

**IMPLICATIONS OF GENOTYPE – BY- ENVIRONMENT INTERACTIONS
IN MAIZE (*Zea Mays L.*) VARIETY SELECTION USING MOTHER AND
BABY TRIALS**

By

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DECLARATION

I, Dibanzilua Nginamau hereby declare that the work presented in this dissertation was my own and has never been submitted for a degree at this or any other university.

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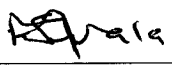
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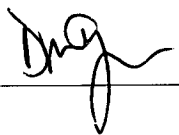
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ABSTRACT

Maize is the main staple food crop in the Southern Africa Development Community (SADC), which includes Zimbabwe and its productivity increases when improved varieties are planted. Development of such technologies is mainly by public and private breeding programs, which in most cases do this in managed stress environments such as research stations while they are deployed in farmers' fields, which have random stresses. This situation creates Genotype by Environment (GxE) interactions, which constitute one of the major complications in plant breeding and has been widely discussed, particularly in relation to their effect on the choice of selection environment(s) and indeed the whole selection process. Repeatability of aspects of GxE interactions is an important factor to be assessed in designing more efficient selection programs. CIMMYT with collaborating National Agricultural Research Systems (NARSs) in the SADC region have been using an evaluation scheme, Mother and Baby Trials (MBTs), to ensure that maize varieties are tested in target environments. In Zimbabwe this testing has been going on since 1999. Analysis of historical data from these multi-environment trials over years can be used to provide some clues on how to improve the testing strategy. Using sequential retrospective pattern analysis based on the SEQRET package Version 1.1 the historical data from Zimbabwe were analyzed to characterize environments, the tested genotypes and identify repeatable GxE interactions across years. The results showed that environments were classified into four groups based on their similarities. Differences among these groups were mainly due to SWHC, EVAPO and soil depth as major determinants of favourable soil water status for plant growth. Elevation and temperature were also important. High grain yield was associated with environment groups characterized by high SWHC, low EVAPO and deep soil profile. Genotypes were also classified into four groups. The type of variety underpinned differences among genotype groups. OPVs, ZM 421, ZM 423 and ZM 521, bred for stress tolerance were in the same group while the hybrids, which were not specifically bred for stress tolerance, were in other groups. Varying soil nitrogen levels effectively created different environments among the locations used. Inclusion of environments representing important stress in the testing environments improved the effectiveness of the selection programme in identifying suitable varieties for the conditions characteristic of farmers' environment in Zimbabwe. Variety testing in Zimbabwe must be rationalized to cover 16 environments represent two locations in agro-ecological zone II, one location in zone III, five locations in zone IV and one locations in zone V.

DEDICATION

I dedicate this work to my son and daughter Ndongala Nginamau and Tusamba Nginamau for their moral support during the course of the study and for the many months I was away from them. My final dedication goes to my late parents Manuel da Silva and Bibiana Dasonama who made me what I am.

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LIST OF ABBREVIATIONS

AREX	Agricultural Research and Extension
AVG YIELD	Average grain yield
CIMMYT	International Maize and Wheat Improvement Center
DEEP_SOIL	Soil depth
ELEV.	Elevation
EVAPO	Evapotranspiration
FAO	Food and Agriculture Organization
FCI	Formal Crop Improvement
FPB	Formal Plant Breeding
GDDCOM	Growing Season length first mode
GDDFT	Growing Season length second mode
GDD05	Growing Season length third mode
GxE	Genotype by Environment
GxL	Genotype by Location
GxLxY	Genotype by Location by Year
GxY	Genotype by Year
IBWSN	International Bread Wheat Screening Nursery
IMETs	International Multi-environment Trials
ISWYN	International Spring Wheat Yield Nursery
ISS	Incremental Sum of Squares
IT	Minimum temperature

Lat.	Latitude
Long.	Longitude
MBT	Mother and Baby Trials
METs	Multi-environment Trials
OPV's	Open-pollinated Varieties
PCI	Participatory Crop Improvement
PHWATER_TO	Soil pH at the surface
PHWATER_SU	Soil pH in the sub-soil
PPB	Participatory Plant Breeding
PRE	Precipitation
PVS	Participatory Variety Selection
RK_ESTAB	Risk to drought during establishment period
RK_FLOWER	Risk to drought during flowering period
RK_GRAFIL	Risk to drought during grain filing period
RK_POSFL	Risk to drought during postflowering period
RK_PREFL	Risk to drought during preflowering period
SADC	Southern African Development Community
SADLF	Southern Africa Drought and Soil Fertility
SEDs	Squared Euclidean Distance
SEQRET	Sequential Retrospective pattern analysis
SWHC	Soil Water Holding Capacity
XT	Maximum temperature

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CHAPTER I

INTRODUCTION

Maize (*Zea mays*) is the most important cereal in the Southern African Development Community (SADC) region and the most preferred staple food. About 11 million hectares are grown to maize in the region covering 71 percent of the area planted to cereals (Aquino et al., 2001). The crop is also a prominent component of the agricultural trade involving various categories of farmers.

In Zimbabwe maize dominates crop production, covering more land than other crops (approx. 1.5 million ha). Maize, sorghum and vegetables are the principal subsistence crops of the country. Production for family consumption remains paramount in the majority of peasant farming areas in Zones III and IV, but increasing quantities of maize and cotton are being marketed from communal areas in the more favored agro-ecological zones. Annual farm output is valued at almost Zim \$ 2 billion, about 20% of the gross domestic product (www.fao.org/ag/ags/AGSe/7mo/69/chap10-pdf).

Maize production in the region is characterized by low yields, averaging 1.2 t ha^{-1} , grown from varieties developed by national and international research organizations (Aquino et al., 2001). On the other hand results from research stations show that yields in excess of 10 t ha^{-1} are obtainable. The low yields are attributed to issues of low usage of inputs coupled with inherent poor soil fertility: only about 35 percent of crop grown is from use of improved seed (Morris, 2001) while use of inorganic fertilizer is far below what is required to maintain a balanced soil nutrient budget (Smaling and Braun, 1997).

In addition the growing conditions in the region aggravate the situation in terms of recurring droughts resulting in low food security.

Given the wide range of environments under which maize grows and therefore the presence of significant genotype by environment (GxE) interactions, variety development and testing programs have been challenged with providing varieties that do well in all these conditions.

Hayes (1923) compared genotypes of maize at two locations in two years and found that genotypes performed differently from location to location and year to year. Inconsistencies of this nature, as represented by GxE interactions, may be due to alterations in the ranking of genotypes from one environment to another or due to changes in differences between genotypes, with ranks unchanged (Allard and Bradshaw, 1964; Hill, 1975). Sprague (1963) interpreted these inconsistencies to mean, that a genotype had variable adaptability to specific favorable environments; that is genotypes were to be selected for specific niches.

Rasmussen and Lambert (1961), as well as Finlay and Wilkinson (1963), questioned whether plant breeders should select for specific or general adaptation in the presence of GxE interactions. Hill (1975) explained that specific adaptation introduced difficulties in defining the ideal environment, in the presence of significant climatic fluctuations. On the other hand, general adaptation had limited value in the presence of GxE interactions.

Comstock and Moll (1963) pointed out that understanding GxE interactions was undoubtedly a significant step towards the improvement of quantitative characters such as seed yield.

Planting high yielding cultivars, which are selected effectively for the target production system, can maximize crop productivity. Test environments must be appropriate samples of the crop production environments targeted by the crop breeding program (Donald, 1962; Hinson and Hanson, 1962; Nyquist, 1991; Cooper *et al.*, 1993a) but are often not ideal due to reasons such as limited resources, politics, conveniences, or difficulties in obtaining appropriate land in the target area (Hamblin *et al.*, 1980). Another complication results from the difficulty in defining “representative” locations, especially if the target environments are highly variable and result in GxE interactions (Nix, 1980; Mucchow *et al.*, 1991; Cooper *et al.*, 1993c).

Breeding programmes always face the problem of whether the environments used in testing varieties are a fair sample of the target environments, to the extent that impact from their programme will depend on how well these environments discriminate varieties (DeLacy *et al.*, 1996).

Efficiency in selection (Nix, 1980; Mucchow *et al.*, 1991; Cooper *et al.*, 1993c) necessitates rationalization of selection locations according to their similarity in discriminating among the genotypes (i.e. exploiting repeatable GxE) while the need for identifying a particular environment for a particular variety becomes important for effective variety deployment (i.e. exploiting predictable GxE).

In the SADC region, National Programs in collaboration with CIMMYT-Zimbabwe have adopted a comprehensive maize breeding strategy that considers farmers' true growing environments. This involves screening of a large number of breeding germplasm under managed stress conditions, followed by farmer-participatory variety testing in random environments using Mother – Baby Trials (Bänziger and de Meyer, 2001; Mwala *et al.*, 2003).

Implementation of the Mother and Baby Trials scheme started during the 1999/2000 cropping season in Zimbabwe. The varieties used and the environments in which they were tested usually varied among years, as inferior varieties were dropped from the evaluation and new varieties included. From the outlook, the use of such data appears limited due to their imbalance. However, new statistical tools have been made it possible to analyze such data across years and draw conclusions on the value of the varieties, the suitability of locations in terms of discriminating the varieties, and the repeatability of GxE interactions (DeLacy *et al.*, 1996). The data collected from such trials over time provides a larger sample of target environments, which are a better assessment of genotypic value than individual year data. Retrospective analysis enables assessing the relationships and similarities among the test environments. Just as it assists in choosing appropriate test locations, thereby contributing to rationalization of resource investments, and targeting cultivars to maximize production (Peterson, 1992). More efficient strategies for selection can be developed and more confident exploitation of GxE interaction can be made.

The principal objectives of this study were: to characterize environments on the basis of tested maize genotypes and identify repeatable GxE interactions across years. There are two questions that need to be answered: (i) Were environments used for Mother – Baby Trials in Zimbabwe similar so that they can be rationalized for increasing selection efficiency and effectiveness, and (ii) were data obtained through the two experiments of the Mother Trials complementing each other to form a better basis for identifying superior maize varieties for small scale farming conditions?

CHAPTER II

LITERATURE REVIEW

2.1 Geographic setting of Zimbabwe

2.1.1 Land Resources

Zimbabwe lies within the tropics between 15° 30'S to 22° 30'S and 33° E and the country is 389000 km² (www.fao.org/ag/ags/AGSe/7mo/69/chap10-pdf). Three broad relief regions are generally recognized on the basis of elevation: the Lowveld (below 900m), the Midlevel (900-1200m) and addition, a narrow belt of mountains (2000-2400m) called the Eastern Highlands, which runs north to south along the eastern border with Mozambique. Relief and rainfall that increase with altitude, largely influence the climate. Mean annual rainfall varies from below 400mm in the extreme south of Lowveld to above 2000mm on isolated mountain peaks in the Eastern Districts. Midlevel rainfall ranges from 500 to 700mm and that of the Highveld from 800 to 1000mm. The rainfall pattern is distinctly seasonal with approximately 90 percent falling in the six months from October to March. Much of the rain falls as intense tropical downpours and is characterized by its extreme variability in both space and time.

Three seasons can be distinguished: (i) a hot and dry spring from mid-September to the onset of the rains; (ii) a hot but moist summer covering the rainy season; and (iii) a dry winter period consisting of cool nights and warm cloudless days lasting from April to September.

The sandy, relatively infertile soils that cover some two-thirds of the country constitutes the main soil type in the communal areas. Isolated areas of heavier more-fertile soils

occur throughout the country, the largest pockets being on the Higveld. Fertile irrigable balsatic vertisols occur extensively in the southern Lowveld.

2.1.2 Agro-ecological zones

Zimbabwe can be divided into five agro-ecological zones broadly defined on the basis of rainfall and temperature (Figure 2.1)

Zone I: comprises 5835 km² situated in the Eastern Highlands, where the climate is cool and moist and the high annual rainfall (>1000mm) is relatively reliable. The land can be used intensively for dairy farming, forestry, orchards and plantations.

Zone II: embraces 72745 km² of intensively cropped farmland in the northeast Highveld receiving 700-1000mm of rain annually. It is the major dryland cropping area producing the highest yields of maize, tobacco, cotton, soybeans and other crops and is the main source of irrigated wheat.

Zone III: comprises 67690 km² of semi-intensively cultivated land on the Midveld and Highveld receiving 650-800mm of annual rainfall. The area is used for ranching and cropping, the main crops being drought-tolerant varieties of maize, cotton, sorghum and soybeans. A large proportion of communal land falls in this region.

Zone IV: covers 128370 km², mainly in the western and the northern areas of the country experiencing 450-650mm of rainfall annually. The land is suited to semi-intensive animal husbandry and is marginal for cropping. A large proportion of the communal land falls in this zone.

Zone V: comprises 112810 km² of very hot low lying land of the southern Lowveld and Zambezi Valley systems, where the annual rainfall is less than 650mm. The area is suited to extensive ranching with intensive crop production using irrigation on pockets of fertile soils.

2.2 Agriculture production in Zimbabwe

2.2.1 General setting

Three-quarters of the population depends directly on land. Agriculture contributes 40% of the inputs to the manufacturing sector and supplies 40-50% of exports. Tobacco, maize, cotton and sugar dominate crop production with wheat, coffee, sorghum, groundnuts, tea, citrus, and vegetables making significantly smaller monetary contributions.

Maize (*Zea mays*) is the most important cereal in the Southern African Development Community (SADC) region and the most preferred staple food. About 11 million hectares are grown to maize in the region covering 71 percent of the area planted to cereals (Aquino et al., 2001). The crop is also a prominent component of the agricultural trade involving various categories of farmers.

Maize production in the region is characterized by low yields, averaging 1.2 t ha⁻¹, grown from varieties developed by national and international research organizations (Aquino et al., 2001). On the other hand results from research stations show that yields in excess of 10 t ha⁻¹ are obtainable. The of the low yields are attributed to issues of low usage inputs coupled with inherent poor soil fertility: only about 35 percent of crop

grown is from use of improved seed (Morris, 2001) while use of inorganic fertilizer is far below what is required to maintain a balanced soil nutrient budget (Smaling and Braun, 1997). In addition the growing conditions in the region aggravate the situation in terms of recurring droughts resulting in low food security.

2.2.2 Importance of maize

In Zimbabwe maize dominates crop production, covering more land than other crops (approx. 1.5 million ha). Maize, sorghum and vegetables are the principal subsistence crops of the country. Production for family consumption remains paramount in the majority of peasant farming areas in Zones III and IV, but increasing quantities of maize and cotton are being marketed from communal areas in the more favored agro-ecological zones.

Annual farm output is valued at almost Zim \$ 2 billion, about 20% of the gross domestic product.

2.3 Variety Development and Testing Strategies

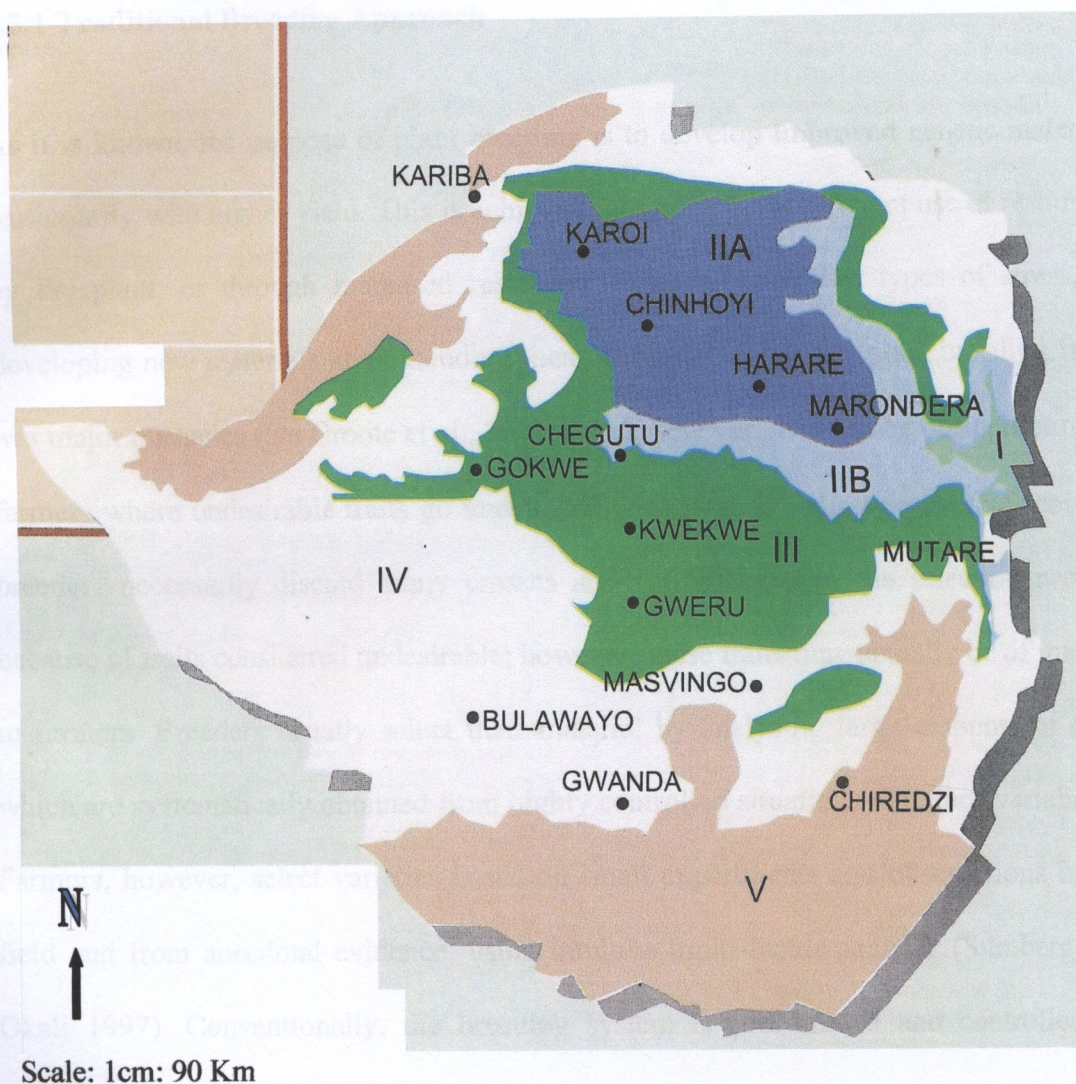


Fig. 2.1 Map of Zimbabwe showing agro-ecological zones and major towns

2.3.1.1 Need for Alternative Crop Development Approaches

Participatory Crop Improvement (PCI), or Participatory Plant Breeding (PPB) in a wider sense, emerged as an alternative approach for developing countries in response to the recognition that conventional and often centralized breeding programs had brought little benefit to the farmers in agro-ecologically and socio-economically marginal and variable

2.3 Variety Development and Testing Strategies

2.3.1 Traditional Breeding Approach

As it is known, the purpose of plant breeding is to develop improved genetic material, particularly with higher yield. This is achieved through a more efficient use of resources by the plant, or through increased resistance to pests and other types of stress. In developing new materials and extending them to farmers, classical plant breeding faces two major obstacles (De Groote et al., 2001). First, new varieties can be disappointing to farmers where undesirable traits go undetected during the breeding process. Secondly, breeders necessarily discard many crosses and varieties during the selection process because of traits considered undesirable; however, these traits may actually be of interest to farmers. Breeders usually select their material by analysing large amounts of data, which are systematically obtained from highly controlled situations to reduce variability. Farmers, however, select varieties based on small experiments and observations in the field and from anecdotal evidence, using intuitive multi-factor analysis (Sumberg and Okali 1997). Conventionally, the breeding system is coordinated and controlled by breeder.

2.3.1.1 Need for Alternative Crop Development Approaches

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environments. One of the reasons is that conventional Formal Crop Improvement (FCI) had not developed materials, which were sufficiently suited to these environments (Hardon & de Boef, 1993). As a consequence, in many of these marginal and variable systems the adoption of improved materials has been low and local crop varieties still dominant. The extreme complexity and variation in conditions of these environments result in different and more variable needs of farmers. Breeding systems need to be redesigned to better address the large genotype by environment (GxE) interactions and genetic diversity needed.

Since the “Green Revolution” production has increased greatly in favourable agricultural environments. However, production is stagnant or has increased only slowly in marginal areas (Hardon & de Boef, 1993). Farmers in these areas have not adopted new cultivars in favour of their local landraces. Maybe farmers have not had access to varieties that were adapted to less favourable conditions, and were perhaps recommended varieties that did not have the attributes, such as high straw yield, that low-resource farmers needed.

In the 1980s, to encourage the adoption of higher yielding varieties by low-resource farmers, scientists initiated farmer participatory research in plant breeding in several countries (Sumberg and Okali 1997). All of this research was devoted to the latter stage of the plant breeding process-the selection among finished, or nearly finished, varieties.

2.3.2 Participatory Breeding Approaches

There has been limited adoption of improved seed and farming technologies by smallholder farmers in many regions of the world. According to participatory research literature, one of the major barriers to uptake has been insufficient attention to understanding farmer priorities and perceptions (Chambers *et al.*, 1989; Ashby and Sperling 1995). Researchers and extension staff are frequently aware that farmers need to be consulted and that indigenous knowledge should be documented, however the time and resources required for participatory research are seen as onerous (Snapp *et al.* 2002a). Rigorous and practical tools are urgently required to improve the process of participatory variety selection and technology development (Bellon 1998).

The aim of participatory approach from the breeders' perspective is principally to involve farmers in early stages in the conventional breeding process to more effectively breed better materials (Sperling *et al.*, 1993; Eyzaguirre and Iwanaga 1996). Participatory plant breeding explicitly brings together farmers, plant breeders and development personnel in the effort to create and disseminate improved varieties and to strengthen farmers' own local materials. The idea is that each brings special insights and skills to the effort. As a result, their combined whole contribution will be greater than the sum of its parts. Participatory development approach creates sense of ownership and enhances awareness among the farming community. Consequently, adoption rate of technology remains high.

2.3.2.1 Involvement of the farmer in the breeding system

The aim of PPB is to improve communication between farmers and breeders so that farmers' circumstances (conditions, concerns and preferences) are incorporated earlier in the research process; research is accelerated; and the adoption rate improves (Sperling et al., 1993; Eyzaguirre and Iwanaga 1996). Elings and Almeknders (1999) define a breeding system of a particular crop as the total of activities that generate and/or recombine genetic diversity and select from this diversity to obtain better performing genetic materials.

The farmers' involvement can have many different forms, which roughly can be described by two aspects: (i) identification/definition of selection criteria, and (ii) actual plant/seed selection (Ashby 1991). These forms of involvement can take place at any stage in the breeding system, i.e. from the stage of identification of suitable parental material to the testing of advanced materials, on-station and on-farm. Selection of materials in Participatory Variety Selection (PVS) means the selection between nearly stable or advanced population. Selection in early PPB phase implies selection of and in genetically unstable and segregating materials. In PCI, final say and responsibility with regards to selection within and among population is with the farmer (Chambers et al., 1989). Farmers' participation in such set-up means for the farmer an increased access to diversity and true decision power in the selection of material. It means for the breeder a shortened breeding process with a strongly decentralized approach which, however, does not necessarily use other breeding tools or principles than the FCI. And, by inviting farmers to make decisions in the research process, it is assumed that they will not only

adopt, but also, and more importantly, adapt the available technology to their own needs and environment (Ashby 1991).

Development and dissemination of improved maize varieties and related production technologies that will lead to increased food production and improved farm-family livelihoods remains a major challenge for researchers. Farmers in marginal environments, where productivity is low due to several constraints, may rarely benefit from improved germplasm that cannot tolerate these stresses (Siambi *et al.*, 2002).

Farmers' participation in selection under their own environmental and agronomic conditions is eventually envisaged as a way to maximize specific adaptation, and to speed up the transfer of new cultivars and their adoption (Ashby 1991). One important consequence of breeding for specific adaptation is that the number of cultivars of a given crop grown at any moment in time will be large and this will maintain more genetic diversity within a crop than with breeding for broad adaptation.

Formal plant breeding (FPB) has been the main strategy in variety development with noted achievements over the past. Recently, however, another strategy, participatory plant breeding (PPB), has been adopted and this has proved to have added value the identification of appropriate varieties for specific farmer needs and agro-ecological conditions. The Southern Africa Drought and Soil Fertility Project (SADLF), which is an effort by the national maize breeding programs of the Southern Africa Development Community (SADC) and CIMMYT, adopted the "Mother and Baby Trials", methodology for participatory variety selection (Bänziger and de Meyer, 2002; Mwala *et*

al., 2003). This methodology incorporated the advantages of participatory approaches in variety development and to complement the comprehensive breeding approach.

2.3.3 Mother and Baby Trials

The Mother and baby Trials were first described by Snapp (1999) and piloted in Zimbabwe by CIMMYT from 1999 by Bänziger and de Meyer (2002). The scheme, undertaken in collaboration with national maize programs was based on: (i) a participatory variety selection (PVS) concept. (ii) assessing the socio-economic and physical adaptability of variety, and (iii) accelerating the dissemination of improved adapted maize cultivars (Bänziger and de Meyer, 2002).

2.4 Genotype by Environment Implications in selection

Large numbers of multi-environment trials (METs) are routinely conducted as part of crop breeding program. Data collected from these METs are readily available source of information, which can be used to assess the repeatability of GxE interactions.

The presence of GxE interactions results in differential response of varieties to environments, implying that there is a most favorable environment for each variety tested. Two features of GxE interactions become important in this context, their repeatability and their predictability. Repeatability of interactions can result when differences in gene combinations possessed by genotypes respond to sets of environmental conditions that can occur at other locations and/or in future years within the target population of environments (e.g. Chapman *et al.*, 2000a; 2000b; 2000c).

Genotype by environment (GxE) interactions complicates selection and testing of plant genotypes. Measuring GxE is important in order to determine an optimum strategy for selecting genotypes with adaptation to target environments (Romagosa *et al.*, 1993; DeLacy *et al.*, 1994; Annicchiarico, 1997). In plant breeding programs, many potential genotypes are usually evaluated in different environments (locations and years) before selecting desirable genotypes. For quantitative traits such as yield, the relative performance of different genotypes often varies from one environment to another. Such statistical interaction results from changes in the relative ranking of the genotypes or changes in the magnitudes of differences between genotypes from one environment to another. Changes in ranking make it difficult for the plant breeder to decide which genotype should be selected (Nguyen *et al.*, 1980).

Genotype by Environment (GxE) Interactions is commonly seen as one of the major complications in plant breeding and has been widely discussed, particularly in relation to the choice of the selection environment(s) (S. Ceccarelli; <http://www.icarda.cgiar.org/f>).

Several statistical methods have been developed for the analysis of GxE interaction (Hill, 1975; Lin *et al.*, 1986; Wescott, 1986; Crossa, 1990; Flores *et al.*, 1998). Plaisted and Peterson (1959) using a combined analysis of variance with pairs of cultivars suggested that lines with the smallest cultivars x location interaction were the most stable cultivars. Campbell and Kern (1982) used this analysis to study the stability of 10 sugarbeet (*Beta vulgaris*) cultivars. The linear regression of genotype values on site mean yield (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Pedersen *et al.*, 1978), commonly termed joint regression analysis, is certainly the most popular method

for stability analysis (Becker and Léon, 1988) due to its simplicity and the fact that its information on adaptive response is easily applicable to locations (Annicchiarico, 1997). Typically, analyses are conducted on the data from each environment and the estimates of performance and errors are taken into a combined analysis over environments. Again in efficiency can be made by using a one-stage analysis (Cullis *et al.*, 1996b), a single analysis of all data, rather than the two-stage procedure described above. However, computing power or programs are still not available to conduct one-stage analyses of large historical data sets.

Where attempts are made to define the underlying nature of the environmental factors conditioning the discrimination among the genotypes it may be more appropriate to discard an approach which distinguishes strata due to years or locations and substitute physiological or agronomic criteria (Eisemann *et al.*, 1990). Several pattern analysis methods have been developed (DeLacy *et al.*, 1990) which address imbalance in the analysis of genotype by location by year (GLY) data where the interest is in the relationship among locations for discrimination among genotypes. Specially, these investigations have addressed the question of rationalization of location selection.

The phenotype is a result of genetic and non-genetic influences (Comstock and Moll, 1963) and selection exploits only those components of phenotypic variability that have a genetic basis. When a phenotypic effect for a gene under selection pressure is consistently observed, achieving a response to selection is relatively straightforward. However, variation for quantitative characters is under control of many genes and their contribution can differ among environments. This conditional contribution of genes is the basis of G x E interactions. Variation among genotypes associated with G x E

interactions complicates selection as it introduces a degree of uncertainty into the measure of superiority of any genotype. This uncertainty increases with magnitude of G x E interactions.

Genotype by environment (GxE) interactions are a known fact in cultivars evaluations and GxE is composed of G x Location, G x Year, and G x L x Y constituents (Simmonds and Smartt. 1999). Measuring G x E is important in order to determine an optimum strategy for selecting genotypes with adaptation to target environments (Romagosa *et al.*, 1993; De Lacy *et al.*, 1994; Annicchiarico, 1997). In plant breeding programs, many potential genotypes are usually evaluated in different environments (Locations and years) before selecting desirable genotypes.

Genotypes by environment interactions are detected when there is a statistically significant change in the relative performance of genotypes across environments (Figure 2.1). It is useful to distinguish between G x E interactions that result in a change in rank of the genotypes between environments (crossover interactions, Figure 2.1c) equalled by a change of the genetic correlation among environments (Eisen & Saxton, 1983; Itoh & Yamada, 1990), and those that do not (non-crossover interactions, Figure 2.1b)(Baker, 1988; Haldane, 1946). Clearly, it is those types of interaction that result in changes in genotypic ranking that have the potential to influence the nature and magnitude of the selection response achieved by any breeding program (Cooper & DeLacy, 1994; Cooper, 1999). In practice, it is common to observe a complex mixture of genotype response profiles showing both crossover and non-crossover types of GxE interaction in the result of multi-environment trials (Figure 2.1d.)

Deciding whether G x E interactions is repeatable requires an understanding of their causes. Having a measure of repeatability will help to determine the relative merits of selection for broad and specific adaptation.

Byth (1981) distinguished between two historical phases in the study of G x E interactions, first, statistical detection and consolidation and second, identification of patterns of interaction, the latter including description of patterns and summarization of patterns.

Structuring multi-environment trials (METs) to exploit G x E interaction is possible where the challenge associated with a macro-environment is repeatable within the target geographical region of breeding program (Cooper *et al.* 1993c) and hence some of the G x E interaction variance component is identified as repeatable. Determining the relative proportions of repeatable and non-repeatable G x E interaction effects is an important issue in the conduct, analysis and interpretation of METs.

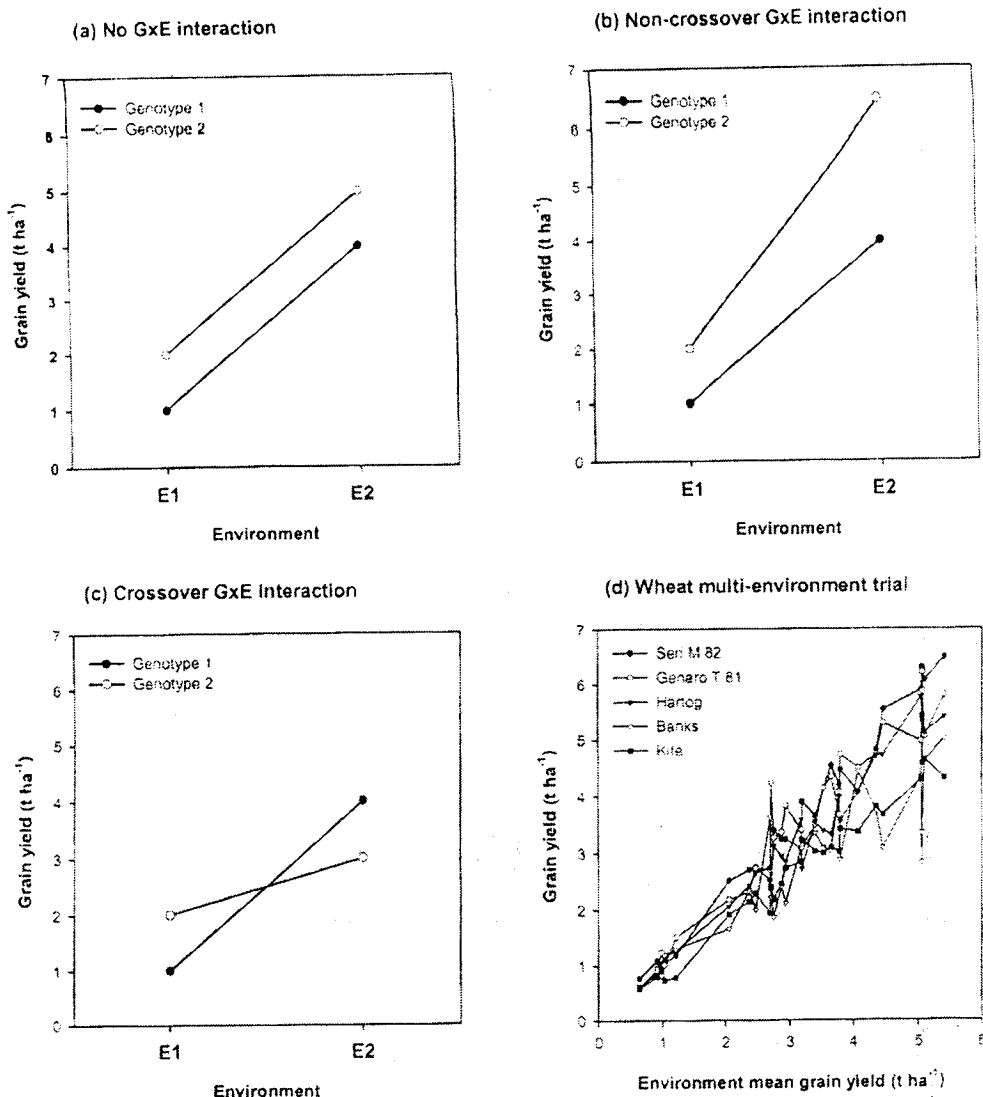


Figure 2.2 Possible genotype response patterns across environments: (a) no genotype-by-environment (GxE) interaction where there is no change in the relative performance of the genotypes between environments, (b) non-crossover GxE interaction due to heterogeneity of genotypic variance between environments where there is no change in rank of genotypes, (c) crossover GxE interaction resulting in change in rank of the genotypes between environments, (d) in practice complex mixtures of different genotype response profiles are observed in the results of multi-environments trials (Source: Banziger and Cooper, 2001).

2.4.1 Analysis of Genotype by Environment (GxE) Interactions

Genotypes x Environment interactions are problematic for both the agronomist and breeder because genotype means (averaged over environments) are unreliable for predicting performance of a genotype and, furthermore, genotypes must be targeted to individual locations in order to maximize performance. Also, the interaction contains “noise” that further complicates cultivars recommendations (Gauch, 1988, 1990; Gauch and Zobel, 1988). “Noise” often causes more genotypes to win in various environments than would be the case where the variety trial is more accurate. Thus, noise causes spurious complexity.

2.4.1.1 Stability Analysis

Although plant breeders have been aware of important genotypic differences in adaptability, they have been unable to exploit them fully in breeding programmes. This has been due largely to problems of defining and measuring either adaptability itself or the complexities of natural environments. Various workers (Immer, Hayes, and Powers, 1934; Salmon, 1951; Horner and Frey, 1957; and Sandison and Bartlett, 1958) have discussed some of the methods and problems of comparing varietal performance in several environments for several years. In their work, the variety x location or varieties x season interactions were the basic measures of adaptability. Although these are useful parameters they fail to give an adequate account of the dynamic response of varieties to different environments. The technique lacks precision, and is difficult to use when large numbers of genotypes are being tested.

Similarly Lin *et al.* (1986) examined nine stability statistics currently in use, to show that they are derived from two components of two-way classification of data, and that there are three types of stability concepts. These concepts were discussed both from statistical and biological points of view. Some limitations of the parametric approach to stability were noted, and as an alternative, a nonparametric approach, namely to group genotypes according to their similarity of response to a range of environments, was discussed. The parametric approach described by Lin *et al.* (1986) gives only the individual aspects of stability but cannot provide an overall picture of the response. The basic reason is that a genotype's response to environment is multivariate, yet the parametric approach tries to transform it to a univariate problem via stability index".

Further more Abou-El-Fittouh *et al.*, 1969, Campbell and Lafever, 1977, Guitard (1960), Horner and Frey (1957) and Liang *et al.*, 1966 based their investigations in grouping sites into homogeneous patterns using plot data or means of the trait measured and this has been demonstrated to be useful approach to improving testing efficiency. But this proposed clustering method would not recognize site-specific factors that raise genotype x environment effect.

2.4.1.2 Sequential Retrospective Pattern Analysis

Large numbers of multi-environment trials (METs) are routinely conducted as part of a plant breeding program. Data collected from these METs are a readily available source of information, which can be used to assess the repeatability of certain types of genotype by environment interactions (DeLacy *et al.*, 1994). Recently, pattern analysis methods

have been developed to conduct retrospective analyses of historical databases as an approach to appraise the relationships and similarities among the test locations in the way they discriminate among genotypes for target environments. An objective for developing this theory was the identification of repeatable genotype by location interactions across years. Retrospective analysis of the historical yield data from CIMMYT International Multi-environment trials (IMETs) in Mexico, the International Spring Wheat Yield Nursery (ISWYN), and International Bread Wheat Screening Nursery (IBWSN), and a southern Queensland (Australia) sugarcane multi-environment trial (MET) (DeLacy et al., 1994) were conducted to investigate the repeatability of genotype by environment (GxE) interactions among locations and over years. These analyses focused on identifying similarities among the test locations in the way they discriminated among the test genotypes grown at them. The retrospective analysis of these data indicated that repeatable patterns can be identified in GxE interaction in these large databases if these exist. The investigations demonstrated that the analytical methods devised to conduct a pattern analysis on the historical data sets, despite their endemic imbalance, could be successfully applied.

The results of analysis of the ISWYN data found groupings of the environments that had both similarities and dissimilarities to the mega-environments classification devised by CIMMYT. The results obtained from the IBWSN analysis did not confirm the ISWYN results. The lower level of repeatability of GxE interaction observed in the IBWSN analysis may be due to the limited number of years examined, the large number of entries in single replicate trials that accumulate a considerable amount of experimental error, and rapid change of entries from year to year.

From the sugarcane analysis it was demonstrated that each location generated a different pattern of discrimination among clones. These results emphasized the importance of clone by location interaction in Queensland and the need to concentrate more on testing across locations than on rationing ability within a location at this stage in the breeding program.

Such investigations were not yet conducted in maize variety selection in the Southern Africa Development Community (SADC) region. Similarly and based on DeLacy *et al.*, (1994) investigations we attempted to characterize environments on the basis of test maize genotypes and identify repeatable GxE interactions across years in Zimbabwe using data sets from Mother and Baby Trials.

2.4.1.3 Cluster analysis

Cluster Analysis is a multivarietal analysis technique for grouping observations (entries or environments) into classes based on the characteristics measured prior to analysis. For example, classify entries based on their site mean. Elements within the same group or cluster are relatively homogenous and elements between clusters are relatively heterogeneous. This technique was initially developed and used in the area of taxonomy for several decades and eventually introduced to the breeding areas in 70's. The term *cluster analysis* (first used by Tryon, 1939) actually encompasses a number of different classification algorithms. A general question facing researchers in many areas of inquiry is how to *organize* observed data into meaningful structures, that is, to develop taxonomies.

Cluster analysis is important to answer specific question such as: (i) how a region can be divided into sub-regions objectively, (ii) in the face of budget cut, which testing sites should be dropped, (iii) if reducing number of replicates but increasing number of testing sites for a particular trial is required, which additional sites should be considered, and (iv) whether the sites where selection in the early generation is performed is representative?

Cluster Analysis is also used to group genotypes into homogenous sets based on their response to the environments considered. This result normally complements the stability parameters calculated using the regression techniques. In terms of $G \times E$ interactions, the objective of cluster analysis is to make $G \times E$ interactions non-exist or relatively small within clusters.

CHAPTER III

MATERIALS AND METHODS

3.1 Cultivars

This study was based on data from maize multi-location trials conducted in Zimbabwe during 2000-2001 to 2003-2004 cropping seasons using the Mother and Baby Trial Scheme. The trials included 40 maize cultivars (Table 3.1) composed of 30 commercial hybrids and 10 open-pollinated varieties (OPV's) from public research institutions, private seed companies and CIMMYT. Not all cultivars were tested in all the seasons thus there was an imbalance in the number of times a given cultivars was tested. The number of cultivars evaluated per year ranged from 12 to 16.

3.2 Environments

Cultivars evaluation was done over a wide range of locations in the country covering all major agro-ecological zones. A total of 41 locations each comprising green (with recommended fertilizer application) and yellow (with sub-optimal fertilizer application) experiments were used giving an overall number of 82 environments (Table 3.2). Lack of data from Bikita yellow experiment, reduced the number of environments to 81.

TABLE 3.1 Genotypes evaluated during 2000 – 2004 Cropping Seasons

No.	GENOTYPE	Origin	Maturity	Type
1	AC 31	Seed Co	Intermediate-Late	Commercial-Hybrid
2	AC 73	Seed Co	Intermediate-Late	Commercial-Hybrid
3	CG 4141	Monsato	Early	Commercial-Hybrid
4	CIM99-2	CIMMYT		Commercial-Hybrid
5	CIM00-3	CIMMYT		Commercial-Hybrid
6	DK 8031	Monsato	Early	Commercial-Hybrid
7	DK 8041	Monsato	Early	Commercial-Hybrid
8	DK 8051	Monsato	Intermediate-Late	Commercial-Hybrid
9	PAN 67	Pannar	Intermediate-Late	Commercial-Hybrid
10	PAN 6479	Pannar	Early-Intermediate	Commercial-Hybrid
11	PAN 6777	Pannar	Intermediate-Late	Commercial-Hybrid
12	PHB 3097	Pioneer	Intermediate-Late	Commercial-Hybrid
13	PHB 3253	Pioneer	Intermediate-Late	Commercial-Hybrid
14	PHB 30G97	Pioneer	Intermediate-Late	Commercial-Hybrid
15	PHB 30R73	Pioneer	Intermediate-Late	Commercial-Hybrid
16	R 201	CBI	Early	Commercial-Hybrid
17	SC 407	Seed Co	Early	Commercial-Hybrid
18	SC501	Seed Co	Early-Intermediate	Commercial-Hybrid
19	SC 513	Seed Co	Early-Intermediate	Commercial-Hybrid
20	SC 517	Seed Co	Early-Intermediate	Commercial-Hybrid
21	SC 519	Seed Co	Early-Intermediate	Commercial-Hybrid
22	ZS 255	CBI	Early	Commercial-Hybrid
23	ZS 257	CBI	Very Early	Commercial-Hybrid
24	CIM00-4	CIMMYT		OPV
25	CZH01021	CIMMYT	Early-Intermediate	Hybrid
26	CZH99055	CIMMYT	Early-Intermediate	Hybrid
27	KEP	NTS	Intermediate-Late	OPV
28	MATUBA	Seed Co	Early-Intermediate	OPV
29	PAN 31	Pannar	Intermediate-Late	Commercial-Hybrid
30	PAN 413	Pannar	Intermediate-Late	Commercial-Hybrid
31	PAN 6243	Pannar	Intermediate-Late	Commercial-Hybrid
32	99SADVE	CIMMYT	Early	OPV
33	SC 403	Seed Co	Early	Commercial-Hybrid
34	SC 521	Seed Co	Early	Commercial-Hybrid
35	ZM 303	CIMMYT	Very Early	OPV
36	ZM 305	CIMMYT	Very Early	OPV
37	ZM 421	CIMMYT	Early	OPV
38	ZM 423	CIMMYT	Early	OPV
39	ZM 521	CIMMYT	Early-Intermediate	OPV
40	ZM 523	CIMMYT	Early-Intermediate	OPV

Table: 3.2 Testing Locations where genotypes were evaluated (2000-2004 cropping seasons)

No.	LOCATIONS	Agro-Ecologic	YEAR			
		Zone	2000-2001	2001-2002	2002-2003	2003-2004
1	BIKITA	IV	X		X	X
2	BINGAGURU	III	X	X	X	X
3	BUHERA	IV	X			X
4	CHEZIYA		X		X	
5	CHIMANIMANI	I				X
6	CHINYUDZE		X			
7	CHIRAU	II	X			
8	CHIREDDI	V	X			
9	CHISUMBANJE	V	X	X		X
10	CHIVI	IV	X		X	X
11	CHIWESHE	III				X
12	DAITI	IV	X	X	X	X
13	DOMBOSHAWA	II			X	X
14	FILABUSI	IV	X			
15	GOKWE	IV			X	X
16	GURUVE	II	X	X	X	X
17	GWEBI	II			X	X
18	GWITIMA	IV	X			
19	HARARE	II	X			
20	HOGWART	II	X			
21	KAROI	II	X			
22	MAKOHOLI	IV	X	X	X	X
23	MANDZIDZIDZVA		X			
24	MANUNURE	IV				X
25	MUREHWA	II		X	X	X
26	MUSHAWASHA	II	X			
27	MUTASA	II	X	X	X	X
28	MUTAWATAWA	II	X			
29	MUTOKO	IV	X	X	X	X
30	MUZARABANI #(Chipendo 2001)	IV	X			X
31	MWENEZI	V	X			
32	NEMBUDZIYA	IV	X			X
33	NKAYI	IV	X	X		X
34	NYANGA	I	X		X	
35	RUKWEZA		X			
36	SAVE VALLEY	V	X			
37	WEDZA	II		X		
38	ZHOMBE	III	X			
39	ZOWA		X			
40	ZVIMBA	II	X		X	X
41	ZVISHAVANE	III				X
Total			32	10	15	22

X: indicates the location was used for genotype evaluation in that particular year

3.3 Trial Design

The trials were planted using a “Mother-Baby” Trial Design (Snapp, 1999) adapted for cultivars evaluation. This design allowed farmers and researchers to test maize cultivars using two types of trials (de Meyer and Bänziger, 2000): a research-managed Mother Trial, and a farmer-managed Baby Trial.

3.3.1 The Mother Trial

The Mother trials were planted under two different levels of nitrogen fertilizer referred to as “green” and “yellow” trials. The yellow experiment, which represented a nitrogen fertilizer level approximating that in farmers’ field plants, showed nitrogen stress symptoms and turned yellow earlier. The green experiment, which represented a nitrogen fertilizer level recommended for the area plants, stayed green longer. Each experiment was an alpha (0,1) lattice design with three replicates. Cultivars were planted in plots of two rows 4.8 m or 5.5 m long rows with inter-row spacing of 0.90 m and intra spacing of 0.30 m (Fig.3.1). The two experiments of any each trial were planted on the same date.

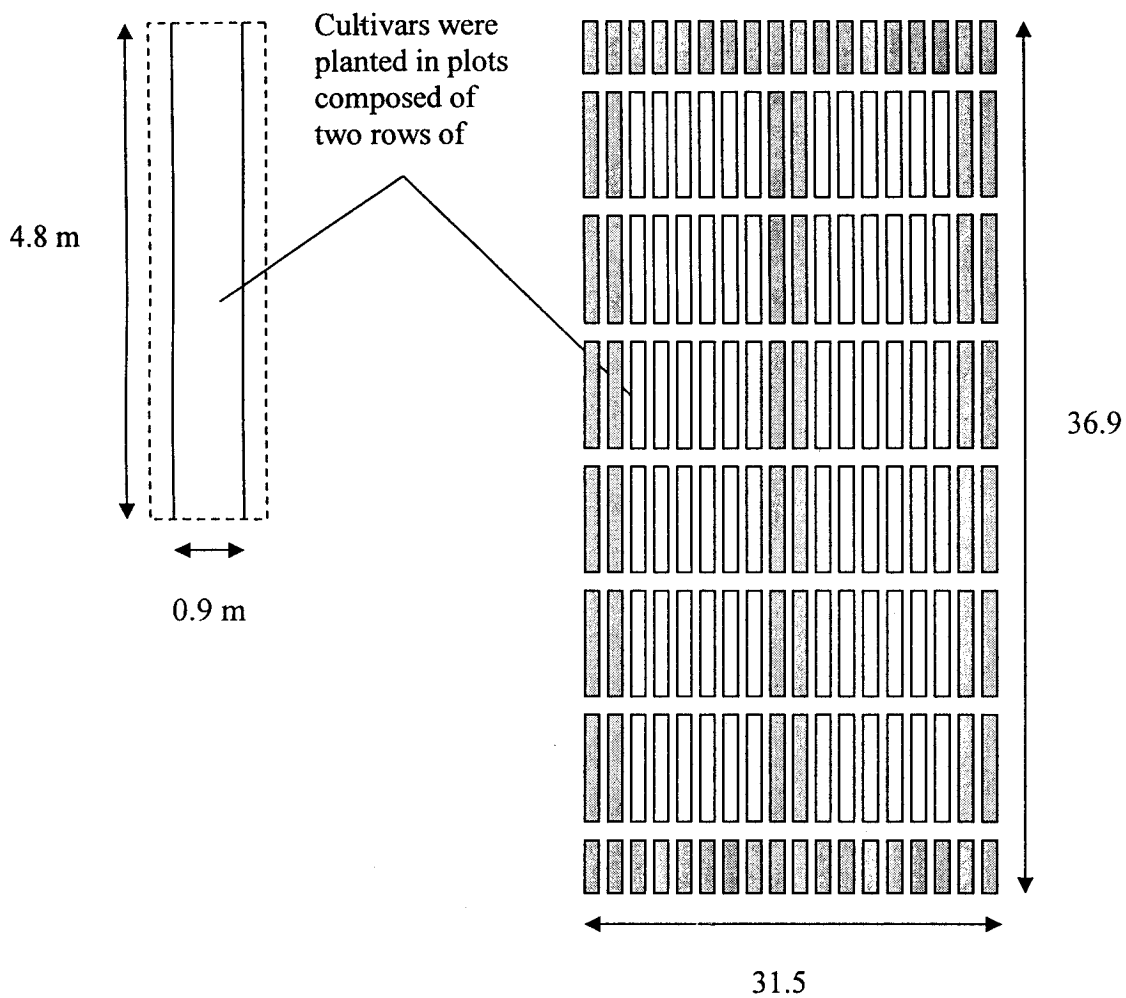


Figure 3.1 General map for Mother Trial grown on-farm during 2000 – 2004 cropping seasons. Border plots are gray and trial plots are transparent

3.3.2 The Baby Trial

Complementing baby trials were planted as described by de Meyer and Bänziger (2000). Data from these trials however were not part of this study.

3.4 Data management

3.4.1 Collection

The analysis was base on yield data from four seasons from the 81 environments. The data from Mother Trials for three years (2001-2003) were collected from the databases at CIMMYT-Zimbabwe and Agricultural Research and Extension (AREX), while those for 2004 were obtained from executed trials during the season.

3.5 Clustering

This was done following the procedure recommended by DeLacy et al., (1996); and was done for environments as well as for genotypes

3.5.1 Environments

The testing environment classification was based on average grain yield over the four years and across the environments, edaphic factors and climatic data, which include rainfall estimates by month derived from FEWSNET, soil type from FAO digital soil map of the world 1:5 million scale and elevation data was from space shuttle SRTM data (originally at 90 m resolution).

For each of the 4 years, an 81 x 81 matrix of squared Euclidean distance (SEDs) between each pair of environments was calculated as per model of DeLacy *et al.* (1996). Environments with empty cells were sequentially eliminated and the final long-term SED matrix, without empty cells, was used for pattern analysis.

The environmental data were adjusted for yield performance, using a linear regression analysis, and standardized within each trial before subjecting them to cluster analysis. Sequential Retrospective Pattern Analysis (SEQRET version 1.1) was used to classify the testing environments according to Mirzawam *et al.*, (1994), DeLacy *et al.*, (1994) and DeLacy *et al.*, (1998).

Sequential retrospective pattern analysis requires for its implementation the mean value of genotypes tested in individual location-year environments. The genotypes were considered to be random genotypes across years. Analysis parameters employed in clustering strategy were incremental sum of squares (ISS) algorithm (Ward, 1963), weighed averages and standard error of the difference. The adequacy of the model was determinate from R^2 statistic, which is a measure of the effectiveness of the model as explained by DeLacy *et al.*, (1996).

3.5.2 Genotypes

The analysis was based on four years of grain yield data of the 40 genotypes. The genotypes were classified using the same procedure in classification of environments, and a 40 x 40 matrix of Squared Euclidean distance (SEDs) between each pair of genotypes was calculated using DeLacy *et al.* (1996) model. To obtain an objective basis

of comparing genotypes their grain yield means were adjusted for missing environments using PROC GLM from SAS (SAS, 2005) with year, environment group (Env. Group) and genotype group (Geno. Group) as factors.

3.5.3 Comparison

T-test was carried to check for the differences between pairs of clusters of environment groups and genotypes groups. Due to the variability of the data set, differences were assessed with an error probability of $p < 0.15$.

CHAPTER IV

RESULTS

4.1 Classification of Testing Environment

Of the initial 81 environments 49 were eliminated by the analysis as they were not sufficiently repeated across years. The remaining 33 environments were grouped into clusters presented in figure 4.1 and table 4.1. Nitrogen supply, as influenced by the amount of N fertilizer applied in “green” versus “yellow” trials, was a more important determinant of the environment than were edaphic factors. This was confirmed by the classification of environments from different agro-ecological zones into same clusters whereas green and yellow experiments grown at the same location often featured in different clusters. The description of this classification was considered at two levels.

4.1.1 Classification at Level 1

Grouping at this level put the environments into two clusters; Cluster 1 comprised of 11 environments and cluster 2 with 22 environments (Table 4.1).

Cluster 1 was composed of environments mostly from agro-ecological zone IV with the exception of three, Domboshawa and Murehwa from zone II and Save Valley from zone V. At this level of grouping, varying soil nitrogen levels effectively created different environments at all locations apart from Buhera and Nembudziya. Soil types in the environments in this cluster were variable and tended to be on the acidic side.

Differences among the environments were apparent for all but soil depth and evapotranspiration (EVAPO).

In cluster 2 most of the locations were from agro-ecological zone II and IV (Table 4.1). Environments at Domboshawa, Murehwa, Gokwe, Daitai, Nkayi and Save Valley were effectively defined by varying soil nitrogen levels, unlike at Chivi, Zvimba, Bingaguru, Chisumbanje, Guruve, Mutasa, Mutoko and Makoholi. Soil types for cluster 2 were equally variable with most environments having the ferric luvisols. Similarly in most environments the soils tended to be alkaline. Differences among the environments were apparent for soil water holding capacity (SWHC), precipitations, temperatures and elevation.

4.1.1.1 Comparisons between clusters

Differences (at $p < 0.15$) between the cluster 1 and 2 were observed for grain yield, evapotranspiration (EVAPO) and soil water holding capacity (SWHC) (Table 4.2).

Cluster 1 was 34 percent lower yielding than cluster 2 (2.41 t/ha and 3.22 t/ha, respectively), and this was associated with higher EVAPO than cluster 2 (723.89 mm vs. 695.50 mm). On the other hand cluster 2 had higher SWHC than cluster 1 (147.50mm vs. 111.11mm). The state of these two factors in cluster 1 created condition, which predisposed the environment group to drought thus, the lower yields.

4.1.2 Classification at level 2

Classification at this level placed the environments into four clusters, cluster 1, cluster 2, cluster 3 and cluster 4 comprising 4, 7, 8 and 14 environments, respectively (Table 4.1 and Fig. 4.1).

Cluster 1 consisted of four environments, which were from three different zones. Domboshawa was from zone II, Nembudziya, Bikita were from zone IV and Save Valley was from zone V (Table 4.1). The environments were defined differently from the locations on the basis of soil nitrogen level as evidenced by placement of corresponding soil N level at the locations (= environments) in different clusters. Soils of the environments in this cluster were variable and tended to be acidic comprising chromic luvisols, rodic ferrasols and lithosols. The values of soil water holding capacity (SWHC) suggested marked differences among the environments in this cluster for the edaphic factor. Similarly differences were suggested for precipitation.

Cluster 2 included seven environments (Murehwa 2, Nkayi 1, Buhera 1, Nembudziya 2, Gokwe 2, Buhera 2 and Daitai 1), which apart from Murehwa 2 were from zone II, the rest were from zone IV. At Buhera, varying of soil nitrogen did not create different environments, so that the seven environments in this cluster represented six effective environments defined on the basis of the soil nitrogen levels. This underscore the effect soil N variation had in defining the environment. Soils in most of the environments of this cluster tended to be alkaline and were predominantly ferric luvisols with lithosols and nithosols in some environments. Differences for temperatures and SWHC were also suggested among the environments.

Cluster 3 comprised of eight environments from four different agro-ecological zones. The environments, however, represented only five effective environments since at Chivi, Zvimba and Chisumbanje varying of soil nitrogen did not create different environments. Soils in these environments were more on the acidic side comprising of varying soil types. Apart from elevation, precipitation and temperature there were no other suggested differences among environments of this cluster for other edaphic factors.

Cluster 4 included 14 environments, which were from four different agro-ecological zones with the majority being in zones II and IV. These represented 10 different environments only, whereby varying of soil nitrogen did not create different environments at Mutoko, Guruve, Makoholi and Mutasa. Neutral to alkalinity characterized the soils of the environments in cluster 4, while the soils were mostly of ferric luvisols type. Strong suggestions were presented for differences among environments for soil water holding capacity (SWHC), elevation and temperatures.

4.1.2.1 Comparison between clusters

Few differences were observed between any given pair of clusters compared. Significant differences ($p = 0.15$) were observed for more factors when the comparison involved cluster 3 and cluster 4.

No significant differences between cluster 1 and cluster 2 were found for the critical factors of classification, whereas cluster 1 and cluster 3 were significant different for risk of drought during grain filling (RK_GRAFL) only. The risk of drought was higher in cluster 1 and very high in cluster 3.

Differences (at $p < 0.15$) for elevation (ELEV.), minimum temperature (IT), maximum temperature (XT), EVAPO and soil depth (DEEP_SOIL) were observed between cluster 1 and cluster 4. Cluster 1 was at lower altitude than cluster 4 (728.00 m vs. 1065.85 m) and had higher temperatures (minimum and maximum) than cluster 4 (18.9°C vs. 17.0°C and 30.2°C vs. 27.9°C, respectively). Soils in cluster 1 were deeper (116.67 cm vs. 100.00 cm), while EVAPO was higher (724 vs. 686) than in cluster 4.

Clusters 2 and cluster 3 were different (at $p < 0.15$) for SWHC, pH sub-soil (PHWATER_SU), risk of drought at pre-flowering (RK_PREFL), flowering (RK_FLOWER) and grain filling (RK_GRAFIL) periods. Cluster 3 had higher SWHC (192.85 vs. 100 mm) and higher pH soil than cluster 2 (6.9 vs. 6.7). The risk of drought during preflowering and flowering periods was lower in cluster 2 than in cluster 3 but higher during grain filling.

Cluster 2 and cluster 4 were different (at $p < 0.15$) for Avg.Yield and EVAPO. Cluster 2 was 29 percent lower yielding than cluster 4 (2.39 t/ha and 3.39 t/ha, respectively) and had higher EVAPO 37.75 mm than cluster 4. The lower yielding potential of cluster 2 was associated with high evapotranspiration.

Soils in cluster 4 were shallower in depth and higher in SWHC and pH than those in cluster 3. The higher SWHC, despite the shallower soil depth, was a determinant of the conducive conditions as represented by risk to drought at ESTAB (risk of drought during the establishment period), RK_PREFL and RK_GRAFIL.

Table 4.2 Analyse of variance and paired T-test for environments

Clusters		N LEV	AVG	LONG	LAT	ELEV	IT	XT	PRE	EVAP0	DEEP	SWHC	FAO	PHWATER	PHWATER	GDDCOM	GDDFT	GDD05	RK	RK	RK	RK	RK
Level 1	Level 2	YIELD									_SOIL		TYPE	_TO	_SU				ESTAB	PREFL	FLOWER	POSFL	GRAFIL
Group1		1.545	2.410	30.270	-19.259	980.556	17.596	28.951	620.000	723.889	105.556	111.111	3.111	6.433	6.744	1722.222	1955.556	1900.000	2.867	1.778	1.444	1.889	4.444
Group2		1.500	3.218	31.053	-18.967	1045.350	17.040	28.160	615.350	695.500	105.000	147.500	3.050	6.470	6.855	1680.000	1905.000	1900.000	2.850	2.000	1.800	1.800	4.400
Equal FTEST?		0.860	0.815	0.988	0.767	0.782	0.291	0.877	0.978	0.024	0.729	0.704	0.796	0.002	0.004	0.030	0.122	0.020	0.867	0.072	0.585	0.811	0.236
TTEST		0.813	0.074	0.129	0.586	0.630	0.321	0.343	0.917	0.041	0.931	0.120	0.937	0.044	0.595	0.067	0.590	1.000	0.970	0.540	0.678	0.830	0.913
Group1	1.500	2.442	30.913	-19.397	728.000	18.867	30.227	604.667	724.000	116.667	133.333	3.000	6.267	6.367	1800.000	1966.667	1966.667	2.333	2.000	2.000	2.000	4.667	
Group2	1.571	2.391	29.948	-19.190	1106.833	17.110	28.313	627.667	723.833	100.000	100.000	3.167	6.517	6.933	1683.333	1950.000	1960.000	2.833	1.667	1.167	1.833	4.333	
Group3	1.500	2.925	30.770	-18.467	1007.286	17.089	28.603	586.429	713.000	114.286	192.857	3.714	6.400	6.686	1657.143	1871.429	1900.000	3.143	2.714	1.857	1.857	5.000	
Group4	1.500	3.386	31.205	-18.728	1065.646	17.014	27.922	630.923	686.077	100.000	123.077	2.892	6.508	6.946	1692.308	1923.077	1900.000	2.385	1.615	1.462	1.769	4.077	
Equal FTEST? 182	0.795	0.048	0.324	0.488	0.759	0.669	0.805	0.051	0.301		0.475	0.757	0.035	0.029	0.957	0.530	0.724	0.369	0.202	0.010	0.117	0.732	
Equal FTEST? 183	0.776	0.595	0.509	0.527	0.521	0.729	0.708	0.275	0.114	0.634	0.007	0.851	0.000	0.009	0.349	0.192	0.099	0.110	0.613	0.179	0.179		
Equal FTEST? 184	0.672	0.301	0.486	0.623	0.970	0.679	0.957	0.201	0.093		0.326	0.459	0.003	0.001	0.115	0.103	0.086	0.469	0.606	0.099	0.245	0.375	
Equal FTEST? 283	0.984	0.086	0.650	0.914	0.595	0.889	0.850	0.255	0.273		0.022	0.480	0.008	0.709	0.248	0.414	0.136	0.414	0.025	0.104	0.713		
Equal FTEST? 284	0.865	0.161	0.591	0.704	0.545	0.151	0.729	0.237	0.172		0.830	0.581	0.747	0.602	0.037	0.247	0.084	0.705	0.258	0.103	0.424	0.352	
Equal FTEST? 384	0.877	0.567	0.973	0.779	0.181	0.182	0.542	0.943	0.824		0.020	0.129	0.009	0.928	0.460	0.854	0.964	0.189	0.088	0.881	0.660		
TTEST	182	0.840	0.957	0.295	0.815	0.125	0.221	0.211	0.853	0.892	0.170	0.470	0.904	0.683	0.383	0.574	0.932	0.637	0.563	0.516	0.493	0.886	0.553
TTEST	183	1.000	0.697	0.891	0.936	0.328	0.188	0.307	0.849	0.564	0.896	0.309	0.682	0.823	0.606	0.329	0.545	0.759	0.459	0.583	0.863	0.863	0.133
TTEST	184	1.000	0.214	0.738	0.446	0.070	0.036	0.075	0.748	0.027	0.032	0.781	0.771	0.692	0.384	0.558	0.839	0.757	0.950	0.511	0.648	0.769	0.448
TTEST	283	0.800	0.353	0.218	0.663	0.662	0.985	0.819	0.443	0.618	0.182	0.007	0.672	0.373	0.106	0.842	0.588	0.779	0.520	0.144	0.183	0.960	0.052
TTEST	284	0.772	0.052	0.650	0.461	0.779	0.899	0.692	0.948	0.106		0.392	0.565	0.947	0.917	0.944	0.778	0.774	0.434	0.896	0.331	0.899	0.656
TTEST	384	1.000	0.416	0.473	0.224	0.712	0.916	0.489	0.406	0.254	0.044	0.001	0.362	0.193	0.029	0.534	0.516	1.000	0.142	0.131	0.353	0.858	0.071

* Shaded figures are the significant ones (p=0.15)

between AC 519 and cluster 2 as well as the consistent ranking of ZM 421 and ZM 422 from optimum N level to sub-optimum N level confirms the tolerance of these varieties to stressed conditions.

Cluster II included five genotypes from the same maturity group (Early to Intermediate) and were all hybrids. Genotype performance ranged from 4.43 t/ha to 2.85 t/ha with PAN 5243 having the best yield (4.43 t/ha), SC 519 came second (4.25 t/ha) followed by CG 4141 (3.94 t/ha), CZH999033 (2.91 t/ha) and DK 8031 (2.85 t/ha) in that order. All but the CIMMYT hybrid were developed for high potential areas and had not been through stress tolerance selection.

4.2 Maize Genotypes Classification

From the 40 genotypes that were tested in the study, 24 genotypes were eliminated by the analysis as they were not sufficiently repeated across years. The remaining 16 genotypes grouped into four main clusters (Fig. 4.2). These 16 genotypes were from four different maturity groups; early, early to intermediate, intermediate to late and late.

Cluster composition is presented in Table 4.3. Cluster I was composed of four genotypes, three OPVs of early to intermediate maturity group and one hybrid, AC 71 in late maturity group. The genotype average yield in this group presented in table 4.3 ranged from 2.70 t/ha to 3.94 t/ha with ZM 523 ranking first (3.94 t/ha) followed by AC 71 (2.93 t/ha), ZM 521 (2.86 t/ha) and ZM 421 (2.70 t/ha) in that order. All the OPVs were from CIMMYT and the one hybrid was from a private company, ACFD. The OPVs are products from stress tolerance breeding at CIMMYT and the switch in ranking between AC 71 and ZM521 as well as the consistent ranking of ZM 421 and ZM 423 from optimum N level to sub-optimum N level confirms the tolerance of these varieties to stressed conditions.

Cluster II included five genotypes from the same maturity group (Early to Intermediate) and were all hybrids. Genotype performance ranged from 4.45 t/ha to 2.85 t/ha with PAN 6243 having the best yield (4.45 t/ha), SC 519 came second (4.25 t/ha) followed by CG 4141 (3.94 t/ha), CZH99055 (3.91 t/ha) and DK 8031 (2.85 t/ha) in that order. All but the CIMMYT hybrid were developed for high potential areas and had not been through stress tolerance selection.

Table 4.3 Mean yield, maturity group and type of genotypes

Cluster Genotypes

1	AC71
1	ZM421
1	ZM521
1	ZM523
2	DK8031
2	CZH99055
2	PAN6243
2	CG4141
2	SC519
3	SC513
3	PHB30G97
3	PAN413
3	ZM423
4	PHB30R73
4	AC31
4	CZH01021

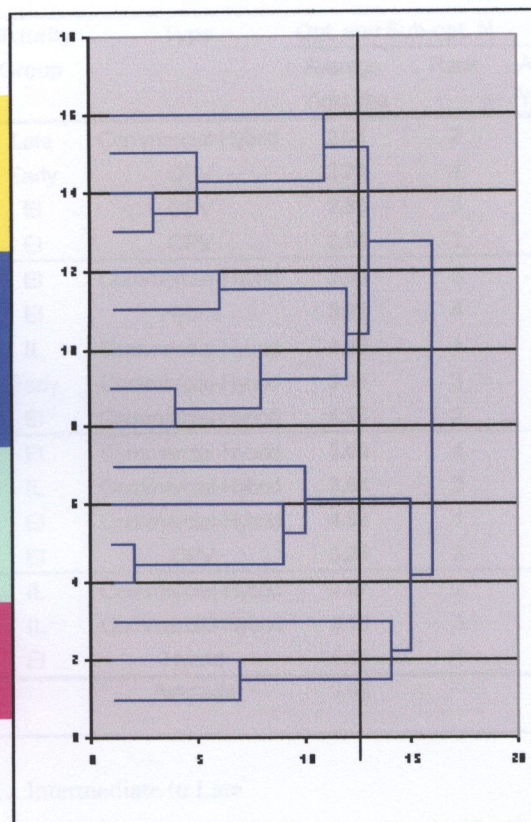


Fig.4.2 Dendrogram for 16 maize genotype classification based on grain yield using weighted environment standardized squared Euclidean distance as the dissimilarity measure and incremental sum of squares as the clustering strategy.

X-axis: % of similarity among genotypes

Y-axis : Genotypes

Table 4.3 Mean yield, maturity group and type of genotypes

Cluster	Genotypes	Origin	Maturity Group	Type	Opt. and Sub-opt. N		Optimum N		Sub-Optimum N	
					Average Yield t/ha	Rank	Average Yield t/ha	Rank	Average Yield t/ha	Rank
1	AC 71	ACFD	Late	Commercial-Hybrid	2.93	2	3.37	2	2.47	3
1	ZM 421	CIMMYT	Early	OPV	2.70	4	3.06	4	2.31	4
1	ZM 521	CIMMYT	EI	OPV	2.86	3	3.19	3	2.51	2
1	ZM 523	CIMMYT	EI	OPV	3.94	1	4.51	1	3.33	1
2	DK 8031	Monsanto	EI	Commercial-Hybrid	2.85	5	3.21	5	2.47	5
2	CZH99055	CIMMYT	EI	Hybrid	3.91	4	4.75	3	3.02	4
2	PAN 6243	Pannar	IL	Commercial-Hybrid	4.45	1	5.19	1	3.65	1
2	CG 4141	Monsanto	Early	Commercial-Hybrid	3.94	3	4.42	4	3.44	3
2	SC 519	Seed Co	EI	Commercial-Hybrid	4.25	2	4.96	2	3.49	2
3	SC 513	Seed Co	EI	Commercial-Hybrid	3.03	4	3.57	4	2.45	4
3	PHB 30G97	Pioneer	IL	Commercial-Hybrid	3.64	2	4.32	2	2.92	2
3	PAN 413	Pannar	EI	Commercial-Hybrid	4.59	1	5.24	1	3.90	1
3	ZM 423	CIMMYT	EI	OPV	3.24	3	3.67	3	2.79	3
4	PHB 30R73	Pioneer	IL	Commercial-Hybrid	4.07	2	4.77	2	3.32	2
4	AC 31	ACFD	IL	Commercial-Hybrid	3.13	3	3.45	3	2.79	3
4	CZH01021	CIMMYT	EI	Hybrid	4.46	1	5.12	1	3.75	1
Average					3.62		4.18		3.04	

*EI: Early to Intermediate, IL: Intermediate to Late

Cluster 3 had four genotypes, which were SC 513, PHB 30G97, PAN 413 and ZM 423. Apart from ZM 423, an OPV, the rest were hybrids. Among these genotypes, only PHB 30G97 was intermediate to late maturity, while others were early to intermediate in maturity. PAN 413 was the best yielder (4.59 t/ha,) while SC 513 was the lowest (3.03 t/ha). ZM 423 as is the case with the other ZM series is a product of stress tolerance breeding.

Cluster 4 comprised of three genotypes PHB 30R73, AC 31 and CZH01021, which were all hybrids from two maturity group; early to intermediate and intermediate to late. CZH01021 yielded highest (4.46 t/ha) and AC 31 the lowest (3.13 t/ha).

4.3 Classification Group Interactions

The performance of genotype groups across environmental groups is presented in Table 4.4. In all cases there was an observed incremental trend in the average yields of the genotype groups from environmental group 1 to group 4. The high yielding potential of environment group 4 is evident and is underpinned by the temperature, evapotranspiration and soil depth factors which collectively created favorable plant growth conditions. Similarly environmental group 2 had a low yielding potential due to the same factors being unfavorable. Genotype group 1 and genotype group 2 showed the sharpest responses to change in environment. In environment group 1, genotype group 1 was the highest yield but fell to be the lowest in environment group 4. Inversely, genotype group 4 was the lowest yield in environment group 1 but the best performer in environment group 4; a similar response was observed for genotype group 3. Genotype group 2 showed consistency across the environments (Table 4.4)

Table 4.4 Interactions for grain yield between genotype groups and environment groups

	Average of grain yield (t/ha)			
	Env Group 1	Env Group 2	Env Group 3	Env Group 4
Geno. Group 1	1.40	1.91	2.56	3.03
Geno. Group 2	1.31	2.38	2.64	3.35
Geno. Group 3	1.26	2.33	2.59	3.69
Geno. Group 4	0.99	2.40	3.21	3.66

CHAPTER V

DISCUSSION

5.1 Environments

Variety testing locations used in Zimbabwe in the four seasons included in this study possessed marked inherent differences based on edaphic and climatic factors (Table 4.1). Similarly, maize variety performance in the environments averaged over the seasons also showed marked differences. In order for variety testing to be effective the environments in which the testing is done should constitute a good sample of target environments. Maize, being the most important staple food crop, is grown in a wide range of environments in Zimbabwe as such the set of environments used in this study represented a good random sample of maize growing environments. To this extent the evaluation of the varieties in these environments over the seasons can be seen to have been adequate to identify suitable genotypes. .

From a total of 41 locations, with two experiments per location representing different soil nitrogen levels, 81 environments were created out of which 33 were used for the pattern analysis. Classification of these environments at either cluster level 1 or level 2 revealed that at some locations the locations were grouped into different clusters. This showed that application of different soil N fertilizer levels effectively created different testing environments within these locations, thereby providing a wider environmental basis of discriminating varieties. The implication of this is that with scarce resources that characterize most national maize programmes in the SADC region, the need to rationalize the testing environments could be achieved through use of different soil

nitrogen levels, given that nitrogen is the most limiting soil nutrient in the region for most crops including maize.

Differences between clusters at classification level 1 were for grain yield (AVG YIELD), evapotranspiration (EVAPO) and soil water holding capacity (SWHC) (Table 4.2). Cluster 2 gave higher AVG YIELD and this was associated with lower EVAPO but higher SWHC. Evapotranspiration is a major source of water losses in plants (Bänziger et al., 2000), and where this is not matched with water saving mechanisms in plants (tolerance, escape or avoidance) the result is water deficit in the crop plants hence lower yield as seen for cluster 1. The low soil water holding capacity of cluster 1 predisposed it to rapid drying and this coupled up with high water loss from plants presented droughty conditions, which as Bänziger et al., (1999) reported adversely affected maize performance. Indeed most environments in the cluster were in agroecological zone IV characterized by high temperatures and loose sandy soils.

The resulting four clusters at level 2 of environment classification were of different sizes in terms of number of environments (Table 4.1). This grouping put environments from most locations into different clusters except three in cluster 3 and four in cluster 4. In all clusters the ratio of the two environments as defined by the different soil nitrogen levels was 1:1. It is once again evident that varying soil nitrogen levels effectively created different testing environments within some locations, which were classified into different groups. Table 5.1 gives a summary of comparisons among clusters of testing environments used in Zimbabwe during 2000-2004 seasons.

Table 5.1 Summary of comparisons among clusters of testing environments used in Zimbabwe during 2000-2004 seasons.

	Environment Clusters being compared							
Factor	1 versus 4		2 versus 4		2 versus 3		3 versus 4	
Grain Yield	^a			Higher (+)				
SWHC						Higher (+)		Higher (+)
Temperature		Lower ^b (+) ^c						
EVAP0		Lower (+)		Lower (+)				
Soil Depth	Deeper (+)						Deeper (+)	
Soil pH						Lower (+)	Lower (+)	
Risk at: Establishment								Lower (+)
Pre-flowering					Lower (+)			
Flowering					Lower (+)			Lower (+)
Grain filling						Lower (+)		Lower (+)
Elevation		Higher (+)						

^a Differences for this factor were not significant based on the T-test (p=0.15)

^b The status of the factor in this cluster is the direct opposite in the corresponding one

^c This signifies the effect/relationship of the factor on7with growth and development of maize, (+) favourable and (-) adverse

Differences among the clusters were mainly when comparisons involved clusters 3 and cluster 4. With regards to grain yield, which was the basis of clustering differences were observed between cluster 2 and cluster 4. Higher grain yield was observed in cluster 4 and this was associated with significant lower evapotranspiration than for cluster 2. The underlining factors to the higher grain yield for cluster 4 were high elevation, high soil water holding capacity, low temperatures and therefore low evapotranspiration. The effects of most these factors on yield have been found to be very significant (Kramer and Boyer, 1995) in maize. High elevation is generally associated with low temperatures, which in turn result in low evapotranspiration.

Cluster differences were also observed for temperature, soil depth and elevation (between cluster 1 and cluster 4 and cluster 3 and cluster 4), soil water holding capacity, risk at establishment, during pre-flowering, during flowering and during grain filling and pH (between cluster 2 and cluster 3 and cluster 3 and cluster 4).

Factors that underpin the differences between cluster 1 and cluster 4 are related in that the higher elevation of cluster 4 was associated with lower temperatures and therefore lower evapotranspiration. Despite the shallower soils in cluster 4, prone to rapid drying, the resulting conditions were more conducive for plant growth. As indicated above the differences in grain yield between cluster 2 and cluster 4 were explained by differences in evapotranspiration, confirming the importance of this climatic factor in influencing crop production conditions.

The lower risk conditions at critical stages of growth and development of maize associated with cluster 4 when compared to cluster 3 are mainly due to the favourable status of SWHC and soil pH. High SWHC has been shown to favourably affect growth and development of maize especially during the reproductive stages (Shaw, 1976; Hartung and Jeschke, 1999; Hartung and Radin, 1989; Dodd *et al.*, 1996). On the other hand the higher risk of cluster 2 when compared to cluster 3 could not be associated with unfavorable status of both SWHC and pH.

Classification of the testing environments at level 1 gave two clusters with 23 effective environments while classification at levels 2 gave four clusters with 25 effective environments. Clustering at level 2, therefore, was better as it gave more options as to testing environments

The implications of the above are that soil nitrogen levels effectively affected total environment status and this was manifested through different plant responses to climatic and edaphic factors such as those considered in this study.

Abou-El-Fittouh *et al.*, 1969, Campbell and Lafever, 1977, Guitard (1960), Horner and Frey (1957) and Liang *et al.*, 1966 in their investigations grouped sites into homogeneous patterns using plot data or means of the trait measured and this has been demonstrated that this approach improved variety testing efficiency.

5.2 Genotypes

The maize varieties tested in the current study were from diverse background comprising different types from different maturity groups (Table 4.3). Marked differences were observed for their performance under low soil nitrogen and optimum soil nitrogen levels, with average yields being higher in the optimum soil nitrogen fields than the sub-optimum. Given that these varieties were developed in line with different objectives in terms of target farmers and environments such marked differences are expected. The CIMMYT varieties, especially the OPVs were products of stress breeding programme, while the other varieties from seed companies were by and large bred for optimum conditions only.

Classification of the varieties followed a pattern with OPVs being grouped separate from hybrids. Also within the hybrids, classification put the earlier varieties separate from the late ones. Within some individual clusters differential response was evident from one level of soil nitrogen to another. From cluster I to cluster IV there was evident increase in maturity i.e. from early to late maturity. A similar trend in terms of average grain yield was observed, with the later varieties having the highest yields. The higher grain yielding of the later maturing varieties has been observed in the regional trials conducted by CIMMYT over the years (Vivek, B., et al 2001, 2002, 2003, 2004) and can be explained by the amount of radiation that the crop receives. (Russel, 1991) in this experiment looking at the effect of radiation observed that those that late maturing varieties, which were exposed for longer periods of radiation, gave higher grain yield.

Cluster 1 was composed of four varieties a hybrid and 3 OPVs. The OPVs were from CIMMYT and were products of a stress breeding strategy, with special reference to low soil nitrogen and drought. The differential response observed for AC 71 and ZM 521 along with the consistency of ZM 421 and ZM 423 from optimum to sub-optimum soil nitrogen levels confirmed the effectiveness of stress breeding using low nitrogen fields. Banziger et al (1997) examining the efficiency of using low N environments in selection programmes concluded that maize breeding programmes targeting low N environments, as is the case for most of the farmers conditions in the SADC region, should include low N test environments to maximize selection gains. The performance of the OPVs also confirmed the adequacy of the environments used in characterizing them as being tolerant to stress.

The differential response observed for cluster 2 cannot be explained apart from noting that such a situation suggests that the early and the late varieties, CG 4141 and PAN 6243, respectively, could have been better adapted to the pattern of stress induced in the low N environments.

The interaction between environment clusters and variety clusters revealed differential response of variety clusters to changing environment clusters (Fig. 5.1). It was evident that the earlier varieties, as a general characteristic of the variety group 1, were better suited for the environments that were stressed, as the general characteristic of environment group 1. These varieties showed good response to improvement in crop growth conditions from environment group 1 through to group 4. On the hand the later maturing varieties, variety group 4, which were mostly hybrids from private seed

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companies were best suited for the environments with less stress, as a general characteristic of the environment group 4.

This differential response to changing environments underscores the type of maize varieties that a breeding programme can develop for the SADC region. The OPVs bred for drought and nitrogen stress tolerance, overwhelmingly defined variety group 1 and performed very well under stress conditions, which suggests that these varieties had special attributes. In describing the CIMMYT approach and comparing it with other breeding strategies Bänziger and Cooper (2001) pointed to the gains that were being made in maize breeding when selection was done under stress environments. Earlier Bänziger et al (1977) and Bänziger et al. (1999) showed the value of inclusion of low N and drought environments when breeding maize for the tropics. The OPVs in variety group 1 are products of this comprehensive breeding approach.

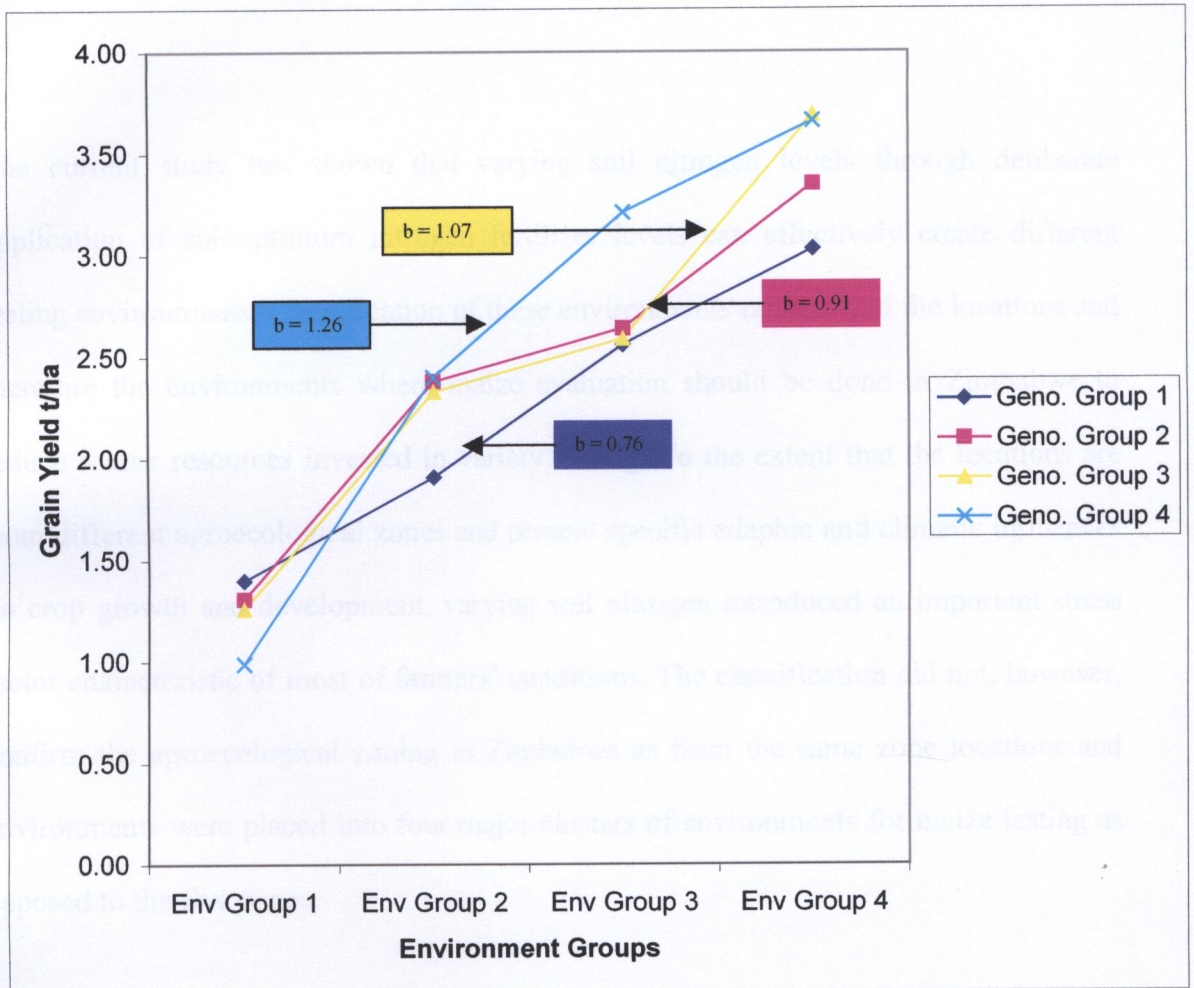


Figure 5.1 Interactions between genotype groups and environment groups

CHAPTER VI

CONCLUSIONS

The current study has shown that varying soil nitrogen levels through deliberate application of sub-optimum nitrogen fertilizer levels can effectively create different testing environments. Classification of these environments rationalized the locations and therefore the environments where maize evaluation should be done in Zimbabwe to reduce scarce resources invested in variety testing. To the extent that the locations are from different agroecological zones and present specific edaphic and climatic influences on crop growth and development, varying soil nitrogen introduced an important stress factor characteristic of most of farmers' conditions. The classification did not, however, confirm the agroecological zoning in Zimbabwe as from the same zone locations and environments were placed into four major clusters of environments for maize testing as opposed to the five zones.

The important exercise of variety testing can be rationalized in terms of efficiency and effectiveness by carefully conducting the evaluations in environments that adequately discriminate varieties. In Zimbabwe, of the 33 environments used in the classification 16 from 8 locations, Domboshawa, Murehwa, Bingaguru, Daitai, Gokwe, Nembidziya, Nkayi and Save Valley, representing different zones, are critical in testing maize varieties.

The most prominent factors that contributed to the differences among the cluster of environments were the soil water holding capacity, elevation, evapotranspiration and temperature. Soil depth, soil pH and elevation were also important but could be mitigated through other factors.

It also has been demonstrated that inclusion of target environments in the testing environments increased the efficiency of breeding for maize for the target environments. The good performance of the ZM 421, ZM 521 and ZM 423 under stress conditions confirmed that varieties can be developed with specific adaptation to the stress-prone conditions of low-resource farmers in Zimbabwe.

The non-conformity of the classification of the testing environments and the agroecological zones calls for the regular analysis of testing environments in Zimbabwe using the retrospective analysis to ensure that the tested genotypes are adequately being discriminated by the testing environments. Also this should allow rationalization of testing environments.

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Annex A: Summary of classification of environments

Environment	N. Level	Ecological zone	Cluster	
			At level 1	At level 2
Domboshawa	1*	II	2	3
Domboshawa	2*	II	1	1
Guruve	1	II	2	4
Guruve	2	II	2	4
Murehwa	1	II	2	4
Murehwa	2	II	1	2
Mutasa	1	II	2	4
Mutasa	2	II	2	4
Zvimba	1	II	2	3
Zvimba	2	II	2	3
Bingaguru	1	III	2	4
Bingaguru	2	III	2	3
Bikita	2	IV	1	1
Buhera	1	IV	1	2
Buhera	2	IV	1	2
Chivi	1	IV	2	3
Chivi	2	IV	2	3
Daitai	1	IV	1	2
Daitai	2	IV	2	4
Gokwe	1	IV	2	4
Gokwe	2	IV	1	2
Makoholi	1	IV	2	4
Makoholi	2	IV	2	4
Mutoko	1	IV	2	4
Mutoko	2	IV	2	4
Nembudziya	1	IV	1	1
Nembudziya	2	IV	1	2
Nkayi	1	IV	1	2
Nkayi	2	IV	2	4
Chisumbanje	1	V	2	3
Chisumbanje	2	V	2	3
Save Valley	1	V	1	1
Save Valley	2	V	2	4

* 1 = Sub-optimal nitrogen fertilizer conditions

* 2 = Optimal nitrogen fertilizer conditions

Gokwe	2	IV	1	2
Makoholi	1	IV	2	4
Makoholi	2	IV	2	4
Mutoko	1	IV	2	4
Mutoko	2	IV	2	4
Nembudziya	1	IV	1	1
Nembudziya	2	IV	1	2
Nkayi	1	IV	1	2
Nkayi	2	IV	2	4
Chisumbanje	1	V	2	3
Chisumbanje	2	V	2	3
Save Valley	1	V	1	1
Save Valley	2	V	2	4

* 1 = Sub-optimal nitrogen fertilizer conditions

* 2 = Optimal nitrogen fertilizer conditions