# IMPROVING DRYLAND MAIZE *(Zea mays* L.*)* WATER PRODUCTIVITY IN THE CHOKWE DISTRICT OF MOZAMBIQUE THROUGH BETTER NUTRIENT MANAGEMENT

**by**

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# DECLARATION

I declare that the dissertation which I hereby submit for the degree MSc (Agric) Agronomy at the University of Pretoria, Department of Plant Production and Soil Science, is my own work and has not previously been submitted by me for a degree at another university or institution of higher education. I also certify that no plagiarism was committed in writing this dissertation.

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# LIST OF ABBREVIATIONS

CPWF - Challenge Program on Water for Food
CV (%) - Coefficient of variation in percentage
DAE - Days after emergence
DAS - Days after sowing
$EC_{1:2.5}$ ($mS\ m^{-1}$) - Electrical conductivity
FAEF - Faculty of Agronomy and Forestry Engineering of Eduardo Mondlane University
FAO - Food and Agriculture Organization of the United Nations
FSSA - The Fertilizer Society of South Africa
INE - Mozambican National Institute of Statistics
INIA - Mozambican National Institute for Agronomic Research
KCl - Potassium Chloride
N - Nitrogen
LAD - Leaf area duration
LAI - Leaf area index
$LSD_{0.05}$ - Least significant difference at 5% probability level
LRB - Limpopo River Basin
P - Phosphorus
$P_2O_5$ - Phosphorus pentoxide
REP - Replication
SWB - Soil Water Balance
USA - The United States of America
WFP - World Food Program of the United Nations
WUE - Water use efficiency
WP - Water productivity

# ABSTRACT

The southern region of Mozambique is characterized by arid to semi-arid climatic conditions with soils of poor fertility and low water retention capacity. The rainfall season is from September to April. In some areas, the rain season accommodates two production cycles, which is augmented by extended or unexpected rains in May and June. Maize is the main crop in this region. The major limiting factors for maize production in the Chókwè District under rainfed agriculture are rainfall amount and its distribution and soil fertility. Water productivity in this region is very low. The Challenge Program on Water and Food (CPWF), for which the slogan was “more crop per drop”, has attempted to identify and address water productivity constraints throughout the Limpopo River Basin (LRB). This study considers the water productivity in dryland areas, assuming that yields may not be only limited by water, but also by soil fertility. The study was aimed at investigating the improvement of water productivity by correcting nutrient deficiencies and recommending strategies to mitigate these deficiencies. A field experiment was conducted at Chókwè Agrarian Research Centre with maize cultivar (cv. Matuba). Matuba was selected because of its high tolerance to drought. Treatments were based on the most limiting soil nutrients at the experimental site. Crop parameters measured included total dry matter, fractional interception of photosynthetically active radiation ($FI_{PAR}$), leaf area and grain yield. In addition, the Soil Water Balance (SWB) model was used to simulate potential yields with no nutrient limitations. Results of this study illustrated that the application of N resulted in improvements in total dry matter yield, leaf area index (LAI), $FI_{PAR}$ and water use efficiency (WUE). Application of both N and P improved the grain yield, leaf area duration (LAD) and WUE. SWB model simulations indicate that in only 1 out of 5 years in Chókwè District, the simulated yields were not higher compared to actual yields (0.2 - 1 ton ha$^{-1}$). In conclusion, grain yield improvements are expected if nutrition is kept at optimum levels. This implies that in most years dryland yields are in fact nutrient limited and better nutrition can be used as a strategy to improve water productivity (WP) and grain yield.

*Keywords: water productivity, maize, dryland, nutrition, grain yield and SWB*

# INTRODUCTION AND PROBLEM STATEMENT

Both extensive and excellent pedologic-climatic conditions endow Mozambique vast areas of arable land. The main activity undertaken on it, is agriculture. However, most soils of Mozambique range from low to moderate in fertility; this constitutes a great limitation for the practice of agriculture, because it is necessary to add nutrients to the soil in order to increase yields (Menete & Chongo, 1999).

The southern region of Mozambique is characterized by arid to semi-arid climatic conditions with soils of poor fertility and low water retention capacity (Consultec, 1998). The decrease in soil fertility is a consequence of poor nutrient management, particularly in the small holder sector, where the use of chemical fertilizers is almost non-existent, they resort to increasing cultivated areas to boost their total yield (Folmer & Francisco, 1997).

Soils with moderate to light acidity prevail; also, there are very acidic soils, largely in the southern areas and along the coast of the country where sandy soils also occur. The scarce precipitation is unevenly distributed throughout the year, making these risky agricultural production regions (Menete & Chongo, 1999).

Dryland maize production accounts for about 96% of national maize production come from small scale and the remaining 4% come from the entrepreneurial sector where the farmers are larger and may involve irrigation and mechanization (FAEF, 2001). The average family farm size varies from 1 to 3 ha (Folmer & Francisco, 1997).

The Chókwè District, located in the lower Limpopo River Basin (LRB), is characterized by a semi-arid climate with dry air, and long dry spells coupled with high temperatures. The Chókwè District is also characterized by clay to silty clay soils with low to moderate fertility. The annual rainfall is on average 620 mm, with high variability within and between years. The annual reference evapotranspiration is about 1580 mm (FAO, 1984 and FAEF, 2001). It is reported by FAEF (2001) that approximately 95% of the rainfall occurs between October to April, on a number of isolated rain days and at isolated locations.

The area planted by small scale farmers is therefore determined by the amount of rainfall and its distribution and soil fertility (FAO & WFP, 2000).

According to FAEF (2001); Amaral & Sommerhalder (2004) water scarcity does not encourage farmers to use chemical fertilizers, and as a consequence yields obtained under dryland production are very low. Maize yield in Chókwè is on average between 200 to 300 kg $ha^{-1}$; varying according to the rainfall pattern and soil type. The probability of drought occurrence in this region is greater than 30% which limits maize production possibilities (FAEF, 2001).

The Challenge Program on Water and Food (CPWF), for which the slogan was “more crop per drop”, has attempted to identify and address Water Productivity (WP) constraints throughout the LRB. This study considers WP in dryland areas, assuming that yields may not only be limited by water, but also by soil fertility as stated by Amaral & Sommerhalder (2004). However, little local research has been done to improve WP through better nutrient management under dryland production in southern Mozambique. Therefore, this project investigated the improvement of WP by correcting nutrient deficiencies and recommending strategies to mitigate these deficiencies. In addition, the Soil Water Balance (SWB) model was used to simulate potential yields in Chókwè for different rainy seasons with non limiting nutrient conditions, in order to investigate the potential for this strategy.

For this study, three hypotheses were considered, (i) dryland yields in Chókwè, resource poor agriculture, are not limited by water, but rather by nutrients (ii) The nutrients limiting yields are both nitrogen (N) and phosphorus (P), and (iii) applying either N or P will improve WP, but not as much as when both are supplied.

# CHAPTER 1: LITERATURE REVIEW

## 1.1 Introduction

This chapter considers maize production and its uses, as well as the effects of nitrogen (N) and phosphorus (P) on maize grain yield and yield components. In, addition, guidelines for N and P application are posted. Finally, the effects of water limitation in different growth stages are illustrated.

## 1.2 Maize production in the world and Mozambique

According to Dowswell *et al.*, (1998); Du Toit, (1999) and Badu-Apraku & Farorede, (2006), world production of maize from 1999 to 2003 was estimated at about 611 million tons per year from 139 million ha. The main producers over this period were the United States of America (USA), China, Brazil, Mexico, France, Argentina and India.

Maize production in tropical Africa over the same period was estimated at 26.6 million tons per year from 21.2 million ha. The main producers in tropical Africa are Nigeria, Ethiopia, Tanzania, Kenya and Malawi (Du Toit, 1999). South Africa produced about 9.4 million tons per year from 3.6 million ha from 1999 to 2003 (Badu-Apraku and Farorede, 2006).

According to the National Statistical Institute (INE, 2008) maize production in Mozambique, increased from 2001 to 2005 to 1.1 million tons per year, while cultivated area also increasing from 1.3 to 1.4 million ha. However, it is reported by FAEF (2001) that maize yield in the Chókwè District, a resource poor cultivation area, is on average only between 200 to 300 kg ha$^{-1}$; varying according to the rainfall pattern and soil fertility.

## 1.3 Maize utilization

Maize grain is used for many purposes, as a staple food, for livestock and poultry, and as a raw material for many industrial products (Dowswell *et al.*, 1998). In tropical Africa, nearly all maize grain is used for human nutrition, prepared and consumed in many ways (Badu-Apraku and Farorede, 2006 and Dowswell *et al.*, 1998). It may be eaten fresh (cob) simply by roasting, but the grain is usually ground and the meal boiled into porridge or fermented into beer (Badu-Apraku and Farorede, 2006). Every part of the plant has economic value, the grain, leaves, and especially, the cobs are used to produce hundreds of food and non food products (Dowswell *et al.*, 1996).

## 1.4 Maize climatic and soil requirements

The maize crop is grown in climates ranging from temperate to tropical during the period when the mean daily temperatures are above $15^{o}C$ and frost free (Badu-Apraku and Farorede, 2006). The minimum temperature requirement for germination is $10^{o}C$. In general, maize should emerge within five to six days. The high temperature affecting yield is approximately $32^{o}C$. Frost can damage maize at all growth stages and, in general, requires a frost free period of 120 to 140 days to prevent damage (Du Toit, 1999).

The maize crop does well on most soils but not as well on heavy clay and sandy soils. The soil should preferably be well aerated, as the crop is susceptible to water logging. In general, maize can be successfully grown if soil fertility is maintained (Du Toit, 1999 and FAO, 2002).

According to Morais *et al.*, (2006) maize requires soils rich in organic matter, with medium texture (30 to 35% clay) or even clay soils with good structure and high water holding capacity. Sandy soils with less than 15% clay must be avoided if possible because of lower water holding capacity and high potential nutrient leaching. The Fertilizer Society of South Africa (FSSA, 2007) report that clay soils with montmorillonite have strong aggregation among soil particles; they are not good for root development, soil permeability and free penetration of the rooting system. The soil must be deeper than 1 m (Du Toit, 1999). Slope must be less than 12% with minimal risk of soil erosion. Du Toit (1999), Badu-Apraku and Farorede (2006) & FSSA (2007) highlight that maize performs well on soil with pH-$H_20$ ranging from 5 to 8, but 5.5 to 7 is optimal.

According to the FSSA (2007), soil acidity is generally one of the major limiting factors in crop production worldwide. Although the mechanisms causing soil acidity are well known, not enough is being done to successfully combat increasing soil acidity. Soil acidity is only a manifestation of soil degradation. Badu-Apraku and Farorede, (2006) & FSSA (2007), stated that it can result in complex changes in the soil, such as the increase in toxic levels of aluminium and manganese (Mn), inhibition of microbial processes, reduction of cation exchange capacity, reduced availability of soil P reserves and diminished solubility of molybdenum (Mo) and boron (Bo).

Menete and Chongo (1999) report that acid soils are in effect also stripped of key macronutrients such as calcium (Ca), magnesium (Mg) and potassium (K). A decrease in root growth coupled with the inability of plants to utilize water effectively and to take up sufficient quantities of plant nutrients is often visible with soil acidity. The lime requirement of soil can be defined as the amount of lime to be applied in order to ensure that soil acidity is not a limiting factor in crop production (Badu-Apraku and Farorede, 2006 & FSSA, 2007)). Liming ensures a more favourable soil environment in which plants can flourish (FSSA, 2007).

### 1.5 Maize varieties and planting density in Mozambique

Du Toit (1999) reported that maize spacing between rows varies between 0.60 to 1 m, and sowing depths from 5 to 7 cm with one to more seeds per sowing point or planting position and the plant population varies from 20000 to 30000 plants ha$^{-1}$ for the large late varieties and 50000 to 80000 plants ha$^{-1}$ for small earlier varieties.

The Faculty of Agronomy and Forestry Engineering (FAEF) of the Eduardo Mondlane University (FAEF, 2001) report that in Mozambique densities vary from 25000 to 40000 plants ha$^{-1}$ in dryland and 50000 to 60000 plants ha$^{-1}$ in irrigated areas. Matuba, Changalane and Djandza are classified as early to medium maturity cultivars, with 100 to 120 days to maturity and are adapted for dryland areas, while Sussuma and Tsangano are some of the late maturity cultivars with 130 to 150 days to maturity.

### 1.6 Nitrogen and phosphorus requirements

According to James *et al.*, (1982) P, K and N are classified as major nutrient elements because of the relatively large amounts consumed by plants. The management of P differs from that of N because of differences in their behaviour in soil. Menete & Chongo (1999) and FSSA (2007) report that N is mobile in the plant while P is quite immobile, moving from old to young leaves. In addition, James *et al.*, (1982) reports oxygen stress in soil has no effect on P, contrary to its effect through denitrification on N.

Maize usually responds well to N and P. N and P demands for maize are relatively high. For high producing maize cultivars, requirements exceed 200 kg N ha$^{-1}$ and 50 to 90 kg P ha$^{-1}$. In general maize can be grown as long as soil fertility is maintained (FAO & WFP, 2000). N is the major limiting nutrient to maize, but in parts of sub-saharian and southern Africa, P is also limiting (Laegrad *et al*, 1999).

Badu-Apraku and Farorede, (2006), found that maize cultivars with potential yields of 2 to 5 tons ha$^{-1}$ can remove about 60 kg N ha$^{-1}$ and 10 kg P ha$^{-1}$ from the soil. Table 1.1 indicates the amount of N and P removed per ton of maize grain as well as for the whole plant.

**TABLE 1.1: Nitrogen and phosphorus removed in kg nutrient ton$^{-1}$ of maize grain (FSSA, 2007)**

| Plant organ | Nitrogen | Phosphorus |
|---|---|---|
| Grain only | 15 | 3 |
| Whole plant(1) | 27 | 4.5 |

(1) Excluding roots

### 1.6.1 The role of nitrogen

According to the FSSA (2007), N plays an important role in photosynthesis, growth, respiration and reproduction. The most noticeable effect is the characteristic green colour of leaves and vegetative growth associated with N. It is reported by Menete & Chongo (1999) that N is the main essential macronutrient that plants need in great amounts to complete its life cycle. Cooke, (1967) and Menete & Chongo, (1999) report that N occurs in amino-acids found in proteins, enzymes and chlorophyll and usually its concentration is greater in seeds than in the leaves, stems and tubers.

According to Menete & Chongo (1999) and FSSA (2007), N absorption occurs in the form of ammonium ($NH_4^+$) or nitrate ($NO_3^-$). Menete & Chongo (1999), state that nitrates are easily absorbed and contribute to plant growth. FSSA (2007) reported that as a rule, the major portion of soil N occurs in the organic component. However, this is not available to plants and must therefore first be mobilized by microbiological processes, like ammonification and nitrification in the soil to N-forms that are available to plants.

### 1.6.2 Symptoms of nitrogen deficiencies in maize

Russele *et al* (1987) reports that a moderate N deficiency in an early growth stage may not reduce maize grain yield as long as sufficient N is supplied to the crop before silking. In addition, the application of N fertilizers can generally correct soil deficiencies. N deficiency is also common where it is applied below-optimal levels or where there are significant risks of drought, frost and or excessive leaching of nitrates (Lafitte & Edmeades, 1994).

Menete & Chongo, (1999) and FSSA (2007) report that its insufficiency or deficiency causes stagnation in photosynthesis; leaves become a very light green, at times even turning yellow. N deficiency yellowing shows up first in the older leaves and often forms an inverted *V* pattern along the midrib (Menete & Chongo, 1999: FSSA, 2007 and Potash and Phosphate Institute and Farmland Industries, 2007). Figures 1.1, 1.2, 1.3 and 1.4 illustrate different causes of N deficiency symptoms on the maize leaves.

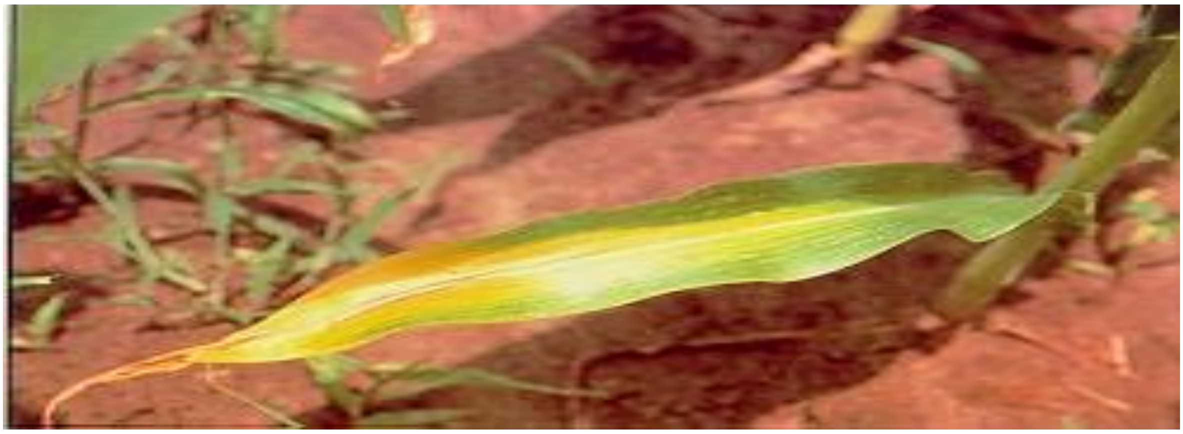


**FIGURE 1.1: Under-application of N fertilizer resulting in yellowing in a *V* shape (Potash and Phosphate Institute and Farmland Industries, 2007).**

**FIGURE 1.2: Leaching of nitrate by rainfall or irrigation causing yellowing of old leaves and stems (Potash and Phosphate Institute and Farmland Industries, 2007)**

**FIGURE 1.3: Overestimation of N release from manure resulting in yellowing of stems (Potash and Phosphate Institute and Farmland Industries, 2007)**

**FIGURE 1.4: Loss of N as a gas from soils caused by standing water or compaction resulting in yellowing of older leaves. (Potash and Phosphate Institute and Farmland Industries, 2007)**

### 1.6.3 Effect of nitrogen on maize grain yield and yield components

Russele *et al* (1987) found in a two year study conducted in the corn belt of the United States of America, that in soil with limitations in N supply capability, some of the N fertilizer should be applied early in the growth cycle of the crop to reduce serious early N deficiencies, and a greater amount should be applied as late in the vegetative growth stage as is practical.

The application of high rates of N can cause lodging of cereals, because the stem is thinner and the plant is taller. N is mobile in the plant and will move from old leaves to newer leaves. This phenomenon occurs because young leaves absorb more N necessary for growth and cell multiplication (Menete & Chongo, 1999).

### 1.6.4 Nitrogen application guidelines

N fertilizer should be applied in split applications. Apply N at planting and the balance should be applied before 5 to 6 weeks have elapsed since emergence as a side dressing under dryland maize cultivation. With irrigation systems, a portion of the N may be applied in the form of fertigation up to the last vegetative stage (FSSA, 2007). The FSSA (2007) guidelines for N fertilization assume that the relationship between maize yield and N requirement is strong enough to serve as a basis for the guideline. Table 1.2 illustrates the relationship between maize yield potential and N application rates obtained in FSSA trials.

**TABLE 1.2: The guideline for nitrogen fertilization in maize (FSSA, 2007)**

| Yield potential | **tons ha$^{-1}$** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| N application | **kg ha$^{-1}$** | | | | | | | | |
| | 20 | 45 | 70 | 95 | 120 | 145 | 170 | 195 | 220 |

Many factors that influence N use efficiencies have been investigated, including application method, N fertilizer type and soil types. One potentially important factor is the uncertainty faced by farmers deciding on the amount of fertilizer. This includes not knowing the existing supply of N available in the soil, because of various factors such as total soil N, organic matter, aeration and microbial activity (FSSA, 2007).

N should always be included in a planting mixture, but climatic factors and residual N content of the soil will determine when most N should be applied (Cassman *et al.*, 2002 as cited by Lobell, 2007). According to Du Toit (1999) most N should be applied early if seasonal rainfall is less than 700 mm and if N supply capacity of soil is low. When seasonal rainfall is above 700 mm and N supply capacity is high (as in clay soils), N can be applied later, but not later than eight weeks after planting.

### 1.6.5 The role of phosphorus

As far as the role in the plant is concerned, P like N, is important in photosynthesis, growth, respiration and reproduction, and also maintenance of genetic identity. In particular, P is associated with cell division, root growth, flowering and ripening (FSSA, 2007).

According to FSSA (2007), P commonly occurs naturally in soils in concentrations of 0.1 to 3 g kg$^{-1}$. In spite of this relatively high occurrence, plant availability of P in soils is often low. In addition, P occurs in the forms of non-liable P in soil minerals such as apatite and aluminium and iron compounds.

### 1.6.6 Symptoms of phosphorus deficiency

Maize P deficiency causes an abnormal dark green colour of leaves in young plants and reduced tillering in small grains. Purple colouration should not be confused with a build up of anthocyanin (Menete & Chongo, 1999 and FSSA, 2007). Figure 1.5 illustrates the symptoms of P deficiency in leaves of maize.

**FIGURE 1.5: P deficiency caused by under application of P fertilizer which results in abnormally dark green leaves in young plants (Potash and Phosphate Institute and Farmland Industries, 2007).**

### 1.6.7 Effect of phosphorus on yield components and grain yield

Menete & Chongo (1999), Plénet (2000) and FSSA (2007) report that growth is retarded if P is deficient, resulting in short internodes and thin stems. In maize, P deficiencies can impede cob formation, thereby reducing the grain yield.

Rodrigues *et al.* (1998) as cited by Plénet (2000) in a controlled environment using young plants, have shown that P deficiency increased the time between the appearance of two successive leaves (decreases radiation intercepted by the canopy) and reduced the leaf expansion rate even though the P content in the plant was above the limiting concentration for photosynthesis. This shows that P deficiency may affect plant growth not only through its effect on photosynthesis. In addition, they have shown that lower leaf area index (LAI) values were recorded in treatments to which P was not applied.

According to Menete & Chongo (1999), the effects of P on yield of many crops depend on the availability of other nutrients. There is a positive interaction between N and P on the yield of many crops. Well watered conditions are favourable for availability of P because of its low solubility.

### 1.6.8 Phosphorus application guidelines

Phosphate is not taken up easily by maize (Badu-Apraku and Farorede, 2006). The uptake of P by plants roots is exclusively through the process of diffusion. The contribution made by direct contact and mass flow uptake is negligible and, moreover, many tropical soils are deficient in available phosphate. It is advisable to apply organic manure before cultivating to improve soil structure and nutrient supply capacity. All the phosphate should be applied at planting or prior to planting, especially when the soil-P reserves are very low (FSSA, 2007).

There is a relationship between the amount of P in the soil and maize target yield. For soils with low soil P and for a high target yield, large amounts of P must be applied. Table 1.3 indicates the guideline for P fertilization of maize.

**TABLE 1.3: Guideline for phosphorus fertilization of maize (FSSA, 2007)**

| | **Yield potential in tons ha$^{-1}$** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Soil-P (Bray 1)** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| **mg kg$^{-1}$** | **Fertilizer requirement in kg ha$^{-1}$** | | | | | | | | |
| 0 - 4 | 20 | 42 | 65 | 88 | 109 | 130 | 130 | 130 | 130 |
| 5 - 7 | 17 | 31 | 47 | 63 | 67 | 90 | 93 | 95 | 97 |
| 8 - 14 | 13 | 19 | 30 | 42 | 50 | 59 | 64 | 67 | 68 |
| 15 - 20 | 10 | 13 | 21 | 29 | 36 | 42 | 47 | 50 | 53 |
| 21 - 27 | 7 | 10 | 15 | 19 | 26 | 31 | 34 | 38 | 41 |
| 28 - 34 | 6 | 9 | 12 | 15 | 18 | 22 | 24 | 27 | 30 |

### 1.7 Water use efficiency

It is reported by FAO (2002) that maize is an efficient user of water in terms of total dry matter yield and among the cereals it is potentially the highest yielding grain crop. For maximum production a medium maturity grain requires between 500 to 800 mm, depending on the climate. Dowswell *et al*. (1996), reports that in a tropical environment, maize requires 600 to 700 mm, and in temperate zones it requires 400 to 500 mm during the growing season.

Du Toit (1999) reports that in South Africa, maize yielding 3 tons ha$^{-1}$ requires between 350 to 450 mm. Approximately 10 to 16 kg of grain are produced per hectare for every mm of water used. Passioura (2006) reports that cereal crops attain maximum water productivity (water use efficiency) of 20 kg ha$^{-1}$ mm$^{-1}$ which is higher than oilseeds and grain legumes that range from 8 to 15 kg ha$^{-1}$ mm$^{-1}$. At maturity, each maize plant uses 250 litres of water if soil water stress does not occur.

According to Morais *et al*. (2006), in hot and dry areas of Brazil, maize water consumption does not exceed 3 mm day$^{-1}$ when the plant height is about 30 cm, and from the early flowering stage to maturity can reach up to 5 to 7 mm day$^{-1}$. Maize water consumption depends on atmospheric evaporative demand, canopy extension and soil physical properties. Several meanings of water consumption in crops can be given according to different points of view in different fields of interest. Table 1.4 illustrates the different meanings given by Passioura to water limiting conditions.

**TABLE 1.4: Drought definitions and significance (Adapted from Passioura, 2002)**

| Practitioner | Time scale | Significance |
|---|---|---|
| Meteorologist | Years | Risk management |
| Farmer and agronomist | Weeks to months, growing season | Water productivity |
| Plant physiologist | Days | Mild shock or survival |

### 1.7.1 Water limitation during the vegetative stage

According to FAO (2002), maize appears relatively tolerant to water limiting conditions during the vegetative stage and effects are relatively insignificant, but Pandey *et al.* (2000) reports that water limitation during vegetative growth is crucial to leaf area development and grain yield. A study conducted by Pandey *et al.* (2000) in Niger has shown that water stress during vegetative growth resulted in reduction in grain yield nearly proportional to the duration of water stress during the growing season and there was less transpiration under water limiting conditions. Table 1.5 illustrates the effect on grain yield through water stress in the vegetative stage.

**TABLE 1.5: Effect of water stress on maize grain yield during two seasons (Pandey *et al.*, 2000)**

| | **1996/1997** | **1997/1998** |
|---|---|---|
| **Irrigation regime** | **Grain yield (kg ha$^{-1}$)** | |
| No stress | 3447 | 3473 |
| Stress in early vegetative stage | 3064 | 2945 |
| Stress in late vegetative stage | 2669 | 2358 |

### 1.7.2 Water limitation during the flowering stage

The flowering stage in maize is vulnerable to plant water stress during anthesis, but the crop becomes less sensitive as the reproductive stage progress. The decrease in sensitivity is a consequence of an increasing supply of reserve assimilates later during grain development (Westgate *et al.*, 1988).

Severe water limitation during the flowering stage, particularly at the time of silking and pollination, may result in little or no grain yield due to silk drying (FAO, 2002). However, Westgate *et al.* (1988) report that when pollination occurs at low water potential, zygotes inevitably are formed but fail to develop beyond a few days. This developmental failure is not a direct effect of low silk water potential, since rehydration of the tissue prior to pollination does not recover grain numbers. This suggests that conditions within ovaries themselves may be affected directly by low water potential, but how plant water stress affects ovary water status and metabolism is not yet known.

Water stress that coincides with the flowering period can cause serious yield instability, because it allows no opportunity for farmers to replant or otherwise compensate for loss of yield (Kamara *et al.*, 2003). The main causes of barrenness in maize during water limitation is reduction in the flush of assimilates to the developing ear below some threshold level necessary to sustain grain formation and growth (Shussler & Westgate, 1995 as cited by Kamara *et al.*, 2003).

Water stress before silking may cause failure of ear development while after pollination results in limitation of kernel number (Claassen & Shaw, 1970; Harder *et al.*, 1982 as cited by Pandey *et al*., 2000). Maize is particularly sensitive to water stress that coincides with the tasseling-silking period, causing marked reductions in grain yield (Otegui *et al*., 1995).

NeSmith & Ritchie (1992) in Michigan in the USA have shown that yield reductions in excess of 90% can be caused by a water limitation during the tassel and silk emergence period in maize grown under dryland conditions. In addition, delayed emergence of tassels and silks in excess of two weeks was observed. Grain number per plant was the yield component most responsible for yield reductions, and the decrease in grain number was proportional to delays in tassel and silk emergence. Water stress during flowering can cause considerable reduction in yields of maize due to influences on reproductive components.

### 1.7.3 Water limitation during the grain filling stage

According to Dowswell *et al.* (1996), soil water stress during grain filling can reduce final grain size and effects on yield are significant. This is supported by Westgate *et al.* (1988) who report that water limitation during grain filling have effects on grain development which continue, even when photosynthesis is inhibited if reserves are available.

## 1.8 Effect of limited water on leaf area index

Table 1.6 illustrates the effect of limited water on leaf area index (LAI) at silking (S), recorded for two cropping seasons. For both seasons maize LAI was significantly different from twenty days before silking (S-20), to twenty days after silking (S+20), due to water limitation, reduced leaf expansion and leaf senescence. Otegui *et al* (1995) reported that reductions in LAI before silking are mainly due to reduced leaf area expansion, whilst after silking, reductions are produced exclusively by accelerated leaf senescence.

**TABLE 1.6: The effect of limited water on LAI (Otegui *et al.*, 1995)**

| **Planting date** | **Treatment** | **LAI** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1988/89** | | | **1989/90** | | |
| | | **S - 20** | **S** | **S+20** | **S - 20** | **S** | **S+20** |
| 12 October | No water stress | 2.60 | 5.63 | 4.18 | 1.91 | 5.41 | 5.26 |
| | Water stress | 2.43 | 5.03 | 3.27 | 1.91 | 4.80 | 4.19 |
| 23 November | No water stress | 2.70 | 5.18 | 4.02 | 3.49 | 5.08 | 3.87 |
| | Water stress | 2.70 | 4.80 | 3.40 | 3.21 | 4.52 | 3.73 |

Silking (S), Twenty days before silking (S-20) and twenty days after silking (S+20)

LAI reduction under water limiting conditions was greater for the second sowing of 1989/90 at late planting. Water limitation during maize vegetative growth stage is crucial to leaf area development and subsequent LAI expansion (Pandey *et al.*, 2000).

### 1.9 Effect of water stress on total dry matter production

According to Kamara *et al.* (2003), total above ground dry matter production is a good estimator of the degree of adaptation of genotype to the environment in which it is grown. It is reported by Kamprath *et al.* (1982) as cited by Kamara *et al.* (2003) that, after eight cycles of recurrent selection, the differences in total above ground dry matter accumulation between maize varieties reflects differences in assimilate efficiencies. Otegui *et al.* (1995) reported that the total above ground dry matter accumulation is correlated with crop evapotranspiration; less water in the soil could result in low transpiration. Moser *et al.* (2006) have shown that varieties respond individually to water limitation, but there is little evidence that the variations in grain yield response to water limit were due to variations in physiological traits that co-determine the tolerance to pre-anthesis drought.

Considering the discussion in this chapter on the effect of N, P and water limitations on maize productivity and the Challenge Program’s goal of “more crop per drop”, a research study was designed and conducted in Chókwè District. The aim of this study was to investigate a strategy to improve water productivity (WP) by eliminating nutrient deficiency as stated in the Introduction and Problem Statement. The detailed description of the Experimental set up is presented in Chapter 2.

# CHAPTER 2: MATERIALS AND METHODS

## 2.1 Study area description

A field experiment was conducted at Chókwè Agrarian Research Centre, Chókwè District, southern Mozambique, in the lower Limpopo River Basin (LRB), from 16 December 2007 to 24 April 2008. The experimental site is located at latitude 24°32’S and longitude 33°00’E and is 33 m above sea level. The Chókwè District is characterized by a semi-arid climate with a hot summer and dry winter season (FAO, 1984; Amaral & Sommerhalder, 2004). The average annual precipitation of Chókwè is 622 mm, falling mainly from October to March, and the annual reference evapotranspiration is 1580 mm (FAO, 1984). Figure 2.1 shows the location of Chókwè District in the LRB.

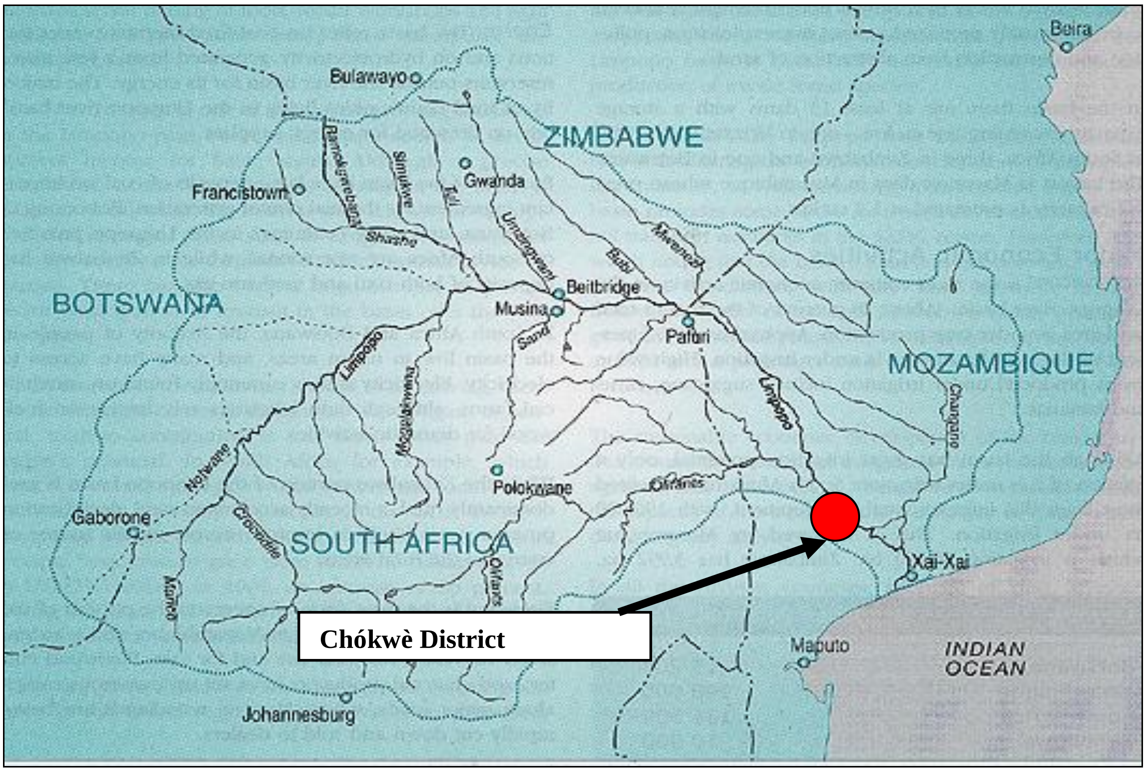


**FIGURE 2.1: Location of Chókwè District in the Limpopo River Basin (INIA, 1996)**

## 2.2 Experimental design

The experimental plots were arranged in a randomized complete block design replicated three times. Nitrogen (N) and phosphorus (P) treatment combinations were assigned randomly to the plots. Treatment randomization was done with *Cropstat* software. There were fifteen plots, each 8 m X 5 m in size. There were 10 rows per plot and each row had 14 plants. The total area of the trial was 812 $m^2$ including paths between plots.

## 2.3 Treatments and experimental procedure

Considering soil analyses, N and P seem to be nutrients that limit dryland resource poor maize crop production in the Chókwè District. It is important that research highlights the factors that limit production, at the importance of addressing these in an attempt to more efficiently use scarce water resources and to achieve an improvement in water productivity (WP) and grain yield.

Soil samples were collected from the top 20 cm of the soil profile for chemical and physical analyses. As recommended by INIA (1996) and FSSA (2007), initially ten sub-samples in the experimental area were collected and mixed in a clean bag. After mixing the ten sub-samples, stones and other material that were present were removed. About one kg of mixed soil sample, which constituted a representative sample of the experimental area, was taken for chemical and physical analyses.

The soil analyses indicated that the experimental area had low levels of N and P, however, calcium (Ca), magnesium (Mg) and potassium (K) were considered to be high and in the range stated by FSSA (2007) as acceptable for maize. The pH was considered slightly alkaline; Mg and the Ca/Mg ratio were in the optimal range for maize as recommended by INIA (1996) and FSSA (2007). Soil texture was classified as silty clay. Detailed chemical and physical soil characteristics of the experimental site are presented in Table 2.1.

**TABLE 2.1: Soil chemical and physical analysis data for Chókwè Agrarian Research Centre in the 0 - 20 cm layer**

| Factor | Level | Factor | Level |
|---|---|---|---|
| Ca (mg $kg^{-1}$) | $4060^{*}$ | pH - $H_2O$ | $7.6^{**}$ |
| Mg (mg $kg^{-1}$) | $1464^{*}$ | P-Olsen (mg $kg^{-1}$) | $5.3^{***}$ |
| K (mg $kg^{-1}$) | $587^{*}$ | Organic matter (%) | 2.3 |
| Na (mg $kg^{-1}$) | $230^{*}$ | N – Total (%) | $0.003^{****}$ |
| Ca/Mg ratio | $2.8^{**}$ | C/N ratio | 11.9 |
| Mg/K ratio | $2.5^{**}$ | Sand (%) | 15.3 |
| (Ca + Mg)/K ratio | $9.4^{**}$ | Silt (%) | 40.8 |
| $CaCO_3$ (%) | <0.50 | Clay (%) | 43.9 |
| $EC_{1:2.5}$ (mS $m^{-1}$) | 20 | Soil texture | Silty clay |

$^{*}$Classified as high for most crops (FSSA, 2007), $^{**}$Optimal for maize, $^{***}$Low for maize (INIA, 1996 & FSSA, 2007) and $^{****}$Low for maize (INIA, 1996).

The treatments are denoted by the letters N and P, with subscript following the N and P to denote the rate, in kg $ha^{-1}$, of the nutrient applied. Five combinations of N and P treatments were selected for this experiment, resulting in:

○ $N_0P_0$ (control): Plants in this treatment were not fertilized with N or P during the growing season. The conceptualization for this treatment is that both N and P are limiting factors for maize grain yield for this site. Water supply will not limit grain yield. The expected yield potential 200 to 300 kg $ha^{-1}$, which represents the yield currently achieved by resources poor farmers that do not fertilize their crops in Chókwè.

○ $N_{45}P_0$: Plants were fertilized only with 45 kg $ha^{-1}$ of N. The conceptualization for this treatment is that supplying maize only with N could improve water productivity. This assumes that P is a limiting factor. Expected yield potential was 3000 kg $ha^{-1}$, as reported by FSSA (2007).

○ $N_0P_{25}$: Plants were fertilized only with 25 kg $ha^{-1}$ of P. The conceptualization for this treatment is that supplying the maize crop with only P, could improve water productivity, assuming that N is the limiting factor. The expected potential yield was 3000 kg $ha^{-1}$, as reported by FSSA (2007).

○ $N_{45}P_{25}$: Plants were fertilized with 45 kg ha$^{-1}$ of N and 25 kg ha$^{-1}$ of P. The conceptualization for this treatment is that supplying the maize crop with both N and P in well balanced amounts will improve water productivity, assuming that N and P could be the limiting factor but not water supply. The expected potential yield was 3000 kg ha$^{-1}$, as reported by FSSA (2007).

○ $N_{120}P_{70}$: Plants were fertilized with 120 kg N ha$^{-1}$ and 70 kg P ha$^{-1}$. The conceptualization for this treatment is that both N and P will not limit maize yield. Assuming normal well distributed seasonal rainfall conditions of 620 mm. The expected potential yield was 6000 kg ha$^{-1}$, as reported by FSSA (2007).

Plots were planted manually at a row spacing of 80 cm and 35 cm within the row, giving a plant population of 35,714 plants ha$^{-1}$. The open pollinated maize cultivar Matuba (medium maturity) was used in the experiment. Matuba is recommended for dryland agriculture in southern Mozambique because of its high tolerance to drought (INIA, 1996 & personal communication with Fato, 2007). Figure 2.2 shows the experimental layout. The arrows indicate rows in the plots

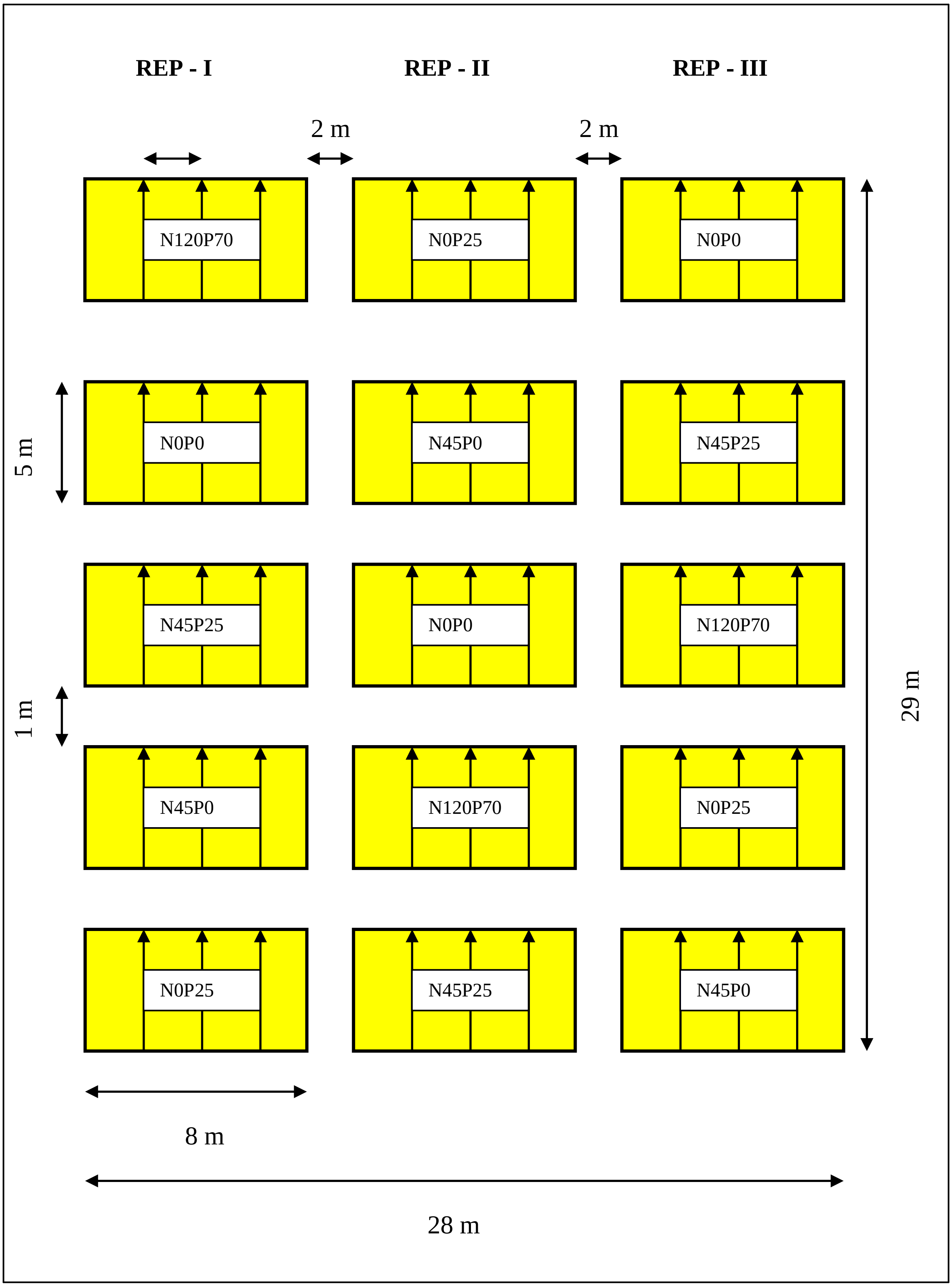


FIGURE 2.2: Experimental layout with five N and P treatments replicated three times.

N, if applied, was split into two applications during the growing season as recommended by FSSA (2007) for dryland conditions. Half was applied at planting and the remainder as a top dressing 35 days after sowing (DAS). All the P was applied at planting as recommended by the FSSA (2007). N was applied in the form of Urea (46% nitrogen), while P was in the form of single super phosphate (19.5% $P_2O_5$). Table 2.2 summarizes the agronomic practices followed.

**TABLE 2.2**: **Agronomic practices applied during the growing season**

| **Agronomic practice** | **Date/Application time/rate** |
|---|---|
| Planting date | 16 December 2007 |
| Plant population | 35,714 plants $ha^{-1}$ |
| Access tube installation | 10 December 2007 |
| Soil water measurements | Weekly |
| **Fertilizers application rates** | |
| Nitrogen and Phosphorus ($N_0$ and $P_0$) | No N or P applied |
| Nitrogen ($N_{45}$ and $N_{120}$) | 50% at planting and 50% 35 DAS |
| Phosphorus ($P_{25}$ and $P_{70}$) | All P applied at planting |
| Weed control | 15, 30, 45 and 60 DAS |
| **Pest management** | |
| Seed treatment by Apron Star 42 WS | 1 day before seeding (250 g/100 kg seed) |
| Growth analysis | Weekly |
| Harvesting | 120 DAS (18 April 2008) |

Weeds were controlled by hand hoeing. N and P application and harvest were also all done manually. No major incidences of disease and insects pests were identified during the growing season. Seed was treated with the chemical Apron Star 42 WS to limit damage from *Agriotes, Rhopalosiphum, Aphis spp., Myzus persicae, Cicadulina* and *Thrips*.

Fifteen access tubes were installed to measure the soil water content in the middle of each plot. Measurements were taken weekly using the AquaPro Soil Water Meter (AP 204 Soil Moisture Meter, Standard Portable probe system) in each plot at 0.15 m soil depth increments down to a soil depth of 0.75 m. The length of access tube was 75 cm. The AquaPro Soil Water Meter was calibrated specifically for the experimental area. Soil profile water content was monitored from the time of planting which was done after the first rain event, so the soil profile was assumed to be at field capacity (FC).

A water balance was determined in all cropping seasons to investigate whether the poor yields in Chókwè District were nutrient limited. Crop model parameters will also be determined for the Soil Water Balance (SWB) model, (calculated in Section 2.5) and used with historical weather data to simulate potential yields.

## 2.4 Growth analysis and sampling approach

Growth analyses were undertaken to evaluate the N and P treatment combinations under experimental conditions and, to evaluate if yields would be water limited. In addition, those analysis provided data for model development and testing so that potential yields in the Chókwè District could be estimated with some confidence. All three replicates were used for destructive harvesting to conduct total above ground dry matter yield measurements as well as for leaf area measurement. An area of 0.84 m$^2$ per plot (three plants) was sampled weekly per plot. Total above ground dry matter was recorded after oven drying at 65$^o$C for five days. Total above ground dry matter yield was determined as the mass of leaves, cobs and stems, measured together. The plots were sufficient in size to allow for destructive measurements without any discernable border effects.

Leaf area index (LAI) was calculated from the one-sided green leaf area measured with a LI 3100 belt driven leaf area meter (LiCor, Lincoln, Nebraska, USA) and the ground sampling area of 0.84 m$^2$. According to Hunt (1990) and Bavec & Bavec (2002), the equations for LAI and leaf area duration (LAD) determinations are:

$$LAI = \frac{LA}{SA} \qquad (2.1)$$

Where, LA is the sampled leaf area and SA is sampled ground area, both in m$^2$ with LAI the leaf area index for which the units are m$^2$ leaf m$^{-2}$ ground.

$$LAD = \frac{[LAI_n + LAI_{n-1}][t_n - t_{n-1}]}{2} \qquad (2.2)$$

Where, LAI$_n$ and LAI$_{n-1}$ are the leaf area at time n (t$_n$) and time n-1 (t$_{n-1}$) respectively; LAD is measured in days m$^2$ m$^{-2}$.

Fractional interception of photosynthetically active radiation ($FI_{PAR}$) was measured weekly between 11:30 and 13:00. Radiation was measured at two heights, one reading above and the second below the canopy, using a Sunfleck Ceptometer (Decagon, Pullman, Washington, USA). $FI_{PAR}$ can be obtained by the following equation (Andrade *et al.*, 1992).

$$FI_{PAR} = (1 - \frac{I}{Io}) \qquad (2.3)$$

Where, I is the incident PAR at ground level below the crop canopy and Io is incident PAR above the crop canopy.

Harvesting was done on a central row of 3 m (8 plants). The net plot area was 2.4 $m^2$ and was harvested by cutting down all the plants and measuring total above ground dry matter production as the sum of leaves, cobs and stems. The cobs were dried to 13% grain moisture content.

Water use efficiency (WUE) is defined by Du Toit (1999) and Panda *et al.* (2004) as the ratio between the grain yield expressed in kg $ha^{-1}$ and the water used in mm. WUE was calculated by the equation:

$$WUE = \frac{GY}{WU} \qquad (2.4)$$

Where, GY is the grain yield in kg $ha^{-1}$ obtained by the field measurement and WU is the water use in mm with WUE in kg $ha^{-1}$ $mm^{-1}$.

Weather data were collected daily from an automatic weather station (Mike Cotton Systems, Cape Town, South Africa) located near to the experimental site. The weather data and field crop measurements were used to estimate crop parameters for the Soil Water Balance model. Historical weather data (five years) from Chókwè District were obtained and used to simulate potential yields.

### 2.5 Crop parameter determination

Seasonal crop evapotranspiration (ET) was calculated using the following equation (Jovanovic *et al*, 1999):

$$ET = P - R - D - \Delta Q \qquad (2.5)$$

Where R is runoff, D is drainage and $\Delta Q$ indicates the change in soil water storage for the top 0.75 m soil layer. Bunds around the plots were installed to avoid R and no high intensity rainfall (precipitation) occurred, and D was also assumed to be zero. P is the rainfall that occurred during the growing season and ΔQ was calculated from soil water content measurements with an AquaPro Soil Water Meter. All are expressed in mm.

Dry matter water ratio (DWR) is a crop specific parameter representing water use efficiency corrected for vapour pressure deficit. DWR was estimated using the equation according to Tanner & Sinclair (1983):

$$DWR = \frac{DM * VPD}{ET} \qquad (2.6)$$

DM (kg $m^{-2}$) was measured at harvest, while VPD represents a seasonal average in Pa, ET is in mm which is equivalent to kg $m^{-2}$, thereby giving units for DWR of Pa. VPD was calculated following the equation in Jovanovic & Annandale (2000):

$$VPD = [(e_{sTmax} + e_{sTmin})]/2 - e_a \qquad (2.7)$$

Where, $e_{sTmax}$ is the saturated vapour pressure at maximum air temperature (Pa), $e_{sTmin}$ is the saturated vapour pressure at minimum air temperature (Pa) and $e_a$ actual vapour pressure (Pa).

Saturated vapour pressures ($e_s$) at maximum ($T_{max}$) and minimum ($T_{min}$) air temperatures were calculated by replacing T with $T_{max}$ and $T_{min}$ ($T_{max}$ and $T_{min}$ in $^oC$) in the following equation (Tetens, 1930 as cited by Jovanovic & Annandale, 2000):

$$e_{s\,=}\ 0.611exp[17.27T/(T + 273.3)] \qquad (2.10)$$

Actual vapour pressure ($e_a$) was calculated as a function of percent relative humidity, as follows (Bosen, 1958):

$$e_a = [e_s(T_{min})*RH_{max}/100 + e_s(T_{max})*RH_{min}/100]/2 \qquad (2.11)$$

Radiation use efficiency (Ec) is a crop specific parameter used to calculate dry matter production under conditions of radiation limited growth and can be calculated by the equation of Monteith (1977):

$$DM = Ec*(FI_{Solar}*RS) \qquad (2.12)$$

DM (kg $m^{-2}$) is dry matter measured at harvest, while Ec represents the radiation use efficiency in g $MJ^{-1}$. FI is the fractional interception of solar radiation and RS is the solar radiation. $FI_{Solar}$*RS is the product of factional interception of solar radiation and solar radiation expressed in W $m^{-2}$.

Emergence day degrees, flowering day degrees and day degrees to maturity were calculated based on field measurements as explained in Jovanovic & Annandale (2000). Maximum crop height (m) was measured in the field during the growing season.

Other crop parameters such as base temperature ($^oC$), optimum light limited temperature ($^oC$) and cut off temperature ($^oC$) were obtained from Du Toit (1999) and Badu-Apratu *et al.* (2006). Transition period day degrees (d $^oC$), day degrees for leaf senescence (d $^oC$), maximum root depth (m), stem to grain translocation parameter, canopy storage (mm), minimum leaf water potential (kPa) at maximum transpiration, maximum transpiration (mm $day^{-1}$), specific leaf area ($m^2$ $kg^{-1}$), leaf - stem partition parameter ($m^2$ $kg^{-1}$), TDM at emergence (kg $m^{-2}$), root fraction, root growth rate and stress index were obtained from the SWB database (Jovanovic & Annandale, 2000).

**2.6 Data analyses**

Statistical analysis of data where performed using the Statistical Analysis System (SAS) for Windows V8.0. Analyses of Variance (ANOVA) were performed for all measured parameters (maximum LAI, maximum $FI_{PAR}$, final TDM and grain yield). Means of these parameters were compared using the least significant difference test at a probability level of 5% ($LSD_{0.05}$), where ANOVA indicated significant diferences. A correlation between total dry matter yield and leaf area duration was also computed using MS Office Excel 2003.

Crop parameters for the cultivar Matuba and soil and climatic data from the experimental site observed during the growing season were used to calibrate the Soil Water Balance (SWB) model. Based on the results of this calibration, historical weather data were used to simulate potential nutrient non limiting yields for the Chókwè District. Results were analysed and are discussed in Chapter 3.

# CHAPTER 3: RESULTS AND DISCUSSION

## 3.1 Introduction

The results of field measurements to be discussed in this chapter include total dry matter yield, leaf area index (LAI), fractional interception of photosynthetically active radiation ($FI_{PAR}$), and grain yield. These parameters, excluding the grain yield, were recorded weekly. Leaf area duration (LAD) was computed based on LAI over time. Sections 3.2 and 3.3 show graphs for LAI and $FI_{PAR}$ followed by discussion of these parameters as influenced by N and P treatments applied. Appendix C shows the statistical procedure used for ANOVA of all field measured parameters.

## 3.2 Leaf area index

The changes in LAI throughout the growing season for all five N and P treatment combinations are presented in Figure 3.1. The curves showed typical sigmoidal growth patterns with rapid leaf expansion after an initial slow start and then slow as the reproductive phase is reached. The highest value for LAI was 5.0, observed at 61 days after sowing (DAS) in the $N_{120}P_{70}$ treatment, while the $N_0P_0$ treatment recorded the lowest value of 2.5, also at 61 DAS.

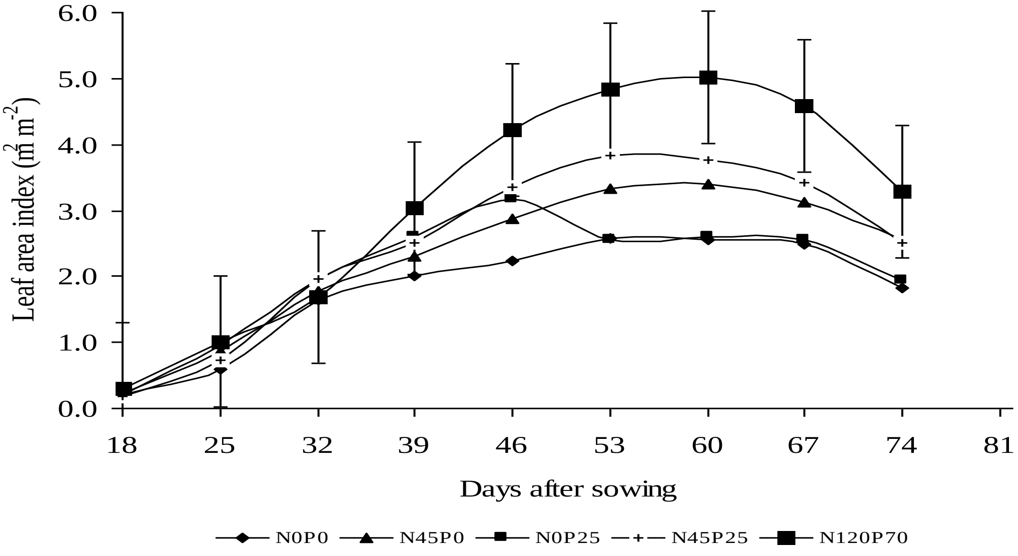


**FIGURE 3.1: Seasonal change in LAI for the five N and P treatments during the growing season. Vertical lines indicate LSD bars**

### 3.3 Fractional interception of photosynthetically active radiation

The $FI_{PAR}$ curves for the different treatments are shown in Figure 3.2. In general, the curves of the five N and P treatment combinations showed similar trends during the growing season. The $N_{120}P_{70}$ treatment had the highest $FI_{PAR}$ from nearly 55 DAS to the end of the growing season, while the $N_0P_0$ treatment had the lowest $FI_{PAR}$ value from 28 DAS onwards.

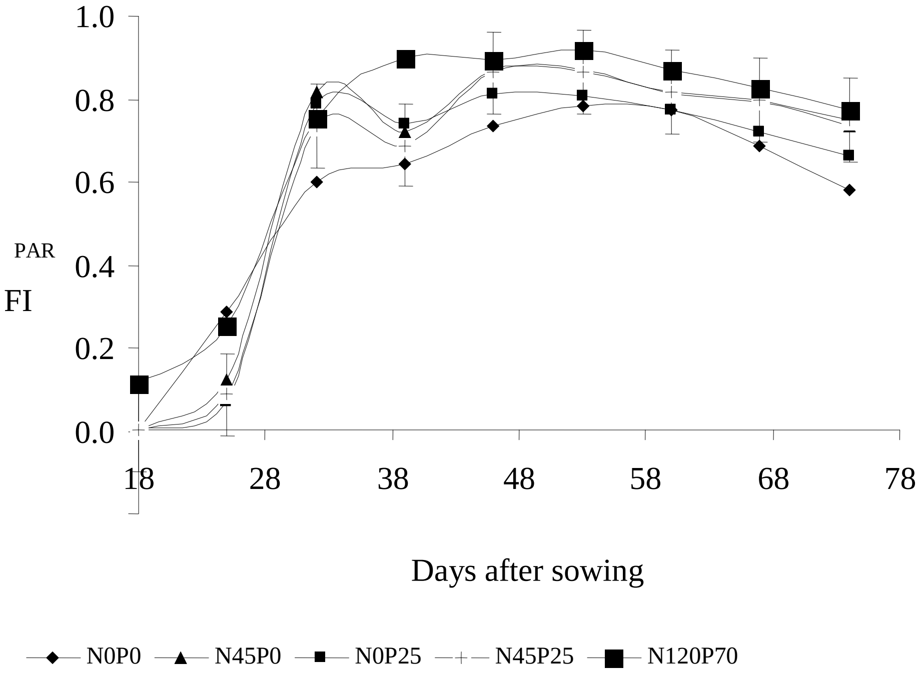


**FIGURE 3.2: $FI_{PAR}$ for the five N and P treatment combinations during the growing season. Vertical lines are LSD bars**

### 3.4 General discussion

In relation to LAI, the $N_{120}P_{70}$ treatment had a significantly higher LAI value during the growing season compared to all other treatments. The $N_{45}P_{25}$ and $N_{45}P_0$ treatments did not differ significantly in maximum LAI. Likewise, the $N_0P_{25}$ and $N_0P_0$ treatments also did not show significant differences in terms of maximum LAI. However, the $N_{45}P_0$ and $N_0P_{25}$ treatments did differ significantly in maximum LAI. Lemcoff & Loomis (1994) observed that N deficiency reduced LAI in a two year study, but Plenet (2000) reports that deficiency in P can reduce LAI in maize depending on the soil P availability. From these statements it seems that N could be the most limiting for LAI. LAI maximum values are shown in Table 3.1.

Finally, maximum $FI_{PAR}$ values recorded are also shown in Table 3.1. Here it can be seen that the $N_{120}P_{70}$ treatment had a significantly greater maximum $FI_{PAR}$ than the other treatments. The $N_{45}P_{25}$ and $N_{45}P_0$ treatments did not show significant differences as was the case for the $N_0P_{25}$ and $N_0P_0$ treatments. It seems that the rates of P applied did not, therefore, significantly affect radiant interception. LAI is the canopy structure parameter and radiation interception is its function (Jones & Kiniry, 1986). At these levels P seems not to limit $FI_{PAR}$, but N clearly does, as expected. High LAI results in high $FI_{PAR}$, as can be seen in Table 3.1.

**TABLE 3.1: Maximum LAI and maximum $FI_{PAR}$ obtained during the growing season**

| Treatment | Maximum LAI in $m^2$ $m^{-2}$ (61 DAS) | Maximum $FI_{PAR}$ (53 DAE) |
|---|---|---|
| $N_{120}P_{70}$ | 5.00a | 0.92a |
| $N_{45}P_{25}$ | 3.03b | 0.86b |
| $N_{45}P_0$ | 2.73b | 0.86b |
| $N_0P_{25}$ | 2.07c | 0.80c |
| $N_0P_0$ | 2.03c | 0.78c |
| CV (%) | 8.3 | 2.2 |
| Mean | 2.8 | 0.85 |
| $LSD_{0.05}$ | 0.65 | 0.05 |

Means followed by the same letter in column are not significantly different at $p = 0.05$

### 3.5 Correlation between leaf area duration and total dry matter yield

Table 3.2 summarizes the final LAD values of all the N and P treatment combinations. LAD gives an indication of the length of time that foliage remains photosynthetically active and reflects the extent of radiation interception (Hunt, 1990). From Table 3.2 it can be seen that final LAD was greatest for the $N_{120}P_{70}$ treatment (155 days $m^2$ $m^{-2}$). The $N_0P_0$ treatment had the lowest final LAD value of only 90 days $m^2$ $m^{-2}$. In Section 3.2 and 3.3 it is stated that N and P significantly affected LAI, and therefore this will also affect LAD.

Final LAD for $N_{120}P_{70}$, $N_{45}P_{25}$, $N_0P_{25}$ and $N_{45}P_0$ treatments compared to the $N_0P_0$ treatment (control) increased by 65, 37, 19 and 24 days $m^2$ $m^{-2}$. These differences between treatments were expected mainly due to the effect of N on dry matter accumulation and LAI as reported by Lemcoff & Loomis (1994), Du Toit (1999) and FSSA (2007). It is clear that N improved final LAD. As an example, the correlation between LAD and TDM yield for the $N_{120}P_{70}$ treatment is presented in Figure 3.3. A linear relationship between LAD and TDM yield was found in all treatments as indicated in for example in Figure 3.3. Table 3.2 indicates final leaf area duration and the coefficient of determination of the five treatments.

**TABLE 3.2: Determination coefficients ($r^2$) between LAD and TDM yield obtained during the growing season**

| Treatment | Final LAD (day $m^2$ $m^{-2}$) | $r^2$ of LAD vs. TDM yield (kg $m^{-2}$) |
|---|---|---|
| $N_{120}P_{70}$ | 155 | 0.85 |
| $N_{45}P_{25}$ | 127 | 0.88 |
| $N_{45}P_0$ | 114 | 0.85 |
| $N_0P_{25}$ | 109 | 0.91 |
| $N_0P_0$ | 90 | 0.86 |

Annandale (1987) used a linear relationship to explain grain yield of wheat under different soil fertility and water supply conditions. The longer a large canopy is maintained, the more dry matter is produced. High total dry matter yield resulted in greater LAD in all treatments, with greater LAD for the nutrient non limiting treatment ($N_{120}P_{70}$ treatment). For all treatments the coefficient of determination ($R^2$) between LAD and TDM yield was high, as can be seen in Figure 3.3. The relationship between LAD and TDM yield for the rest of treatments can be seen in Appendix A.

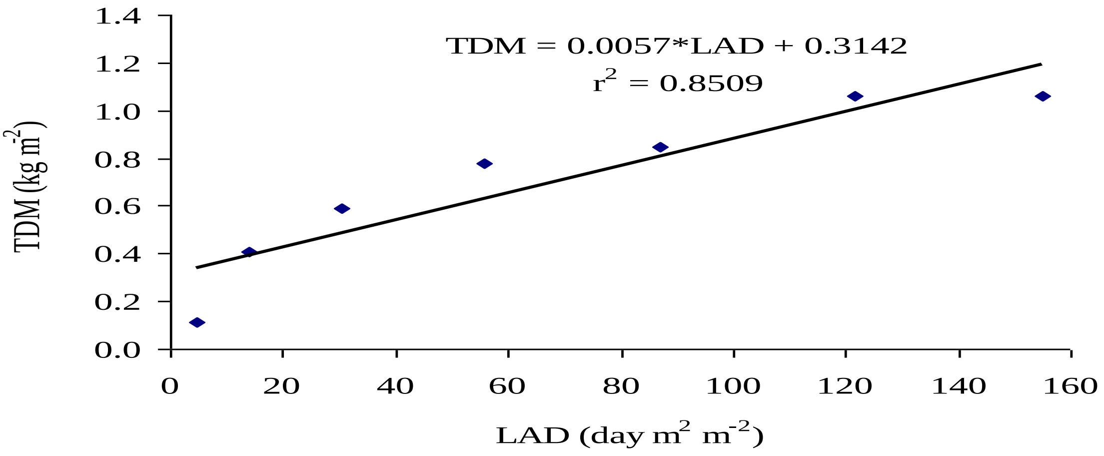


**FIGURE 3.3: Relationship between LAD and TDM yield for $N_{120}P_{70}$**

### 3.6 Total dry matter yield and maize grain yield

The total above ground dry matter yield (TDM) over the growing season is shown in Figure 3.4. The curves for all N and P treatments showed similar trends between 18 to nearly 33 DAS. The $N_{120}P_{70}$ treatment showed high TDM yield during the growing season from 25 DAS onwards compared to all treatments. The $N_0P_0$ treatment showed lowest TDM yield from about 35 DAS up to the end of the field measurements compared to all other nitrogen and phosphorus treatments.

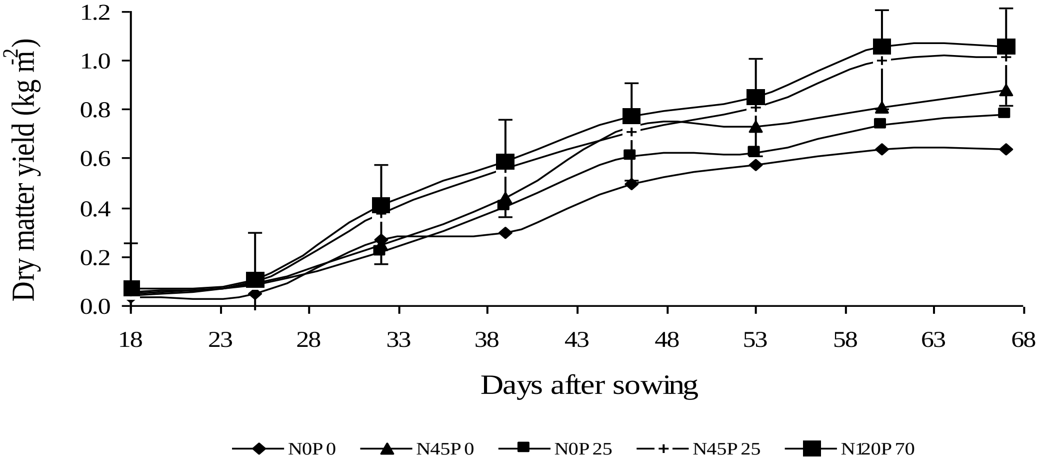


**FIGURE 3.4: Maize TDM yield for all treatments during the growing season. Vertical lines indicate LSD bars.**

Final TDM of the $N_{120}P_{70}$ treatment was significantly greater than all other treatments. The $N_{45}P_0$ and $N_{25}P_0$ treatments did not differ significantly in final TDM yield. From, these results, it seems that N and P separately did not give significant increases in TDM yield, while both N and P application had a significant effect on TDM yield.

The TDM yield is a result of crop canopy efficiency in intercepting and utilizing the solar radiation available (Gardner, 1985). Balanced N and P treatments produced higher TDM yield, in accordance with the study of Annandale (1987). The differences in final TDM yield are mainly due to the rates of both N and P applied. It seems from these results, the

TDM responses to P vary. So, the response of TDM yield depends on both N and P. According to FSSA (2007) there is a relationship between N and maize grain yield, also there is relationship between P and maize grain yield. The plots were harvest on same day. Table 3.3 presents final TDM yields and grain yield per treatment applied.

**TABLE 3.3: Final TDM and grain yield**

| **Treatment** | **Final TDM yield (tons ha$^{-1}$)** | **Grain yield (tons ha$^{-1}$)** |
|---|---|---|
| $N_{120}P_{70}$ | 10.8a | 4.8a |
| $N_{45}P_{25}$ | 9.4b | 2.7b |
| $N_{45}P_0$ | 8.0c | 1.9c |
| $N_0P_{25}$ | 7.7c | 1.8c |
| $N_0P_0$ | 6.3d | 0.9d |
| CV (%) | 5.49 | 2.4 |
| Average | 8.5 | 3.8 |
| $LSD_{0.05}$ | 0.13 | 0.5 |

Means followed by the same letter in column are not significantly different at p = 0.05

The $N_{120}P_{70}$ and $N_0P_0$ treatments gave the highest and the lowest grain yields of 4.8 and 0.9 tons ha$^{-1}$. The $N_{45}P_0$ and $N_0P_{25}$ treatments grain yield did not differ significantly. Separate application of N and P differed significantly compared to application of both N and P ($N_{45}P_{25}$).

Application of only 45 kg N ha$^{-1}$ gave the same grain yield of 2 tons ha$^{-1}$compared to an application only of 25 kg P ha$^{-1}$. It is stated by the FSSA (2007) that application of 120 kg N ha$^{-1}$ and 70 kg P ha$^{-1}$ is expected to give 6 tons ha$^{-1}$ if rain is not limiting. From the results obtained, separate applications of N and P did not differ significantly.

FSSA (2007) report that the response of grain yield to P depends on the level of P in the soil. This is supported by Moser *et al*, (2006) whose three year study under dryland conditions applied 80 kg P ha$^{-1}$ and 10 kg P ha$^{-1}$ and obtained grain yields of 5 to 6 tons ha$^{-1}$. It seems that differences in maize grain yield are mainly due to the application of both N and P. Also, similarly final TDM yield results indicated that variations are mainly due to application of both N and P nutrients as stated in section 3.5. Also, it seems that N and P had similar response with LAI and $FI_{PAR}$.

### 3.7 Water use efficiency

Water use efficiency (WUE) is defined by Du Toit (1999) and Panda *et al.* (2004) as the ratio of grain yield to the total WU per unit area, generally expressed in kg ha$^{-1}$ mm$^{-1}$. The length of access tube was 75 cm and in this case was considered sufficient because dryland root system do not develop that deeply. The WU as well as WUE recorded are given in Table 3.4.

**TABLE 3.4: WU and WUE of five N and P treatment combinations**

| **Treatment** | **Grain yield (kg ha$^{-1}$)** | **Rain (mm)** | **$I_\theta$ (mm)** | **$F_\theta$ (mm)** | **WU (mm)** | **WUE (kg ha$^{-1}$ mm$^{-1}$)** |
|---|---|---|---|---|---|---|
| $N_{120}P_{70}$ | 4800 | 200 | 296 | 93 | 403 | 11.9 |
| $N_{45}P_{25}$ | 2700 | 200 | 297 | 80 | 417 | 6.5 |
| $N_{45}P_0$ | 1900 | 200 | 288 | 88 | 400 | 4.8 |
| $N_0P_{25}$ | 1800 | 200 | 287 | 111 | 376 | 4.8 |
| $N_0P_0$ | 940 | 200 | 296 | 96 | 400 | 2.4 |

$I_\theta$(mm) - Initial profile soil water content and $F_\theta$ (mm) - Final profile soil water content in mm

The five N and P treatments received the same amount of rainfall during the growing season. WUE varied with level of N and P as indicated in Table 3.4. The $N_{120}P_{70}$ treatment gave the highest WUE value of 11.9 kg ha$^{-1}$ mm$^{-1}$ compared to the other treatments. The $N_0P_0$ treatment had the lowest WUE of only 2.4 kg ha$^{-1}$ mm$^{-1}$, which shows how inefficiently water is used when nutrients limit growth.

Du Toit (1999) reported values of WUE ranging from 10 to 16 kg ha$^{-1}$ mm$^{-1}$ for maize. The $N_{120}P_{70}$ treatment is the only treatment that fell within the range mentioned by Du Toit (1999). The other treatments gave WUEs below the optimum range. From these results it is clear that water may not be the main factor limiting yields under dryland agriculture in many regions, and it is important that we identify factors that limit crop growth if we are to maximize production from available rainfall. In this example we illustrate limitations of N and P but it could just as easily be due to poor weed control, preparation, tillage, untimely planting, disease, insect damage and soil acidity.

Based on the results discussed in this chapter, the Soil Water Balance (SWB) model is parameterized in the following chapter and used to make predictions of potential yields in the Chókwè District under dryland conditions to indicate whether yields --- to be water or nutrient limited.

# CHAPTER 4: MODELLING MAIZE POTENTIAL YIELD

## 4.1 Introduction

It is reported by Jovanovic and Annandale (2000) that the interest in computer models for agriculture is rapidly increasing, particularly since personal computers have become accessible to crop producers. Several crop growth and water balance models have been developed with different levels of complexity depending on specific requirements. Computer models, like the Soil Water Balance (SWB) model, could facilitate simulation of several crop growth components for different locations, taking into consideration specific crop parameters, soil and weather data. Modelling will help give a clearer picture of the potential yields under good practice under dryland agriculture in southern Mozambique.

For this virtual experiment, modelling was used to determine, by simulation for several years, if maize grain yields are generally limited by rainfall or by other factors. As stated by FAEF (2001), farmers believe that their actual yields are limited by water, and not nutrients. To run simulations with SWB the well fertilized treatment was used to generate crop parameters to use in the model.

## 4.2 Soil Water Balance model

The SWB model is a crop growth simulator, designed as a real-time, user friendly, irrigation scheduling tool, based on the improved generic crop version of NEWSWB (Benadé *et al*, 1997). The SWB model gives a detailed description of the soil-plant-atmosphere continuum, making use of weather, soil and crop databases. The crop database includes several crop specific growth parameters; vapour pressure deficit-corrected dry matter/water ratio, radiation conversion efficiency, specific leaf area, stem-leaf dry matter partitioning parameter, canopy extinction coefficient for solar radiation, maximum root depth, maximum crop height and growing day degrees for the completion of several phenological stages (Jovanovic and Annandale, 2000).

Very little or no information is available on growth parameters for the maize cultivar Matuba, grown under dryland conditions in Mozambique. The objective of this study was to collect field data, to determine crop-specific model parameters for maize (cv. Matuba), to calibrate and validate the Soil Water Balance model for this cultivar and to use the calibrated model to simulate potential yields with no nutrient limitation to simulate potential yield for the Chókwè District and then to compare this to typical yields for the area. The experimental set-up and field measurements are described in Chapter 2. Simulated potential maize grain yields using historical weather data for Chókwè will be discussed in this Chapter.

The Challenge Program on Water and Food, for which the slogan was “more crop per drop” focused on identifying and addressing water productivity constraints throughout the Limpopo River Basin. This study was designed to concentrate on water productivity in dryland areas, assuming that yield could be limited not only by water, but also through soil nutrients as stated by Amaral & Sommerhalder (2004). For this reason this study was carried out in the Chókwè District.

### 4.2.1 Crop parameter determination

Crop parameters such as the base temperature ($^{o}$C), optimum light limiting temperature ($^{o}$C) and cut off temperature ($^{o}$C) were obtained from Du Toit (1999) and Badu-Apratu *et al.* (2006). Transition period day degrees (d $^{o}$C), day degrees for leaf senescence (d $^{o}$C), maximum root depth (m), stem to grain translocation, canopy storage (mm), minimum leaf water potential (kPa), maximum transpiration (mm day$^{-1}$), specific leaf area (m$^{2}$ kg$^{-1}$), leaf - stem partitioning parameter (m$^{2}$ kg$^{-1}$), TDM at emergence (kg m$^{-2}$), root fraction, root growth rate and stress index typical for maize were obtained from the SWB database (Jovanovic & Annandale, 2000).

Extinction coefficient, dry matter to water ratio (Pa), radiation use efficiency (kg MJ$^{-1}$), emergence day degrees (d $^{o}$C), flowering day degrees (d $^{o}$C) and day degrees to maturity (d $^{o}$C) were calculated based on field measurements. Maximum crop height (m) was measured in the field. Formulae to calculate these parameters can be found in Jovanovic *et al*. (1999) and Jovanovic and Annandale (2000).

### 4.2.2 Weather variables

Weather variables were obtained from an automatic weather station (Mike Cotton Systems, Cape Town, South Africa) located 300 m from the experimental site. The weather data recorded included maximum and minimum temperatures (°C), wet and dry bulb temperatures (°C), maximum and minimum relative humidity (%), reference evapotranspiration (mm day$^{-1}$), precipitation (mm) and solar radiation (W m$^{-2}$).

### 4.2.3 Soil parameters

Soil samples were collected before planting to obtain soil chemical and physical analysis results. Soil chemical and physical analysis results were used both for definition of treatments and for SWB soil inputs. The soil parameters for Chókwè used in the SWB model were taken from Table 2.1

## 4.3 Results and discussion

The high water productivity treatment, fertilized with 120 kg N ha$^{-1}$ and 70 kg P ha$^{-1}$ ($N_{120}P_{70}$), as described in Chapter 2, was selected to determine crop-specific growth parameters, because the model predicts growth under nutrient non-limiting conditions. This treatment presumably had no N and P nutrient limitation; and therefore yield and growth were only limited by water supply. The crop parameters for the $N_{120}P_{70}$ treatment used in the SWB model are summarized in Table 4.1.

**TABLE 4.1: Crop parameters used for the $N_{120}P_{70}$ treatment**

| Crop parameters | Value |
|---|---|
| [1]Canopy radiation extinction coefficient for solar radiation, $K_c$ | 0.5 |
| [1]Dry matter to water ratio, DWR (Pa) | 5 |
| [1]Radiation use efficiency, Ec (kg $MJ^{-1}$) | 0.0014 |
| [3]Base temperature ($^{o}$C) | 10 |
| [4]Optimum temperature ($^{o}$C) | 25 |
| [4]Cut-off temperature ($^{o}$C) | 30 |
| [1]Emergence day degrees (d $^{o}$C) | 103 |
| [1]Flowering day degrees (d $^{o}$C) | 966 |
| [1]Maturity day degrees (d $^{o}$C) | 1641 |
| [3]Transition period day degrees (d $^{o}$C) | 10 |
| [3]Day degrees - Leaf senescence (d $^{o}$C) | 500 |
| [2]Maximum crop height, $H_{max}$ (m) | 2.27 |
| [3]Maximum root depth, $RD_{max}$ (m) | 1.5 |
| [3]Minimum leaf water potential (kPa) | -2000 |
| [3]Specific leaf area, SLA ($m^2$ $kg^{-1}$) | 15.0 |
| [3]Leaf-stem partition p, ($m^2$ $kg^{-1}$) | 1.5 |
| [3]Root growth rate ($m^2$ $kg^{-0.5}$) | 8.0 |
| [3]TDM at emergence (kg $m^{-2}$) | 0.0019 |
| [3]Maximum transpiration (mm $day^{-1}$) | 9 |
| [3]Stem-grain translocation | 0.05 |
| [3]Canopy storage (mm) | 1.0 |
| [3]Root fraction | 0.20 |
| [3]Stress index | 0.95 |
| [3]Root growth rate | 8.0 |

[1]Calculated from field measurements

[2]Measured

[3]Obtained from SWB model database (Jovanovic & Annandale, 2000)

[4]Obtained from Du Toit (1999) & Badu-Apraku *et al.* (2006)

The calculated dry matter water ratio (DWR) of 5.0 Pascal (Pa) estimated in this study is somewhat low compared to that published by Jovanovic & Annandale (2000) for sweet corn (cvs. cabaret, dorado, jubilee and paradise) with a range of 8-9. The SWB model database shows DWR values in the range of 6 to 9 Pa for maize.

The radiation use efficiency (Ec) of 0.0014 kg $MJ^{-1}$ obtained for maize (cv. Matuba) was also relatively low compared to that published by Jovanovic & Annandale (2000) for sweetcorn (cvs. cabaret, dorado, jubilee and paradise) which ranged from 0.0022 to 0.0038 kg $MJ^{-1}$. However, the SWB model database indicates values of maize radiation use efficiency ranging from 0.0012 to 0.0015 kg $MJ^{-1}$. Therefore, the Ec value determined in this study for maize (cv. Matuba) is within this range. Figure 4.1 represents radiation use efficiency as the slope of the graph.

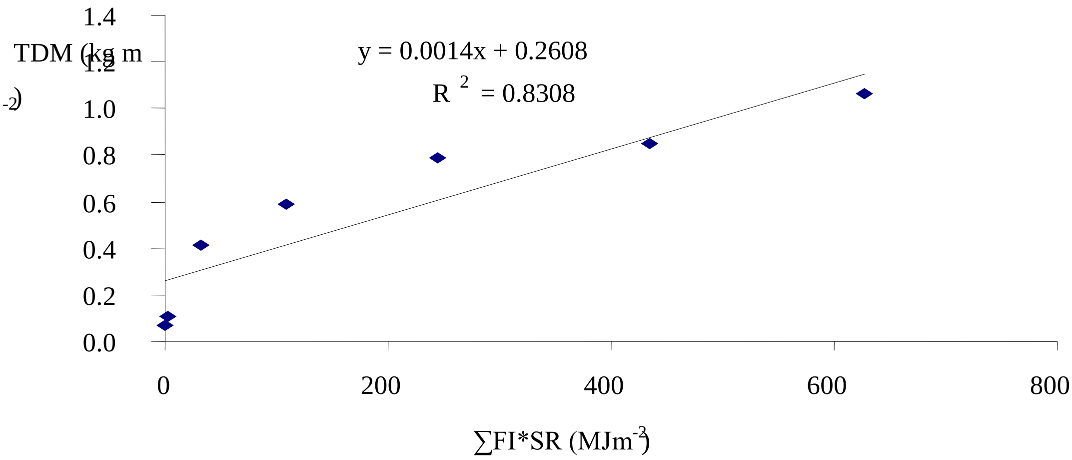


**FIGURE 4.1: Total above ground dry matter yield (TDM) of maize as a function of the cumulative product of fractional interception and incident solar radiation (FI*SR). The slope of the function is the radiation use efficiency (Ec) for the $N_{120}P_{70}$ treatment.**

The canopy radiation extinction coefficient value (Kc = 0.5) obtained in this study is in the range compared to what was found by Jovanovic & Annandale (2000) for sweet corn (cvs. cabaret, dorado, jubilee and paradise) which ranged from 0.30 to 0.50. The SWB model database indicates a value of radiation use efficiency between 0.50 and 0.60 for maize. Figure 4.2 presents the canopy radiation extinction coefficient.

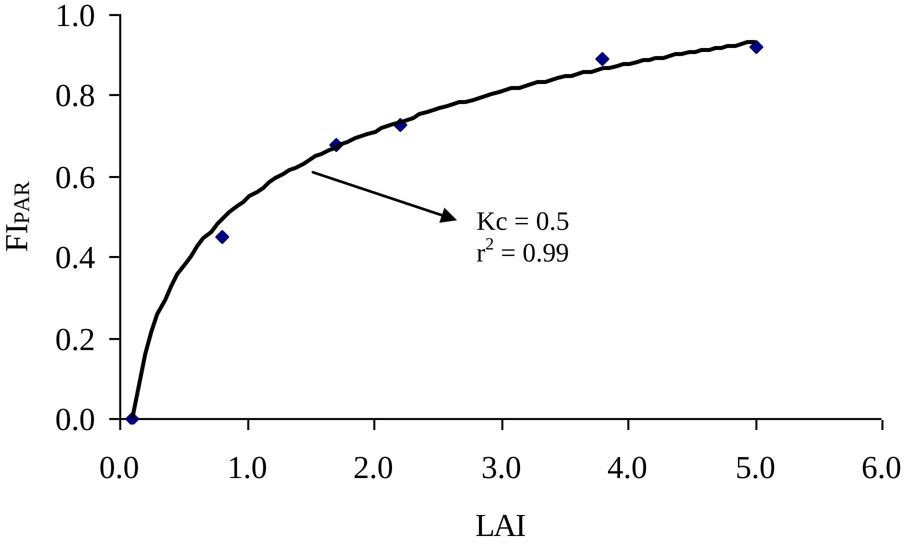
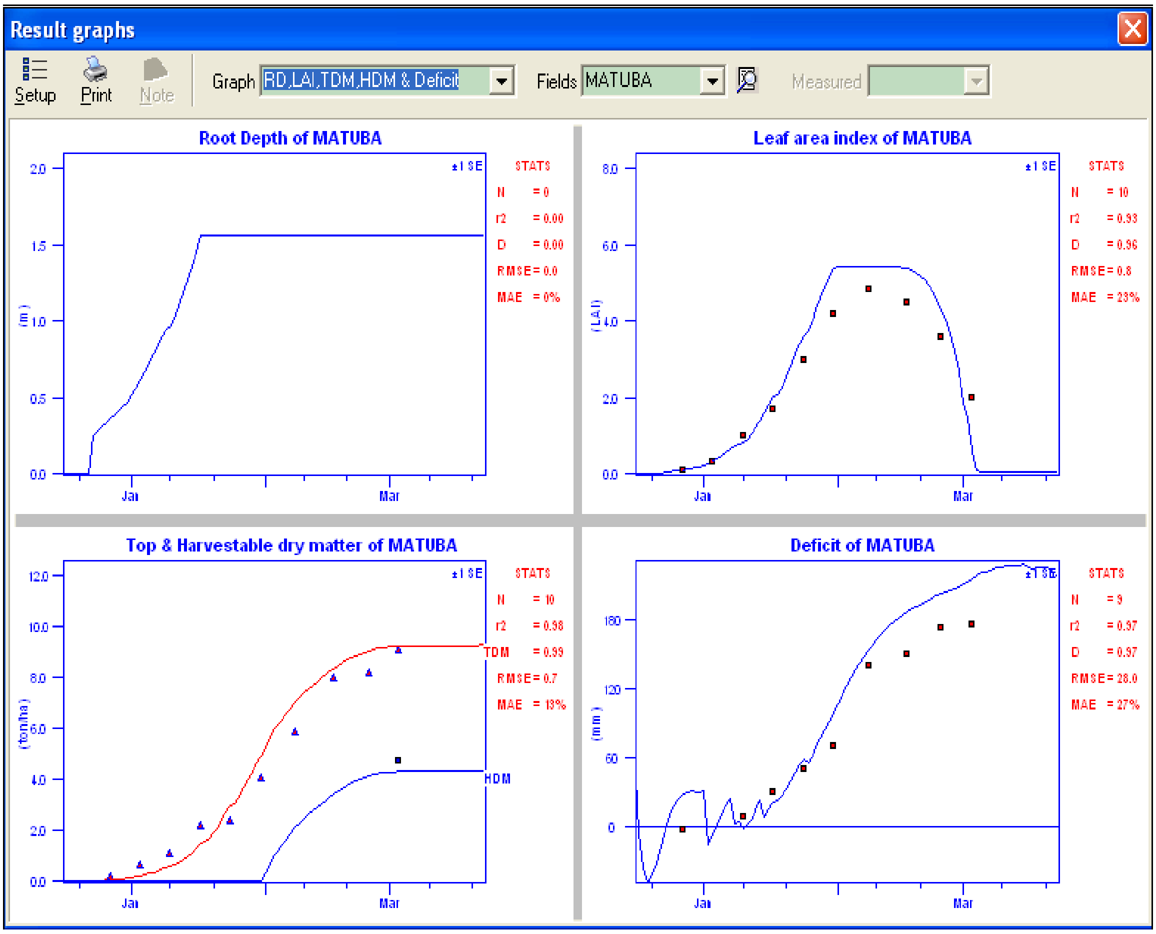


**FIGURE 4.2: Fractional interception of photosynthetically active radiation ($FI_{PAR}$) as a function of leaf area index (LAI).**

### 4.3.1 SWB model calibration for nutrient non-limiting conditions

The outputs of calibration simulations are shown in Figures 4.3 to 4.5. Figure 4.3 represents simulated root depth, simulated and measured LAI, harvestable dry matter (HDM) and top dry matter (TDM), and the soil water deficit to field capacity (SWD). No measured data points were made for root depth. The measured data point in the HDM graph represents the final grain yield (Figure 4.3). All parameters measured and simulated, except for SWD, are in the range of de Jager's (1994) recommended values for $r^2$ and D > 0.80, whilst MAE should be < 20%.



Graph RD,LAI,TDM,HDM & Deficit

Fields MATUBA

**FIGURE 4.3: Measured (symbols) and simulated (lines) for root depth, LAI, above-ground dry matter yield (TDM, left) and harvestable dry matter production (HDM, right), as well as SWD for maize (cv. Matuba). The parameters for statistical analysis of measured and simulated data are the number of observations (N), coefficient of determination ($r^2$), Willmott's index of agreement (D), root mean square error (RMSE) and mean absolute error (MAE).**

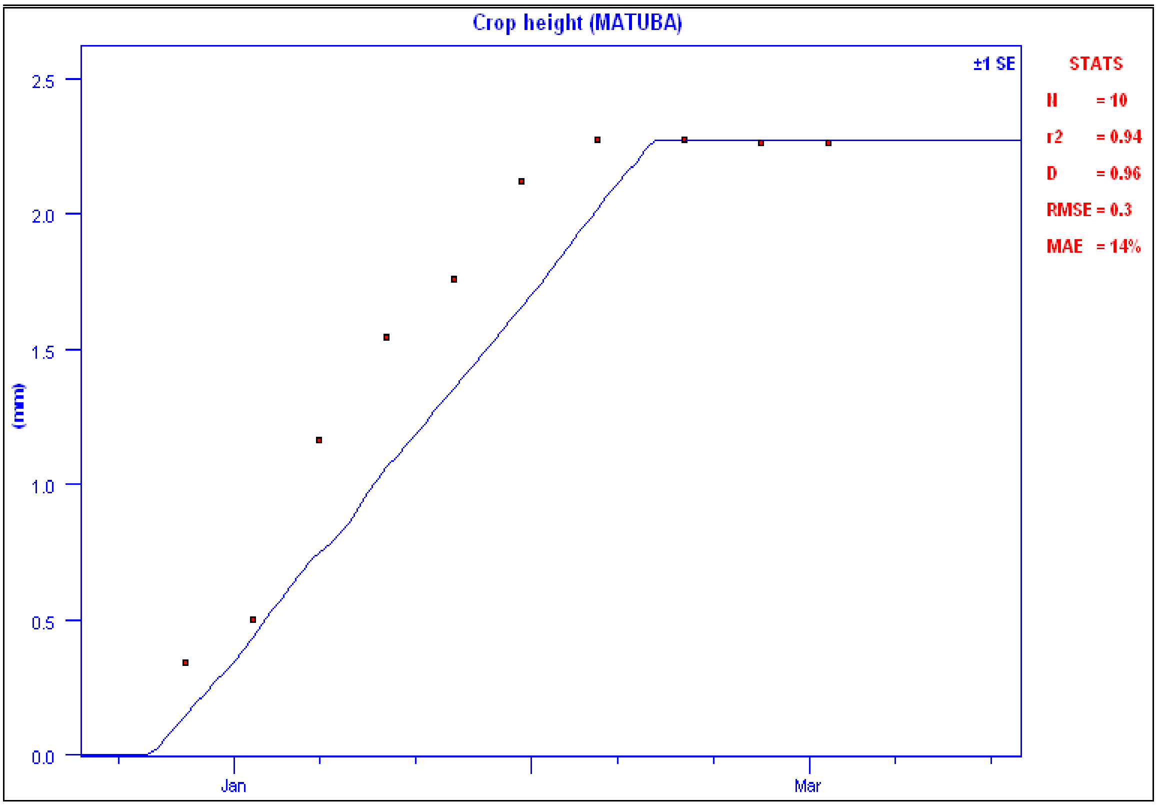


**FIGURE 4.4: Measured (symbols) and simulated (lines) for crop height of maize (cv. Matuba). The parameters for statistical analysis of measured and simulated data are the number of observations (N), coefficient of determination ($r^2$), Willmott's index of agreement (D), root mean square error (RMSE) and mean absolute error (MAE). Crop height is incorrectly labelled on the vertical axis in millimetres (mm) but should be in (m).**

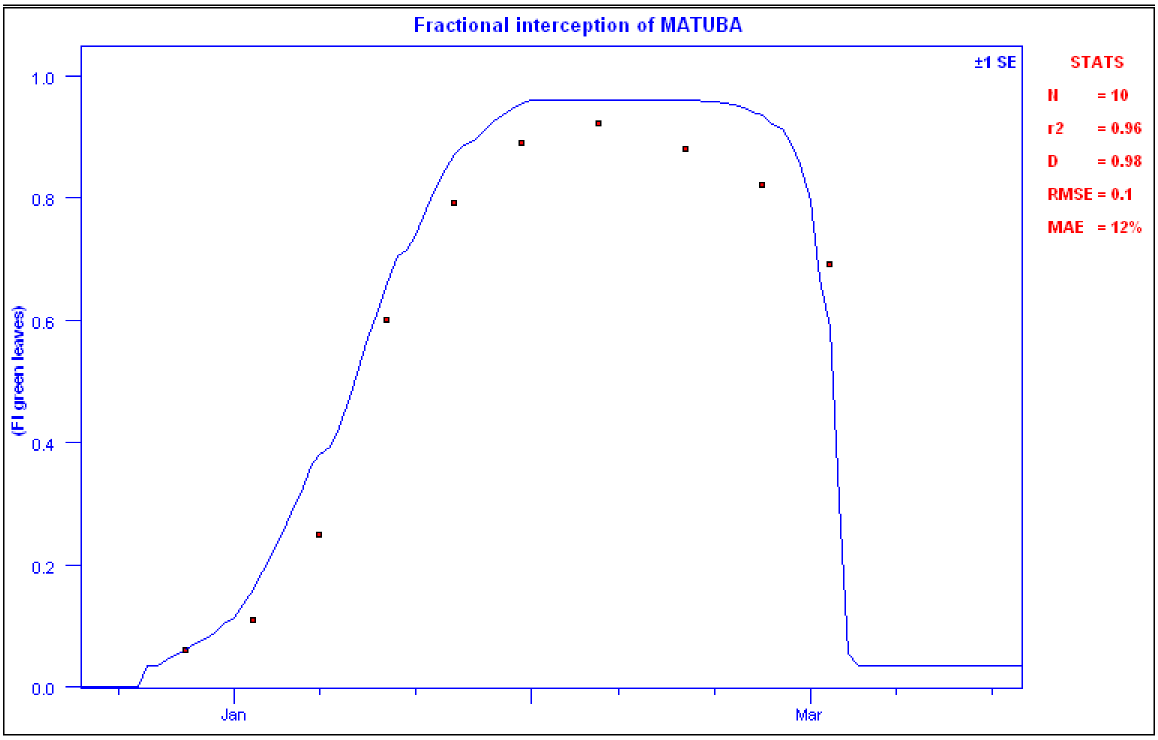


**FIGURE 4.5: Measured (symbols) and simulated (lines), fractional interception of solar radiation (cv. Matuba). The parameters for statistical analysis of measured and simulated data are the number of observations (N), coefficient of determination ($r^2$), Willmott's index of agreement (D), root mean square error (RMSE) and mean absolute error (MAE).**

### 4.3.2 Scenarios

Table 4.2 presents simulated potential grain yields for five years in the Chókwè District. Historical weather data were used to run simulations. Chókwè is located downstream of the LRB. Simulated potential maize grain yields, if nutrients were not limiting are in most years higher than what farmers actually obtain. The simulation scenarios for 2002 to 2006 are shown in Appendix B.

**TABLE 4.2: Simulated maize grain yield for dryland agriculture in Chókwè District**

| Year | Rainfall (mm) | Simulated grain yield (tons ha$^{-1}$) |
|---|---|---|
| 2002/2003 | 99 | 1.4 |
| 2003/2004 | 542 | 5.0 |
| 2004/2005 | 448 | 4.5 |
| 2005/2006 | 436 | 4.0 |
| 2006/2007 | 400 | 4.0 |

Table 4.2 shows the potential yields obtained by SWB model simulation for Chókwè. Simulations for limiting nutrients were not done because the objective was to show that simulated potential yields, if nutrients were not limiting, are in most years higher than what farmers currently obtain which is lower than 1 ton ha$^{-1}$. Thus, only in 1 out of 5 years in Chókwè, was potential yield lower than actual yields. In most years, nutrients (N and P) are most likely the most limiting factors. Also, it is important to have long-term weather data, recorded by automatic weather stations, to amongst other users predict potential yields in different places and climates.

## CONCLUSIONS

The application of N resulted in improvements to total above ground dry matter yield (TDM), leaf area index (LAI) and fractional interception of photosynthetically active radiation ($FI_{PAR}$). Application of both N and P improved the grain yield as Pandey (2000) reported. Leaf area duration (LAD) and water use efficiency (WUE) were also improved due to N and P application. This implies that in the dryland area of the Chókwè District, better nutrition with N and P, can be used as strategy to improve water productivity. In addition, farmers believe that water is the most limiting factor rather than nutrients, as referred to in the study hypothesis. Farmers therefore have to take care of soil nutrition. Also, results obtained from SWB model simulations indicated that actual yields are indeed influenced by nutrients rather than rainfall in most years. In addition, it is crucial to have tools which allow climatic parameters (automatic weather stations) to be measured so that it becomes possible to simulate potential yields for many years in more Districts with greater precision, so that recommendations for farmers will likely be more reliable and this will allow them to improve farm income and to reduce the risk of crop failure.

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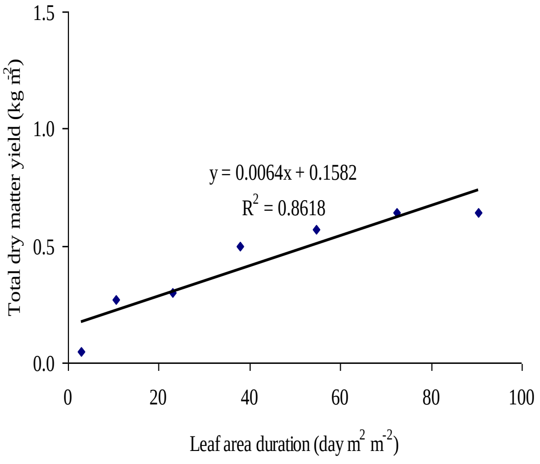
# APPENDICES

## APPENDIX A: Relationship between LAD and maize TDM yield



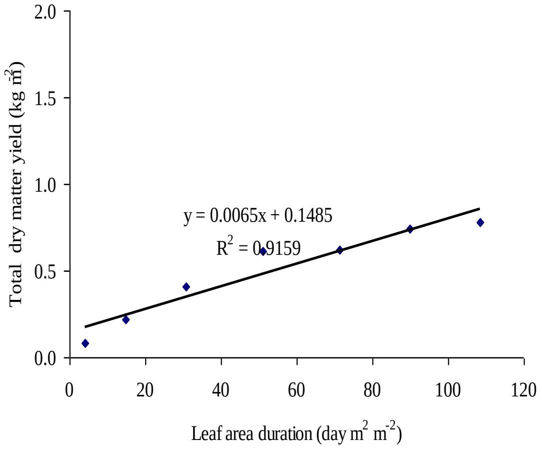
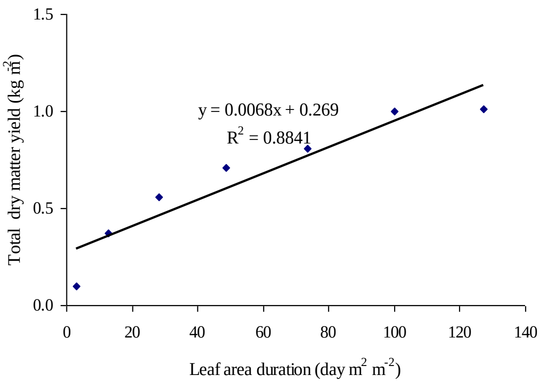


**FIGURE A1: LAD and TDM - $N_{45}P_0$**

**FIGURE A2: LAD and TDM - $N_0P_{25}$**



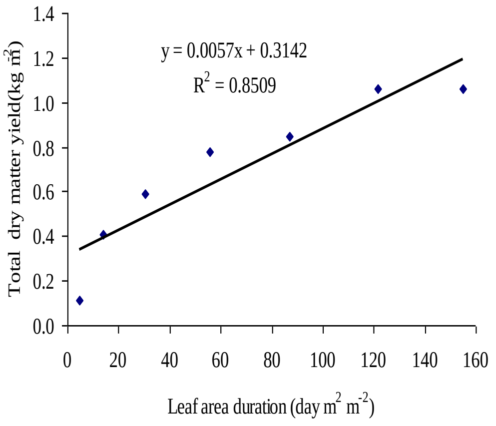


**FIGURE A3: LAD and TDM - $N_{45}P_{25}$**

**FIGURE A4: LAD and TDM - $N_{120}P_{70}$**

## APPENDIX B: Grain yield simulations for Chókwè District

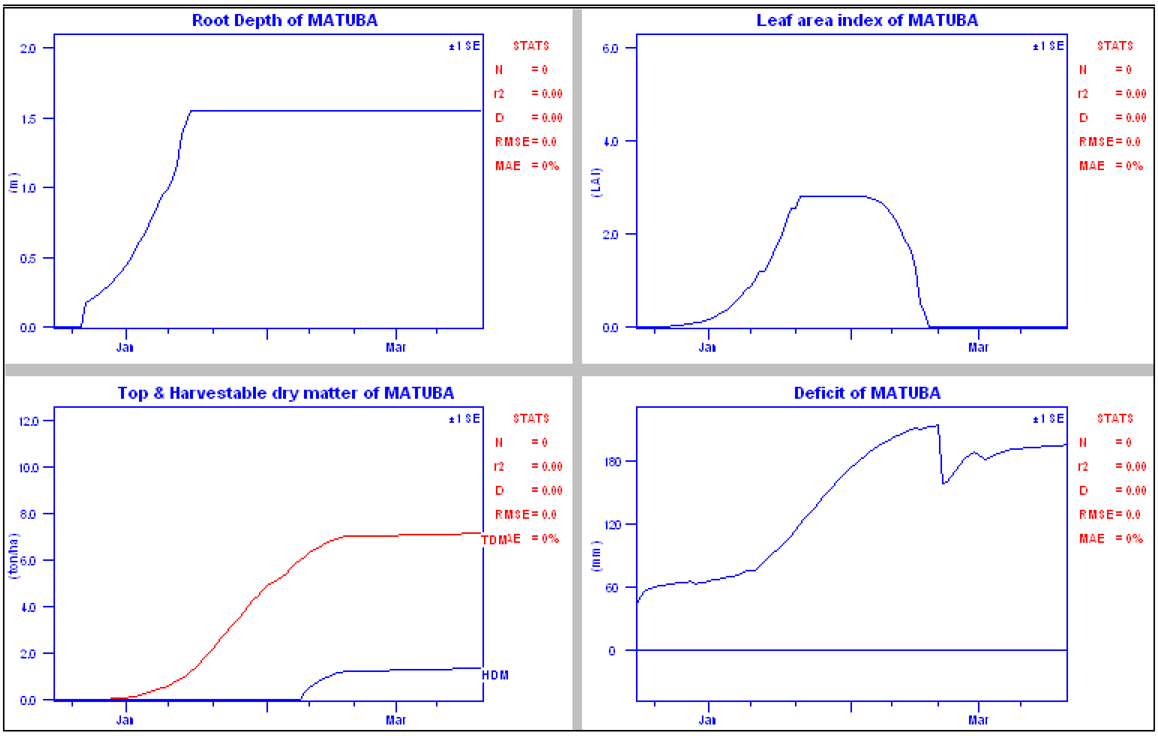


FIGURE B1: Grain yield simulations for Chókwè District year 2002

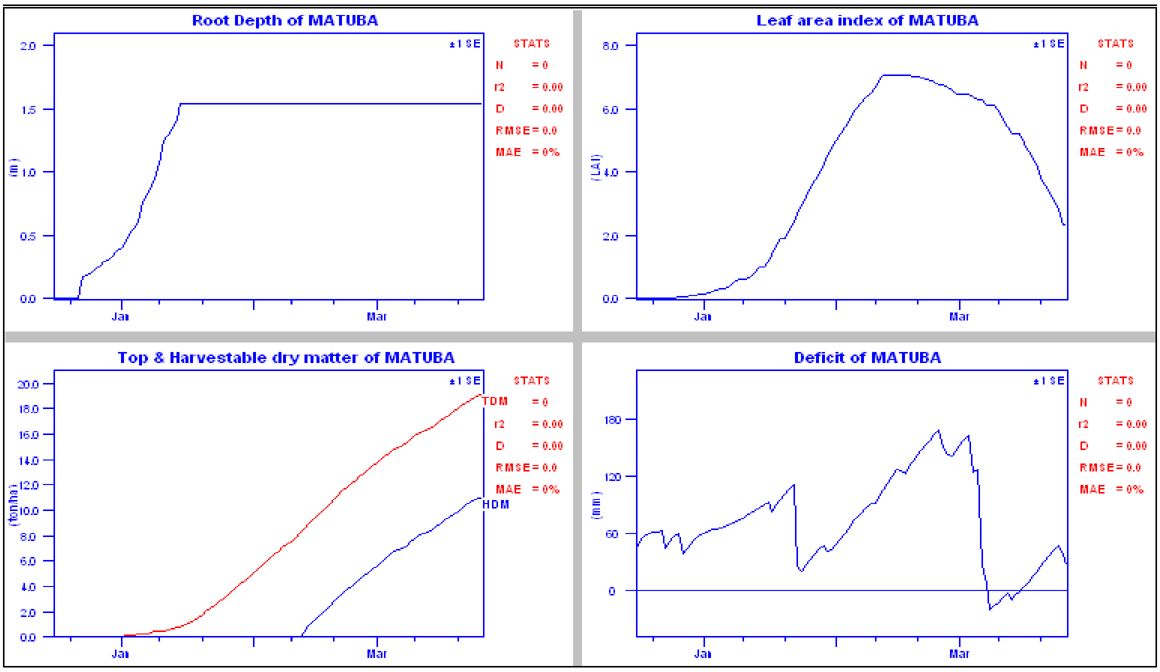


FIGURE B2: Grain yield simulations for Chókwè District year 2003

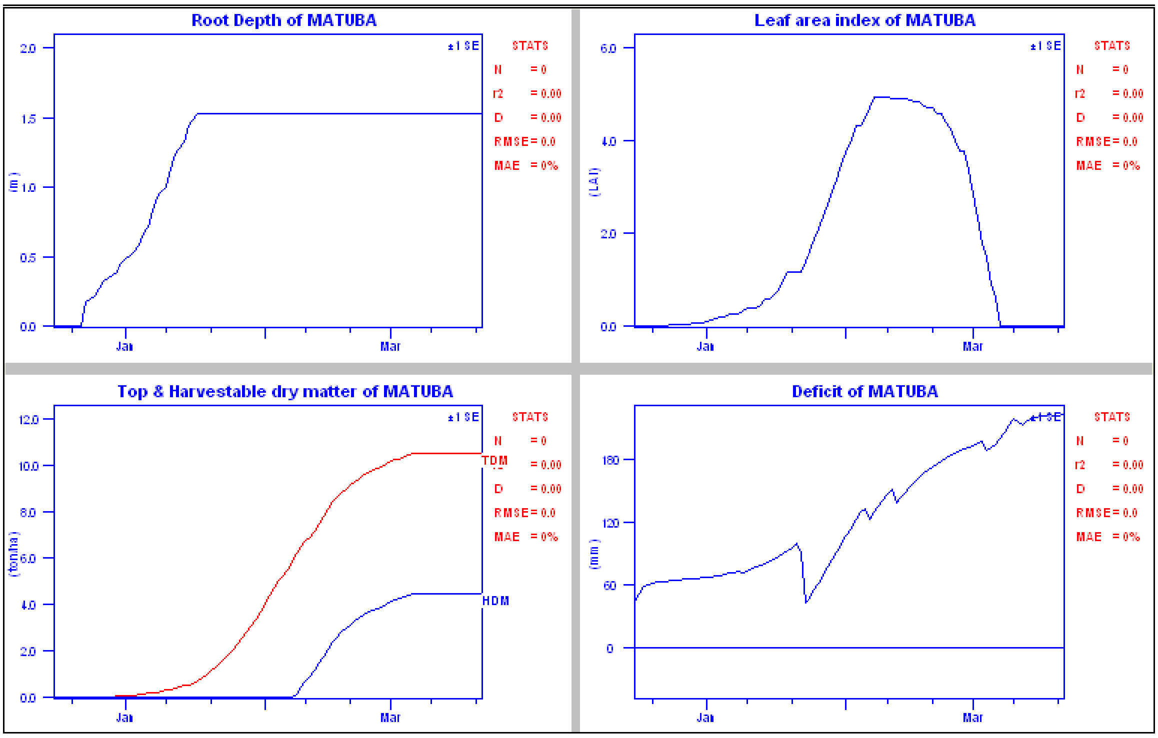


FIGURE B3: Grain yield simulations for Chókwè District year 2004

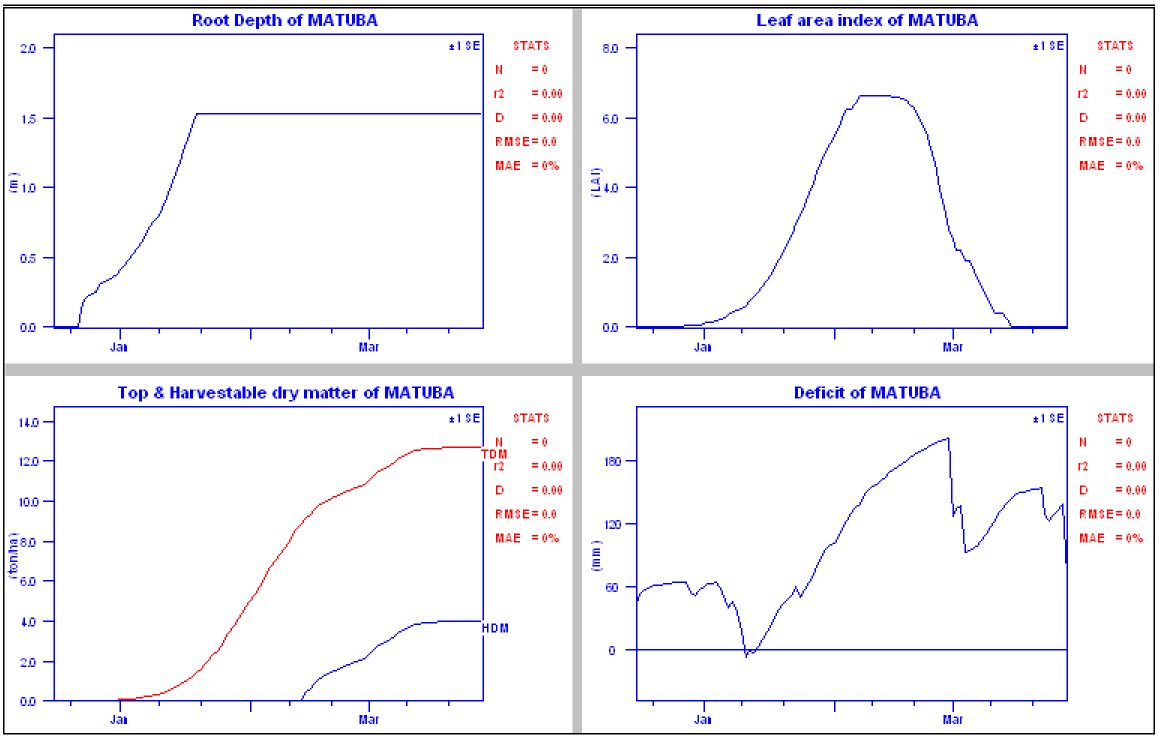


FIGURE B4: Grain yield simulations for Chókwè District year 2005

# APPENDIX C: Statistical Procedure

```
CHOKWE MAIZE TRIAL   1     20:42 Thursday, December 30, 2009
Obs  TREAT      REP    NR LEAVES    CROP PHEIGHT     LAI    PAR    TDM     YIELD
1    N0P0        1        15           170          1.9    0.8    0.6     0.9
2    N45P0       1        16           200          2.3    0.8    0.8     1.9
3    N0P25       1        15           192          2.1    0.8    0.8     1.6
4    N45P25      1        16           215          2.9    0.9    0.9     3.0
5    N120P70     1        17           229          3.9    0.9    1.1     5.0
6    N0P0        2        15           180          2.0    0.8    0.7     0.9
7    N45P0       2        16           198          3.0    0.9    0.8     1.8
8    N0P25       2        15           198          2.4    0.8    0.8     1.8
9    N45P25      2        17           225          3.1    0.9    1.0     2.5
10   N120P70     2        17           227          4.0    0.9    1.1     4.7
11   N0P0        3        15           185          2.2    0.8    0.6     1.0
12   N45P0       3        16           219          2.9    0.9    0.8     2.1
13   N0P25       3        16           190          1.7    0.8    0.7     1.9
14   N45P25      3        15           215          3.1    0.9    1.0     2.6
15   N120P70     3        16           225          4.1    0.9    1.0     4.6

Variable:  LAI
Tests for Normality
Test                  --Statistic---    -----p Value------
Shapiro-Wilk          W     0.921631    Pr < W      0.2040

Variable:  PAR
Tests for Normality
Test                  --Statistic---    -----p Value------
Shapiro-Wilk          W     0.643408    Pr < W     <0.0001

Variable:  TDM
Tests for Normality
Test                  --Statistic---    -----p Value------
Shapiro-Wilk          W     0.922252    Pr < W      0.2085

Variable:  YIELD
Tests for Normality
Test                  --Statistic---    -----p Value------
Shapiro-Wilk          W     0.861931    Pr < W      0.0257


The GLM Procedure
Class Level Information
Class         Levels    Values
TREAT              5    N0P0 N0P25 N120P70 N45P0 N45P25
REP                3    1 2 3
Number of observations    15

Dependent Variable: LAI
                                       Sum of
Source                     DF         Squares      Mean Square     F Value     Pr > F
Model                       6      8.06400000       1.34400000       25.28     <.0001
Error                       8      0.42533333       0.05316667
Corrected Total            14      8.48933333
TREAT                       4      7.86266667       1.96566667       36.97     <.0001
REP                         2      0.20133333       0.10066667        1.89     0.2122
R-Square     Coeff Var     Root MSE      LAI Mean
```

```
0.949898      8.314146      0.230579      2.773333

Dependent Variable: PAR
                                      Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F
Model                        6      0.03200000      0.00533333       8.00    0.0049
Error                        8      0.00533333      0.00066667
Corrected Total             14      0.03733333
TREAT                        4      0.03066667      0.00766667      11.50    0.0021
REP                          2      0.00133333      0.00066667       1.00    0.4096
R-Square     Coeff Var      Root MSE      PAR Mean
0.857143      3.025768      0.025820      0.853333

Dependent Variable: TDM
                                      Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F
Model                        6      0.36000000      0.06000000      27.69    <.0001
Error                        8      0.01733333      0.00216667
Corrected Total             14      0.37733333
TREAT                        4      0.35066667      0.08766667      40.46    <.0001
REP                          2      0.00933333      0.00466667       2.15    0.1785
R-Square     Coeff Var      Root MSE      TDM Mean
0.954064      5.497732      0.046547      0.846667



Dependent Variable: YIELD
                                       Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F
Model                        6     25.42933333      4.23822222     123.44    <.0001
Error                        8      0.27466667      0.03433333
Corrected Total             14     25.70400000
TREAT                        4     25.37733333      6.34433333     184.79    <.0001
REP                          2      0.05200000      0.02600000       0.76    0.4998
R-Square     Coeff Var      Root MSE    YIELD Mean
0.989314      7.656717      0.185293      2.420000

Tukey's Studentized Range (HSD) Test for LAI
Minimum Significant Difference        0.6504
Means with the same letter are not significantly different.
Tukey Grouping          Mean       N    TREAT
             A        4.0000       3    N120P70
             B        3.0333       3    N45P25
             B        2.7333       3    N45P0
             C        2.0667       3    N0P25
             C        2.0333       3    N0P0

Tukey's Studentized Range (HSD) Test for PAR
Minimum Significant Difference        0.0728
Means with the same letter are not significantly different.
Tukey Grouping          Mean       N    TREAT
              A       0.90000       3    N45P25
              A       0.90000       3    N120P70
              B    A  0.86667       3    N45P0
              B       0.80000       3    N0P25
              B       0.80000       3    N0P0

Tukey's Studentized Range (HSD) Test for TDM
```

```
Minimum Significant Difference        0.1313
Means with the same letter are not significantly different.
Tukey Grouping          Mean       N     TREAT
             A       1.06667       3     N120P70
             A       0.96667       3     N45P25
             B       0.80000       3     N45P0
             B       0.76667       3     N0P25
             C       0.63333       3     N0P0

Tukey's Studentied Range (HSD) Test for YIELD
Minimum Significant Difference        0.5227
Means with the same letter are not significantly different.
Tukey Grouping          Mean       N     TREAT
             A        4.7667       3     N120P70
             B        2.7000       3     N45P25
             C        1.9333       3     N45P0
             C        1.7667       3     N0P25
             D        0.9333       3     N0P0
```