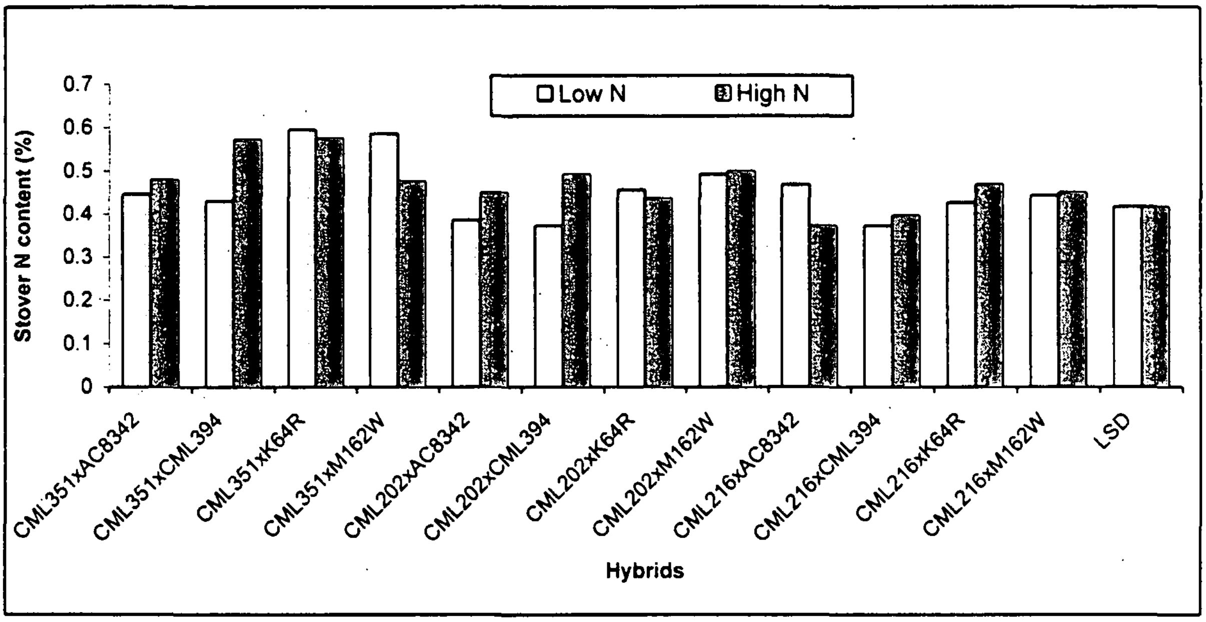

Figure7. Mean stover N-content of the F_1 hybrids at two N-levels at Bloemfontein (Doornpan)

4.5 Mean performance of F_1 hybrids at two different N-levels at Bethlehem

Plant height (PLHT)

The effects of the different N-levels on plant height at Bethlehem trial are illustrated in figure 8. The results indicated no significant effects by the two N-levels on the plant height of the F_1 hybrids. Significant differences existed between the F_1 hybrids at both the low and the high N-levels. The F_1 hybrids CML351 x AC8342, CML216 x AC8342, CML216 x CML394 and CML216 x K64R were the tallest at both the low and the high N-levels. These F_1 hybrids were significantly taller than most of the other hybrids.

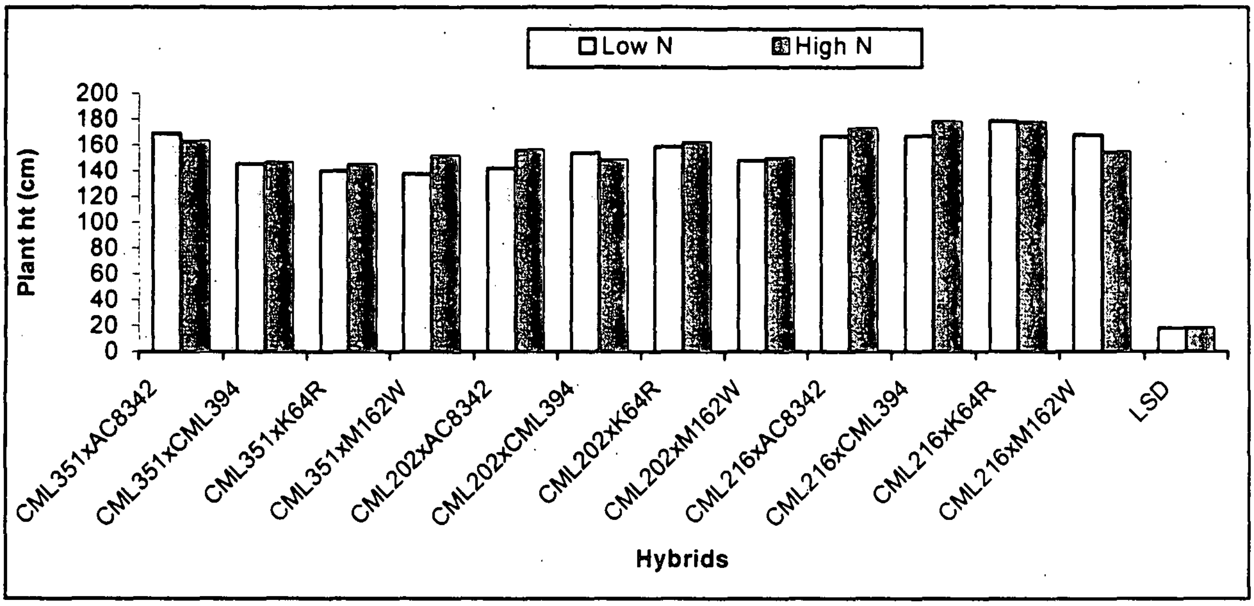

Figure 8. Mean plant height of the F_1 hybrids at two different N-levels at Bethlehem trial

Grain yield (GY)

The grain yield data for the Bethlehem trial are illustrated in figure 9. Two hybrids namely CML216 x K64R and CML216 x M162W showed significant differences between the low and the high N-levels. The grain yield of both these hybrids was significantly higher at the low N-level. This could be explained by excessive damage on the high N-level block caused by porcupines. The rest of the hybrids showed no significant differences between the two N-levels. Significant variability was observed between F_1 hybrids for grain yield at both N-levels. At the high N-level the yield of CML216 x AC8342 was significantly higher than that of the rest of the hybrids. The only exception were CML202 x K64R and CML216 x K64R.

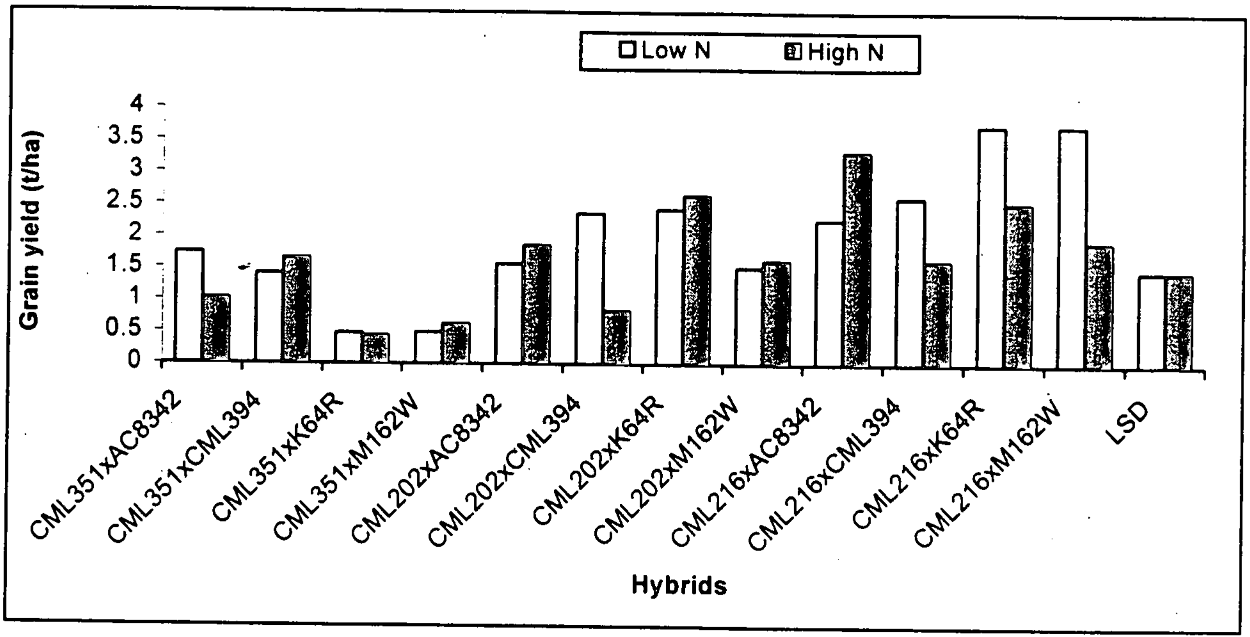

Figure 9. Mean grain yield of the F_1 hybrids at two different N-levels at Bethlehem trial

At the low N- level CML216 x K64R and CML216 x M162W had higher yields than the rest of the hybrids. The hybrid CML202 x K64R performed reasonably well at both N-levels indicating that it did not respond to the higher N-level. This hybrid would probably be suitable for both the low and the high N-levels. The results showed few significant differences in the rankings of the F_1 hybrids especially with regard to the low N-level. This could be the result of the damage done to part of the trial.

Seed weight (SDW)

The seed weight effect of the F_1 hybrids are illustrated in figure 10. The two N-levels had no significant effect on seed weight of the F_1 hybrids at Bethlehem. Significant variability existed between the F_1 hybrids at both N-levels for seed weight. No major changes in rankings were observed for seed weight between the F_1 hybrids grown at the two N-levels.

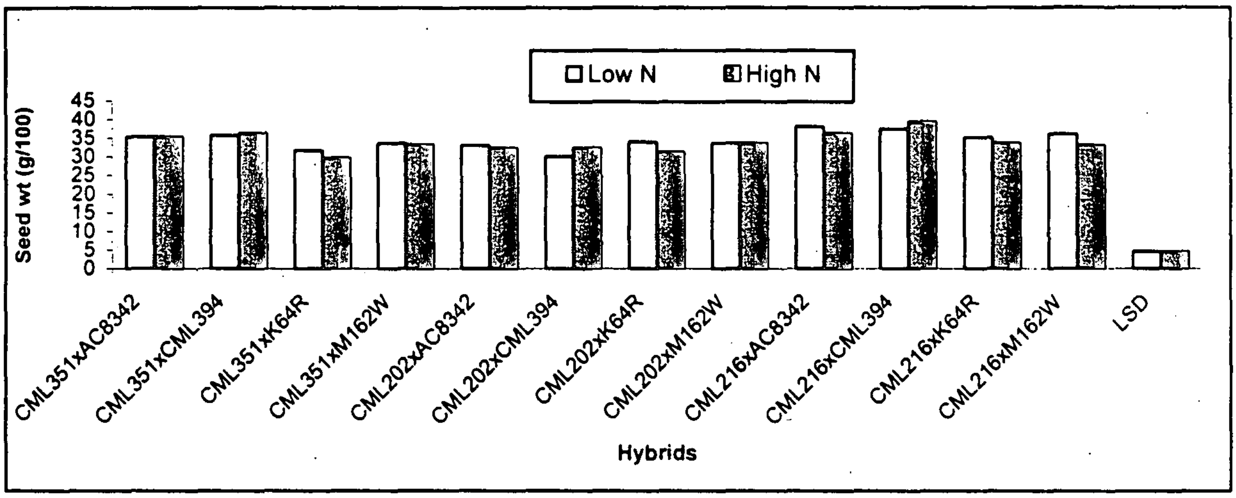

Figure 10. Mean seed weight of the F_1 hybrids at two different N-levels at Bethlehem trial

Seed number (SDN)

The seed number effect of the F_1 hybrids are illustrated in figure 11. The two N-levels had an t effect on the seed number of the F_1 hybrids. The seed number of five of the F_1 hybrids at the

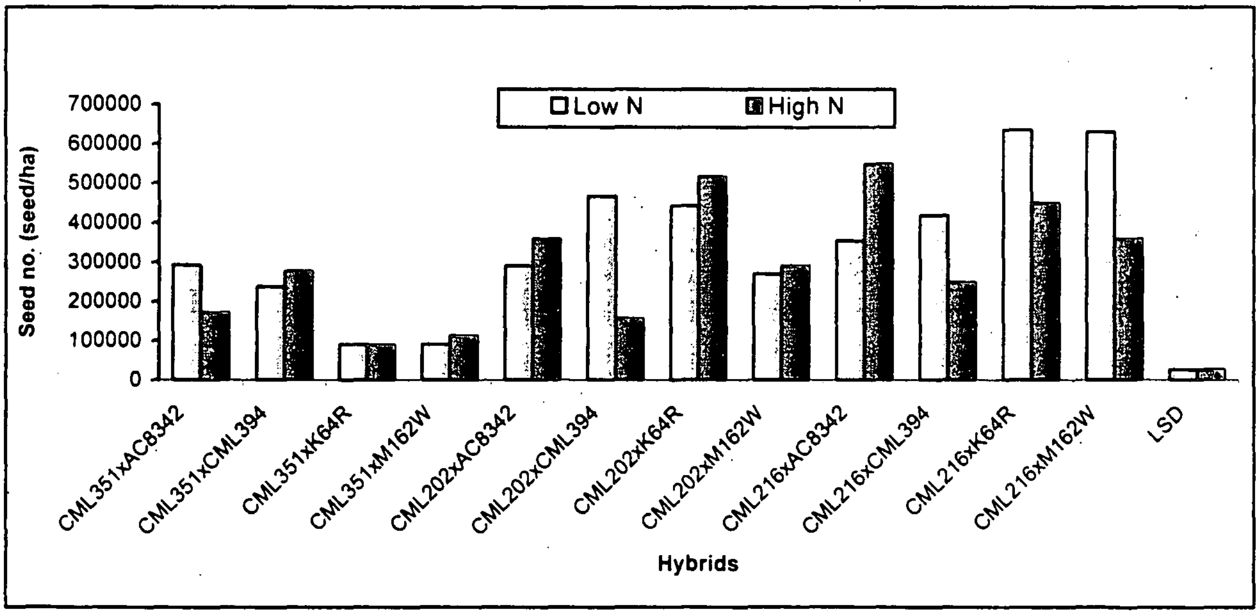

Figure 11. Mean seed number of the F_1 hybrids at two different N-levels at Bethlehem trial

low N-level was unexpectedly higher than those at the high N-level. This could be due to the damage caused to the trial. These were; CML351 x AC8342, CML202 x CML394, CML216 x CML394, CML216 x K64R and CML216 x M162W. The seed number of four of the F_1 hybrids namely; CML351 x CML394, CML202 x AC8342, CML202 x K64R and CML216 x AC8342 was higher at the high N-level, although the N x E interaction were insignificant (Table 4.1, 4.2, and 4.3), the t - distribution showed some significance between the two N-levels for these hybrids. Significant variability for seed number existed between the F_1 hybrids at both the low and the high N-levels. The rankings of the F_1 hybrids were significantly affected by the two N-levels. Due to the damage done to this trial it is very difficult to explain these differences.

Harvest Index (HI)

The harvest index effects of the F_1 hybrids are illustrated in figure 12. The histogram showed no significant differences between the F_1 hybrids for harvest index at both N-levels. The only exception was with CML351 x AC8342 which showed a significant differences for harvest index at the low N-level. There is no significant variability for harvest index between the F_1 hybrids at both the low and the high N-levels.

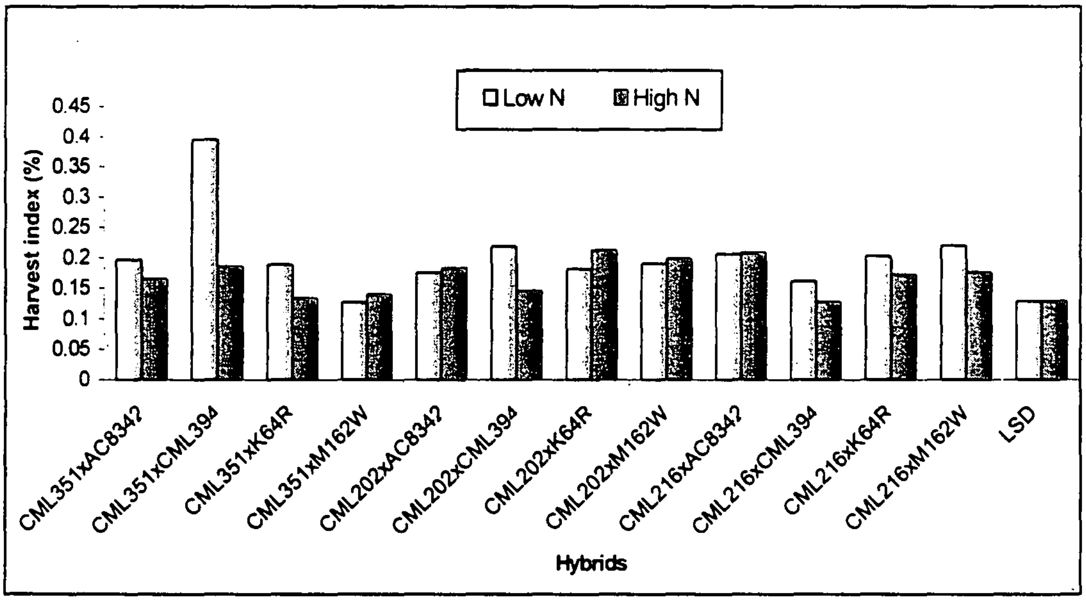

Figure 12. Mean harvest index of the F_1 hybrids at two different N-levels at Bethlehem trial

Grain N- content (GNC)

The grain N-content of the F_1 hybrids grown at the two N-levels is illustrated in figure 13. The two N-levels did not affect the grain N-content of the F_1 hybrids significantly. Significant differences existed between the F_1 hybrids at both N-levels. The hybrids with the highest grain nitrogen content at the high N-level were CML351 x CML394, CML351 x M162W and CML216 x CML394. Their nitrogen content was significantly higher than that of the following hybrids CML351 x AC8342, CML351 x K64R and CML202 x M162W and the rest of the hybrids. Much less variability exists between F_1 hybrids for grain nitrogen content at the low N-level. The F_1 hybrids CML351 x AC8342, CML351 x K64R, CML351 x M162W and CML216 x CML394 had the highest grain nitrogen content. Their grain nitrogen content was significantly higher than that of CML202 x K64R, CML216 x AC8342 and CML216 x M162W. The two N-levels did not cause a significant change in the rankings of the F_1 hybrids.

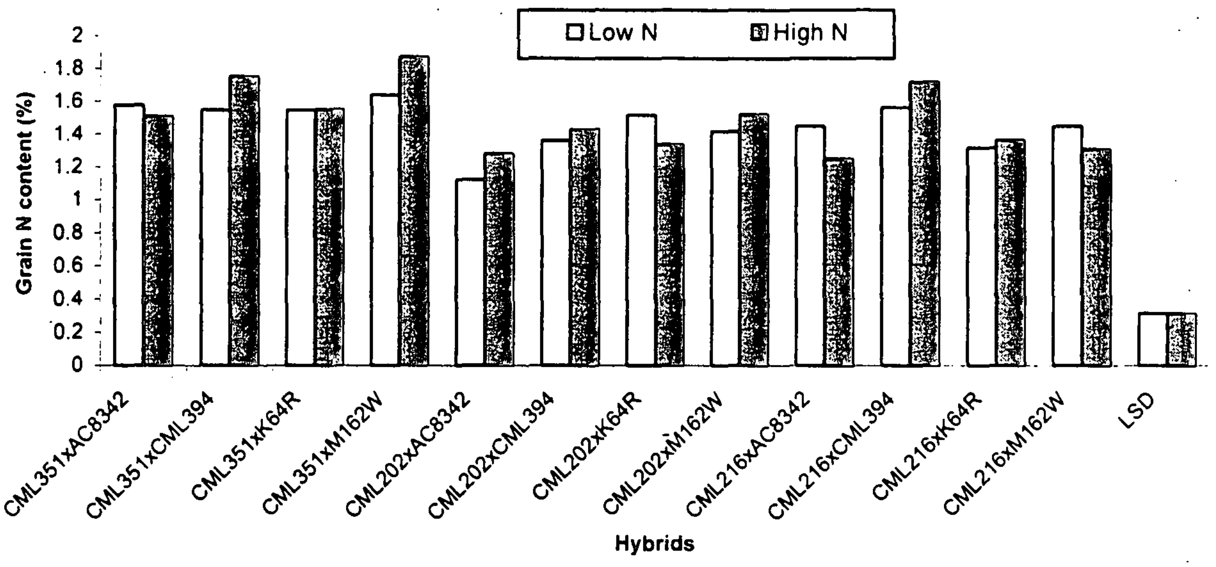

Figure 13. Mean grain N-content of the F_1 hybrids at two different N-levels at Bethlehem trial

Stover N- content (SNC)

The stover N-content effects of the F_1 hybrids at the two N-levels are illustrated in figure 14. The two N-levels had no significant effect on the stover N-content of the F_1 hybrids. No significant variability was observed between the F_1 hybrids for stover N-content at both the low and the high N-levels. The two N-levels had very little influence on the rankings of the different hybrids.

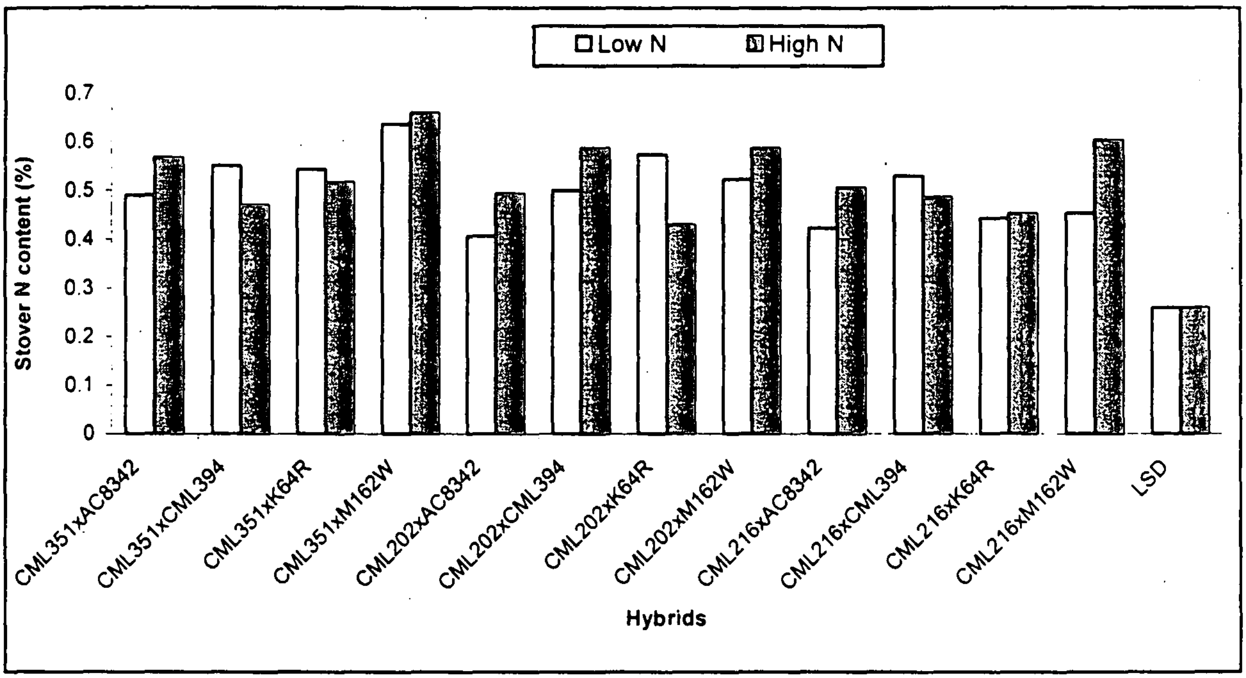

Figure 14. Mean stover N-content of the F_1 hybrids at two different N-levels at Bethlehem trial

Discussion

Application of fertilizer N did not significantly increase maize grain yield at both Doornpan and Bethlehem (Fig 2 and Fig 9). However the magnitude of grain yield was higher at Doornpan than at Bethlehem. Application of 30kg/ha of N did not significantly increase grain yield at Doornpan but only improved maize for some of the hybrids (Fig.2).

4.6 Mean performance of F_1 hybrids for nitrogen use efficiency (NUE) components at Bloemfontein (Doornpan trial)

The means of the hybrids for the different nitrogen use efficiency (NUE) components are presented in Table 4.8. The F_1 hybrids did not differ significantly with regard to yield efficiency, recovery efficiency and nitrogen harvest index. However, F_1 hybrids were significantly different with regard to physiological efficiency. CM216 x AC8342 was significantly higher than the rest of the hybrids, whereas, CML351x CML394, CML351 x K64R, CML202 x K64R, CML216 x AC8342, CML216 x K64R and CML216 x M162W were the second in ranking for physiological efficiency. Therefore, CML351 is an excellent inbred which can be used in maize breeding programme to enhance the physiological efficiency.

Table 4.8- Means for yield efficiency (YE), recovery efficiency (RE), and physiological efficiency (PE) and nitrogen harvest index (NHI) of 12 hybrids evaluated at Bloemfontein (Doornpan trial) in 1999/2000.

	Mean Squares			
	Nitrogen use efficiency components			
Hybrids	Yield efficiency (YE)	Recovery efficiency (RE)	Physiological efficiency (PE)	Nitrogen harvest index (NHI)
	(kg grain/kg N)	(%)	(kg grain/kg N)	(%)
CML351 x AC8342	2.407 c	0.577 bcd	4.174 cd	0.567 a
CML351 x CML394	2.857 bc	0.540 bcd	5.287 abcd	0.653 a
CML351 x K64R	2.446 c	0.633 ab	3.867 d	0.599 a
CML351 x M162W	3.306 ab	0.723 a	4.776 bcd	0.644 a
CML202 x AC8342	3.250 ab	0.597 bc	5.394 abcd	0.638 a
CML202 x CML394	2.869 bc	0.510 cd	5.609 abc	0.637 a
CML202 x K64R	3.023 bc	0.549 bcd	5.473 abc	0.622 a
CML202 x M162W	3.610 ab	0.637 ab	5.724 ab	0.593 a
CML216 x AC8342	3.890 a	0.634 ab	6.129 ab	0.589 a
CML216 x CML394	3.167 abc	0.511 cd	6.278 ab	0.567 a
CML216 x K64R	3.304 ab	0.488 d	6.774 a	0.636 a
CML216 x M162W	3.944 a	0.600 bc	6.610 a	0.597 a
Mean	3.173	0.583	5.508	0.612
CV(%)	14.580	10.700	16.430	8.260
LSD (0.05)	0.783	0.107	1.532	0.0927

Means in a column followed by the same letter are not significantly different at 0.05 level using LSD.

4.7 Mean performance of F_1 hybrids for nitrogen use efficiency (NUE) components at Bethlehem trial

The mean performance of F_1 hybrids for the nitrogen use efficiency (NUE) components in the Bethlehem trial was listed in Table 4.9. Similarly as in Doornpan there was no significant differences found between the F_1 hybrids for yield efficiency and recovery efficiency. CML216 x CML394 was significantly higher than the rest of the F_1 hybrids for physiological efficiency, and CML216 x Ac8342 significantly higher than the rest of the F_1 hybrids for nitrogen harvest index. Therefore, CML216 was the best inbred to be used at this environment to enhance these two components.

Table 4.9 - Means for yield efficiency (YE), recovery efficiency (RE), physiological efficiency (PE) and nitrogen harvest index (NHI) of 12 hybrids evaluated at Bethlehem trial in 1999/2000.

	Mean Squares			
	Nitrogen use efficiency components			
Hybrids	Yield efficiency (YE)	Recovery efficiency (RE)	Physiological efficiency (PE)	Nitrogen harvest index (NHI)
	(kg grain/kg N)	(%)	(kg grain/kg N)	(%)
CML351 x AC8342	0.591 cde	0.199 abc	2.893 efg	0.609 ab
CML351 x CML394	0.974 bcd	0.230 abc	4.110 defg	0.602 ab
CML351 x K64R	0.257 e	0.155 bc	1.807 g	0.617 ab
CML351 x M162W	0.368 de	0.165 bc	2.176 fg	0.684 a
CML202 x AC8342	1.096 bcd	0.226 abc	4.483 cdef	0.622 ab
CML202 x CML394	0.473 cde	0.170 bc	3.271 efg	0.605 ab
CML202 x K64R	1.551 ab	0.271 a	5.683 abcd	0.625 ab
CML202 x M162W	0.956 bcde	0.247 ab	3.860 defg	0.620 ab
CML216 x AC8342	1.964 a	0.265 a	7.563 a	0.680 a
CML216 x CML394	0.939 bcde	0.146 c	6.737 abc	0.662 ab
CML216 x K64R	1.469 ab	0.207 abc	7.127 ab	0.578 b
CML216 x M162W	1.108 bc	0.212 abc	4.877 bcde	0.653 ab
Mean	0.979	0.208	4.549	0.630
C.V. (%)	43.930	26.200	30.520	8.020
LSD (0.05)	0.728	0.093	2.351	0.093

Means in a column followed by the same letter are not significantly different at 0.05 level using LSD.

4.8 General and specific combining ability effects

4.8.1 Analysis of variance (ANOVA) for combining ability effects at Bloemfontein (Doornpan trial)

The combining ability effects for F_1 hybrids, lines and testers at Doornpan trial were determined by using a Line x Tester analysis. It was done on all characters measured. The mean squares are presented in Table 4.10.

Significant differences were found between the F_1 hybrids at both N-levels. The significance of the mean squares for SDW and HI were affected by the two N-levels. For both characteristics the mean squares were significantly different at the high N-level but not significantly different at the low N-level. The mean squares for SNC were not significant at both N-levels.

The mean squares for lines were significantly different for GY, SDW and SDN at both N-levels. The mean squares for PLHT were significant at low N-level and that of HI and GNC at the high N-level and for HI and GNC at the high N-level.

The mean squares for testers were highly significant for PLHT at both N-levels. Significant differences were observed for GY, SDW, SDN and HI only at the high N-level, and for GNC at the low N-level. The line x tester interactions was significantly different for PLHT at the low N-level only. The means and coefficient of variations (CVs) for most characters were similar at both N-levels.

Table 4.10 - Mean squares of crosses, lines and testers for various maize parameters at both low and high N-levels at Bloemfontein (Doornpan trial), in 1999/2000.

		Characteristics													
Source Variance	***df***	***PLHT (cm)***		***GY ($t\ h^{-1}$)***		***SDW (g/100)***		***SDN (10^9) (no./ha)***		***HI (%)***		***GNC (%)***		***SNC (%)***	
		LN	HN	LN	HN	LN	HN	LN	HN	LN	HN	LN	HN	LN	HN
Replication	2	223.528*	127.194ns	8.792**	6.323***	23.583ns	27.028*	163.779***	63.409**	0.235ns	0.001ns	0.231***	0.138***	0.023ns	13.503**
Crosses	11	1451.414***	1662.960***	2.089*	2.151**	25.364ns	21.505**	42.115*	27.773*	0.286ns	0.002**	0.050*	0.037*	0.016ns	1.595ns
Lines (L)	3	322.741**	49.593ns	3.938*	2.769*	62.630**	32.630**	97.606**	58.851**	0.217ns	0.004***	0.033ns	0.103***	0.026*	0.775ns
Tester (T)	2	6191.694***	8336.028***	2.361ns	5.867***	25.083ns	61.194***	23.354ns	38.469*	0.333ns	0.002*	0.150**	0.035ns	0.030*	4.403ns
L x T	6	435.657***	245.287ns	1.074ns	0.604ns	6.824ns	2.713ns	20.622ns	8.669ns	0.305ns	0.001ns	0.025ns	0.005ns	0.006ns	1.069ns
Error	22	55.952	123.043	0.909	0.604	11.947	5.210	16.847	8.793	0.294	0.000	0.021	0.013	0.009	1.707
Means		168.111	185.944	4.632	5.449	46.833	47.278	0.00059	0.00069	0.446	0.366	1.299	1.384	0.457	1.063
C.V. %		4.45	5.97	20.59	14.26	7.38	4.83	0.000000023	0.000000014	121.50	6.03	11.25	8.09	20.50	122.9

ns = non -significant, *, **,*** = significantly different from zero at 0.05, 0.01 and 0.001 levels of probability respectively. **PLHT** = plant height, **GY** = grain yield, **SDW** = seed weight, **SDN** = seed number, **HI** = harvest index, **GNC** = grain N-content, **SNC** = stover N-content. LN = low nitrogen and HN = high nitrogen.

4.8.2 *General combining ability (GCA) effects of inbred lines at Bloemfontein (Doornpan trial)*

The estimates for general combing ability (GCA) effects of lines and testers at Doornpan trial are presented in Table 4.11.

The two N-levels had a little effect on the GCA-values of some of the lines for PLHT. AC8342 had the highest positive GCA effect for PLHT at the low N-level. The effect of AC8342 for PLHT exceeded that of CML394, K64R and M162W. CML394 was the second best with effect higher than K64R (-5.33) and M162W (-4.89). The lines K64R and M162W were the best combiners to reduce plant height at the low N-level. At high N-level, CML394 had the highest positive GCA effect for plant height. Its value was higher than of AC8342 and K64R. M162W was the second best with a higher effect than AC8342 and K64R.

AC8342 and CML394 lines are good combiners for plant height, and they could be used to increase plant height at both low and high N-levels, while K64R could be used for decreasing plant height at both low and high N-levels. The two N-levels had an effect on the GCA-values of the testers for PLHT. The GCA-values for CML216 were much higher at both N-levels. Its effect exceeded that of CML351 and CML202. These testers (CML351 and CML202) were the best combiners to reduce plant height at both N-levels.

For GY, the two N-levels had very little effect on the GCA-values of the lines. M162W exhibited a higher positive GCA effect for GY at the low N-level followed by K64R. Under the high N-level the same line (M162W) showed higher positive GCA effect. AC8342 had the second highest value at the high N-level. Therefore, M162W would be the best combiner to enhance grain yield at both high and low N-levels. No significant differences were found between lines at the low N-level. Little variation was observed between the rankings of the lines at the low and high N-levels. It indicates that N-levels had only a very small effect on the GCA values of the lines at Doornpan. The two N-levels had a little effect on the GCA-values of testers for GY. However, differences were found between the GCA-values of testers at both N-levels. Again CML216 had the largest positive GCA effect for GY at both N-levels, followed by CML202 with GCA effects larger than that of CML351.

The two N-levels had no major effect on the GCA-values of the lines for SDW. The inbred (CML394) with the highest SDW value at the low N-level also was the highest in ranking at the high N-level. CML394 had a highly positive GCA-value for SDW at the low N-level. Its value was higher than that of the other three inbreds AC8342. K64R and M162W. Line CML394 also had the highest GCA-value for SDW at the high N-level. Again its (CML394) GCA-value was higher than that of lines AC8342, K64R and M162W. The two N-levels had a little effect on the GCA-values of testers for SDW. The tester CML216 had the highest value at both N-levels. Its value was higher than that of the other two testers.

The GCA-values of three of the lines and testers namely; M162W, CML202 and CML216 were affected by the two N-levels. M162W had a high positive GCA-value for SDN at the low N-level. The value was higher than that of K64R, CML394 and AC8342. K64R had the second highest GCA-value for SDN that was higher than the values of CML394 and AC8342. M162W also had the highest GCA-values for SDN at the high N-level. It was higher than the values of AC8342, CML394 and K64R at the high N-level. AC8342 had the second highest GCA-value for SDN that was higher than that of CML394 and K64R. With the exception of M162W, the two N-levels had an effect on the rankings of the GCA values of the inbreds. Two testers CML202 and CML216 had positive values at both N-levels with values higher than that of CML351.

The two N-levels had very little effect on the GCA-values of the lines and testers for HI. The variability between the lines and testers was also insignificant at both N-levels. This indicates a lack of genetic variability for HI. The two N-levels had no effect on the GCA-values of the lines and testers for GNC and SNC. No significant differences were found between the lines and testers for these characters at both N-levels. These results indicate a lack of genetic variability in maize for these characteristics.

Table 4.11. - Estimates of general combining ability (GCA) of lines and testers for various maize parameters under both low and high N-levels at Bloemfontein (Doornpan trial) in 1999/2000.

	Characteristics													
	PLHT (cm)		**GY ($t\ h^{-1}$)**		**SDW (g/100)**		**SDN 10^3 (no./ha)**		**HI (%)**		**GNC (%)**		**SNC (%)**	
	LN	**HN**	**LN**	**HN**	**LN**	**HN**	**LN**	**HN**	**LN**	**HN**	**LN**	**HN**	**LN**	**HN**
LINES														
AC8342	6.333	0.389	-0.183	0.014	-0.611	-1.167	-13.103	13.204	-0.099	0.008	-0.073	-0.12	-0.023	-0.173
CML394	3.889	1.944	-0.736	-0.369	3.833	2.833	-12.778	-80.455	0.232	-0.031	0.075	0.137	-0.065	-0.202
K64R	-5.333	-3.389	0.064	-0.424	-0.467	-1.056	15.162	-3.955	-0.067	-0.009	0.005	-0.01	0.036	-0.074
M162W	-4.889	1.056	0.856	0.779	-0.056	-0.611	125.722	106.798	-0.066	0.027	-0.008	-.002	0.052	0.433
LSD (0.05)	2.309	2.548	1.380	1.311	1.904	1.716	0.662	0.563	1.198	0.539	0.865	0.807	0.772	0.839
TESTERS														
CML351	-17.611	-20.529	-0.481	-0.712	-0.750	-2.361	-47.657	-57.224	-0.079	0.013	0.120	0.056	0.058	-0.546
CML202	-8.028	-9.194	0.087	0.025	-0.918	0.222	8.247	1.228	0.191	-0.003	-0.101	-.052	-0.029	-0.122
CML216	25.639	29.722	0.393	0.686	1.668	2.139	39.409	55.996	-0.113	-0.011	-0.019	-.004	-0.029	0.657
LSD (0.05)	2.788	3.076	1.666	1.583	2.299	2.072	0.833	0.708	1.447	0.651	1.042	0.975	0.932	1.802

PLHT = plant height, **GY** = grain yield, **SDW** = seed weight, **SDN** = seed number, **HI** = harvest index, **GNC** = grain N-content, **SNC** = stover N-content. LN = low nitrogen and HN = high nitrogen.

4.8.3 *Analysis of variance (ANOVA) for combining ability effects at Bethlehem trial*

The mean squares for combining ability effects for crosses, lines and testers measures under the low and the high N-levels at Bethlehem trial are presented in Table 4.12.

The mean squares for crosses differed significantly for PLHT, GY, and SDN at both the low and the high N-levels. The results indicated significant variability for these characteristics at both the low and the high N-levels. It differed significantly for SDW and GNC only at the high N-level. The mean squares for lines were significant for PLHT and GY only at the high N-level. The mean squares at the low N-level were non-significant for all characteristics measured. It indicated a lack of genetic variability between lines at the low N-level. The mean squares for testers were significant for PLHT, GY, SDW, SDN and GNC at both the low and the high N-levels. The line x tester interaction was significant for PLHT and GY only at the high N-level.

Table 4.12. - Mean squares of crosses, lines and testers for various maize parameters under both low and high N-levels at Bethlehem trial in 1999/2000.

		Characteristics													
Source Variance	***df***	***PLHT (cm)***		***GY ($t\ h^{-1}$)***		***SDW (g/100)***		***SDN (10^7) (no./ha)***		***HI (%)***		***GNC (%)***		***SNC (%)***	
		LN	HN	LN	HN	LN	HN	LN	HN	LN	HN	LN	HN	LN	HN
Replication	2	560.583 *	68.778ns	5.073 *	0.579ns	0.528ns	4.194ns	158.449*	29.839ns	0.004ns	0.002ns	0.137*	0.108ns	0.016ns	0.044*
Crosses	11	547.483 *	419.846***	3.328 *	2.248***	15.535ns	20.202*	94.702 *	70.640**	0.013ns	0.002ns	0.060ns	0.122*	0.014ns	0.015ns
Lines (L)	3	125.519ns	227.213 *	0.260ns	1.097ns	5.407ns	32.444*	11 827ns	41.236ns	0.012ns	0.002ns	0.026ns	0.157*	0.018ns	0.035ns
Tester (T)	2	1724.250***	1322.028***	12.713***	6.042***	47.194**	30.528 *	332.169***	180.920**	0.004ns	0.002ns	0.149*	0.287**	0.026ns	0.005ns
L x T	6	366.213ns	215.435*	1.734ns	1.558 *	10.046ns	10.64ns	56.983ns	48.583ns	0.016ns	0.003ns	0.047ns	0.049ns	0.007ns	0.007ns
Error	22	173.886	70.778	1.057	0.529	7.861	7.497	33.137	20.604	0.013	0.001	0.035	0.039	0.036	0.014
Means		156.500	158.972	2.027	1.675	34.444	33.889	0.00035	0.00029	0.205	0.171	1.459	1.493	0.506	0.530
C.V. %		8.43	5.28	50.73	43.40	8.14	8.08	0.000000052	0.000000048	56.03	21.76	12.25	13.29	37.35	22.9

ns = non -significant, *, **,*** = significantly different from zero at 0.05, 0.01 and 0.001 levels of probability respectively. **PLHT**=plant height, **GY**= grain yield, **SDW**= seed weight, **SDN** = seed number, **HI** = harvest index, **GNC** = grain N-content, **SNC** = stover N-content. LN = low nitrogen and HN = high nitrogen.

4.8.4 General combining ability (GCA) effects of lines and testers at Bethlehem trial

Estimates of general combing ability (GCA) effects of lines and testers at Bethlehem trial are presented in Table 4.13.

The lines and testers with the highest GCA-values for PLHT at the low N-level have also the highest values at the high N-level. The only exception was line AC8342, which the GCA-value at the high N-level was almost twice as large as its GCA-value at the low N-level. The variability was found between the GCA-values of the lines and testers at both N-levels. AC8342 had the highest positive GCA effect for PLHT at the low N-level. Its effect exceeded that of CML394, K64R and M162W, but did not differ that much from K64R. K64R was the second best combiner for PLHT and its effect was larger than that of CML394 and M162W, which had negative GCA-values, which will reduce plant height. The GCA-values of the tester CML216 was larger than the rest of the tester. AC8342 had also the highest positive GCA effect for PLHT at high N-level. K64R was the second best at the high N-level. The best combiners to reduce plant height at the high N-level are CML394 and M162W.

The line with the highest GCA-value at the low N-level was K64R while AC8342 had the highest GCA-value at the high N-level. The two N-levels had no effect on the GCA-values of the testers. The tester CML216 with the highest GCA-value for GY at the low N-level had also the highest GCA-value at the high N-level. One of the three testers (CML216) differed from CML351 and CML202.

The lines and testers with the largest GCA-value at the low N-level had also the largest GCA-value at the high N-level. The only exception was the line CML394 that had a negative GCA-value at the low N-level and a high positive value at the high N-level. This indicates an improve performance of CML394 under the high N-level.

With the exception of line CML394 the two N-levels had no effect on the GCA-values of the lines and testers for SDN. The lines with the largest GCA-values at the low N-level had also the largest GCA-value at the high N-level. CML394 had a positive GCA-value at the low N-level and a highly negative value at the high N-level. The line AC8342 and tester

CML216 had the largest GCA-values under both the low and the high N-levels. Differences were found between the GCA-values of the lines and testers at the low N-level as well as between the lines and testers at the high N-level. The two N-levels had a smaller effect on the GCA-values of the lines and testers for HI. Also the variability between the lines and the testers was not significant. For GNC and SNC the two N-levels had no effects on the GCA-values of the lines and testers. Two lines CML394 and M162W and tester CML351 had positive GCA-values for GNC at both N-levels. Their values were higher than others. M162W and CML351 had positive GCA-values for SNC at both N-levels.

Discussion

The lines did not seem to offer much choice with the exception of M162W, which was desirable from the point of GCA for yield as it could yield dwarfish hybrids under the low N-level. It was superior with the respect to yield and seed number at both low and high N-levels. Among the three testers CML202 was desirable from the point of GCA for grain yield and could also produce dwarfish plants. CML216 was very desirable for grain yield, seed number and large seeds besides being relatively tall at both N-levels. At Bethlehem unlike at Doornpan the line M162W did not have desirable grain yield at both N-levels although it could produce short plants under both N-levels. This line also had small seeds at both N-levels. K64R can produce hybrids which yield higher than other lines at both N-levels besides being relatively tall. Among the testers CML216 again would produce high yielding hybrids than other testers although their yields are confined to the tall plants. This tester also was the best with regard to the GCA effects for seed weight and seed number. Generally results showed that line K64R appeared to be good general combiner for grain yield at the low N-level as it produced short or dwarfish plants at both N-levels. M162W besides being relatively tall, was the best combiner with regards to its positive GCA values for grain yield, and seed number at both N-levels. The tester CML216 was the best combiner for grain yield, seed weight and seed number besides being intermediate in height. Therefore, on the basis of GCA effects line K64R and tester CML216 should be the best general combiners for nitrogen tolerance and yield performance under N-stress environment.

Table 4.13. - Estimates of general combining ability (GCA) of lines and testers for various maize parameters under both low and high N-levels at Bethlehem trial in 1999/2000.

	Characteristics													
	PLHT (cm)		**GY $(t\ h^{-1})$**		**SDW (g/100)**		**SDN 10^3 (no./h)**		**HI (%)**		**GNC (%)**		**SNC (%)**	
	LN	**HN**	**LN**	**HN**	**LN**	**HN**	**LN**	**HN**	**LN**	**HN**	**LN**	**HN**	**LN**	**HN**
LINES														
AC8342	2.944	5.028	-0.173	0.394	1.000	0.778	39.359	61.902	-0.013	0.015	-0.076	-0.145	-0.066	-0.008
CML394	-0.833	-1.083	0.099	-0.305	-0.111	2.111	22.526	-71.2589	0.053	-0.018	0.032	0.142	0.021	-0.016
K64R	2.833	2.583	0.185	0.193	-0.889	-2.333	37.947	53.628	-0.014	0.002	0.0006	-0.074	0.014	-0.063
M162W	-4.944	-6.528	-0.112	-0.283	0.000	-0.556	-21.114	-44.271	-0.026	0.0008	0.044	0.076	0.032	0.087
LSD (0.05)	2.660	2.378	1.406	1.289	1.807	1.796	0.784	0.696	0.813	0.613	0.250	0.257	0.252	0.198
TESTERS														
CML351	-8.250	-7.306	-0.997	-0.740	-0.361	-0.222	-17.383	-13.576	0.022	-0.014	0.118	0.178	0.049	0.023
CML202	-5.500	-4.722	-0.062	0.066	-1.778	-1.472	16.083	32.440	-0.014	0.014	-0.104	-0.098	-0.005	-0.006
CML216	13.750	12.028	1.059	0.675	2.139	1.694	157.749	103.309	-0.008	0.0003	-0.014	-0.080	-0.044	-0.018
LSD (0.05)	3.213	2.871	1.698	1.557	2.181	2.168	0.986	0.876	0.982	0.739	0.233	0.239	0.234	0.184

PLHT = plant height, **GY** = grain yield, **SDW** = seed weight, **SDN** = seed number, **HI** = harvest index, **GNC** = grain N-content, **SNC** = stover N-content. LN = low nitrogen and HN = high nitrogen.

4.8.5 Combing ability effects of nitrogen use efficiency (NUE) components at Bloemfontein (Doornpan) and Bethlehem trials.

Analysis of variance (ANOVA)

The mean squares of the combining ability effects of the nitrogen use efficiency (NUE) components at Bloemfontein (Doornpan) and Bethlehem trials are presented in Table 4.14. Significant differences were found between the combining ability effects of the crosses for PE at Doornpan. The mean squares for lines differed significantly for PE and the testers for YE and RE.

At Bethlehem, significant differences were found between the combining ability effects of the crosses for YE and RE. No significant differences were found between lines for NUE components. The coefficients of variations (CVs) at Bethlehem trial were much higher than those at Doornpan trial, which might have influenced the significance of the lines in the trial. The testers differed significantly for YE and RE at both locations. The lines differed significantly for YE at Bethlehem trial.

Table 4.14 - Mean squares for combining ability (LxT) analysis for crosses, lines and testers for nitrogen use efficiency components at Bloemfontein (Doornpan) and Bethlehem trials in 1999/2000.

		Nitrogen use efficiency components							
		Doornpan trial				**Bethlehem trial**			
Source	df	YE	RE	PE	NHI	YE	RE	PE	NHI
Variance									
Replication	2	2.658**	0.007ns	5.329ns	0.006*	0.196ns	0.007ns	4.793ns	0.001ns
Crosses	11	0.811ns	0.014**	3.554ns	0.002ns	0.783**	0.005ns	11.885***	0.001ns
Lines (L)	3	1.014ns	0.030**	0.503ns	0.001ns	0.394ns	0.003ns	3.373ns	0.001ns
Tester (T)	2	2.109**	0.012ns	15.942***	0.003ns	2.043***	0.004ns	45.370***	0.001ns
L x T	6	0.276ns	0.007ns	0.949ns	0.001ns	0.557ns	0.006ns	4.980*	0.001ns
Error	22	0.357	0.004	1.447	0.001	0.185	0.003	2.002	0.004
Means		3.117	0.583	5.386	0.746	0.979	0.205	4.466	0.749
C.V. %		19.170	10.690	22.330	4.850	43.930	25.920	31.840	8.710

ns = non –significant. *, **,*** = significantly different at 0.05 and 0.01 levels of probability respectively. YE= Yield efficiency, RE = recovery efficiency, PE = Physiological efficiency and NHI = Nitrogen harvest index.

Combining ability

The GCA effects of the lines and testers for the nitrogen use efficiency (NUE) components are presented in Table 4.15. No significant differences were found between the GCA-values of the lines and testers for YE, RE and PE at Doornpan trial. Significant differences were only found between the GCA-values of the testers for RE. The tester with the largest GCA-value for RE was CML216.

At Bethlehem trial no significant differences were found between the GCA-values of the lines and testers for YE, RE and PE. Significant differences were found between the GCA-values of the lines and testers for YE and RE. AC8342 had the largest GCA-value of the lines for RE and CML216 had the highest GCA-value of testers for RE.

Table 4.15. - Estimates of general combining ability (GCA) of lines and testers for nitrogen use efficiency components at Bloemfontein (Doornpan) and Bethlehem trials in 1999/2000.

	Nitrogen use efficiency components							
	Doornpan trial				**Bethlehem trial**			
	YE	**RE**	**PE**	**NHI**	**YE**	**RE**	**PE**	**NHI**
LINES								
AC8342	0.002	-4.1151	21.7563	-0.0006	0.0001	1.5286	12.1624	0.0050
CML394	0.0151	1.0135	-9.2239	0.0142	0.0008	-0.2767	31.3741	0.0100
K64R	-0.0118	-3.7640	0.2436	-0.0111	-0.0007	1.0508	-41.7096	-0.0121
M162W	-0.0035	6.8655	-12.7759	-0.0025	-0.0001	-2.3026	-1.8268	-0.0029
LSD (0.05)	0.1748	3.4035	8.0443	0.2281	0.1136	3.0041	14.1179	0.3062
TESTERS								
CML351	0.0024	-3.9842	17.0470	-0.0118	-0.0028	-4.7785	-29.6866	0.0055
CML202	-0.0059	-1.1484	-20.8224	-0.0078	-0.0015	-0.0337	-21.9562	-0.0088
CML216	0.0035	5.1327	3.7754	0.0196	0.0043	4.9121	51.6429	0.0033
LSD (0.05)	0.1619	3.1674	7.4861	0.2115	0.1058	2.7956	13.1382	0.2844

YE= Yield efficiency, RE = recovery efficiency, PE = Physiological efficiency and NHI = Nitrogen harvest index.

4.8.6 Specific combining ability (SCA) effects of the F_1 hybrids planted at Bloemfontein (Doornpan trial)

The specific combining ability (SCA) effects of the F_1 hybrids planted at Bloemfontein (Doornpan trial) are given in Table 4.16.

Plant Height (PLHT)

The magnitude of the SCA-values of the F_1 hybrids for plant height was more or less the same at the two N-levels. The crosses CML351 x AC8342 and CML216 x K64R which had the largest SCA-effects at the low N-level had also the largest SCA-effects at the high N-level. The crosses with the largest negative SCA-effects at the low N-level (CML351 x K64R and CML216 x AC8342) had also the largest negative effects at the high N-level. The only exceptions were the crosses CML202 x AC8342, CML202 x M162W and CML216 x M162W. Large differences were found between the SCA-effects of the F_1 hybrids at the high N-level. The crosses with the largest positive SCA-effects were CML351 x AC8342 (11.83) and CML216 x K64R (10.91). The cross with the largest negative effect was CML351 x K64R.

Large differences were also found between the SCA-values of the F_1 hybrids at the low N-level. The crosses with the largest positive SCA-effects were CML351 x AC8342 and CML216 x K64R. The crosses with largest negative effects were CML351 x K64R and CML216 x AC8342. The results indicate that the two N-levels had very little effects on the SCA-values of the crosses for plant height.

Grain Yield (GY)

The magnitude of the SCA-values of the F_1 hybrids for grain yield were more or less the same at the two N-levels The two N-levels had no major effects on the SCA-values of the F_1 hybrids for grain yield. The two crosses with the largest positive SCA-values at the low N-level (CML216 x AC8342 and CML351 x CML394) had also the largest SCA-values at the high N-level. The cross with the largest negative SCA-value at the low N-level (CML351 x AC8342) had also the largest negative SCA-value at the high N-level. The SCA-values of only a few of the crosses were affected by the two N-levels.

Seed Weight (SDW)

There was some similarity between the SCA-values of the crosses for seed weight at the low and high N-levels. Some of the crosses like CML351 x CML394 and CML216 x M162W which had large positive SCA-values at the low N-level, had also large positive effects at the high N-level. However, a few of the crosses showed no similarity between their SCA-values at the low and the high N-levels. Significant differences were found between the SCA-values of the crosses within each N-level. CML202 x K64R had the largest positive SCA-value at the low N-level and CML216 x M162W the largest positive SCA-value at the high N-level.

Seed Number (SDN)

With only a few exceptions the two N-levels had very little effect on the SCA-values of the crosses for seed number. The crosses with the largest positive SCA-value at the low N-level had also the largest value at the high N-level. Most of the crosses that possessed positive values at the low N-level had also positive values at the high N-level. The two crosses CML216 x AC8342 and CML351 x M162W which had the largest positive SCA-values at the low N-level had also the largest positive SCA-values at the high N-level. Large variability was found between the SCA-values of the crosses within the low and the high N-levels. The results showed that seed number is a function of specific cross and that it will be possible to enhance seed number either under low or high N-levels.

Harvest Index (HI)

There was no consistency in the rankings of the SCA-values of the crosses for harvest index. The crosses with the largest positive SCA-values at the low N-level had no necessarily positive effects at the high N-level. The variability for harvest index was not very large and no significant differences were found between the SCA-values of the crosses at either the low and the high N-levels.

Grain N-content (GNC)

The SCA-values of the crosses for gain N-content showed no similarities between the low and the high N-levels. The crosses with the positive SCA-values at the low N-level had not necessarily positive SCA-values at the high N-level. The variability among the SCA-values of the crosses at both the low and the high N-levels was insignificant.

Stover N-content (SNC)

The two nitrogen levels affected the SCA-values of the crosses for stover N-content differently. No clear pattern could be observed since some of the crosses had positive values at the low N-level while others had positive effects at the high N-level. Significant differences were found between the SCA-values of the crosses for stover N-content at both N-levels.

Table 4.16. - Specific combining ability estimates of crosses for various maize parameters under both low and high N-levels at Bloemfontein (Doornpan trial) in 1999/2000.

	Characteristics													
	PLTH (cm)		**GY ($t\ h^{-1}$)**		**SDW (g/100)**		**SDN (no./ha)**		**HI (%)**		**GNC (%)**		**SNC (%)**	
Crosses	LN	HN	LN	HN	LN	HN	LN	HN	LN	HN	LN	HN	LN	HN
CML351 x AC8342	11.833	9.528	-0.728	-0.623	0.194	-0.750	-101.754	-69.503	0.024	-0.024	0.077	-0.026	-0.046	0.122
CML202 x AC8342	-4.417	0.528	0.115	0.094	-0.306	0.333	36.509	6.337	-0.146	0.002	-0.076	0.025	-0.018	-0.324
CML216 x AC8342	-7.417	-10.056	0.613	0.529	0.111	0.417	65.246	63.166	0.121	0.022	0.001	0.001	0.064	0.202
CML351x CML394	4.944	3.972	0.761	0.542	1.083	0.917	68.741	53.081	-0.248	-0.004	0.032	-0.027	-0.020	0.242
CML202x CML394	-7.306	-3.361	-0.388	-0.195	-1.750	0.000	-24.960	-20.263	0.548	-0.001	-0.057	0.001	0.011	-0.254
CML216x CML394	2.361	-0.611	-0.373	-0.347	0.667	-0.917	-43.781	-32.817	-0.300	0.004	0.025	0.026	0.002	0.012
CML351 x K64R	-18.500	-13.032	-0.133	-0.094	0.417	0.472	-3.874	-23.783	0.105	0.018	-0.131	0.038	0.045	0.119
CML202 x K64R	7.583	4.972	-0.061	0.129	1.250	0.222	-58.726	12.840	-0.198	0.003	0.089	0.018	-0.007	-0.437
CML216 x K64R	10.917	8.056	0.191	-0.035	-1.665	-0.694	62.600	10.942	0.093	-0.018	0.041	-0.056	-0.038	0.319
CML351 x M162W	1.722	-0.472	0.100	0.175	-1.694	-0.641	36.888	40.204	0.118	0.011	0.022	0.015	0.021	-0.483
CML202 x M162W	4.139	-2.141	0.330	-0.028	0.806	-0.561	47.178	1.087	-0.204	-0.002	0.043	-0.044	0.015	1.015
CML216 x M162W	-5.861	2.611	-4.431	-0.147	0.889	1.194	-84.066	-41.291	0.086	-0.009	-0.065	0.029	-0.036	-0.533
LSD (0.05)	2.591	2.859	1.302	1.471	2.136	1.926	0.029	0.027	1.344	0.604	0.291	0.254	0.233	0.869

PLTH = plant height, **GY** = grain yield, **SDW** = seed weight, **SDN** = seed number, **HI** = harvest index, **GNC** = grain N-content, **SNC** = stover N-content, **LN** = Low N and **HN** = High N.

4.8.7 *Specific combining ability (SCA) effects of the F_1 hybrids planted at Bethlehem trial*

The estimates of specific combining ability (SCA) effects of the F_1 hybrids planted at Bethlehem trial are presented in Table 4.17.

Plant Height (PLHT)

The crosses CML351 x AC8342, CML202 x K64R and CML216 x K64R had higher positive SCA-effects for plant height at both N-levels. The crosses with the largest negative SCA-effects at the low N-level also had the largest negative SCA-effects at the high N-level. These were CML202 x AC8342, CML216 x AC8342 and CML351 x K64R with exceptions of CML202 x CML394, CML216 x CML394, CML351 x M162W and CML216 x M162W.

Large differences were observed between the SCA-effects of F_1 hybrids for plant height at the low N-level. The cross CML351 x AC8342 (17.806) exhibited large positive SCA-effects. The crosses CML202 x AC8342 and CML351 x K64R contributed highest negative SCA-effects of -11.611 and -10.754 respectively. Large differences were also found between the SCA-effects of F_1 hybrids at the high N-level. The crosses with the largest positive SCA-effects for plant height at the high N-level were CML216 x CML394 (8.417), CML351 x AC8342 (6.306) and CML351 x M162W (6.861) Two crosses with the largest negative SCA-effects were CML351 x K64R (9.250) and CML216 x M162W (-9.139). The results showed a little effect of the two N-levels on the SCA-values of the crosses for plant height.

Grain Yield (GY)

The two N-levels had an effect on the SCA-values of the lines for grain yield. CML351 x AC8342 and CML216 x M162W had the largest positive SCA-values at the low N-level but contributed negative SCA-values at the high N-level. The cross CML351 x K64R with the largest negative SCA-values at the low N-level also had the largest negative SCA-values at the high N-level. Only a few differences were observed between the SCA-effects of the F_1 hybrids at both N-levels. The crosses with the largest positive SCA-values at the low-level were CML351 x AC8342 (0.878) and CML216 x M162W (0.765), while

CML351 x K64R exhibited the largest negative SCA-value (-0.737) for grain yield at the low N-level. At the high N-level, the crosses with the largest SCA-values were CML351 x CML394 (1.024) and CML202 x K64R (0.705). Again CML351 x K64R was the cross with the largest negative SCA-values (-0.689) at the high N-level. For CML351 x CML394, CML202 x K64R, the SCA effects was significantly different for grain yield between N-levels indicating that an increase of N-level had an effect. CML351 x AC8342, CML202 x CML394 and CML216 x K64R exhibited larger SCA effect at the low N-level than at high N-level. This also indicated that an increase of N level had no effect.

Seed Weight (SDW)

The crosses with positive SCA-effects at the low N-level had also positive SCA-effects at the high N-level. Furthermore, those that had negative SCA-effects at the low N-level had also negative SCA-effects at the high N-level, with the exception of CML216 x AC8342, CML216 x M162W and CML351 x M162W.

Large differences were found between the SCA-effects of the F_1 hybrids at both N-levels. The crosses with the largest positive SCA-values for seed weight at the low N-level were CML202 x K64R (2.222), CML351 x CML394 (1.694) and CML202 x M162W (1.000), while those with the largest negative SCA-values were CML202 x CML394 (-2.556) and CML351 x K64R (-1.528). At the high N-level the crosses with the largest positive SCA-values were CML202 x M162W (1.806), CML216 x CML394 (1.639) and CML202 x K64R (1.250). The crosses with the largest negative SCA-values for seed weight were CML202 x CML394 (-2.194), CML216 x M162W (-2.028) and CML351 x K64R (-1.667). CML202 x CML394 had the largest negative SCA-value for seed weight at both N-level.

Seed Number (SDN)

The two N-levels had a little effect on the SCA-values for seed number. With few exceptions the crosses with large positive SCA-values at the low N-level also had large positive SCA-values at the high N-level. The crosses CML351 x CML394 and CML202 x K64R had the higher positive SCA-value at both N-levels. Large variability was observed between the SCA-values of the crosses for seed number at both N-levels. This indicate that seed number could be enhanced either under low or high N-levels.

Harvest Index (HI)

Four of the crosses showed positive SCA-values for harvest index at both N-levels, the rest contributed negative SCA-values at both N-levels with an exception of CML202 x K64R and CML216 x K64R. No variability was found between the SCA-values of the crosses within the low and the high N-levels.

Grain N-content (GNC)

Four crosses with positive SCA-values for grain N-content at the low N-level had also positive SCA-values at the high N-level, while the other four crosses with negative SCA-values at the low N-level also had negative SCA-values at the high N-level. The remaining four crosses had either positive or negative SCA-values at either low or high N-levels.

Stover N-content (SNC)

The two N-levels had an effect on the SCA-values of the crosses for stover N-content. Some differences were observed between the SCA-values of the crosses for stover N-content at both N-level. The crosses with positive SCA-values at the low N-level had not necessarily positive at the high N-level.

Discussion

With regard to the SCA effects at Doornpan most of the hybrids exhibited negative SCA effects for grain yield. The high yielding combinations (CML351 x CML394) was confined to the tall plants at both N-levels. This hybrid (CML351 x CML394) besides being tall at both N-levels was a good combiner for grain yield, seed weight and seed number at both N-levels. However, CML216 x AC8342 the dwarfish hybrid, was the best combiner for grain yield seed weight, seed number, harvest index, nitrogen content in grain and stover at both N-levels.

The magnitude and property of SCA effects varied considerably between the two N-levels, and among crosses and characteristics studied. Most of the SCA-values at Doornpan trial were not significantly different for grain yield, suggesting that the increase of N-level had no effects in this respect.

It is evident that effects of both GCA and SCA varied under different nitrogen levels. Consequently, this procedure enables the breeder to identify the suitable conditions for exploiting both additive and non-additive genetic effects in maize improving programs. Our results agree with earlier findings (Mohamed 1993), that effects of both GCA and SCA showed some differences under various nitrogen levels. In general, results of this study revealed the importance of evaluating genotypes under various environments in order to get thorough evaluation for genotypes performance and to recognise the favourable conditions for exploiting both types of gene action in maize breeding programs.

Table 4.17. - Specific combining ability estimates of crosses for various maize parameters under both low and high N-levels at Bethlehem trial in 1999/2000.

	Characteristics													
	PLHT (cm)		**GY ($t\ h^{-1}$)**		**SDW (g/100)**		**SDN 10^3 (no./ha)**		**HI (%)**		**GNC (%)**		**SNC (%)**	
Crosses	LN	HN	LN	HN	LN	HN	LN	HN	LN	HN	LN	HN	LN	HN
CML351 x AC8342	17.806	6.306	0.878	-0.308	0.250	0.889	154.076	-52.38	-0.175	-0.006	0.075	-0.019	0.001	0.021
CML202 x AC8342	-11.611	-2.944	-0.276	-0.274	-0.667	-0.861	-38.074	-33.259	-0.004	-0.017	-0.156	0.034	-0.028	-0.023
CML216 x AC8342	-6.194	-3.361	-0.652	0.582	0.417	-0.028	-116.002	85.642	0.021	0.023	0.081	-0.014	0.027	0.002
CML351 x CML394	-1.750	-3.917	0.283	1.024	1.694	0.556	37.409	185.844	0.115	0.047	-0.063	-0.059	-0.026	-0.068
CML202 x CML394	4.167	-4.500	0.297	-0.599	-2.556	-2.194	76.345	-103.659	-0.026	-0.021	-0.024	-0.106	-0.021	0.078
CML216 x CML394	-2.417	8.417	-0.576	-0.425	0.861	1.639	-113.754	-82.185	-0.089	-0.026	0.087	0.166	0.047	-0.010
CML351 x K64R	-10.754	-9.250	-0.737	-0.689	-1.528	-1.667	-125.491	-127.588	-0.024	-0.025	-0.031	-0.047	-0.025	0.027
CML202 x K64R	5.167	5.167	0.270	0.705	2.222	1.250	37.686	132.602	0.004	-0.026	0.160	0.019	0.059	-0.031
CML216 x K64R	5.583	4.083	0.467	-0.016	-0.678	0.417	87.805	-5.014	0.021	-0.001	-0.129	0.028	-0.033	0.004
CML351 x M162W	-5.306	6.861	-0.425	-0.027	-0.417	0.222	-65.994	-5.873	-0.074	-0.017	0.019	0.126	0.050	0.020
CML202 x M162W	2.278	2.278	-0.336	0.169	1.000	1.806	75.957	4.316	0.025	0.013	0.020	0.053	-0.009	-0.024
CML216 x M162W	3.028	-9.139	0.765	-0.141	-0.576	-2.028	141.951	1.557	0.048	0.005	-0.039	-0.179	-0.041	0.004
LSD 0.05	2.985	2.668	1.577	1.447	2.027	2.015	0.032	0.031	2.885	0.688	0.329	0.338	0.331	0.261

PLTH = plant height, **GY** = grain yield, **SDW** = seed weight, **SDN** = seed number, **HI** = harvest index, **GNC** = grain N-content, **SNC** = stover N-content, **LN** = Low N and HN = High N. **LN** = Low N, **HN** = High N.

4.8.8 Specific combining ability (SCA) effects of the F_1 hybrids for nitrogen use efficiency (NUE) components at Bloemfontein (Doornpan) and Bethlehem trials

The specific combining ability (SCA) effects of the F_1 hybrids for NUE components at Doornpan and Bethlehem trials are presented in Table 4.18.

Doornpan trial

The F_1 hybrids showed positive as well as negative SCA-values. No significant differences were found between the SCA-effects of the F_1 hybrids for yield efficiency. Five of the hybrids had positive SCA-effects for yield efficiency. The two hybrids with the largest positive SCA-effects for yield efficiency were CML216 x AC8342 and CML351 x CML394. The results indicate very efficient nitrogen use by these two hybrids.

The F_1 hybrids showed positive as well as negative SCA-values. No significant differences were found between the SCA-effects of the F_1 hybrids for recovery efficiency. Five of the hybrids had positive SCA-effects. The hybrid with the largest SCA-effect for recovery efficiency was CML351 x CML394.

The F_1 hybrids showed positive as well as negative SCA-values. No significant differences were found between the SCA-effects of the F_1 hybrids for physiological efficiency. Six of the hybrids had positive had positive SCA-effects. The cross CML216 x CML394 had the largest positive SCA-effect for physiological efficiency. The results indicate the possibility to enhance the NUE components in maize.

Bethlehem trial

The F_1 hybrids showed positive as well as negative SCA-values. No significant differences were found between the SCA-values of the F_1 hybrids for yield efficiency at Bethlehem. Four of the crosses had positive SCA-effects for yield efficiency. The cross with the largest positive SCA-effects for yield efficiency was CML351 x CML394.

Significant differences were found between the SCA-effects of the F_1 hybrids for recovery efficiency. Six of the crosses had positive SCA-effects. The cross with the largest positive

SCA-effects for recovery efficiency was CML351 x CML394. Its effect was significantly larger than a few other crosses.

The F_1 hybrids showed positive as well as negative SCA-values. No significant differences were found between the SCA-effects of the F_1 hybrids for physiological efficiency. Seven of the crosses had positive SCA-effects. The cross with the largest positive SCA-effects was again CML351 x CML394. The results indicate the possibility to enhance NUE components in the F_1 hybrids. The cross CML351 x CML394 performed the best for the three NUE components.

Table 4.18. - Specific combining ability estimates of crosses for nitrogen use efficiency components at Bloemfontein (Doornpan) and Bethlehem trials in 1999/2000.

Nitrogen use efficiency components								
	Doornpan trial				**Bethlehem trial**			
Hybrids	**YE**	**RE**	**PE**	**NHI**	**YE**	**RE**	**PE**	**NHI**
CML351 x AC8342	-0.191	-0.061	0.167	-0.002	-0.195	0.013	-0.368	-0.005
CML202 x AC8342	-0.281	0.004	-0.002	-0.005	-0.161	-0.020	-0.106	0.014
CML216 x AC8342	0.470	0.057	-0.165	0.007	0.356	0.033	0.473	-0.009
CML351 x CML394	0.256	-0.015	0.788	-0.013	0.611	0.067	1.456	0.003
CML202 x CML394	0.0003	-0.0004	-0.281	-0.003	-0.363	-0.029	-1.710	-0.006
CML216 x CML394	-0.256	0.016	-0.508	0.015	-0.248	-0.038	0.254	0.004
CML351 x K64R	-0.115	0.041	-0.279	-0.006	-0.404	-0.029	-1.346	0.001
CML202 x K64R	0.195	0.002	-0.062	0.025	0.419	0.026	1.202	-0.014
CML216 x K64R	-0.079	-0.044	0.341	-0.018	-0.015	0.003	0.144	0.132
CML351 x M162W	-0.049	0.035	-0.677	0.021	-0.011	-0.025	0.258	0.001
CML202 x M162W	0.086	-0.006	0.344	-0.017	0.105	0.023	0.614	0.007
CML216 x M162W	-0.135	-0.029	0.333	-0.004	-0.094	0.002	-0.870	-0.008
LSD 0.05	1.531	0.870	1.824	0.299	1.410	0.936	1.902	0.403

YE= Yield efficiency, RE = recovery efficiency, PE = Physiological efficiency and NHI = Nitrogen harvest index.

4.9 GCA: SCA ratios

The GCA: SCA ratios for the various characters under both N-levels and for nitrogen efficiency components at Bloemfontein (Doornpan) and Bethlehem trials are presented in Table 4.19.

Doornpan trial

Most of the variance components for dominance as provided by the L x T analysis were negative and make any comparison between two N-levels for most of the characteristics impossible. The two N-levels showed an effect on the GCA: SCA ratios for plant height. The GCA: SCA ratio for plant height at the low N-level was lower than unity, indicating the importance of dominant effects in the expression of plant height at the low N-level. The GCA: SCA ratio for plant height at the high N-level was above three, indicating the importance of additive gene effects in the expression of plant height a the high N-level. With the exception of seed number the additive variance components of seed weight, grain N-content and stover N-content were higher at the high N-level, indicating the importance of the expression of additive genes under high N-level. Due to too much negative variance components it was impossible to make any comparison between the NUE components.

Bethlehem trial

In the Bethlehem trial the GCA: SCA ratios for plant height, seed weight and grain N-content were higher at the high N-level, indicating larger expression of additive genes under the high N-level for these characteristics. The GCA: SCA ratios for grain yield and seed number were much lower at the high N-level, indicating larger expression of dominant genes. Seed weight had the largest GCA: SCA ratios under both N-levels. The GCA: SCA ratios for recovery efficiency were much larger than that of yield efficiency indicating larger additive gene effects for recovery efficiency.

Table 4.19 - Genetic variance components and GCA: SCA ratios for maize parameters and nitrogen use efficiency components evaluated under low and high N-levels at Bloemfontein (Doornpan) and Bethlehem trials in 1999/2000.

		Doornpan trial			**Bethlehem trial**		
Parameters	***NL***	***Additive genetic variance (σ^2_A)***	***Dominance genetic variance (σ^2_D)***	***GCA: SCA Ratios***	***Additive genetic variance (σ^2_A)***	***Dominance genetic variance (σ^2_D)***	***GCA: SCA Ratios***
Plant height	LN	87.634	126.568	0.692	15.639	64.109	0.243
	HN	122.309	40.748	3.002	17.635	48.219	0.366
Grain yield	LN	0.088	0.055	1.600	0.138	0.226	0.611
	HN	0.134	-	-	0.059	0.343	0.172
Seed weight	LN	1.599	-	-	0.474	0.728	0.651
	HN	1.621	-	-	0.825	1.047	0.788
Seed number (10^8)	LN	18.542	12.583	1.474	32.542	79.486	0.409
	HN	16.482	-	-	19.030	93.262	0.204
Harvest index	LN	-	0.004	-	-	0.001	-
	HN	-	-	-	-	0.001	-
Grain N. content	LN	0.002	0.001	2.000	0.001	0.004	0.250
	HN	0.003	-	-	0.006	0.003	2.000
Stover N. content	LN	0.001	-	-	0.001	-	-
	HN	0.045	-	-	0.001	-	-
NUE Components							
Yield efficiency		0.046	-	-	0.019	0.124	0.153
Recovery efficiency		0.225	-	-	0.596	0.986	0.605
Physiological efficiency		0.001	0.001	1.000	-	0.001	-

- = Negative variance components. NL = nitrogen levels, LN = low nitrogen and HN = high nitrogen.

4.10 Narrow-sense and broad-sense heritability estimates

The heritabilities of the various characters for both N-levels at Bloemfontein (Doornpan) and Bethlehem trials are listed in Table 4.20.

Doornpan trial

Due to the many negative variances provided by the L x T analysis, it was impossible to calculate most of the heritabilities for characters measured at Doornpan. It was therefore almost impossible to make a meaningful study about the effect of the two N-levels on the different characters measured. Plant height and grain N-content are the only characters where comparison was possible. The narrow-sense heritabilities for these two characteristics were the largest at the high N-level probably due to the expected large phenotypic variance at the high N-level. The narrow-sense heritabilities for NUE components were very low. They vary between 0.12 and 0.16.

Bethlehem trial

The two N-levels showed an effect on the narrow and broad sense heritabilities calculated. The narrow sense heritabilities of plant height, grain yield, seed weight, grain N-content and stover N-content were much larger at the high N-level than at the low N-level. A similar pattern was observed for the broad sense heritabilities. The broad sense heritabilities of plant height, grain yield, seed weight, seed number, harvest index and grain N-content were much higher at the high N-level than at the low N-level.

The narrow and broad sense heritabilities calculated for the characters measured at the Bethlehem trial were very low. This could be explained by the large environmental variances obtained for most characters. The narrow and broad sense heritabilities obtained for yield and nitrogen efficiency components were very low. Low-N resulted in lower broad-sense heritabilities for grain yield under stress conditions have been reported in many other studies (Atlin and Frey, 1990; Frey, 1964).

Table 4.20 - Estimates of narrow-sense (h^2) and broad-sense (H^2) heritabilities for maize parameters and nitrogen efficiency components planted under low and high N-levels at Bloemfontein (Doornpan) and Bethlehem trials in 1999/2000.

		Doornpan trial		**Bethlehem trial**	
Parameters	***NL***	***Narrow - sense heritabilty (h^2)***	***Broad-sense heritability (H^2)***	***Narrow-sense heritability (h^2)***	***Broad-sense heritability (H^2)***
Plant height	LN	0.3244	0.7929	0.0617	0.3144
	HN	0.4275	0.5699	0.1291	0.4821
Grain Yield	LN	0.2267	(- -)	0.0971	0.2562
	HN	(- -)	(- -)	0.0634	0.4318
Seed weight	LN	(- -)	(- -)	0.0523	0.1326
	HN	0.2702	(- -)	0.0881	0.1998
Seed number (10^8)	LN	0.3865	0.6488	(- -)	0.2527
	HN	(- -)	(- -)	(- -)	0.8451
Harvest index	LN	(- -)	0.0067	(- -)	0.0714
	HN	(- -)	(- -)	(- -)	0.5000
Grain N. content	LN	0.0833	0.1250	0.0250	0.1250
	HN	0.2143	(- -)	0.1250	0.1875
Stover N. content	LN	(- -)	(- -)	0.0370	(- -)
	HN	(- -)	(- -)	0.0769	0.0769
NUE Components					
Yield efficiency		0.122	(- -)	0.056	0.436
Recovery efficiency		0.149	(- -)	0.165	0.439
Physiological efficiency		0.167	(- -)	(- -)	0.250

(- -) = heritability unestimable due to negative variances. NL = nitrogen levels, LN = low nitrogen and HN = high nitrogen.

4.11 Phenotypic and Genetic Correlation Coefficients

4.11.1 Phenotypic correlation coefficients calculated on the F_1 hybrids at Bloemfontein (Doornpan) and Bethlehem trials.

In order to understand the nature and degree of interrelationships among the different characteristics both phenotypic (r_p) and genotypic (r_A) correlation coefficients were computed for all possible pairs of characteristics in both experiments.

The phenotypic correlation coefficients between the different characteristics measured on the F_1 hybrids planted at Doornpan and Bethlehem trials are given in Table 4.21.

Doornpan trial

At the high N-level, grain yield was correlated positively with plant height. Grain yield was significantly and positively correlated with seed number at both the low (0.963***) and the high (0.942***) N-levels. Plant height also was significantly correlated with seed weight but negatively correlated with stover N-content at the high N-level. Seed weight and harvest index were negatively correlated at both N-levels.

Bethlehem trial

Phenotypic correlation coefficients at Bethlehem trial between grain yield with plant height, seed weight, seed number and harvest index were positive. Significant positive correlations between grain yield and plant height was observed at both N-levels, but a very strong significant positive correlations with seed number at both low (0.989***) and the high (0.986***) N-levels. Grain N-content influenced grain yield negatively at the high N-level.

The magnitudes of phenotypic correlation coefficients between seed number with grain yield, plant height and seed weight at Bethlehem trail were generally larger than those at Doornpan trial. Phenotypic correlation coefficients between characteristics at Doornpan trial followed almost a pattern similar to those characteristics in the Bethlehem trial.

Table 4.21 – Phenotypic correlation coefficients for F_1 hybrids planted under two different N-levels at Bloemfontein (Doornpan) and Bethlehem trials in 1999/2000.

		Doornpan trial						***Bethlehem trial***					
Traits	**NL**	**Grain yield**	**Plant height**	**Seed weight**	**Seed number**	**Harvest index**	**Grain N-content**	**Grain yield**	**Plant height**	**Seed weight**	**Seed number**	**Harvest index**	**Grain N-content**
Plant height	LN	0.241						0.856**					
	HN	0.627*						0.629*					
Seed weight	LN	-0.256	0.483					0.379	0.565				
	HN	0.425	0.650*					0.271	0.577				
Seed number	LN	0.963***	0.103	-0.496				0.989***	0.809**	0.254			
	HN	0.942***	0.440	0.101				0.986***	0.559	0.132			
Harvest Index	LN	0.360	-0.539	-0.692*	0.521			0.407	0.326	0.010	0.424		
	HN	0.063	-0.559	-0.637*	0.309			0.601	-0.065	0.059	0.623		
Grain N-content	LN	-0.335	-0.050	0.249	-0.357	-0.201		-0.328	-0.051	0.259	-0.379	-0.202	
	HN	-0.316	-0.115	0.340	-0.453	-0.032		-0.616*	-0.248	0.322	-0.674*	-0.419	
Stover N-content	LN	0.269	-0.605	-0.592	0.403	0.616*	0.227	-0.544	-0.491	-0.227	-0.526	-0.460	0.753*
	HN	-0.577	-0.674*	-0.366	-0.497	0.266	0.396	-0.572	-0.450	-0.119	-0.581	-0.195	0.303

*,**,*** = significantly different from zero at 0.05, 0.01 and 0.001 levels of probability respectively. NL = nitrogen levels, LN = low nitrogen and HN = high nitrogen.

4.11.2 Genotypic correlation coefficients calculated on the GCA-values of the inbred lines at Bloemfontein (Doornpan) and Bethlehem trials.

The genotypic correlation coefficients calculated on the inbred lines planted at Bloemfontein (Doornpan) and Bethlehem trials is given in Table 4.22.

Doornpan trial

The two N-levels showed an effect on some of the genotypic correlation coefficients calculated on the inbred lines. Grain yield and plant height were highly negatively correlated at the low N-level (r_A = -0.719) and low positively correlated (r_A = 0.396) at the high N-level. The results indicate a relationship between the shorter inbreds and yield at the low N-level.

Grain yield was negatively correlated (r_A = -0.692) with harvest index at the low N-level and highly positively correlated (r_A = 0.919) with harvest index at the high N-level. Plant height was highly negatively correlated (r_A = -0.869) with stover N-content at the low N-level and low positively correlated (r_A = 0.118) at the high N-level. Seed weight was highly and positively correlated (r_A = 0.938) with harvest index at the low N-level and negatively correlated (r_A = -0.683) at the high N-level. Seed weight was also highly and positively correlated (r_A = 0.893) with grain N-content at the high N-level and negatively correlated (r_A = -0.868) with stover N-content at the low N-level. Seed number was negatively correlated with harvest index at the low N-level (r_A = -0.776) and highly positively correlated (r_A = 0.988) at the high N-level. Seed number was also highly and positively correlated with stover N-content at both N-levels. Large differences between the correlation coefficients were also found between harvest index and grain N-content at the low N-level and between harvest index and stover N-content at the high N-level. The rest of the correlation coefficients were not affected by the different N-levels. High positive correlation coefficients were found between grain yield and seed number and grain yield and stover N-content at both N-levels.

Bethlehem trial

The two N-levels had a significant effect on some of the genotypic correlation coefficients. The correlation coefficients between grain yield and plant height, seed weight, grain N-content and stover N-content were largely affected by the two N-levels. The two N-levels had also a large effect on the correlation coefficients between plant height and seed number, seed weight and stover N-content, seed number and grain N-content and harvest index and grain N-content.

Grain yield was negatively correlated with seed weight (r_A = -0.882) and highly and positively correlated with seed number (r_A = 0.998) at the low N-level. Grain yield was also positively correlated with plant height (r_A = 0.885), seed number (r_A = 0.973) and harvest index (0.813), but negatively correlated with grain N-content (r_A = -0.984) at the high N-level. Plant height was positively correlated with seed number (r_A = 0.799) and negatively correlated with stover N-content (r_A = -0.794) at the high N-level. Seed weight was negatively correlated with stover N-content (r_A = -0.801) at the low N-level. Seed number was again positively correlated with harvest index and negatively correlated with grain N-content at the high N-level, while harvest index was negatively correlated with grain N-content. High positive correlation coefficients were found between grain yield and seed number at both N-levels.

Table 4.22. - Genotypic correlation coefficients calculated on the GCA-values for two different N-levels at Bloemfontein (Doornpan) and Bethlehem trials in 1999/2000.

		Doornpan trial						*Bethlehem trial*					
Traits	**NL**	**Grain yield**	**Plant height**	**Seed weight**	**Seed number**	**Harvest index**	**Grain N-content**	**Grain yield**	**Plant height**	**Seed weight**	**Seed number**	**Harvest index**	**Grain N-content**
Plant height	LN	-0.719						0.256					
	HN	0.396						0.885**					
Seed weight	LN	-0.711	0.599					-0.882**	0.059				
	HN	-0.344	0.596					-0.317	-0.027				
Seed number	LN	0.992***	-0.682	-0.779				0.998***	0.190	-0.896			
	HN	0.965***	0.168	-0.578				0.973***	0.799*	-0.526			
Harvest Index	LN	-0.692	0.343	0.938**	-0.776			0.428	0.016	-0.077	0.442		
	HN	0.919***	0.086	-0.683	0.988***			0.813*	0.463	-0.406	0.828*		
Grain N-content	LN	-0.405	-0.142	0.670	-0.508	0.878*		0.419	-0.771	-0.639	0.478	0.262	
	HN	-0.276	0.335	0.893**	-0.479	-0.609		-0.984***	-0.789	0.420	-0.984***	-0.894**	
Stover N-content	LN	0.919***	-0.869*	-0.868*	0.927**	-0.744	-0.355	0.625	-0.512	-0.801**	0.668	0.222	0.893**
	HN	0.892**	0.118	-0.327	0.876*	0.804*	-0.062	-0.533	-0.794*	0.169	-0.518	0.042	0.409

*, **, *** = significantly different from zero at 0.05, 0.01 and 0.001 levels of probability respectively. NL = nitrogen level, LN = Low nitrogen and HN = high nitrogen.

4.11.3 Genotypic correlation coefficients between grain yield and nitrogen use efficiency (NUE) components at both N-levels at Bloemfontein (Doornpan) and Bethlehem trials.

The genotypic correlation coefficients were also calculated between the grain yield of the F_1 hybrids at both low and high N-levels and the NUE components. It was done for each trial separately. The correlation coefficients for the two trials are listed in Table 4.23.

Doornpan trial

The two N-levels had no significant effect on the correlation coefficients between yield efficiency and grain yield. The correlation coefficients between these two characters were highly significant for both N-levels. This indicates the possibility to use yield efficiency as a selection parameter to enhance grain yield under any nitrogen condition. The two N-levels had a significant effect on the correlation coefficients between recovery efficiency and grain yield. The correlation coefficients between these two characters were significant only at the high N-level. Physiological efficiency and selection index were not significantly correlated with grain yield at either the low or the high N-levels. The correlation coefficients of these two characters at the low N-level were much larger than at the high N-level. This indicates the preference of these two characters to enhance grain yield only under low nitrogen conditions.

Bethlehem trial.

The two nitrogen levels had no effect on the correlation coefficients between yield efficiency and grain yield. The correlation coefficients between these two characters differ significantly only at the high N-level. The two N-levels had no effect on the significance of the correlation coefficients between recovery efficiency and grain yield. Both these correlation coefficients were highly significant indicating the successful use of recovery efficiency to enhance grain yield under both the low and the high N conditions. Physiological efficiency was significantly correlated with grain yield only at the high N-level. Although the selection index was not significantly correlated with grain yield at both N-levels, the correlation coefficient at the low N-level was larger than that at the high N-level. This indicates some preference to improve yield at the low N-level using the selection index.

Table 4.23 - Correlation coefficients between grain yield at both low and high N-levels and nitrogen use efficiency components and selection index at Bloemfontein (Doornpan) and Bethlehem trials in 1999/2000.

Characters	***Doornpan trial*** **Grain yield**		***Bethlehem trial*** **Grain yield**	
	LN	HN	LN	HN
Grain yield	1.000	1.000	1.000	1.000
Yield efficiency	0.858**	0.999***	0.583	0.999***
Recovery efficiency	0.523	0.754*	0.723*	0.896**
Physiological efficiency	0.434	0.253	0.212	0.766**
Selection index	0.502	0.013	0.474	-0.314

*,**,*** = significantly different from zero at 0.05, 0.01 and 0.001 levels of probability respectively. LN = low nitrogen and HN = high nitrogen.

CHAPTER 5

SUMMARY

The general objectives of this research were to study the genetic variability for nitrogen use efficiency components, to identify suitable inbred parental lines with out standing nitrogen efficiency characteristics, to calculate the inheritance of nitrogen use efficiency (NUE) components and to develop a strategy for the development of nitrogen efficient maize hybrids.

Four parental lines (AC8342, CML394, K64R and M162W) were individually crossed to each tester (CML351, CML202 and CML216) in a Line x Tester fashion to produce F_1 hybrids seed. The F_1 hybrids were evaluated in two different environments each under two different nitrogen levels. Six agronomic and yield characteristics and three nitrogen use efficiency components were measured. The data were analysed using the computer program 'AGROBASE 2000'. Analyses such as Line x Tester, additive main effects and genetic correlations were performed.

In the combined ANOVA, significant differences between locations were found for all characters measured. The nitrogen levels differed significantly for PLHT and GNC. The F_1 hybrids differed significantly for PLHT, GY, SDW, SDN and GNC. Significant differences were also found among the F_1 hybrids for PLHT, GY, SDW, SDN, HI, GNC and SNC at Doornpan. Similar significant differences were observed at Bethlehem except for HI and SNC.

Significant variability between F_1 hybrids was observed for yield efficiency, recovery efficiency and physiological efficiency. There was a large environmental difference between locations for the nitrogen use efficiency components. In the simple ANOVA, significant differences between F_1 hybrids were observed for yield efficiency, recovery efficiency and physiological efficiency at Doornpan. Significant differences were also found between the F_1 hybrids for yield efficiency and recovery efficiency at Bethlehem.

With a few exceptions in the Bethlehem trial, the selection indices of the F_1 hybrids for PLHT were less than one. The selection index for GY exceeds the value of one in three and nine of the F_1 hybrids in the Doornpan and Bethlehem trials respectively. For SDW three of the F_1 hybrids in the Doornpan trial had values above one and nine of the F_1 hybrids in the Bethlehem trial. The selection index values for SDN were lower than one in the Doornpan trial. In the Bethlehem trial the values of three of the crosses were larger than one. The selection indices for HI in both trials were relatively high.

At Doornpan the F_1 hybrids responded significantly different to the two N-levels for PLHT, GY, SDW, SDN, HI and GNC. Significant differences between the F_1 hybrids at the low N-level were found for all characters measured except for SNC. At the high N-level the F_1 hybrids differed significantly for PLHT, GY, SDW, SDN, HI and GNC. At Bethlehem, F_1 hybrids responded significantly different to the two N-levels for GY, SDN and HI. Significant differences were found between the F_1 hybrids at both N-levels for PLHT, GY, SDW, SDN and GNC.

At Doornpan significant differences existed between the F_1 hybrids for yield efficiency, recovery efficiency and physiological efficiency. At Bethlehem significant variability was found between the F_1 hybrids for all three nitrogen use efficiency components.

The two N-levels had a significant effect on the GCA-values of the lines and testers for PLHT and SDN in the Doornpan trial. Significant variability was also found between the GCA-values for PLHT, GY and SDN at both N-levels. The GCA-values of the inbred lines in the Bethlehem trial responded differently to the two N-levels for GY and SDN. Significant differences were found between the GCA-values of the inbred lines for PLHT at both N-levels and for GY only between the testers at the high N-level.

At Doornpan significant differences between the GCA-values of the lines were found only for physiological efficiency and between the testers for yield efficiency and recovery efficiency. At Bethlehem the GCA-values for testers differed significantly for yield efficiency and recovery efficiency. No significant differences were found between the GCA-values of the lines for nitrogen use efficiency components at Bethlehem.

The F_1 hybrids responded differently with regard to their SCA-values for GY, SDW. HI, GNC and SNC in the Doornpan trial. Significant differences for SCA-values were found for PLHT, GY, SDW, SDN and SNC at both N-levels. In the Bethlehem trial the two N-levels had only an effect on the SCA-values of a few of the hybrids for SDN and GNC. Significant differences were found between the SCA-values of the F_1 hybrids for PLHT, GY, SDW, SDN and GNC at both the low and the high N-levels.

The F_1 hybrids showed significant differences between the SCA-values for all three nitrogen use efficiency components in the Doornpan trial and only for yield efficiency and recovery efficiency in the Bethlehem trial.

The GCA:SCA ratios differed significantly at the two N-levels for PLHT in the Doornpan trial. With the exception of SDN the additive variance components of SDW, GNC and SNC were higher at the high N-level. In the Bethlehem trial the GCA:SCA ratios for PLHT, SDW and GNC were higher at the high N-level. SDW had the largest GCA:SCA ratios under both N-levels. The GCA:SCA ratios for recovery efficiency was larger than that of yield efficiency.

In the Doornpan trial the narrow-sense heritabilities for PLHT and GNC were the largest under the high N-level. The narrow-sense heritabilities for nitrogen use efficiency components were very low. The narrow-sense heritabilities of PLHT, GY, SDW, GNC and SNC were much larger at the high N-level at Bethlehem. Again the heritabilities obtained for nitrogen use efficiency components were very low.

Significant phenotypic correlation coefficients were found between GY and PLHT at the high N-level in the Doornpan trial. Significant correlation coefficients were also found between GY and SDN at both N-levels. In the Bethlehem trail significant correlation coefficients existed between GY and PLHT and between GY and SDN at both N-levels. GNC was significant but negatively correlated with GY at the high N-level.

The genotypic correlation coefficients in the Doornpan trial were significant between GY and SDN and between GY and SNC at both N-levels. HI and GY were significantly correlated at the high N-level. In the Bethlehem trial SDN was highly correlated with GY at both N-levels. GY was significantly correlated with PLHT at the high N-level, negatively correlated with SDW at the low N-level and negatively correlated with GNC at the high N-level.

In the Doornpan trial GY at the low and the high N-levels was significantly correlated with yield efficiency. It was also significantly correlated with recovery efficiency at the high N-level. In the Bethlehem trial GY was significantly correlated with the three nitrogen use efficiency components at the high N-level. Recovery efficiency was significantly correlated with GY at the low N-level.

OPSOMMING

Die algemene doel van hierdie studie was die bestudering van die genetiese variabiliteit vir stikstof gebruik effektiwiteit, die identifisering van geskikte ingeteelde ouerlyne met uitstaande stikstof gebruik eienskappe, asook die bepaling van die oorerflikheid van die stikstof gebruik effektiwiteit en die ontwikkeling van 'n strategie vir die ontwikkeling van stikstof effektiewe mielie basters.

Vier ouer lyne (AC8342, CML394, K64R, en M162W) is elk individueel gekruis met die toetsers (CML351, CML202 en CML216). 'n Lyn x toetser model is gebruik om die F_1 baster saad te produseer. Die F_1 basters is in twee verskillende omgewings, elk met twee verskillende stikstof vlakke geëvalueer. Ses agronomiese en opbrengs eienskappe en drie stikstof gebruik komponente is gemeet. Die data is geanaliseer deur die rekenaar program 'Agrobase 2000'. Analises vir lyn x toetser, additiewe hoof effekte en genetiese korrelasie is uitgevoer.

Volgens die gekombineerde ANOVA is betekenisvolle verskille tussen die lokaliteite waargeneem vir alle eienskappe wat gemeet is. Die stikstof vlakke het vir PLHT en GNC betekenisvol verskil. Die F_1 basters het betekenisvolle verskille getoon vir PLHT, GY, SDW, SDN en GNC. Betekenisvolle verskille is ook gevind vir die F_1 basters by Doornpan vir PLHT, GY, SDW, SDN HI, GNC en SNC. Dieselfde betekenisvolle verskille is ook waargeneem vir die F_1 basters by Bethlehem behalwe vir HI en SNC.

Betekenisvolle variabiliteit tussen F_1 basters is waargeneem vir opbrengsvermoë, herstelvermoë en fisiologies prestasie. Daar was 'n groot omgewings verskil tussen lokaliteite vir die effektiewe stikstof gebruik komponente. In die eenvoudige ANOVA, was daar betekenisvolle verskille tussen die F_1 basters by Doornpan vir opbrengsvermoë, herstelvermoë en die fisiologies prestasie waargeneem. Betekenisvolle verskille is ook in die proef by Bethlehem gevind tussen die F_1 basters vir opbrengsvermoë en herstelvermoë

Met 'n paar uitsonderings in die Bethlehem proef, was die seleksie indeks vir die F_1 basters vir PLHT minder as een. Die seleksie indeks vir GY was groter as een in drie en nege van die F_1 basters in die Doornpan en Bethlehem proewe onderskeidelik. Vir SDW

het drie van die F_1 basters in die Doornpan proef waardes bo een getoon en nege van die F_1 basters in die Bethlehem proef. Die seleksie indeks waardes vir SDN was laer as een in die Doornpan proef. In die Bethlehem proef was die waardes vir drie van die kruisings groter as een. Die seleksie indeks vir HI was relatief hoog vir albei proewe.

By Doornpan het die F_1 basters betekenisvol verskillend gereageer op die twee N-vlakke vir PLHT, GY, SDW, SDN, HI en GNC. Betekenisvolle verskille tussen die F_1 basters by die lae N-vlak is gevind vir alle eienskappe wat gemeet, behalwe vir SNC. By die hoë N-vlak het die F_1 basters betekenisvol verskil vir PLHT, GY, SDW, SDN, HI en GNC. Die F_1 basters by Bethlehem het betekenisvolle verskille getoon by die twee N-vlakke vir GY, SDN en HI. Betekenisvolle verskille is gevind tussen die F_1 basters by albei N-vlakke vir PLHT, GY, SDW, SDN en GNC.

By Doornpan het betekenisvolle verskillle bestaan tussen die F_1 basters vir opbrengsvermoë, herstelvermoë en fisiologiese effektiwiteit. By Bethlehem het betekenisvolle verskille voorgekom tussen die F_1 basters vir al drie stikstof verbruik effektiwiteit komponente.

Die twee N-vlakke het 'n betekenisvolle effek op die GCA-waarde vir die lyne en toetsers vir PLHT en SDN by die Doornpan proef getoon. Betekenisvolle variabiliteit is ook tussen die GCA-waardes vir PLHT, GY, en SDN by albei N-vlakke gevind. Die GCA-waarde vir die ingeteelde lyne in die Bethlehem proef het verskillend gereageer vir die twee N-vlakke vir GY en SDN. Betekenisvolle verskille is tussen die GCA-waarde vir die ingeteelde lyne vir PLHT by beide N-vlakke en vir GY slegs tussen die toetser by hoë N-vlakke gevind.

By Doornpan is betekenisvolle verskille tussen die GCA-waardes vir die lyne slegs vir die fisiologiese persentasie gevind en tussen die toetsers vir opbrengsvermoë en herstelvermoë. By Bethlehem het die GCA-waarde vir die toetsers betekenisvol verskil vir opbrengsvermoë en herstelvermoë. Geen betekenisvolle verskil is tussen die GCA-waardes van die lyne vir effektiewe stikstof gebruik komponente by Bethlehem gevind nie.

Die F_1 basters het verskillend gereageer ten opsigte van die SCA-waarde vir GY, SDW, HI, GNC en SNC in die proef by Doornpan. Betekenisvolle verskille vir die SCA-waarde vir PLHT, GY, SDW, SDN en SNC by albei N-vlakke is waargeneem. In die Bethlehem proef het die twee N-vlakke slegs 'n effek getoon tussen die SCA-waardes van 'n paar basters vir SDN en GNC. Betekenisvolle verskille is tussen die SCA-waardes van die F_1 basters vir PLHT, GY, SDW en GNC by beide hoë en lae N-vlakke gevind.

Die F_1 basters het betekenisvolle verskille getoon vir SCA-waardes vir al drie die effektiewe stikstof gebruik komponente in die Doornpan proef en selgs vir die opbrengsvermoë en herstelvermoë in die Bethlehem proef.

Die GCA:SCA verhouding het betekenisvol verskil by die twee N-vlakke vir PLHT in die Doornpan proef. Met die uitsondering van SDN, was die additiewe afwykings komponente vir SDW, GNC en SNC ook hoër by die hoë N-vlak. In die Bethlehem proef was die GCA:SCA verhouding vir PLHT, SDW en GNC weer hoër by die hoë N-vlak. SDW het die grootste GCA:SCA verhouding vir beide N-vlakke getoon. Die GCA:SCA verhouding vir herstelvermoë was groter as die vir opbrengsvermoë.

In die Doornpan proef was die smal sin oorerflikheid vir PLHT en GNC die grootste onder die invloed van die hoë N-vlak. Die smal sin oorerflikheid vir die effektiewe stikstof gebruik komponente was baie laag. Die smal sin oorerflikheid vir PLHT, GY, SDW, GNC en SNC was baie groter by die hoë N-vlak in die Bethlehem proef. Die oorerflikheid verkry vir die effektiewe stikstof gebruik komponente was baie laag.

'n Betekenisvolle fenotipiese korrelasie koëffisient is gevind tussen GY en PLHT by die hoër N-vlak in die Doornpan proef. Betekenisvolle korrelasie koëffisiente is ook tussen GY en SDN by beide N-vlakke gevind. In die Bethlehem proef het betekenisvolle korrelasie koëffisiente bestaan tussen GY en PLHT en tussen GY en SDN vir beide N-vlakke. GNC was betekenisvol maar negatief gekorreleer met GY by die hoë N-vlak.

Die genotipiese korrelasie koëffisient in die Doornpan proef was betekenisvol tussen GY en SDN en tussen GY en SNC vir albei die N-vlakke. HI en GY was betekenisvol gekorreleer by die hoë N-vlak. In die Bethlehem proef was SDN sterk gekorreleer met GY by beide N-vlakke. GY was betekenisvol gekorreleer met PLHT by die hoë N-vlak, maar negatief gekorreleer met SDW by die lae N-vlak en negatief gekorreleer met GNC by die hoë N-vlak.

In die Doornpan proef het GY by die lae en hoë N-vlakke betekenisvol gekorreleer met die opbrengsvermoë. Dit was ook betekenisvol gekorreleer met herstelvermoë by die hoë N-vlak. In die Bethlehem proef was GY betekenisvol gekorreleer met die drie effektiewe stikstof gebruik komponente op 'n hoë N-vlak. Herstelvermoë was ook betekenisvol gekorreleer met GY op 'n lae N-vlak.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

The significant effect observed between the two N-levels for most of the characters is of little value to determine a strategy to develop nitrogen efficiency maize hybrids. The nitrogen x entry interaction calculated on the means of the F1-hybrids was not significant in this study. This indicates that the two N-levels had no major effect on the rankings of the F1-hybrids. Therefore the high yielding hybrids under low N-conditions performed much the same under high N-levels.

However, to develop N-efficiency maize will be much more complicated. The results indicated that inbred lines with high GCA values for yield under low nitrogen conditions will not necessarily produce hybrids with high yields under high N-levels. This infact will complicate the breeding process of maize, since it will force breeders to screen their inbred lines also under low N-conditions.

Both yield efficiency and recovery efficiency were highly correlated with grain yield under both low and high N-levels. The selection index characteristics as described by Fischer et al., (1983) was only moderately correlated with yield at the low N-level. Therefore, the results in this study indicates a much larger relationship between the two yield efficiency components and grain yield than between the selection index and grain yield at the low N-level. These results accentuate the importance of these two nitrogen use efficiency components as selection criteria under both low and high N-levels. The only disadvantage about these two characteristics is the relatively low heritabilities obtained for them. It will certainly affect the genetic progress when selection is applied for these two nitrogen use efficiency components.

Due to an absence of some of the heritability values, it was impossible to make a descent calculation of the correlated response between grain yield and the nitrogen use efficiency components. Such information will be of vital importance to plant breeders when indirect selection is applied for grain yield by means of nitrogen use efficiency components. Therefore, future studies on this topic should include the correlated response between yield and nitrogen use efficiency components.

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