

**Improving dryland water productivity of maize through cultivar selection
and planting date optimization in Mozambique**

by

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DECLARATION

I hereby certify that this dissertation is my own work, except where duly acknowledged. I also certify that no plagiarism was committed in writing this dissertation.

Signed -----

ABSTRACT

Mozambique is a semi-arid area with unreliable rainfall distribution; therefore optimal planting dates are critical to ensure that maize is not stressed during critical stages. The objective of this research was to study the effect of sowing date and cultivar on maize (*Zea mays* L.) yields in Mozambique. A further objective was to establish whether the SWB model could be utilized to help select the optimum planting window for different maize cultivars and localities.

An experiment was conducted during the 2007/08 season at the Chókwè Agricultural Research Station, Mozambique, in which a short (or early cultivar, Changalane) and long (or late) season maize cultivar (Tsangano) were sown on three different dates: 5 December 2007 (PD1), 25 December 2007 (PD2) and 15 January 2008 (PD3).

Sowing date had a significant effect ($p < 0.05$) on yield and yield components. The 25 December planting (PD2) out yielded (4.3 t ha^{-1}) the 5 December (PD1) (2.5 t ha^{-1}) and 15 January (PD3) (1.5 t ha^{-1}) plantings for cv. Changalane. However, for cv. Tsangano, PD1 (3.2 t ha^{-1}) out yielded PD2 (2.3 t ha^{-1}) and PD3 (0.7 t ha^{-1}). Cultivars varied significantly in yield potential.

The most responsive cultivar to water supply was Changalane, which when planted late in December (PD2), gave a water productivity (WP) of $17 \text{ kg ha}^{-1} \text{ mm}^{-1}$, while Tsangano, the late cultivar, performed better when planted early in December (PD1), with a WP of $8.5 \text{ kg ha}^{-1} \text{ mm}^{-1}$.

The Soil Water Balance (SWB) model was calibrated on the data from one planting date per cultivar and successfully validated on independent data sets from the other two planting dates. Long-term historical weather data sets were obtained for Chókwè and Umbeluzi, two important dry land maize production areas in Mozambique. The calibrated SWB model was used to simulate maize yields for different planting dates to establish the best planting date for different cultivar x plant date x soil combinations. Simulation results for the two cultivars across three planting dates showed that the simulated grain yields per planting date varied substantially from year to year and between the two sites.

The SWB scenario simulation results showed that for both Umbeluzii and Chókwè sites, in four out of five years, best yields can be achieved by planting Changanane late in December and Tsangano early in December.

It can be concluded that the SWB model can be a very useful tool to help select the most suitable maize cultivars and planting dates for different localities, based on differences in plant water availability during the growing season.



In memory of the valour of my mother, Catarina Tembe

I dedicate and offer

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LIST OF ABBREVIATIONS

AWC	Crop available water
CO ₂	Carbon dioxide
CRDB	Completely Randomized Block Design
Cm	Centimeter
D	Drainage
DM	Dry matter yield
DTA	Departamento de Terra e Água
DWR	Vapour pressure deficit corrected dry matter water ratio
e_{sTmax}	Saturated vapour pressure at maximum air temperature
e_{sTmin}	Saturated vapour pressure at minimum air temperature
E _a	Actual vapour pressure
E _c	Radiation use efficiency
ET ₀	Reference evapotranspiration
ETP	Potential evapotranspiration
FI	Fractional interception of photosynthetically active radiation
G	Gram
GDD	Growing day degree
Ha	Hectare
HI	Harvest Index
INIA	Instituto de Investigação Agronomica de Moçambique
Kg	Kilogram
K	Potassium
LAD	Leaf area duration
LAI	Leaf area index
LSD	Least Significant Difference
M	Meter
mbar	Milibar
N	Nitrogen
PAR	Photosynthetically active radiation
PD (1, 2, 3)	Planting dates 1, 2 or 3
PT	Potential transpiration



R	Rain
r^2	Coefficient of determination
RHmax	Maximum relative humidity
RHmin	Minimum relative humidity
RHmean	Average of relative humidity
Rs	Daily total incident solar radiation
SWB	Soil Water Balance model
SWD	Soil water deficit
$t\ ha^{-1}$	Tons per hectare
Tmax	Maximum temperature
Tmin	Minimum temperature
Tmean	Mean temperature
Tday	Temperature during a day
Tnight	Temperature during the night
WU	Water use
WUE	Water use efficiency
V (1, 2)	Cultivars 1 or 2
VPD	Vepour pressure deficit

INTRODUCTION

For over 50 years now, the causes of low productivity in rain-fed agriculture in southern Mozambique have been studied. There is general consensus that rainfall irregularity is the main reason for the low productivity in rain-fed agriculture. Rainfall fluctuates widely between years and is very irregular, resulting in an absolutely unpredictable optimal time for sowing (Monteiro, 1955). Even under the circumstances where, based on the total amount of annual rainfall, one would expect good crop production, during the year rainfall distribution is so irregular that it leads to low crop production and thus, food shortage in small family-holdings (Mafalacusser & Ussivane, 1997).

A study on yield response to water deficit in southern Mozambique over 20 years has thrown more light on this subject (Schouwenaars, 1986; Schouwenaars, 1987). No correlation was found between yields of maize and planting date during the year. In some years, better yields were obtained by sowing within the 'most favourable period' (i.e. favourable from an agro-hydrological point of view); in other years, better yields were obtained by sowing either sooner or later than the apparently most favourable period. Hence, with a negligible stock-building capacity for food in most small family holdings, it seems a reasonable practice to sow whenever enough rain has fallen. This might be logical from a risk-spreading point of view but the consequence is that crops are often completely lost.

A further study on sowing strategies by Schouwenaars and Pelgrum (1990) has made it even clearer that in small-scale farming in the south, water availability does play a dominant role in farmer sowing strategies. Independently of other factors causing food shortages like crop damage from pests and diseases as well as storage losses, farmers did change their strategy of sowing continuously during the year only if water availability improved. Improving the efficient use of soil water, by simulating the optimum time of planting and making more efficient use of the limited water supply from rainfall, especially during the fallow period seems promising. Hopefully such practice will increase chances of successful sowing during the year and therefore minimize the period of food shortage in small family-holdings.

PROBLEM STATEMENT

The south of Mozambique is characterized by a semi arid climate and predominantly sandy soils. Water scarcity, erratic rainfall and low soil water holding capacity can cause a considerable yield reduction in rainfed agriculture. According to Reddy (1985), 50% of the area in southern Mozambique has soil water holding capacity less than 100 mm m^{-1} and 25% of the area has a soil water holding capacity of less than 50 mm m^{-1} in the root zone. The same author also stated that this area consequently experiences a high risk of dryland crop failure due to poor and erratic rainfall.

The wide range of climatic conditions and the severe risk of drought occurrence, which limits the productivity of rainfed agriculture in that region of the country, prompted a search for better adapted crop varieties and to predict the optimum planting time in order to minimize risk and increase crop yields. Selection of maize planting date to ensure physiological maturity before the end of the rainy season is a possible management consideration for maize producers in southern Mozambique. As such, maize producers in these regions often need information on how planting date and cultivar selection affect grain yield and water use at a given location (Lauer *et al.*, 1999).

For optimization of yield, planting at the appropriate time to fit cultivar maturity length and growing season is critical. However, in the south of Mozambique, previous research mostly focused on irrigated agriculture, while almost no research had been carried out on planting date response of maize cultivars under dryland conditions. A crop model could be useful to help determine the optimum planting window for a specific locality. Therefore, a field experiment was carried out in the Chókwè area to calibrate the Soil Water Balance (SWB) model (Schouwenaars, 1987).

Two sites with different soil types and rainfall regimes in the Chókwè and Umbeluzi districts (Limpopo and Umbeluzi Rivers Basins respectively) were selected to carry out experiments to better understand the response of two maize cultivars to different planting dates under dryland conditions.

General objective

To derive a procedure for selection of optimal planting dates and cultivars for two important dryland maize producing regions in Mozambique in order to improve water productivity.

Specific objectives of the research project

- ❑ To calibrate the SWB model for two maize cultivars of different growing season lengths;
- ❑ To determine, the optimum planting date for cultivars of different growing season lengths in different rainfall regions, using the calibrated SWB model;
- ❑ To determine how the optimal planting date and cultivar combinations will affect water productivity;
- ❑ To propose a procedure for optimum maize planting date selection

CHAPTER 1

LITERATURE REVIEW

1.1 Maize production in Mozambique

1.1.1 Economical importance of maize

Maize (*Zea Mays L.*) is one of the most important food crops in Mozambique, contributing more than 40% of the total calorie intake in human nutrition. More than 95% of the total maize area is occupied by open pollinated varieties grown mainly by small-scale farmers, which contribute 90% of the total maize production (1.2 million tons per year). Most of the maize produced in the country is for human food (dry grain form), and a small part is used to balance animal feed (Bueno *et al.*, 1989).

1.1.2 Distribution of maize production areas

The maize production areas are dispersed over the whole country and include a vast range of climate and soil conditions (Bueno *et al.*, 1989). According to Nunes (1985), the country can be divided into three areas for maize production: (1) an area where maize is the main food, (2) an area where it is as important as grain sorghum, and (3) an area where it is of secondary importance.

According to Bokde (1980), the distribution of maize production areas is influenced by the availability of favourable ecological conditions for maize cultivation. The same author affirms that in the southern area, maize occupies a large area (>43% of the total area) but it only contributes 19% of the production.

The central region consists of Manica, Sofala, Tete and Zambézia provinces, with about 37% of the total area, and contributes 70% of the production. The northern region consists of three provinces (Niassa, Nampula, and Cabo Delgado) with 12% of the total area and 11% of the total production (Bokde, 1980). However, according to agro-climate analysis of suitability of maize production in Mozambique, the southern region of the country is classified as marginal or not suitable for dry land maize production. Irregular rains characterize this area, with

maximum annual precipitation of about 750 mm and risk of long drought periods during the maize growing season (Nunes, 1985).

1.1.3 Production systems

Maize is cultivated as a single crop by the commercial or private sector with possibilities of using improved technology, using different mechanization levels and, in general applying fertilizers, pesticides and improved seeds (Bueno *et al.*, 1989), while for the small scale farming sector, maize is sown together with other crops such as beans and peanut (intercropped), depending on the local climatic conditions (Nunes, 1985). In this sector all the cultivation operations are manual, no pesticides and fertilizers are usually used, and local open-pollinated varieties are grown (Bueno *et al.* 1989).

1.1.4 Current maize planting date and cultivar selection practices in Mozambique

Selection of maize planting date to ensure physiological maturity before long dry spells is an important management consideration for maize producers in Mozambique. According to Lauer *et al.* (1999), maize producers often need information on how planting date and cultivar selection affect grain yield and water use at a specific locality. The main maize planting period in southern Mozambique is between October and November (Schouwenaars, 1987), but better crop performance and yield when maize was planted before or after this period have also been reported (Schouwenaars, 1987).

In general, all the reported planting date recommendations were based on field experiments that were conducted periodically, with limited multiyear, multi-location replication, and conclusions were extrapolated statistically or otherwise. However, planting date responses depend on weather variability at each location. A field experiment to capture all the multiyear, multilocation variability in an area is nearly impossible. According to Mathews *et al.* (2002), cropping system simulation models, which are well calibrated and validated against field experimental data, hold promise for extrapolating short duration field experiment results to other years and other locations, using long-term weather data and soil information.

1.2 Production factors which affect maize production

In spite of good potential for maize production in Mozambique, production is low and insufficient to meet internal needs for food and industry (Bokde, 1980).

Among the several factors which restrict the expansion of maize cultivation, Bokde (1980) has listed the low level of agricultural practices (especially the small scale farming sector which generally applies a low technology level), lack of inputs (seeds with high potential; fertilizers; pesticides, machinery), lack of infrastructure and information (Nunes, 1985). The agronomic factors that limit the production of the maize are: poor soil and water management, poor soil fertility, weed management, pest and disease control, incorrect sowing date and density, poor seed quality and pathology management (Bueno *et al.*, 1989; Nunes, 1985).

1.3 Main pests and diseases

According to Nunes (1985), the most important pests and diseases of maize in Mozambique are the following:

Pests

Maize stalk borer (*Busseola fusca* Fuller).
Chilo borer (*Chilo partellus*)
Cutworms (*Agrotis* spp.)
Lagarta invasora (*Spodoptera exempta* Wik)
Termites (*Hodotermes mossambicus* Hagen)
Maize aphids (*Aphis gossypli* Glov.)
Black maize beetle (*Heteronychus licas* Klug)
Rats (Gen. *Mastomys*)

Diseases

Maize streak virus
Sorghum downy mildew (*Peronosclerospora sorghi*)
Grey leaf spot (*Helminthosporium* spp.)

Ear rot (*Fusarium* ear rot; *Diplodia* ear rot, *Macrospora* ear rot, *Gibberella* ear rot, *Nigrospora* ear rot)

1.4 General description of the case study area

1.4.1 Climate and soils

Mozambique has a tropical climate, with a warm season from September to April. There are three climatic zones: a hot rainy zone in the north and centre, a drier warm zone in the southern half of the country, and a relatively cool and rainy zone in the plateaux and mountainous region of Namaacha, Manica, Maravia-Angonia, Gurne and Lichinga (Spaan, 1993).

Rainfall intensity and amount increases from south to north in the country (Figure 1.1). The frequency of spells with intensive rain shows considerable regional differentiation. Three patterns in terms of occurrence of rainfall spells can be defined: (a) southern zone, where the intensity of spells are generally $<40 \text{ mm hr}^{-1}$ and their occurrence is frequent; (b) central zone, with spells generally in the range of 20 - 60 mm hr^{-1} and, (c) northern zone, where the spells generally range between 40 and 100 mm hr^{-1} but their occurrence is not frequent (Spaan, 1993).

In the south, mean annual rainfall ranges from 800-1000 mm near the coast to 550 mm in the interior (50-75 km from the coast). Rainfall is concentrated in the period between October and April.

The coastal plains cover about 44% of the country, mainly in the south. To the north, these give way to uplands (200-500 m) and the high plateau (500-1000 m), which cover respectively 17 and 26% of the country's area. The remaining 13% are mountains, rising to more than 1000 m (Spaan, 1993).

Soil erodibility varies considerably in the different regions of Mozambique. Very often high erodibility classes coincide with the steep and high plateaux in the central and the northern parts of the country (Spaan, 1993). Sandy soils are the most predominant in the south,

covering 41% in Maputo Province; 61% in Gaza and 72% in Inhambane Province (Geurts, 1997, as referenced by Gomes and Jolamo 1997).

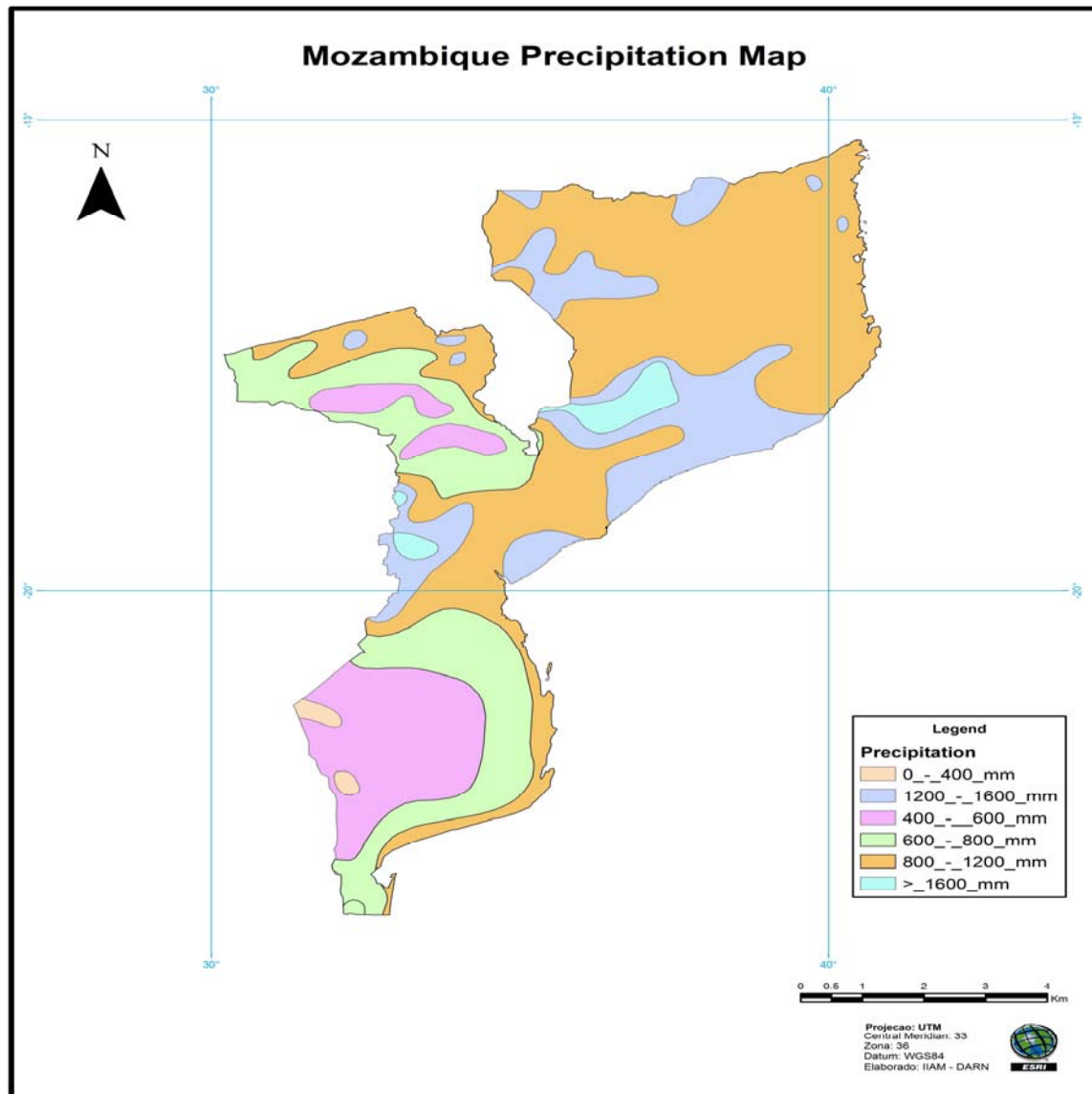


Figure 1.1 Map of Mozambique showing mean annual rainfall distribution (Agroclimatic Data Bank, INIA-DTA).

1.4.2 Farming practices

1.4.2.1 Southern Mozambique

Smallholder farmers in southern Mozambique practice maize production mainly under rainfed conditions. Each family cultivates several fields with a total area of 1-2 ha. The most

common food crops are cassava (*Manihot sp.*), maize (*Zea mays*), groundnut (*Arachis hypogaea*), sweet potato (*Ipomoea batatas*), cowpea (*Vigna spp.*), and pigeon pea (*Cajanus cajan*). These other crops are generally intercropped with maize and normally only cover a small fraction of the soil surface area (<25%). Their growing periods do also not correspond to those of maize (Massango, *et al.*, 1997).

Maize is the most important cereal crop. Its average yield is very low (less than 1000 kg ha⁻¹ and yields vary considerably with the amount and distribution of rainfall during the growing period (Schouwenaars, 1987). Soil tillage is done with a hoe or with animal traction and normally starts before the rains; weeding is done whenever necessary. Irregularity of the rainfall, even within the rainy season, together with the low water holding capacity of sandy soils led to a farming strategy of minimizing seasonal risks, rather than to one of maximizing production over a longer period (Schouwenaars, 1987).

Sowing does not occur in a fixed period, but generally takes place between September and October. This is often not the most favourable period from an agro-hydrological point of view due to the high fluctuation and erratic occurrence of rains (Schouwenaars and Pelgrum, 1990). Risks of water deficiency may be lower when sowing is done between December and January. Earlier sowing may be explained by the almost permanent food shortage, inducing people to sow as early as possible and by the higher risks of crop damage caused by pests and diseases when sowing is between December and January due to wetter conditions, which promote a good environment for pest and diseases.

Furthermore, labour availability for land preparation and weeding is a limiting factor, whereas land availability is much less limiting (except in the suburban zones). Thus, the extended sowing period seems to be a way to spread both labour and risk (Schouwenaars, 1987; Schouwenaars and Pelgrum, 1990).

1.4.2.2 Central Mozambique

1.4.2.2.1 Intermediate altitude region

The intermediate altitude region of central Mozambique includes land between 200 and 1000 meters above sea level, located in the provinces of Sofala and Manica. The region has a moderate to high human population.

The annual rainfall ranges between 1000-1200 mm and is concentrated in the period between November and March. The crop growing period varies between 120 and 180 days. The majority of soils are light, with some occurrence of heavy soils. The average temperature during the crop growing period varies between 17.5 and 22.5 °C and the main crops are maize, sorghum, cassava, cowpea, sweet potato and rice. In this region there is a good potential for cotton production.

Maize / sorghum / pulse production system is practiced in regions with 900-1100 mm annual rainfall and a moderately warm thermal regime. The main crop is maize, while sorghum (sole or intercropped with maize) is planted in middle of the season; the extent depending on the forecast of maize harvest. Cowpea and beans are also produced. Farmers also use extensive stream line borders of banana and other horticultural crops for the fresh market. Cattle are raised by richer farmers in the regions less affected by tsetse fly. There is a high erosion risk due to undulated topography and rainfall intensities. Farmers normally grow and consume fruits like orange, lemon, mango and papaya.

A sorghum / millet production system is practiced in the northern areas of the region where annual rainfall reaches 600-800 mm and the thermal regime is warm. The main crop is sorghum, while millet and maize are grown to a similar extent, and cotton is an important cash crop.

1.4.2.2.2 Low altitude region (Sofala and Zambezia Provinces)

The low altitude region covers partially the provinces of Sofala and Zambezia. Depending on the topography, the soils are mostly sandy in texture, alternating with regions of heavy soil texture (fluviosols and vertisols) in-between. In general the region has a moderate to high

annual rainfall (1000 - 1400 mm). The rainy period starts in November and ends between March and May, depending on the area.

In the areas with heavy soils the cultivation of rainfed rice predominates, while in the regions with better drained soils maize, sorghum, millet, cassava and cowpea are intercropped, depending on the availability of land and water. Cashew and cotton are important cash crops in the farming systems.

1.4.2.2.3 Semi-arid region (Zambeze Valley and southern Tete Province)

The semi-arid region of the Zambeze Valley and Southern Tete Province consists of a large area of land, from the driest region of the Zambeze watershed upstream from Mopeia district to the border of Zambia. Most of the land does not exceed 200 meters in elevation and the rainfall is 500-800 mm, concentrated between November and March. The zone more downstream has a higher rainfall and annual potential evapotranspiration (1200-1400 mm), and an area with a large water deficit for most of the year and high risk of crop loss. Sorghum and millet are predominant, while no cassava is cultivated due to the complete absence of rain during the cool season and the high evapotranspiration rate. There is great potential for the cultivation of cotton on well-drained rice lands on the margins of water courses.

In the sorghum/millet based production region, the rainfall ranges between 400-700 mm, with warm thermal regime and normally one growing season per year. In drier zones pearl millet is dominant (> 50% of cropped area), and in other zones sorghum is the major crop. Maize occupies 10-20% of cultivated areas and cassava is almost non-existent. Cotton is produced in the intermediate Zambeze region and stream line margins are cultivated with rice when possible. Sweet potato and vegetables are also produced, mainly for household consumption. Goats, pigs and poultry are the most important livestock activities.

1.4.2.3 Northern Mozambique

The most important food crops are maize, cassava (*Manihot sp.*), sorghum (*Sorghum bicolor*), rice (*Oryza sativa*), groundnut (*Arachis hypogaea*), cowpea (*Vigna sp.*), pigeonpea (*Cajanus cajan*), bambara groundnut (*Vigna subterranean*), and sweet potatoes (*Ipomoea*

batatas). Mixed cropping is practiced. Usually, the legumes crops are intercropped with cereals and cassava (Schouwenaars, 1987; Schouwenaars and Pelgrum, 1990).

The start of the rainy season (November) indicates the start of the growing season. At the end of growing season, when the last crops have been harvested, some farmers practice burning of the stubble. Burning is a measure to kill weeds and to reduce their seed-bank in the top soil. It is also thought to have a positive effect on the short-term nutrient availability (Geurts, 1997).

Soil tillage is done with hoe and is normally started after the first rains, especially in the crusted soils because these are very hard when dry, thereby reducing workability. However, some farmers start before the rains. Their strategy is to sow very early to give their crops some time ahead. The sequence of sowing crops is also important for a good development of all crops. For instance, maize is sown before cowpea to prevent that cowpea inhibits maize from emerging. At the end of the growing period a lot of fields are encountered fully invaded and overgrown by weeds (Geurts, 1997)

1.5 Hypotheses

Taking into account that planting date varies with factors such as water availability and cultivar differences in time to maturity, the following hypotheses were set for the research project:

- A short season maize cultivar will perform better at Chókwè than Umbeluzi area when planted late due to high soil water holding capacity of clay soils, which may permit water conservation in the soil profile for the crop growth;
- A late maturing cultivar will perform better when planted early at Chókwè in order to complete all the critical growth stages within the rainy season, escaping the late-season drought.

- At Umbeluzi a late maturing cultivar will perform better than a short cultivar due to higher rainfall with better distribution, and higher yield potential of a late maturing cultivar.
- The SWB model will be able to provide a good prediction of long-term optimum planting dates, given reliable long-term weather and soil data are available.

CHAPTER 2

MATERIALS AND METHODS

2.1 Experimental procedures and treatments

A field trial was conducted during the 2007/2008 growing season at Chókwè Agricultural Research Station, 23° 5'S, 33° 45' E, altitude of 33 m, in southern Mozambique. According to the modified Thornthwaite Climate Classification (Reddy, 1985) the area is classified as a semi-arid climate zone with a rainy season starting at the end of October and ending in March. The mean annual rainfall is 622 mm y⁻¹, where January is the month with the highest mean maximum temperature of 34°C, whilst July is the month with the lowest mean minimum temperature of 12°C. Daily reference evapotranspiration (ET_o) rate ranges from 2.8 to 7.2 mm day⁻¹, with an annual total of 1408mm (Annexure A). Figure 2.1 represents the monthly variation in rainfall and reference evapotranspiration (ET_o) for 29 years and also illustrates the annual water deficit in the region.

The experiment was carried out on a clay soil (30% sand, 24% silt and 46% clay) with a plant available water capacity (AWC) of 221 mm m⁻¹ (between soil water potential of –30 and –1500 kPa) and an infiltration rate of 30 mm h⁻¹.

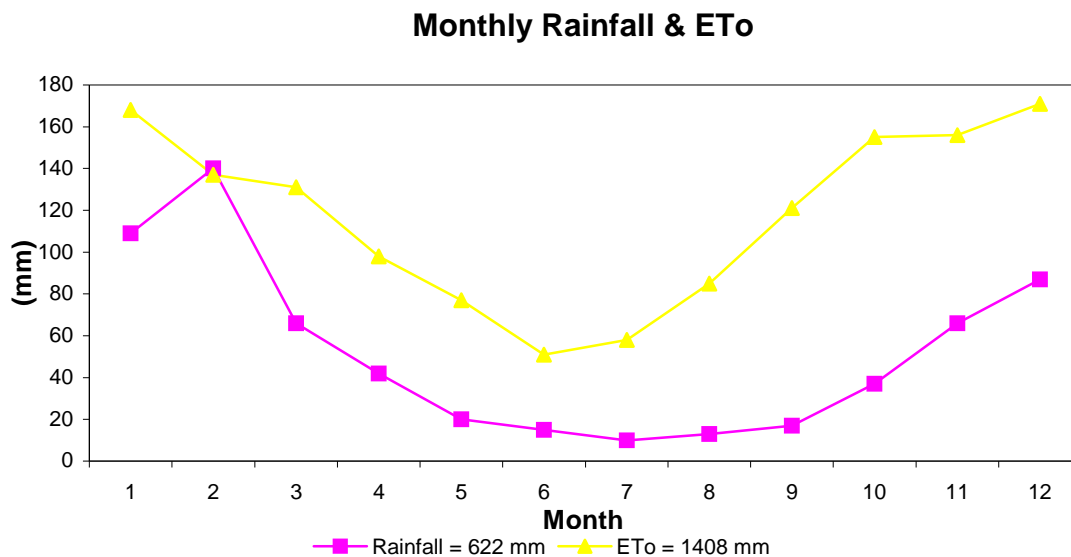


Figure 2.1: Monthly means of rainfall and reference evapotranspiration (29 year record), showing the annual water deficit in the Chókwè region (Agroclimatic data bank, INIA-DTA).

The experiment was carried out as a 2x3 factorial trial in a completely randomized block design (CRBD) with two cultivars and three planting dates. The two maize cultivars (i) Changalane, and (ii) Tsangano ZM 621 have maturity ratings of 110 and 140 days respectively and were selected to represent earlier and late maturity cultivars. These open-pollinated cultivars were selected based on their adaptation to and popularity in the area. The three planting dates used were 5 December 2007, 25 December 2007 and 15 January 2008. The total experimental area was 55.4 x 22.6 m, divided into three replicated blocks with dimensions of 17.8 x 22.6 m each. The blocks were separated from each other by 1m paths. Individual plots (each containing one cultivar x one planting date) were 5.6 m wide and 7 m long, consisting 7 rows of 7 m long with any inter-row spacing for 0.8 m and in- row spacing of 0.25 m. Trial layout is shown in Annexure E.

2.2 Crop management and measurements

The maize was sown manually by placing three seeds per planting hole. Twenty days after emergence, plants were thinned to adjust the number of plants to the recommended density of 50,000 plants ha⁻¹. Based on soil analysis results and target yields (5 t ha⁻¹ for cv. Changalane and 6 t ha⁻¹ for Tsangano), 120 kg ha⁻¹ N, 40 kg ha⁻¹ P and 50 kg ha⁻¹ K were applied to all plots to minimize nutrient stress. N application was split, with 50 kg ha⁻¹ applied at planting, followed by a 70 kg ha⁻¹ top dressing eight weeks after planting. Weeds were controlled manually. Preventative spraying for maize stalk borer and aphids (which transmit maize streak virus) was done chemically, using Cypermetrin. At final harvest, the plants from a 3 m² area were harvested for biomass yield, grain yield and harvest index determination.

Soil water deficit to field capacity was measured with an Aquapro capacitance type instrument (Aquapro Sensor, California, USA). The Aquapro water meter was calibrated against water content from gravimetric soil samples that were collected at the time of access tube installation. Readings were taken weekly, at 0.15 m depth increments down a soil depth of 0.75 m, from access tubes installed in the middle of each plot and positioned between rows.

Rain gauges were installed in order to measure rainfall (R). Fractional interception (FI) of photosynthetically active radiation (PAR) was measured weekly using a Decagon sunfleck

ceptometer (Decagon Devices, Pullman, Washington, USA). A series of measurements consisted of one reference reading above and five readings below the canopy, which were averaged. FI_{PAR} was then calculated as follows:

$$FI_{PAR} = 1 - \left(\frac{PAR \text{ below canopy}}{PAR \text{ above canopy}} \right) \quad (1)$$

Growth analyses were carried out at 7 to 15 day intervals by harvesting four plants from each plot. Leaf area was measured with an LI 3100 belt driven leaf area meter (LiCor, Lincoln, Nebraska, USA). Samples were then oven dried at 60 °C to a constant mass and weighed. Daily weather data (rainfall, solar radiation, wind speed, temperature and relative humidity) was recorded using an automatic weather station (Campbell Scientific, Inc., Logan, Utah, USA) located about 80 m from the experimental site.

2.3 Soil Water Balance model

SWB is a mechanistic, real time, generic crop irrigation-scheduling model. It gives a detailed description of the soil-plant-atmosphere continuum, making use of weather, soil and crop databases. Each of these are briefly described below. A more detailed description of the SWB model can be found in Annandale *et al.* (1999).

Weather unit

The weather unit of SWB calculates Penman-Monteith grass reference daily evapotranspiration (ET_o) according to the recommendations of the Food and Agriculture Organization (FAO) of the United Nations (Smith *et al.*, 1996; Smith, 1992b).

Soil unit

In the soil unit of SWB, potential evapotranspiration (ETP) is divided into potential evaporation and potential transpiration by calculating canopy radiant interception from simulated leaf area (Ritchie 1972). This represents the upper limits of evaporation and transpiration and these processes will only proceed at these rates if atmospheric demand is limiting. Supply of water to the soil surface or plant root system may, however, be limiting.

This is simulated in the case of soil water evaporation, by relating evaporation rate to the water content of the surface soil layer.

In the case of transpiration, a dimensionless solution to the water potential based water uptake equation is used. This procedure calculates a root weighted average soil water potential, which characterizes the water supply capability of the soil-root system. This solution has been shown to work extremely well by Annandale *et al.* (1999). If actual transpiration is less than potential transpiration the crop has undergone some stress and leaf area development will be reduced. The multi-layer soil component of the model ensures a realistic simulation of the infiltration and crop water uptake processes. A cascading soil water balance is used, once canopy interception and surface runoff have been accounted for.

Crop unit

In the crop unit, SWB calculates crop dry matter accumulation in direct proportion to transpiration, corrected for vapour pressure deficit (Tanner & Sinclair, 1983). It also calculates radiation-limited growth (Monteith, 1977) and takes the lower of the two. This dry matter is partitioned to roots, stems, leaves and grain. Partitioning depends on phenology, calculated with thermal time and modified by water stress.

SWB also includes a model based on the FAO crop factor approach (Smith, 1992b). This model can be used to calculate the soil water balance, if crop-specific growth parameters do not exist for the cultivars or species used.

SWB has previously been parameterized to simulate many crops, including maize, and was extensively validated against measured data in South Africa (Annandale *et al.*, 1999). The model has also been used for simulations to select optimal planting dates for various crops. However, for new crops or cultivars not currently included in the SWB crops database, crop specific growth parameters need to be determined from field experiments.

2.4 Crop specific parameter determination and data analysis

Weather and growth analysis data were used to determine crop specific SWB model growth parameters for the two local maize cultivars (Changalane and Tsangano). These included canopy radiation extinction coefficient, radiation conversion efficiency, specific leaf area, vapour pressure deficit-corrected dry matter water ratio and thermal time requirements for different growth stages (Jovanovic and Annandale, 1999).

The canopy radiation extinction coefficient for PAR (K_{PAR}) was determined using a basic equation describing transmission of solar radiation through the plant canopy, which is similar to Bouguer's law (Campbell & Van Evert, 1994):

$$FI_{PAR} = 1 - \exp(-K_{PAR} LAI) \quad (2)$$

Where FI_{PAR} is fractional interception of PAR, and LAI is leaf area index ($m^2 m^{-2}$).

Radiation conversion efficiency (E_c , $g MJ^{-1}$) was determined based on a linear relationship established by Monteith (1977) between accumulated crop dry matter yield and intercepted solar radiation.

$$\sum DM = E_c \sum FIR_s \quad (3)$$

where DM is dry matter production ($g m^{-2}$), FI is fractional interception of solar radiation, and R_s is daily total incident solar radiation ($MJ m^{-2}$). Since DM production is better related to PAR, instead of R_s , total solar radiation (R_s) in Eq. (3) is substituted by PAR by multiplying the value of R_s by 0.45 (Meek *et al.*, 1984). E_c was determined by fitting a linear regression equation between cumulative biomass production and cumulative PAR interception. The slope of the regression line represents E_c .

Leaf area index (LAI) and leaf area duration (LAD) were calculated following the equations recommended by Hunt (1990):

$$LAI = \frac{\text{measured total leaf area}}{\text{sampled area}} \quad (4)$$

$$LAD = \frac{[LAI_n + LAI_{n-1}][t_n - t_{n-1}]}{2} \quad (5)$$

where LAI is the leaf area index, LAI_n and LAI_{n-1} are the leaf areas at time n (t_n) and time n-1 (t_{n-1}) respectively; LAD is measured in weeks.

Vapour pressure deficit-corrected dry matter: water ratio (DWR) of the two maize cultivars was calculated following Tanner & Sinclair, (1983):

$$DWR = (DM \ VPD) / PT \quad (6)$$

where DM (kg m⁻²) is the total above-ground biomass, measured at harvest, whilst VPD represents the seasonal average vapour pressure deficit. Both VPD and DWR are in Pascal (Pa). PT (mm) is the potential transpiration and was calculated from potential evapotranspiration and canopy cover, following Allen *et al.* (1998). Daily VPD was calculated from measurements of maximum air temperature (T_{max}), minimum air temperature (T_{min}), maximum relative humidity (RH_{max}) and minimum relative humidity (RH_{min}), adopting the procedure recommended by the Food and Agriculture Organization (FAO) of the United Nations (Allen *et al.*, 1998):

$$VPD = \left(\frac{e_{sT_{max}} + e_{sT_{min}}}{2} \right) - e_a \quad (7)$$

where:

e_{sT_{max}} = Saturated vapour pressure at maximum air temperature (kPa)

e_{sT_{min}} = Saturated vapour pressure at minimum air temperature (kPa)

e_a = Actual vapour pressure (kPa)

Saturated vapour pressure (e_s) at maximum (T_{max}) and minimum air temperature (T_{min}) was calculated by replacing T with T_{max} and T_{min} (°C) in the following equation (Allen *et al.*, 1998):

$$e_s = 0.6108 \exp \left[\frac{17.27 T}{T + 237.3} \right] \quad (8)$$

e_a was calculated from measured daily T_{max} , T_{min} , RH_{max} and RH_{min} , using the following equation (Allen *et al.*, 1998):

$$e_a = \frac{e_s(T_{min}) \frac{RH_{max}}{100} + e_s(T_{max}) \frac{RH_{min}}{100}}{2} \quad (9)$$

Growing day degrees (GDD) ($d \text{ } ^\circ\text{C}$) were determined from daily average air temperatures (T_{avg}) following Monteith, (1977):

$$GDD = (T_{avg} - T_b) \Delta t \quad (10)$$

Where T_b is the temperature ($^\circ\text{C}$) below which development is assumed to cease and Δt is the time step (one day). The T_b value recommended by Knott (1988) (10°C) was used in this study.

2.5 Model calibration and validation

The Soil Water Balance model was calibrated for the two maize varieties using the data collected from the first planting date (5 December) for cultivar Tsangano and second planting date (25 December) for cultivar Chagalane. Calibration of the model was based on field-measured values of leaf area, dry biomass yield (leaves, stems and grains), calculated crop ET, and soil water deficit measurements. The model was then validated against the remaining independent experimental data sets (the two remaining planting dates for each cultivar).

2.6 Soil water content and crop water use

In order to demonstrate how the soil water deficit (SWD) developed for each planting date treatment, the changes in SWD with time were calculated on a daily basis throughout the season, using the following water balance equation:

$$\Delta PAW = P - ET - R - D \pm \Delta S \quad (11)$$

where ΔPAW is the change in plant available water in the soil, ET is evapotranspiration, P is precipitation (rain), R is runoff, D is drainage and ΔS represents the change in soil water storage. All terms are expressed in mm. R was assumed to be negligible as no high intensity rainfall occurred. A positive sign for ΔS indicates a gain in soil water storage. ΔS was calculated from soil water content measurements (θ) with the Aquapro meter. Crop water use (ET) over the season was estimated using equation 11 for the top 75 cm of the profile, where maize roots are concentrated.

The initial SWD at all planting dates was not known, since the initial water content was not measured. However, taking the amount of rainfall that occurred just before planting into consideration (Fig. 3.1), it was assumed that the profile was close to the field capacity at all planting dates.

2.7 Statistical analysis

Analyses of variance were performed on the data using Statistical Analysis System (SAS Institute, 2003) software. Means were compared using the Least Significant Differences (LSD) test at 5% probability level. Correlations between parameters were also computed when applicable.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Rainfall and air temperature at Chókwè

The rainfall and air temperature distributions during the experiment at Chókwè are presented in Figures 3.1. and 3.2. Rainfall and reference evapotranspiration data for the 2007-2008 season shows that the magnitude of rainfall shortage is considerable throughout the year, except for December.

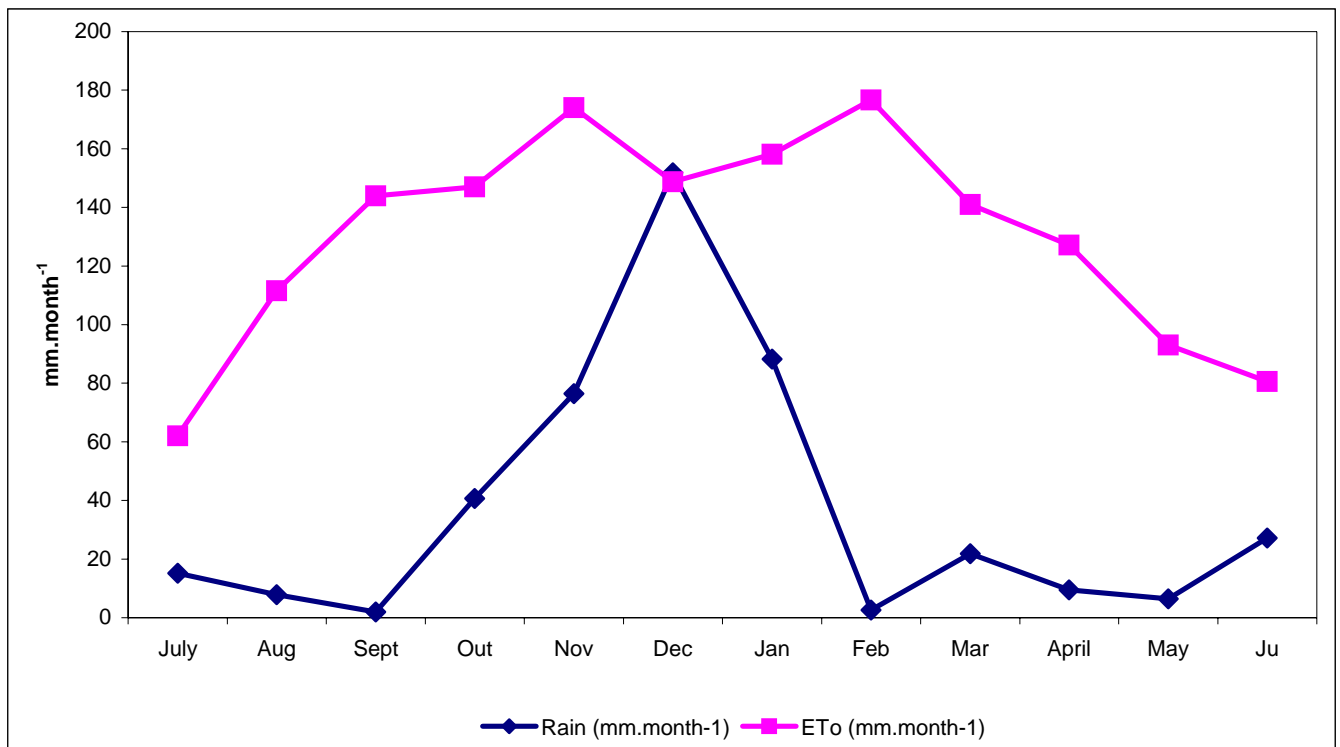


Figure 3.1: Rainfall distribution and ETo for Chókwè from July 2007 to June 2008

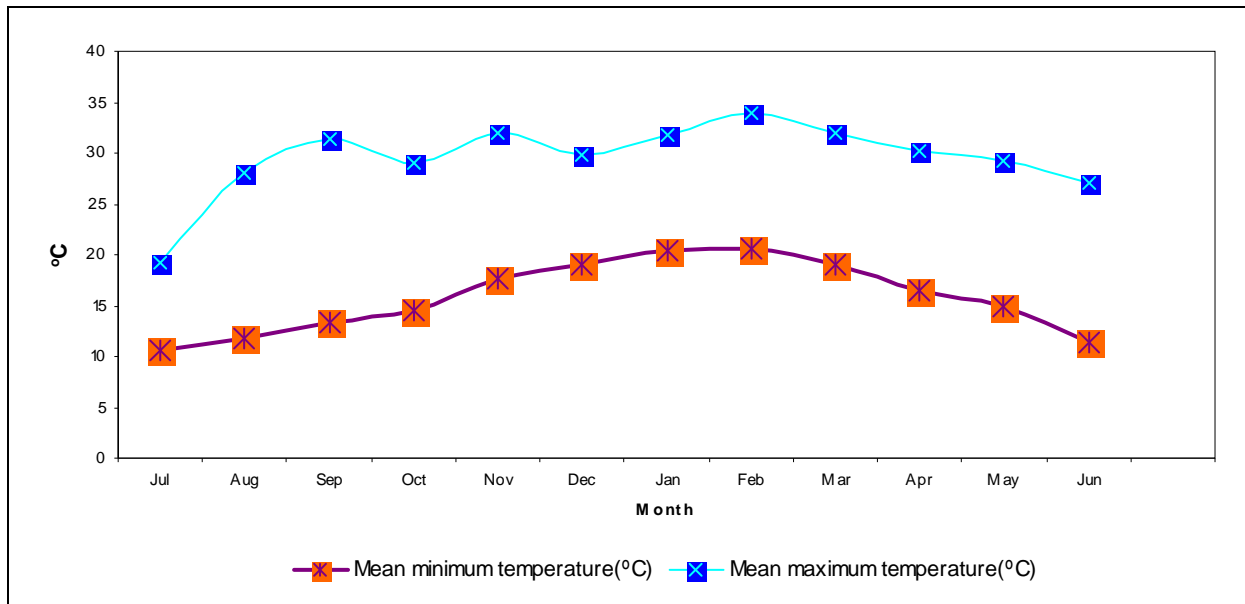


Figure 3.2: Monthly averages of maximum and minimum air temperature for Chókwè from July 2007 to June 2008

The long period of water deficit observed, was associated with high atmospheric evaporative demand (related to the high temperatures) and low rainfall (including the uneven distribution) during the cropping season. The result of this was large soil water deficits and low soil water availability for crops later in the season (February – May 2008), which could result in water stress and lower crop yields.

3.2 Measured soil water deficits and crop water use

3.2.1 Soil water deficits

Soil water deficits (SWD) were calculated in order to analyze the differences in water deficits and water use between treatments (Table 3.1). Initial SWD was not measured, but taking the amount of rainfall just before planting into consideration, the deficits at all three planting dates were probably (assumed as about 20 mm for all). The insufficient amount of rain recorded during the growing season did not completely alleviate the soil water deficit in all cultivar x planting date treatment combinations (Table 3.1), probably resulting in increasing deficits and severe stress for some treatments.

The soil water deficit graphs (Fig. 3.3) show similar trends for all planting date x cultivar treatment combinations, but PD1 gave the lowest final deficits, followed by PD2 and PD3, which had the highest final deficits. For all three planting dates the final deficits were lower for Changalane than Tsangano.

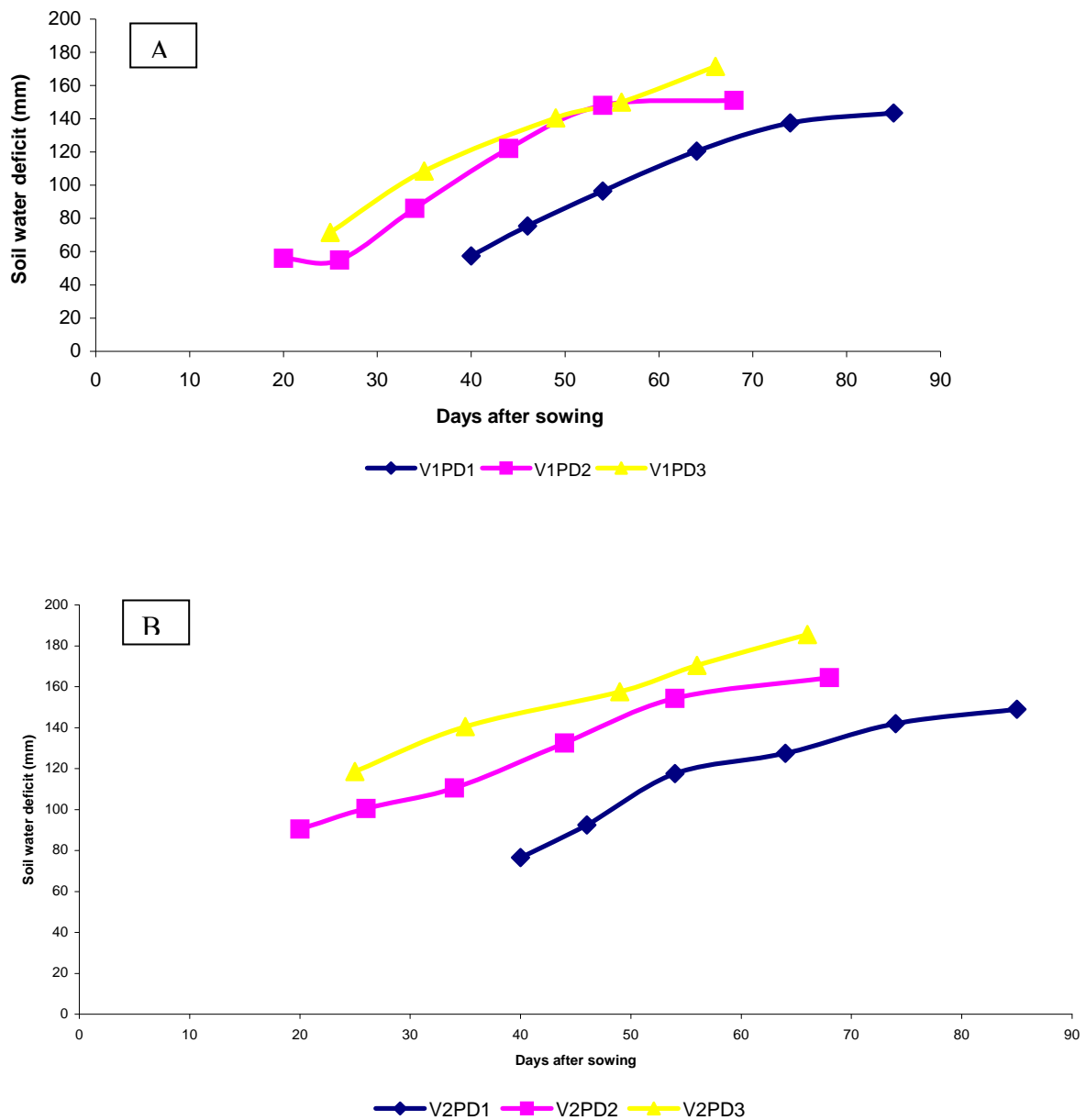


Figure 3.3: Measured soil water deficits for the different planting date treatments for cultivars Changalane (a) and Tsangano (b).

3.2.2 Crop water use (ET) and water productivity (WP)

Agricultural production commonly refers to crop yield per unit area (e.g. tons per hectare). The term water productivity (kg m^{-3}) is defined in terms of utilisable portion of the crop biomass produced (i.e. grain or seed yield in kg), per unit of transpiration or evapotranspiration (in m^3 or mm of water) (Molden, 1997), as opposed to water-use efficiency, which often refers to total dry matter production. In this dissertation, the term water productivity (kg m^{-3} or $\text{kg ha}^{-1} \text{mm}^{-1}$) is used to express maize grain yield produced per unit water used.

The cumulative crop water use was estimated using the soil water balance equation described in equation 11, assuming no runoff, as fields were flat and no high intensity rainfall events occurred during the crop growing season. There was a lot of rain early in the season (December and January), and therefore some drainage was expected. However, this is not easy to measure, and was therefore estimated from SWB model simulations. Substantial drainage was simulated for planting date 1 (PD1, Table 3.1). The calculated seasonal crop water use for all treatments are summarized in Table 3.1.

For Changalane (V1) the first planting date treatment (PD1) had the highest water use (ET) of 316 mm, which was 61 mm more than the second planting date (PD2) and 134 more than the last planting date (PD3) treatments. The same tendency was observed for cultivar Tsangano. The early planting date (PD1) also had the highest water use (376 mm), followed by the second planting date (PD2) and late planting date (PD3) treatments.

For both cultivars, maize that was planted early (PD1) used most water ($376 - 316 \text{ mm season}^{-1}$), followed by the second (PD2; $255 - 233 \text{ mm/season}$) and late planting dates (PD3; $182 \text{ mm.season}^{-1}$) (Table 3.1).

TABLE 3.1: Seasonal rainfall, soil water deficits, drainage, evapotranspiration and maize water productivity for Chókwè trial (July 2007-June 2008)

Treatment	Effective Rain (mm)	Initial Deficit (mm)*	Final Deficit (mm)	Estimated drainage	ET calculated (WUC) (mm)	ET simulated (WUS) (mm)	Water productivity (kg ha ⁻¹ mm ⁻¹ grain)
V1PD1	282	20	109	55	316	333	7.8
V1PD2	152	20	147	29	255	257	17
V1PD3	31	20	171	0	182	161	8.1
V2PD1	296	20	167	67	376	337	8.5
V2PD2	156	20	127	30	233	253	5.5
V2PD3	42	20	160	0	182	147	4.0

* Initial deficits estimated at 20mm for all treatments.

These results therefore clearly show that the different planting dates caused substantial variation in the amount of water used by the crop, which eventually, resulted in the different maize yields recorded. This was probably directly related to the rainfall amount and distribution during the growing season.

3.3 Effect of planting date on leaf area index

The leaf area index (LAI) progression throughout the growing season for the three planting dates (PD1, PD2 and PD3) and two maize cultivars (V1 and V2) are presented in Figure 3.4.

Overall the LAI values ranged from 0.23 to 2.76 for cultivar Changalane and from 0.29 to 2.94 for Tsangano. The LAI curve trends were similar for the same planting dates in both cultivars, but for Changalane the highest LAI value of 2.76 was reached at PD2, while for Tsangano the highest LAI of 2.94 was recorded for PD1. Late planting (PD3) in general resulted in the lowest maximum LAI values for all cultivars. This can be explained by the limited plant water available in the soil (little rain late in the season, Table 3.1) and high atmospheric evaporative demand (Fig.3.1) during this period. Therefore, plants from this planting date did not attain a well-developed canopy, resulting in a lower fraction of photosynthetic active radiation intercepted. This, together with water stress during flowering and grain filling stages, probably reflected in the low final grain yields observed for the late planting date (sections 3.5 – 3.6).

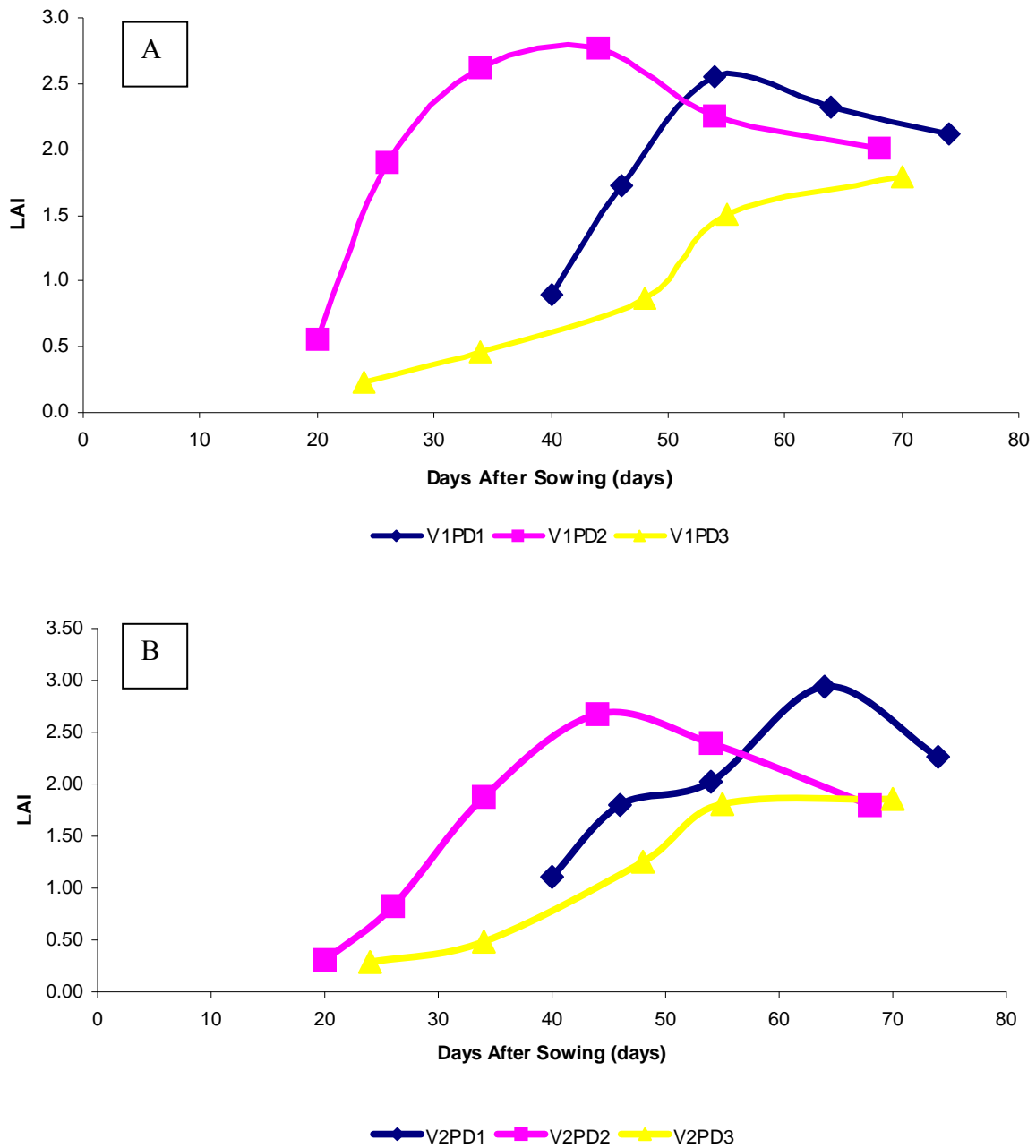


Figure 3.4: Effect of different planting date treatments on LAI during the growing season for cultivars Changalane (a) and Tsangano (b)

3.4 Effect of planting date treatments on leaf area duration

Leaf area duration gives an indication of the time that foliage remains photosynthetically active on plants and reflects the extent of light interception. Table 3.2 gives a summary of LAD results for the different planting date x cultivar treatments combinations.

Leaf area duration ranged from 46 to 115 days for Changalane and from 54 to 100 days for Tsangano (Table 3.2). Table 3.2 shows that LAD was longest for the PD2 and shortest in PD3 for both cultivars. For PD1, LAD was found to be 27 days shorter for Changalane and 8 days shorter for Tsangano, when compared to their respective PD2 values.

TABLE 3.2: Leaf area duration (LAD) and determination coefficients between LAD and total dry matter yield as affected by planting date treatments

Maize	Planting	LAD	r^2
Cultivar	Date	[day m ² m ⁻²]	LAD x TDM yield [kg m ⁻²]
Changalane	PD1	88	0.99
	PD2	115	0.96
	PD3	46	0.92
Tsangano	PD1	92	0.97
	PD2	100	0.92
	PD3	54	0.99

The correlation between leaf area duration (LAD) and total dry matter (TDM) produced for all treatment combinations (planting dates and cultivars) are presented in Figure 3.5. A linear relationship was found in all the treatment as indicated in Table 3.2 and Figure 3.5. The coefficient of determination (r^2) between LAD and total dry matter was high. This clearly illustrates that the differences in yield recorded for the different planting dates (Section 3.6) were at least partly due to differences in LAD.

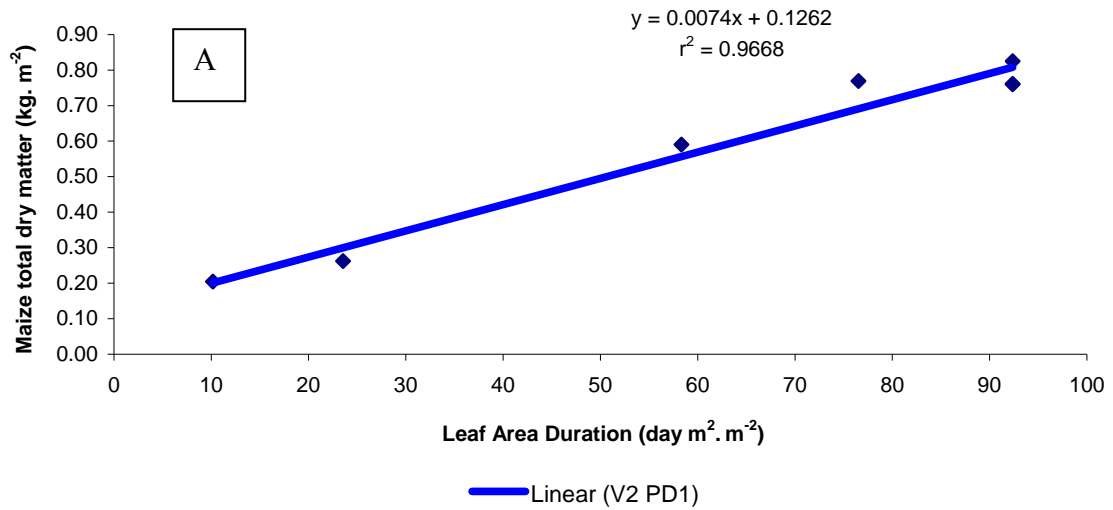


Figure 3.5 a: Relationship between LAD and maize total dry matter yield for the PD1 x V2 treatment combination.

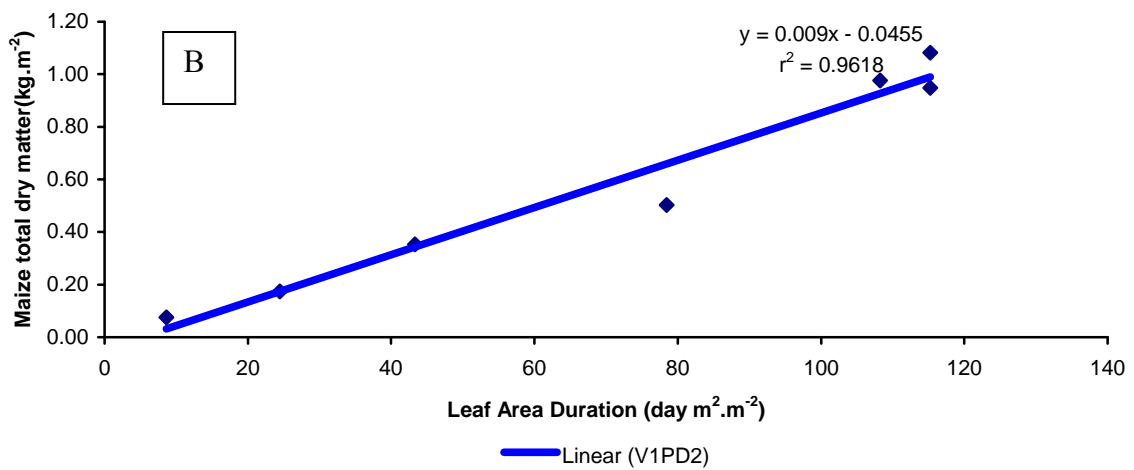


Figure 3.5 b: Relationship between LAD and maize total dry matter yield for the PD2 x V1 treatment combination.

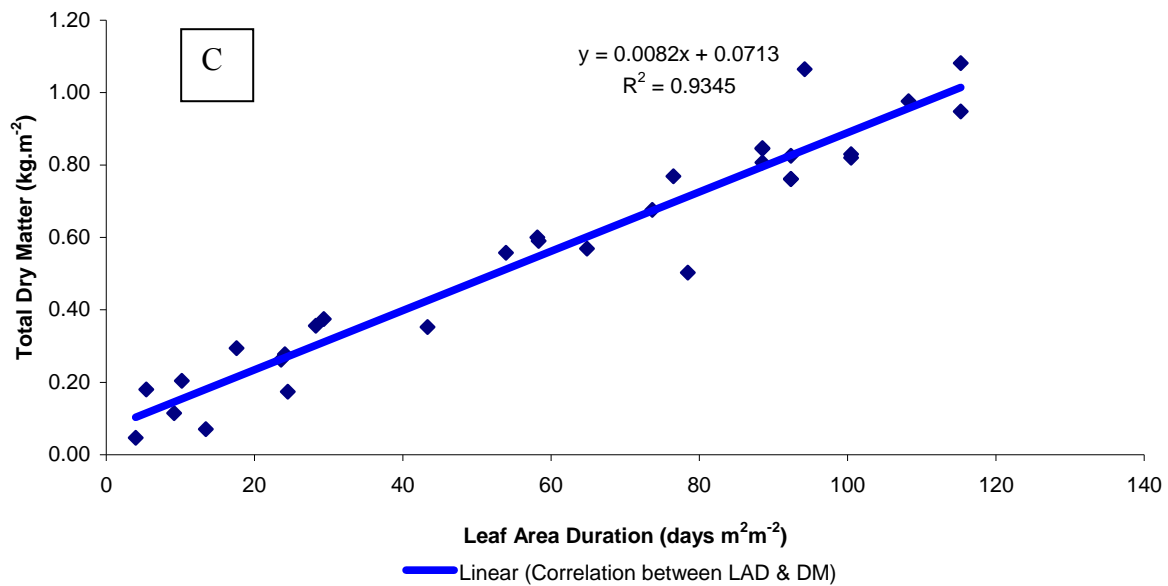


Figure 3.5 c: Relationship between LAD and maize total dry matter yield for all plant date and cultivar treatment combinations.

3.5 Effect of planting date on total dry matter production

The total above-ground dry matter yields (TDM) over time for cultivars Changanane and Tsangano are shown in Figure 3.6.

The trends for the different planting date treatments (PD1, PD2 and PD3) were found to be approximately similar for both cultivars. For cultivar Changanane PD2 gave the highest TDM yield, while for Tsangano the highest TDM yield was achieved at PD1. Changanane, the short season cultivar, could still develop a full canopy before the end of the rainy season when planted late in December (PD2). However, Tsangano, which has a longer growing season, needed the longest growth period (PD1) to produce maximum TDM.

Although cultivar Changanane also attained a high total above ground dry matter yield at PD3, this did not reflect in a high final grain yield (Table 3.1). This phenomenon can be explained by high rainfall observed during January, which coincided with the crop development stage, and resulted in the development of a large canopy. However, in the following months very low rainfall was recorded, which most likely resulted in drought stress during the reproductive stage, resulting in lower final grain yields.

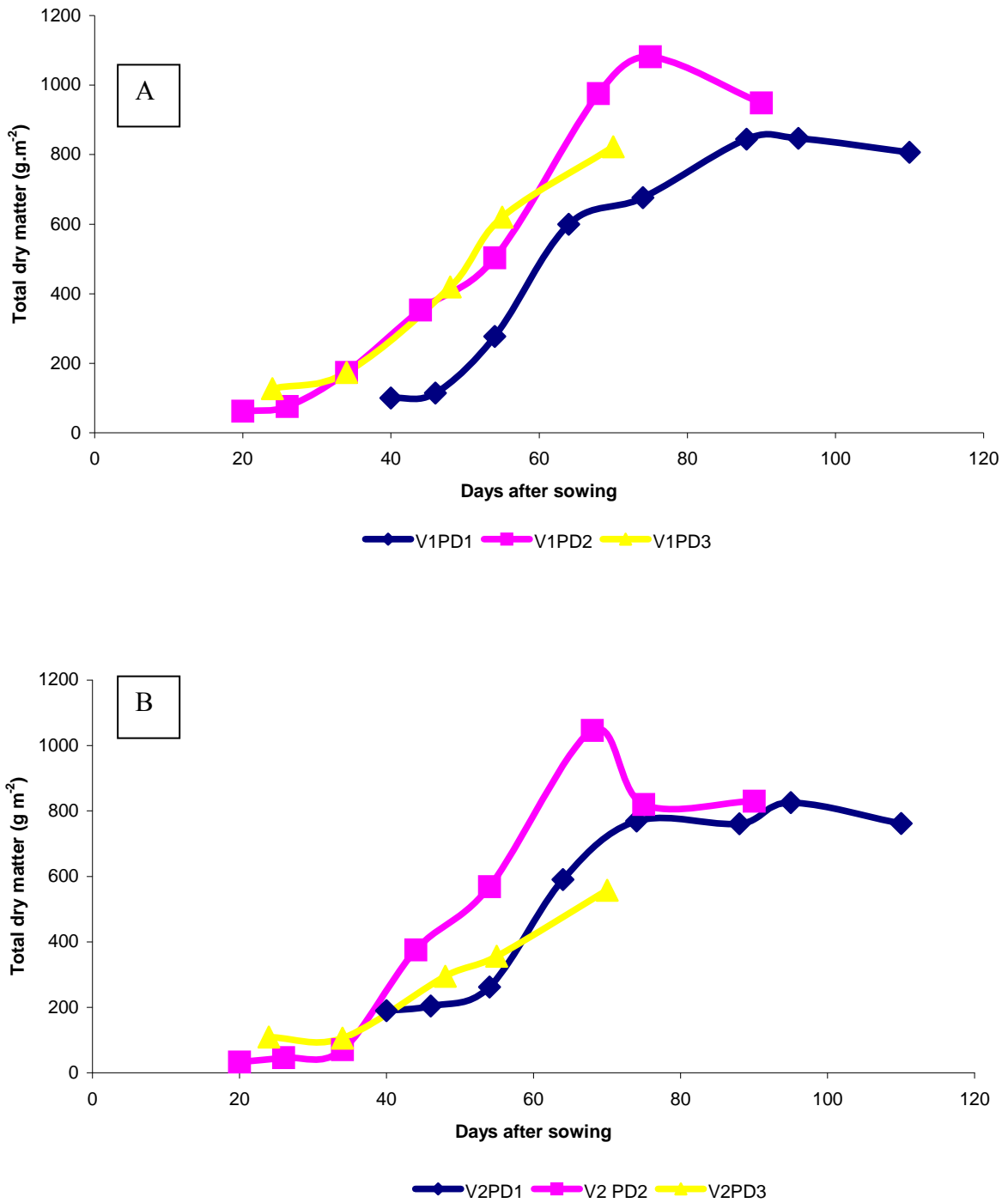


Figure 3.6: Total measured above ground dry matter yields for different planting date treatments during the growing season of cultivars Changalane (a) and Tsangano (b)

The lower total above ground dry matter yields observed at PD3 for Tsangano was due to little available soil water later in January and February, when this late cultivar was still in its development stage. The stress experienced by the crop during its growing season had cumulative negative effects, which were ultimately expressed as a reduction in total biomass production, and finally in low grain yields.

3.6 Grain yields

The yield response of each cultivar to the different planting date treatments is illustrated in Table 3.3. The table summarises the effect of planting date and cultivar treatment combinations on yield and thousand seed mass.

Different planting dates resulted in significant grain yield differences for both cultivars. Table 3.3 shows that cultivar Changalane x PD2 gave 43% and 66% higher yields compared to PD1 and PD3, respectively. However, for Tsangano best yield was achieved at the first planting date, which gave 60% and 77% higher yields than PD2 and PD3 respectively. For both cultivars lowest yields ($p < 0.05$) were observed at PD3 (Table 3.3).

TABLE 3.3: Effect of planting date on grain yield and 1000-seed mass of two maize cultivars

Planting date treatments	Yield (t ha ⁻¹)		1000 seed-mass (g)	
	Cultivar		Cultivar	
	Changalane	Tsangano	Changalane	Tsangano
PD1	2.46c	3.2b	199b	212.6b
PD2	4.33a	2.28c e	281.6a	184.6b
PD3	1.47d	0.73f	99.3c	72.3c
LSD $p < 0.05$	0.55		0.55	
Means	2.8	1.7	193.3	156.5
CV (%)	15.8		14.6	

Values followed by the same letter are not significantly different at $p = 0.05$

3.7 Yield response to water

In order to relate yield with the total water used by the different cultivars of maize, the crop water productivity (WP) was determined (Table 3.1).

The most responsive cultivar to water supply was Changalane. When sown late in December (PD2), this cultivar gave the highest yield with 255 mm of soil water, with a yield rate increase per mm of water received of $17 \text{ kg ha}^{-1} \text{ mm}^{-1}$. However, when sown early in December or mid January, the rate of yield increase per mm of water received was substantially lower at 7.8 and $8.1 \text{ kg ha}^{-1} \text{ mm}^{-1}$ respectively. Taking into account that there was a low soil water deficit from early December until January, it was expected that Changalane would have attained a high yield and WP when planted early December (V1PD1). However, this treatment combination attained a lower yield compared to the V2PD1 treatment combination. Taking into account that early in December cultivar Changalane probably still had a shallow root system, the high rainfall at that time could possibly have resulted in the leaching of nutrients beyond the root zone, which may have resulted in the lower yield.

On the other hand, WP for the cultivar Tsangano decreased from $8.5 \text{ kg ha}^{-1} \text{ mm}^{-1}$ for the early December planting (PD1) to 5.5 and $4.0 \text{ kg ha}^{-1} \text{ mm}^{-1}$, for the late December (PD2) and mid January (PD3) planting dates, respectively.

These results suggest that Tsangano (long season cultivar) was susceptible to drought when sown late in December and mid January, as the period prior to anthesis coincided with a long dry spell. As a consequence, the yields obtained were substantially lower, around 2.28 and 0.73 t ha^{-1} , respectively. However, it gave a much higher yield of 3.2 t ha^{-1} when sowed early December, as the longer period of soil water availability (rain) allowed the crop to develop a much bigger canopy, for high photosynthetically active radiation interception and conversion into carbohydrates for plant growth and yield increase (Table 3.3).

The results also suggest that the effect of planting date on maize performance is related to the rainfall distribution during the different crop growing stages, namely the crop development, leaf expansion and anthesis, which finally culminate in the grain yield.

3.8 Effect of planting date versus cultivar interaction on harvest index

Plant harvest index, the ratio of grain mass to total plant mass, reflect the partitioning of photosynthate between the grain and the vegetative plant and improvements in harvest index emphasize the importance of carbon allocation in grain production. The harvest index response of each cultivar to different planting date treatments is illustrated in Figure 3.7.

Among the cultivars, HI was greatest in the earlier maturing cultivar (Changalane) (Figure 3.7). For Changalane, the harvest index at planting date 2 was superior when compared to planting dates 1 and 3, attaining 33% and 61% of the value at PD2 respectively. However, for Tsangano, the HI at planting date 1 was greater than planting dates 2 and 3 by 35% and 69 % respectively.

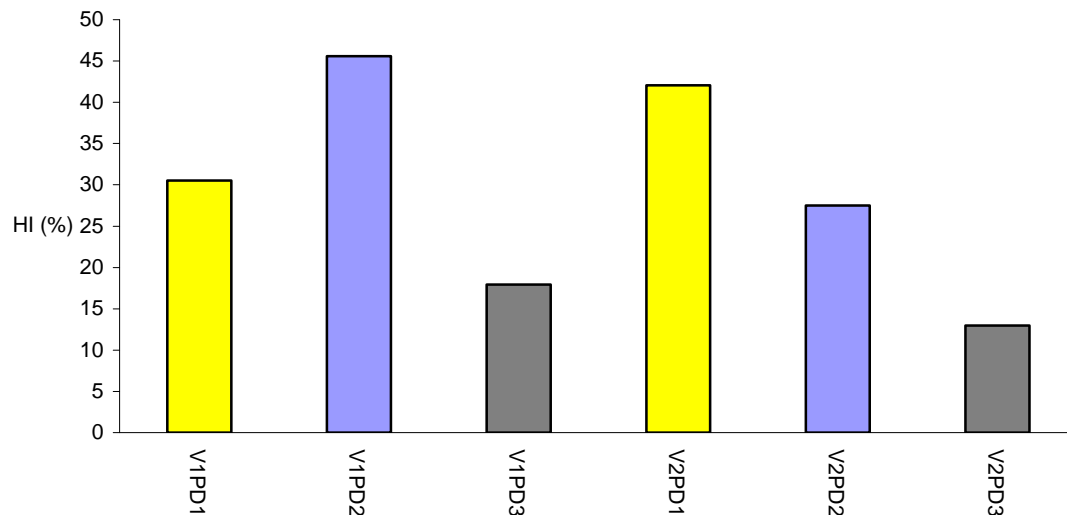


Figure 3.7 Effect of planting date X cultivar interaction on maize harvest index

As expected, a strong positive relationship was detected between HI and grain yield under different water regimes (planting dates) for cultivars Changalane and Tsangano (Fig. 3.8). Bolanos and Edmeades (1993) and Edmeades *et al.* (1993) found that high HI under drought was associated with rapid early ear growth and suggested that it was an increase in partitioning to the ear that was responsible for increases in HI under water stress regimes.

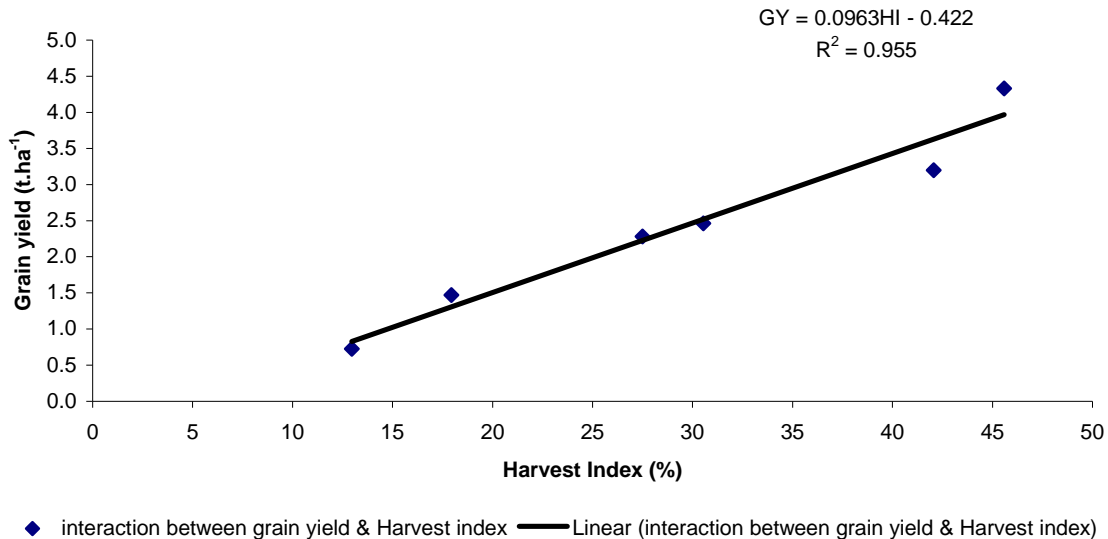


Figure 3.8: Relationship between grain yield and harvesting index of cultivars Tsangano and Changalane observed for different planting dates at Chokwe Agricultural Research Station

In the present study, lowest HI values were observed for the late planting date, which also had the lowest grain yields due to late water stress. It is, therefore, clear that not only the intensity, but also the timing of water stress will influence the HI.

3.9 Effect of different planting date treatments on 1000-seed mass

The effect of planting date x cultivar interaction on grain kernel mass was significant (Table 3.3). For Changalane, the 25 December (PD2) planting date gave a better result by out weighting the seed mass of the PD1 and PD3 planting dates by 29.3% and 64.7% respectively. This good performance of Changalane for planting date 2 contributed to the higher grain yield observed, compared with planting dates 1 and 3. However, for Tsangano, the delay in planting date from 5 December (PD1) to 15 January (PD3) reduced the grain kernel mass by 66% and consequently also contributed to the reduction in observed grain yield.

On other hand, Changalane had a 1000- seed mass of 34.4% higher compared to Tsangano when sowed on December 25. However, when sown on December 5 and January 15, the cultivars did not show any significant differences in grain 1000-seed mass (Table 3.1). These results are in accordance with the findings of (Tanaka and Hara, 1974), (for long season and not for short season cultivars), who reported that a delay on sowing from October 1 to

December 1 reduced the 1000-seed mass and, therefore low grain yield was obtained from this planting date. It had been reported that variation in maize grain yield due to reduction in 1000-seed mass was mainly due to the decrease in translocation photosynthates to the ripening grain (Tanaka and Hara, 1974)

3.10 Model application to determine optimum planting window

3.10.1 Model calibration

The Soil Water Balance (SWB) model was calibrated for the two maize cultivars using the data collected from the second planting date (25 December) for cultivar Changanane and first planting date (5 December) for cultivar Tsangano. Calibration of the model was based on field-measured values of LAI, biomass produced, photosynthetically active radiation, calculated soil water deficit, crop water used and grain yield. The model parameters obtained for the two cultivars are listed in Annexure F.

The relationship between the measured and the simulated root depth, top and harvestable dry matter yields, leaf area index and soil water deficits for the calibration data sets (treatment combinations V1PD2 and V2PD1) are represented in Figures 3.9a and 3.9b. In general good agreement was observed between all measured and simulated values for cultivar Changanane (Figure 3.9a).

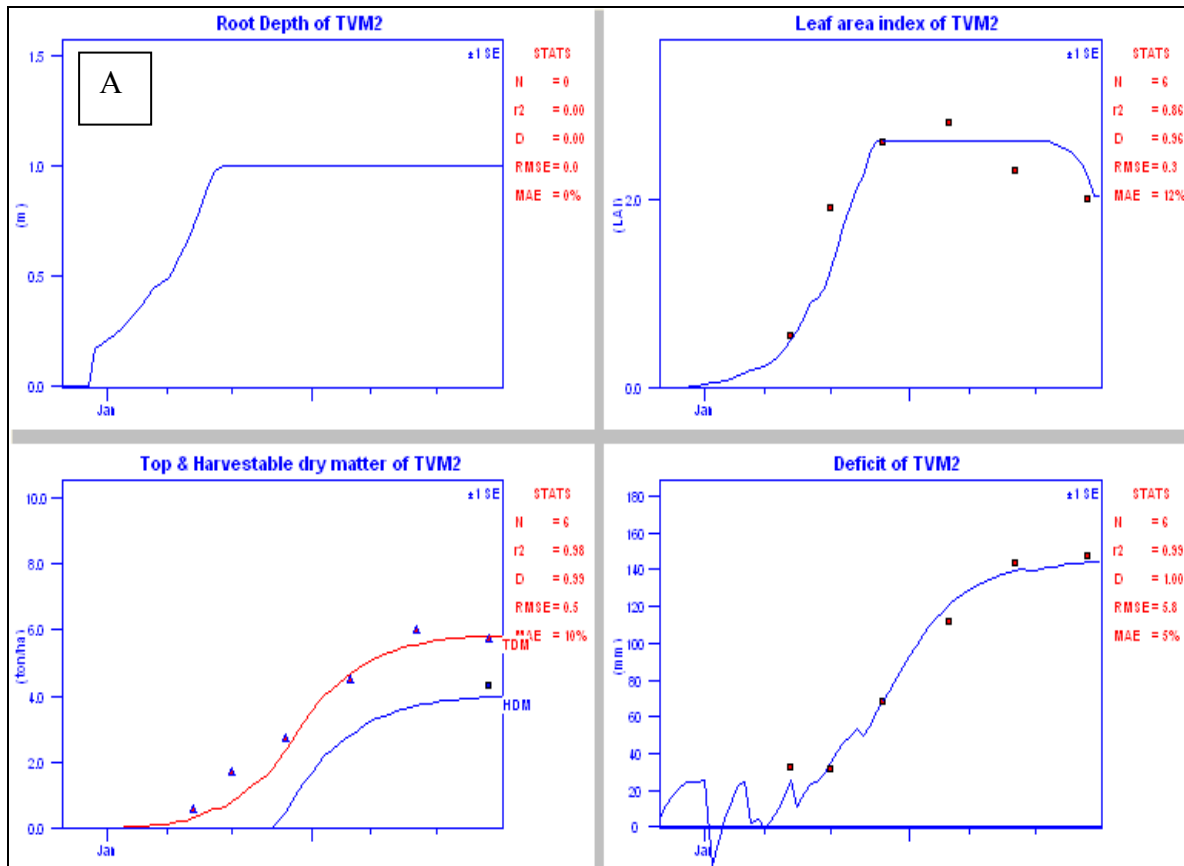


Figure 3.9a: Measured and simulated leaf area index, top and harvestable dry matter and soil water deficits for cultivar Chagalane at planting date 2 (PD2) (calibration data set).

For cultivar Tsangano (Figure 3.9b) the agreement between observed and simulated values of top and harvestable dry matter yields, leaf area index and soil water deficits was not as good as for Chagalane. Both top and harvestable dry matter yields, as well as soil water deficits were slightly under estimated by the model. Deviations in soil water deficits could possibly be linked to inaccuracies in the determination of the soil water contents.

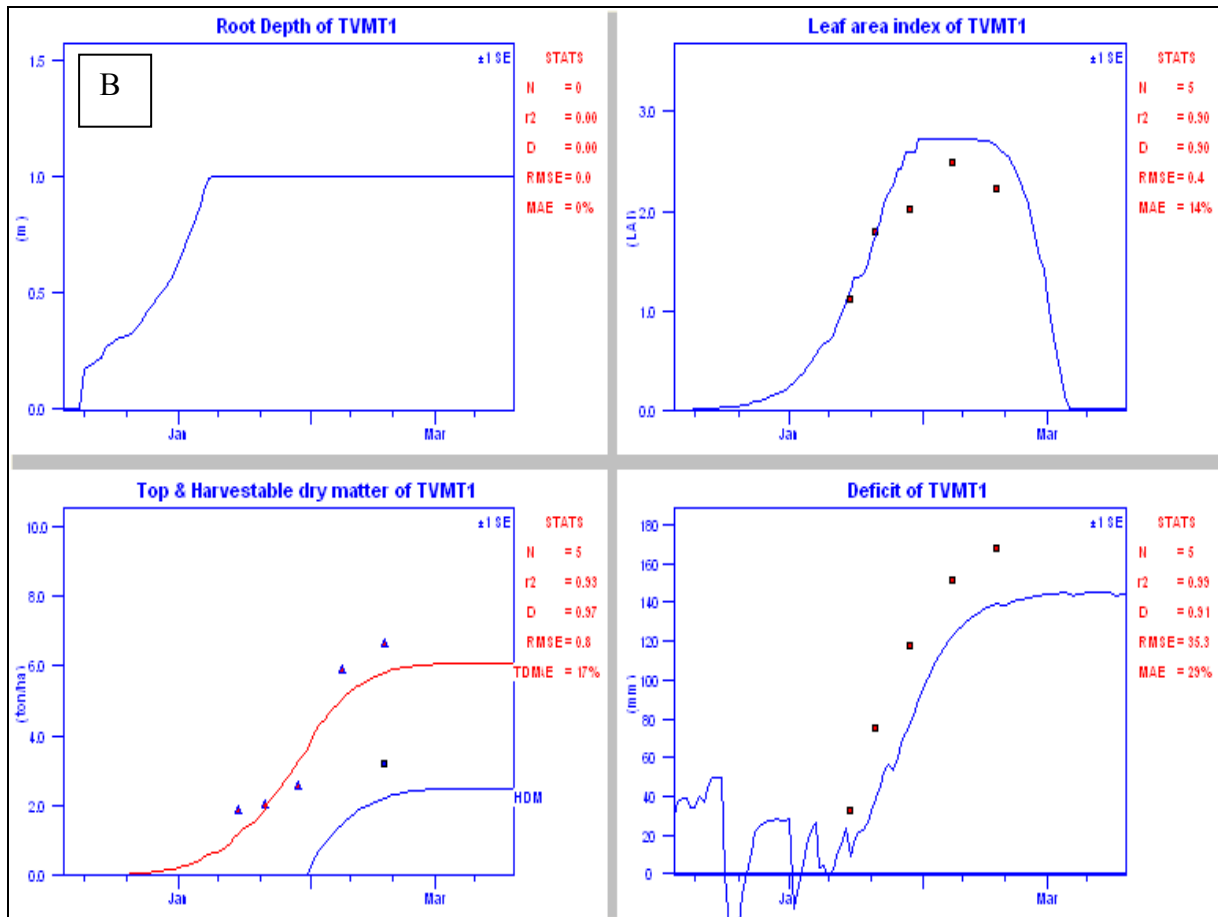


Figure 3.9b: Measured and simulated leaf area index, top and harvestable dry matter and soil water deficit for cultivar Tsangano at planting date 1 (PD1) (calibration data set).

In spite of these deviations, the statistical comparison between measured and simulated values shows that agreement was still within acceptable limits.

3.10.2 Model validation

The experimental results generated from the maize trial at Chokwe Agricultural Research Station also gave the opportunity to test the SWB model on independent data sets. Data from the two later planting dates of Tsangano and first and third planting dates of Changalane were not used for model calibration and could therefore be used to validate the model. A comparison between observed and predicted top and harvestable dry matter yields, time progression of leaf area index (LAI) and soil water deficits of both cultivars and planting dates are shown in Figures 3.10 and 3.11.

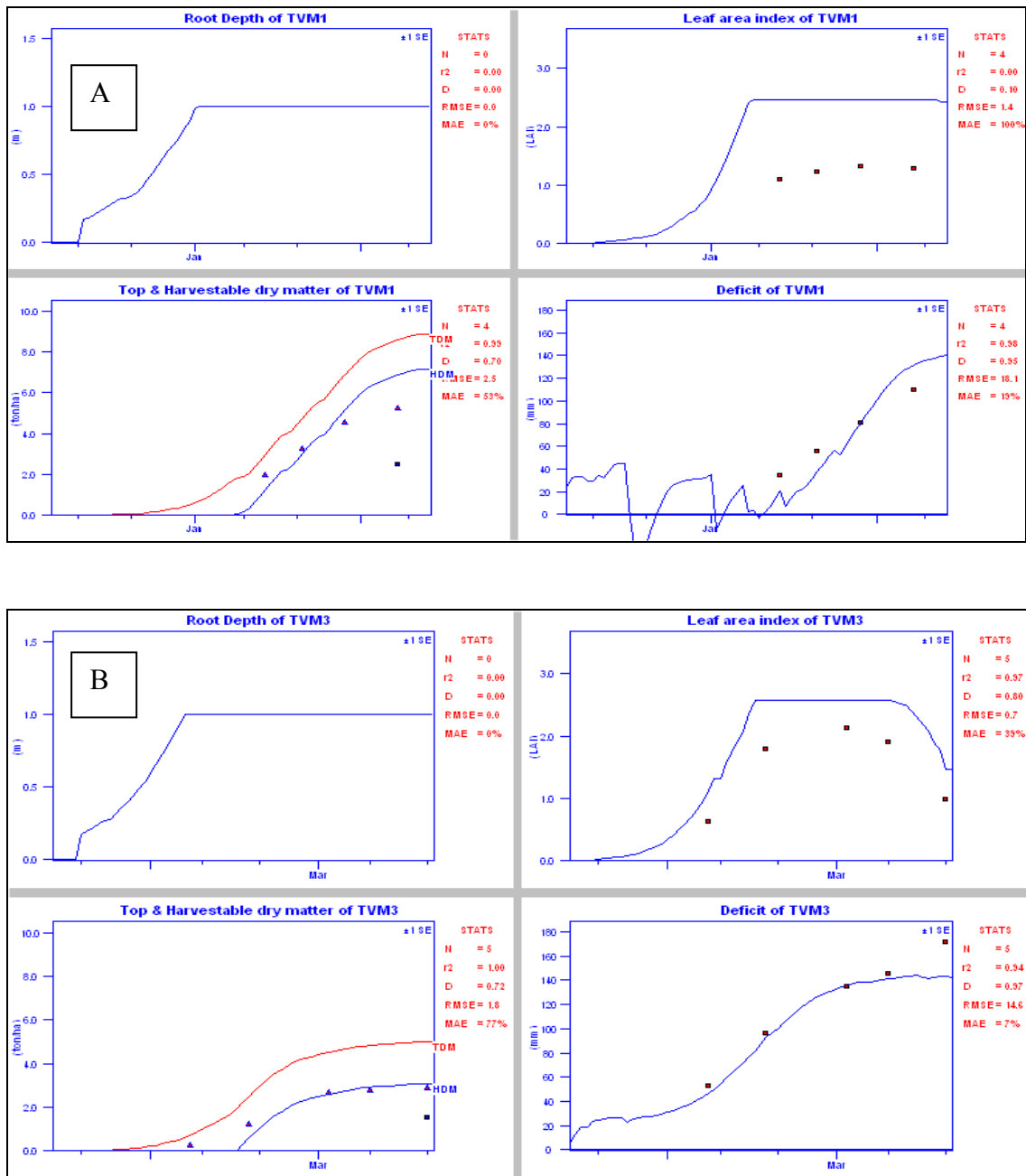


Figure 3.10. Measured and simulated leaf area index, top and harvestable dry matter and soil water deficit for Changanale at PD1 (a) and PD3 (b)

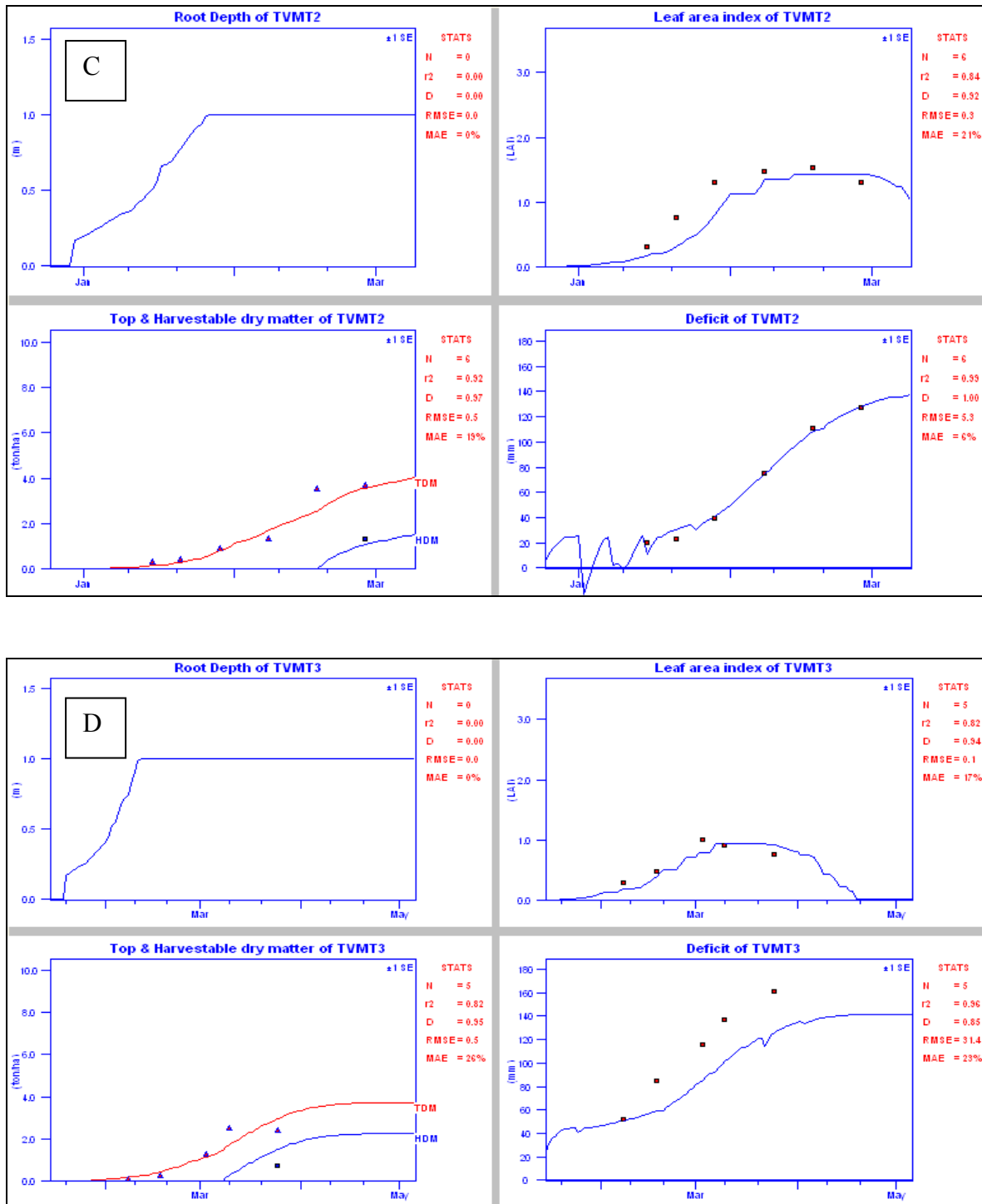


Figure 3.11. Measured and simulated leaf area index, top and harvestable dry matter yields and soil water deficits for cultivar Tsangano at PD2 (c) and PD3 (c)

SWB model simulation results of LAI development, top and harvestable dry matter yields generally showed good correspondence with measured values for all planting dates and both cultivars, except for cv. Tsangano at PD2 (Figure 3.11a), where simulated values were higher

than observations. In general, RMSEs of soil water content prediction of SWB showed good correspondence with the field-measured values, indicating that soil water deficits were generally very well simulated for both cultivars and all planting dates.

These results show that both the growth and water use estimations of the SWB model are adequate to capture planting date effects on crop development, water use and grain yields with reasonable accuracy. It therefore gives sufficient confidence that the model can mimic growth and development of the two maize cultivars under a range of soil and planting date conditions. The calibrated SWB model was consequently used to establish the best planting date for each of the two cultivars in the long term.

3.10.3 Scenario simulations to optimize planting dates

Historical weather data (period of five years) was obtained for two important dry land maize production areas in Mozambique, namely Chókwè and Umbeluzi. The calibrated SWB model was then used to simulate maize yields for each of the three planting dates used in this study (5 December, 25 December and 15 January) in an effort to establish the best planting date for the different cultivar x rainfall x soil combinations.

Simulation results of five year runs for the two cultivars across three planting dates showed that the simulated grain yields per planting date varied substantially from year to year and between the two sites (Tables 3.4 and 3.5). The main reason for the seasonal variation is probably the high variability in rainfall from year to year, as well as unevenly distributed rainfall within any season (Annexure C and D). As annual rainfall decreases within-season, the inter-annual variability usually also increases.

The average long-term maize yields simulated by SWB at Umbeluzi were generally lower than those simulated for Chókwè. This can be explained by low water holding capacity of the soils at Umbeluzi site (light sandy soils), which result in high more severe water stress experienced by the crop during dry spells. Therefore, there are frequent instances when low or zero maize grain yields are simulated.

Table 3.4: Simulated yields for maize at Chókwè Agricultural Research Station

Sowing	Yield (t ha ⁻¹)					
	Changalane Cultivar			Tsangano Cultivar		
	Dec-5	Dec-25	Jan-15	Dec-5	Dec-25	Jan-15
2001-2002	4.8	5.3	2.9	4.8	1.9	1.1
2001-2002	1.3	3.1	1.1	3.7	1.1	0.6
2003-2004	3.8	6.5	2.8	5.7	2.1	1.4
2004-2005	1.3	3.1	2.6	3.5	1.1	0.8
2005-2006	3.6	4.0	1.3	6.5	2.2	0.9

Table 3.5: Simulated yields for maize at Umbeluzi Agricultural Research Station

Sowing	Yield (t ha ⁻¹)					
	Changalane Cultivar			Tsangano Cultivar		
	Dec-5	Dec-25	Jan-15	Dec-5	Dec-25	Jan-15
2001-2002	0.7	2.3	0.1	1.8	0.0	1.8
2001-2002	0	0	0	1.1	0.1	0.2
2003-2004	0.1	2.2	0.1	2.7	0.7	0.1
2004-2005	0.1	1.2	0.5	0.9	0.1	0.8
2005-2006	0.2	1.3	0	1.1	0.6	0.5

It is interesting to note that in four out of five years, simulated yields for cv. Tsangano were highest at PD1, while cv. Changalane gave highest yields at PD2 for both localities (Tables 3.4 & 3.5). These findings are similar to those of the field experiment carried out at Chókwè Agricultural Research Station, and give a clear indication that longer growing season varieties should in most years perform best when planted early, while shorter season varieties should rather be planted in late December. Late plantings (mid January) gave low and variable yields in most years.

The average yield observed for commercial farmers at national level was 4.3 t ha⁻¹ during the 2007 – 2008 season (Master, 1994), which is slightly lower than some of the simulated yields reported here. Although higher simulated yields are expected because of not taking other yield limiting factors such as weeds and insect pests into account, the results reported here give a good indication of typical yields that could be expected at the two localities. It also clearly illustrates the high risk of dry land maize production due to seasonal and annual rainfall variability.

CHAPTER 4

GENERAL DISCUSSION

The most important results arising from this experiment are: a) the yield response to planting date/water observed for the different cultivars of maize; b) the potential of using a crop model to help select optimum planting dates and best cultivars for different localities.

4.1 Yield response to planting date /water availability

The observed responses can be explained by the effects of planting date/water availability on: crop establishment, development and leaf expansion and photosynthetic active radiation use efficiency.

4.1.1 Crop establishment and development

Favourable soil water regimes (rain) at the early stage would have improved the formation and development of a strong root system. Related to this, Rebella *et al.* (1976) pointed out that water availability is particularly important during the establishment of a maize crop because this is one of the decisive periods for posterior grain formation. In the case of the present study, cultivar Changalane performed best when it was planted on PD2, while Tsangano did best when it was planted on PD1. At these planting dates each cultivar could enjoy the most favourable soil water regime, develop a big canopy and accumulate as much as possible biomass before water became limiting. It is interesting that cv. Changalane did not perform well when planted on PD1, although it appears that it probably experienced a favourable soil water regime (high rainfall). This situation could possibly be ascribed to leaching of nutrients from the root zone, assuming that Changalane had a shallow root system at that early stage.

4.1.2 Leaf expansion and photosynthetic active radiation use efficiency

The production of dry matter depends on the solar energy that the crop can intercept and utilize to convert CO₂ and water (rain) to sugars in the process of photosynthesis (Turner and Begg, 1981). The amount of solar energy captured depends on its interception by the leaves and this implies that the crop productivity depends on the development of leaf area to

intercept the radiant energy, and the rate of net photosynthesis to convert it into dry matter. The distribution of assimilates within the plant determines the proportion of the total yield that is harvested. The highest HI achieved by the early maturing cultivar (Changalane) when planted late in December (PD2) could be associated with rapid early ear growth under favourable growing conditions (January and February). Bolanos and Edmeades (1993) and Edmeades *et al.* (1993) have shown that an increase in partitioning to the ear under favourable water regimes was responsible of increases in HI observed.

Measurements of leaf area development for the different planting dates have shown that the process most sensitive to water stress appear to be expansive growth. The highest reduction of leaf area in conditions of water stress is a consequence of slowed cell expansion, which can inhibit the cell division, reduce the potential size of the leaf and lead to a slowing down of the rate of cell initiation (Hsiao *et al.*, 1976). In this study it arises that planting date had a significant effect on the rate of maize leaf area expansion as a result of water availability. Under favourable soil water conditions LAI development was more rapid, and consequently the amount of intercepted solar radiation increased, resulting in higher total CO₂ assimilation rates.

In conditions of moderate water stress, cell expansion is reduced and cell solutes can be built up, lowering the total water potential and causing an accelerated water uptake, restoration of turgor and hence growth (Hsiao et.al., 1976). Sung (1985), concluded in sweet potato that at moderate water stress, leaves can maintain full turgor by osmotic adjustment, but as the water stress increases, the leaf water potential decreases and stomatal closure occurs, decreasing transpiration rate and directly affecting the CO₂ exchange and assimilation rate, which inevitably will lead to a decrease in the final yields.

Maize is a determinate crop, which implies that dry matter accumulation in the economically important part, the grain, only starts when the stems and leaves have stopped growing. According to the findings of this study, in most years the best period for maximum dry matter production at Chokwe is from December to January for both cultivars, since the period of highest rainfall coincides with expansive growth, anthesis and grain filling. These results are in accordance with those of Schouwenaars (1987), who reported that the period from December to January is the best time for maximum dry matter production in Southern

Mozambique. The same author also pointed out that dry matter production, crop development and yield of maize are determined by many environmental factors, such as, radiation, daily mean temperature and soil water supply.

4.2 Using a crop model to optimize planting dates and cultivar selection

SWB model simulation results indicated that environmental conditions are in general very risky for rainfed maize production in Southern Mozambique (Chókwè and Umbeluzi sites). For each locality, simulated yields varied considerably from year to year. However, for the five years of simulation, both the late (Tsangano) and early (Changalane) cultivars performed best when planted early and late December, respectively. These results are not in accordance with the opinion of Schouwenaars (1987), who reported that there are many years in which better yields are obtained by planting either sooner or later than the “most favourable period” (October – November). Moreover, according to the simulations, in most years the consequence of delaying planting later than the favourable period will give catastrophic results, because rainfall in that period usually remains too low.

Umbeluzi Agricultural Station has a relatively high rainfall and sandy loam soils with low water holding capacity, while Chókwè Agricultural Station is characterized by relatively low rainfall and clayey soils with higher water holding capacity. In spite of the lower rainfall at Chókwè, the soil with higher water holding capacity makes it possible to save more water into soil profile at Chókwè, compared to Umbeluzi, contributing to better canopy development, promoting more rapid expansive growth (Squire, 1990), faster ground cover and lower evaporation losses from the bare soil. Accordingly, the simulation results suggest that in most seasons environmental and soil conditions were more favourable at Chókwè than Umbeluzi.

It should be recognised that these simulation results may show slightly different trends if historical weather data over a longer period (10 – 20 years) could be obtained to enable longer term simulations.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The main conclusions from the experiment can be summarized as follows: Determination of optimum planting dates for maize is very crucial to ensure more stable crop yields. This study has revealed that planting date had significant effects on grain yield and yield components of maize. The variation in yield with planting date can mainly be explained by the changes in soil water availability due to rainfall distribution during the growing season, resulting in more or less favourable conditions for plant establishment, growth, development and yield.

The most responsive cultivar to water supply was Changalane (early cultivar), when planted late in December (PD2), giving the highest yield of 4.3 t ha⁻¹ with 255 mm of water used. This also gave the highest water productivity (WP) of 17.3 kg ha⁻¹ mm⁻¹. However, when this cultivar was planted early in December or mid January, it gave a lower yield increase per additional mm of water received (7.8 and 8.1 kg ha⁻¹ respectively). On the other hand, cultivar Tsangano (late cultivar) performed better when planted early in December (PD1), giving a Wp of 8.5 kg ha⁻¹ mm⁻¹, while when planted late December (PD2) or mid January (PD3), its PW was lower at 5.5 kg ha⁻¹ mm⁻¹ and 4.0 kg ha⁻¹ mm⁻¹ respectively.

Planting date responses, depending on the weather variability at the location, vary a great deal among years and locations. The more favourable water holding capacity of soils at Chókwè, which resulted in more rapid expansive growth, faster ground cover (LAI) and higher interception of solar energy, appear to have created more favourable conditions for maize growth and production.

SWB model generally performed satisfactory with regard to the simulation of dry matter production and water deficit in the soil profile for both early to late planting dates at Chókwè. SWB model simulations suggest that, for Umbeluzi and Chókwè sites, Changalane should be sown late December and Tsangano early December. In most years the consequence of delaying sowing up to January is catastrophic, because the crop flowering period coincides with shortage of rainfall. The results also suggest that more favourable environmental and soil conditions were present at Chokwe than at Umbeluzi station.

The results of this study, along with those of other previous experiments (Mariote, 2006) suggest that an early cultivar, represented in this study by Changalane, with an early vigorous establishment, large accumulated biomass at the beginning of grain filling and ability to transfer photo-assimilates to pod filling, would be suitable for growing in semiarid areas to escape late-season drought.

The longer term goal of this study was to establish whether the SWB model can be utilized to select the optimum planting window for different localities. According to Mathews *et al.* (2002), calibrated models that can stand the test of validation with independent data sets, can potentially be used as tools for operational, tactical, and strategic decision support in on-farm crop management (cultivar, planting date and planting density selection, as well as N fertilizer management). In this study the SWB model was successfully calibrated and validated on independent data for two local maize cultivars. The SWB model has also proven itself as a useful tool that can help select the most suitable maize cultivars and planting dates by predicting attainable crop yields, based on differences in plant water availability during the growing season.

To make the SWB model more useful, it is recommended that crop parameters should also be determined for cultivars of other maturity classes, which will require complete growth analysis studies.

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ANNEXURES

TABLE A - CLIMATIC DATA FOR CHOKWE RESEARCH STATION

STATION 1011400
LATITUDE -24.32

LONGITUDE 33.00

ALTITUDE 33 m

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
R mm	109	140	66	42	20	15	10	13	17	37	66	87	622
T-mean °C	27.3	27.0	25.8	24.2	21.4	18.8	18.5	20.2	22.7	24.6	26.0	26.8	23.6
T-max °C	33.7	33.0	32.1	30.7	28.6	26.2	26.1	27.9	30.2	31.8	32.6	33.3	30.5
T-min °C	21.0	21.1	19.5	17.6	14.2	11.5	10.9	12.6	15.3	17.5	19.3	20.3	16.7
T-DAY °C	29.5	29.1	28.0	26.4	24.0	21.5	21.3	23.0	25.5	27.3	28.4	29.2	26.1
T-NIGHT °C	24.6	24.2	23.1	21.5	18.6	16.1	15.9	17.8	20.4	22.5	24.0	24.9	21.1
RH-mean %													
Ea mbar	25.3	26.0	24.5	22.6	19.0	16.2	15.9	17.4	18.4	20.3	22.5	22.9	20.9
U m/s	1.9	1.9	1.6	1.4	1.7	1.2	1.3	1.7	2.1	2.3	2.1	2.1	1.8
n/N %	61	61	66	68	77	74	74	71	69	62	54	57	66
Rg cal/cm²/month	533	501	464	392	347	302	316	365	436	478	489	521	428
ETPENMAN mm	168	137	131	98	77	51	58	85	121	155	156	171	1408

Source: Agroclimatic data bank – INIA, DTA (29 years records)

ANNEXURE

TABLE B - CLIMATIC DATA FOR UMBELUZI RESEARCH STATION

STATION 1001400
LATITUDE 26.03 S

LONGITUDE 32.23 E

ALTITUDE 12 m

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
R mm	126.5	118.7	69.1	59.9	16.6	17.5	17.6	13.6	34.1	54.5	71.1	79.4	678.6
T-mean °C	26.6	26.5	25.6	23.6	20.5	18.0	17.8	19.8	21.7	23.6	24.6	26.2	22.9
T-max °C	32.5	32.2	31.5	30.3	28.6	26.7	26.7	27.9	29.3	30.4	30.9	32.2	29.9
T-min °C	20.8	20.8	19.8	17.0	12.5	9.2	9.0	11.7	14.1	16.8	18.4	20.2	15.9
T-DAY °C	28.7	28.5	27.7	26.1	23.5	21.2	21.1	22.8	24.4	26.0	26.8	28.2	25.4
T-NIGHT °C	24.0	24.1	23.4	21.4	18.1	15.4	15.3	17.2	19.0	20.9	21.9	23.5	20.4
RH-mean %	69.0	71.0	72.0	72.0	71.0	72.0	70.0	65.0	65.0	66.0	66.0	66.0	68.8
Ea mbar	34.9	34.6	32.8	29.2	24.1	20.6	20.4	23.1	26.0	29.1	30.9	34.1	28.3
Ed mbar	24.1	24.6	23.6	21.0	17.1	14.8	14.3	15.0	16.9	19.2	20.4	22.5	19.5
Ea-Ed mbar	10.8	10.0	9.2	8.2	7.0	5.8	6.1	8.1	9.1	9.9	10.5	11.6	8.8
U m/s	2.1	2.1	1.6	1.9	1.9	1.9	2.0	2.1	2.3	2.2	2.3	2.1	2.0
n/N %	62.0	62.0	56.0	67.0	74.0	78.0	75.0	75.0	66.0	52.0	53.0	54.0	64.5
Rg cal/cm²/d	548.1	514.3	426.4	390.9	336.2	307.5	313.8	377.6	425.2	443.7	490.0	517.2	424.6
ETPENMAN mm	224.8	188.8	148.1	127.4	104.8	84.0	93.2	125.3	147.9	187.7	203.8	220.7	1858.3
Mm/d	7.3	6.7	4.8	4.2	3.4	2.8	3.0	4.0	4.9	6.1	6.8	7.1	

Source: Agroclimatic data bank – INIA, DTA (29 years records)



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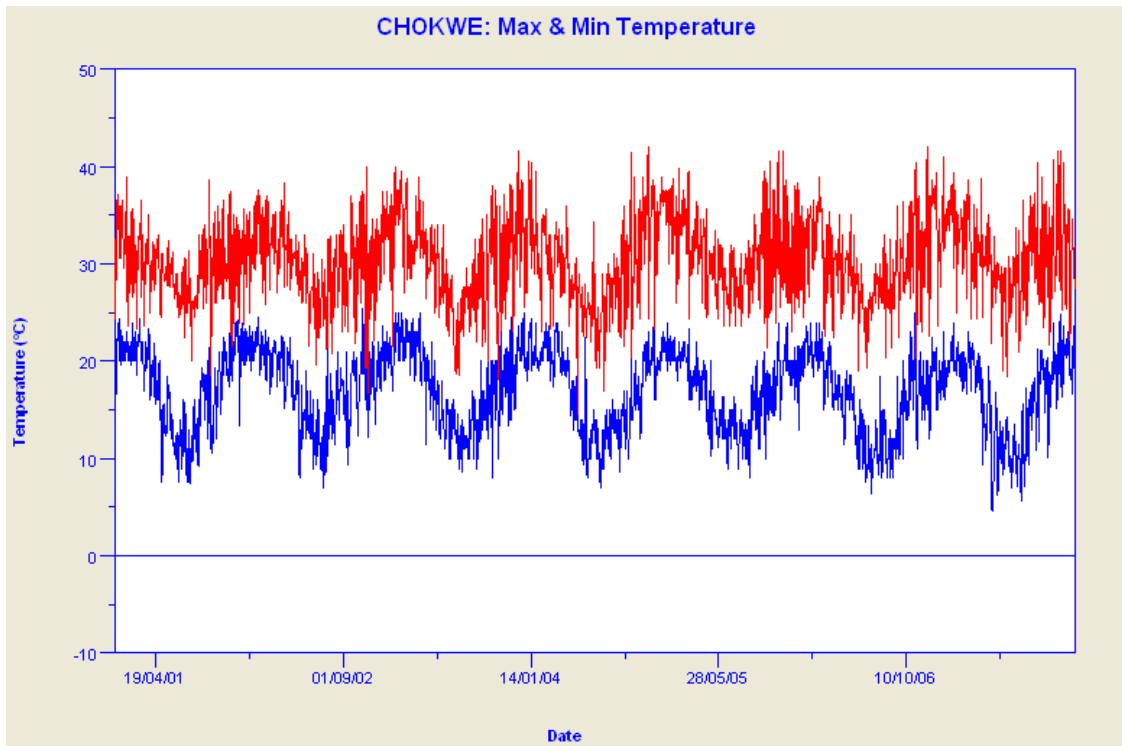
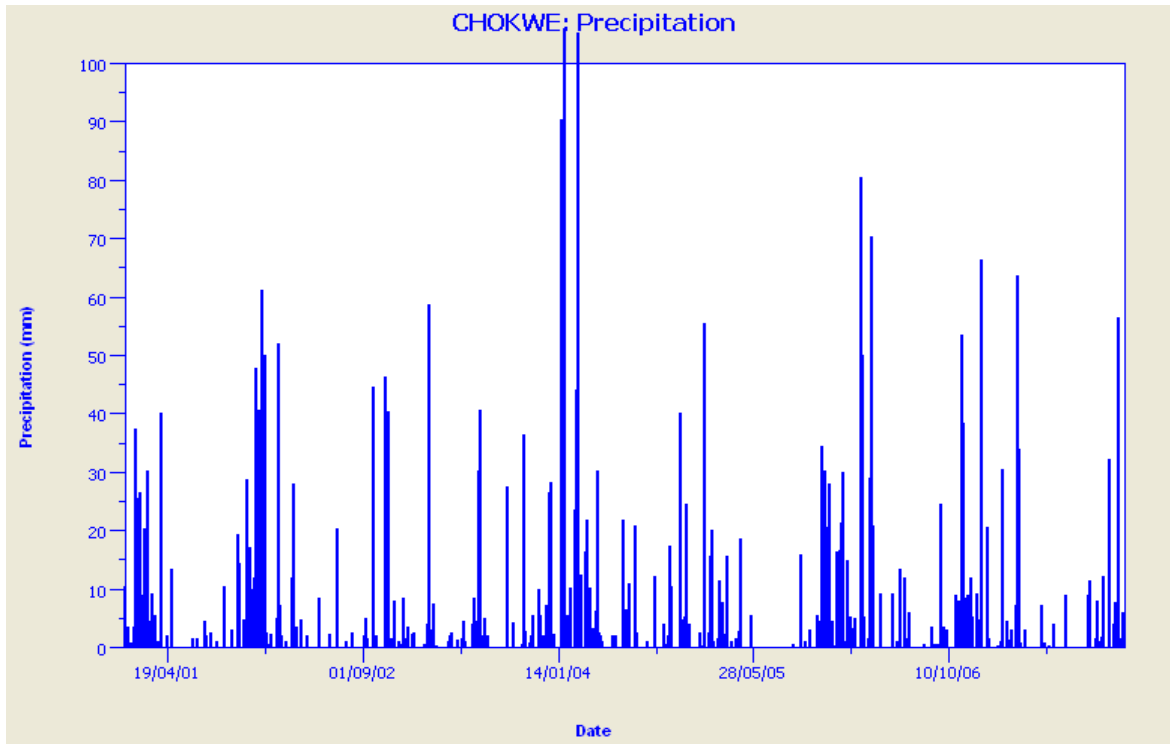


FIGURE C: RAINFALL (TOP) & AIR TEMPERATURE (BOTTOM) DISTRIBUTION FOR CHÓKWÈ RESEARCH STATION (2001 –2006)

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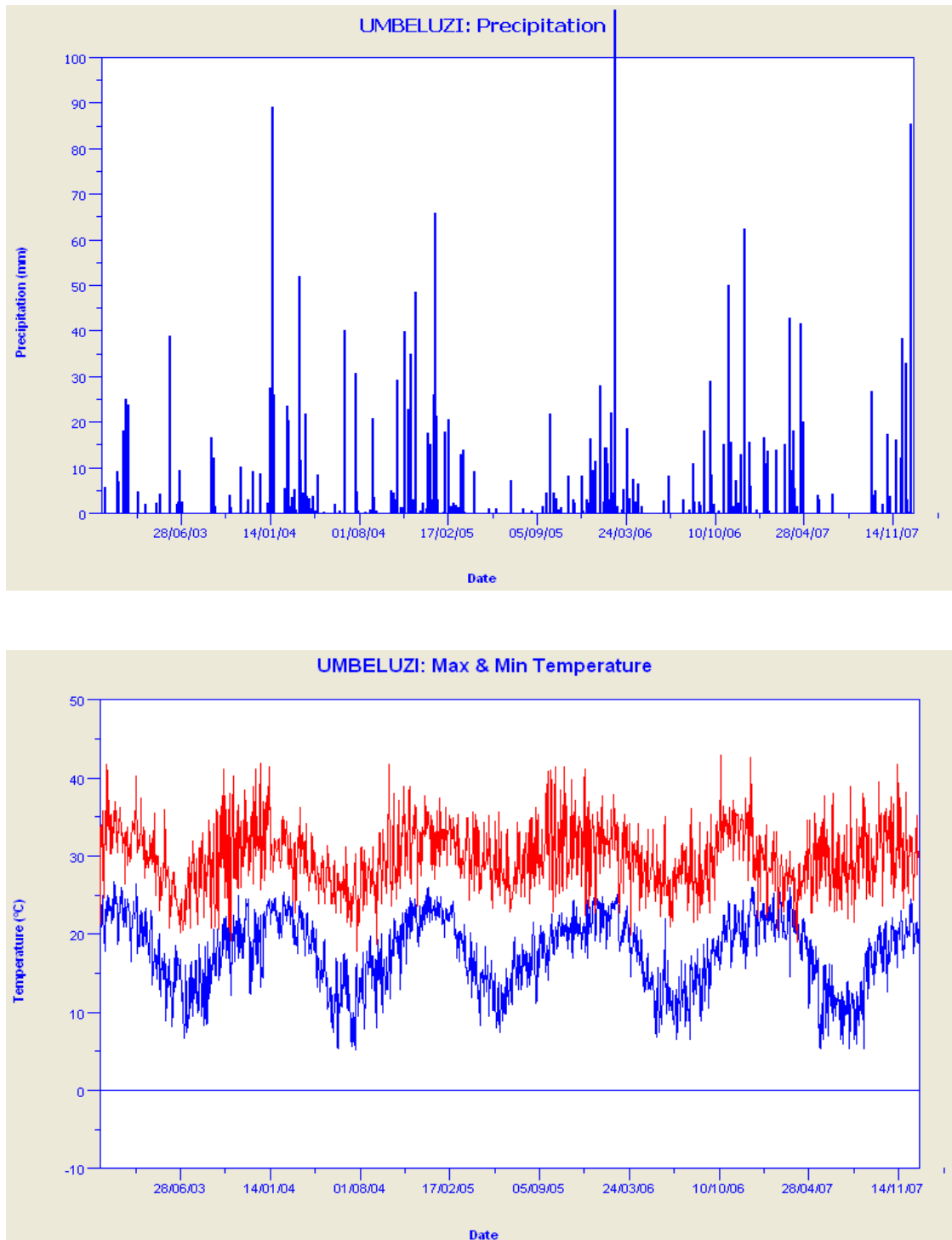


FIGURE D: RAINFALL (TOP) & TEMPERATURE (BOTTOM) DISTRIBUTION FOR UMBELUZI RESEARCH STATION (2003 – 2007)

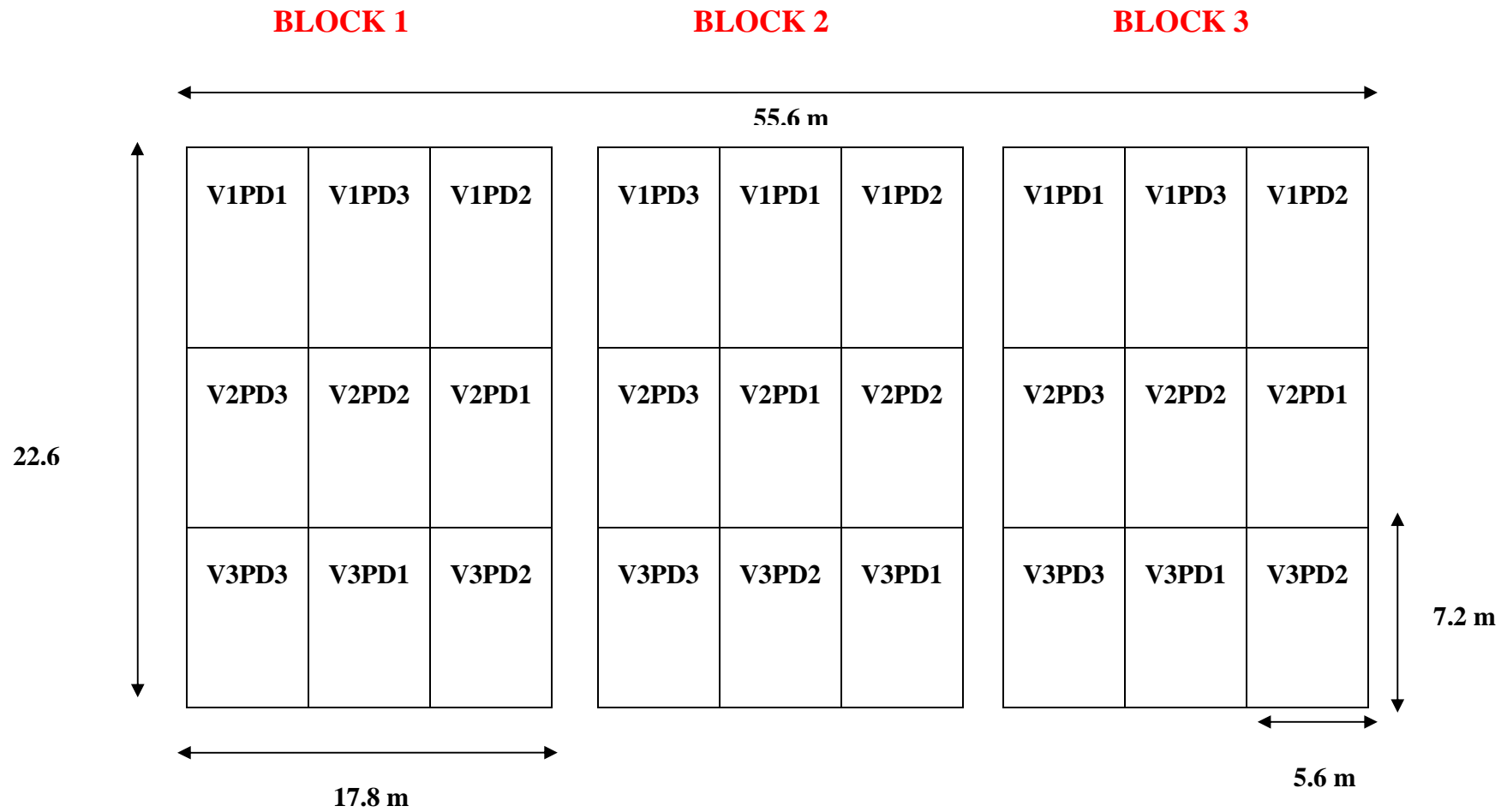


FIGURE E: EXPERIMENTAL FIELD LAYOUT

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TABLE F: YIELD, SOIL WATER BALANCE AND SPECIFIC CROP GROWTH PARAMETERS FOR TWO MAIZE CULTIVARS AT CHOKWE RESEARCH STATION, 2007/2008

Yield, water use and crop parameter	Cultivars	
	Changalane	Tsangano
Dry matter production (kg m ⁻²)	1.9	1.80
Harvestable dry matter (kg m ⁻²)	0.95	0.85
Gravimetric water content of harvestable organ (%)	13.0	14.0
Evapotranspiration ET (mm)		
Rainfall R (mm)	130	274
Vapour pressure deficit VPD (Pa)		
Dry matter/evapotranspiration ratio corrected for vapour pressure deficit DWR (Pa)	9.0	9.0
Radiation conversion efficiency E _c (g MJ ⁻¹)	0.00170	0.0158
Specific leaf area SLA (m ² kg ⁻¹)	12.0	11.0
Canopy extinction coefficient for PAR K _{par}	0.55	0.55
r ²	0.96%	0.97%
Maximum rooting depth (m)	1.5	1.5
Base temperature T _b * (°C)	10.0	10.0
Optimum temperature T _{op} * (°C)	25.0	25.0
Day degrees for emergence (day deg)	76.0	76.0
Day degrees for flowering (day deg)	540.0	930.0
Day degrees until harvest (day deg)	1140	1774.0
*Knott (1988)		

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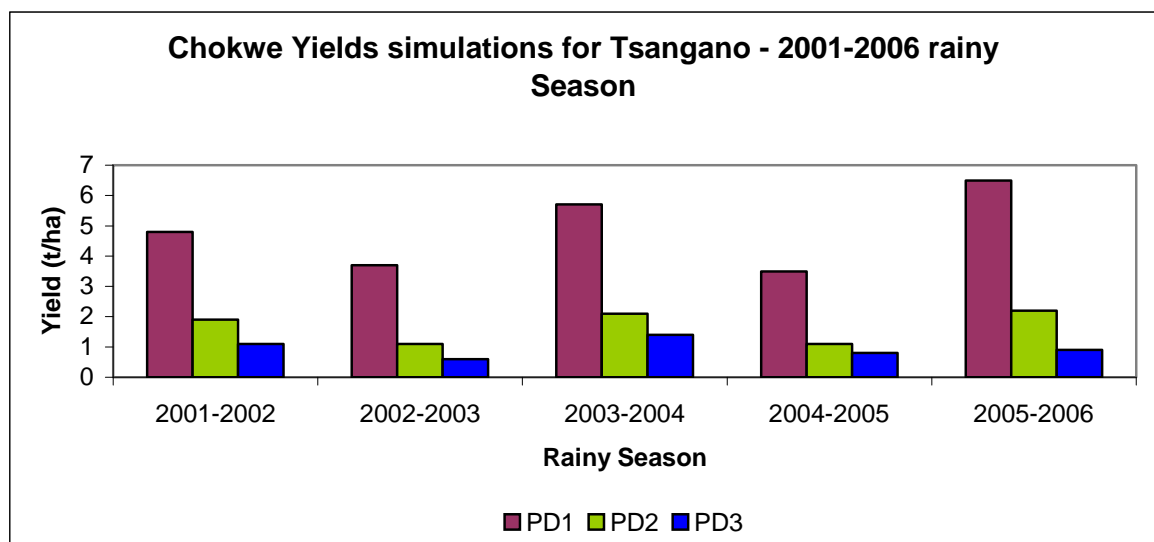
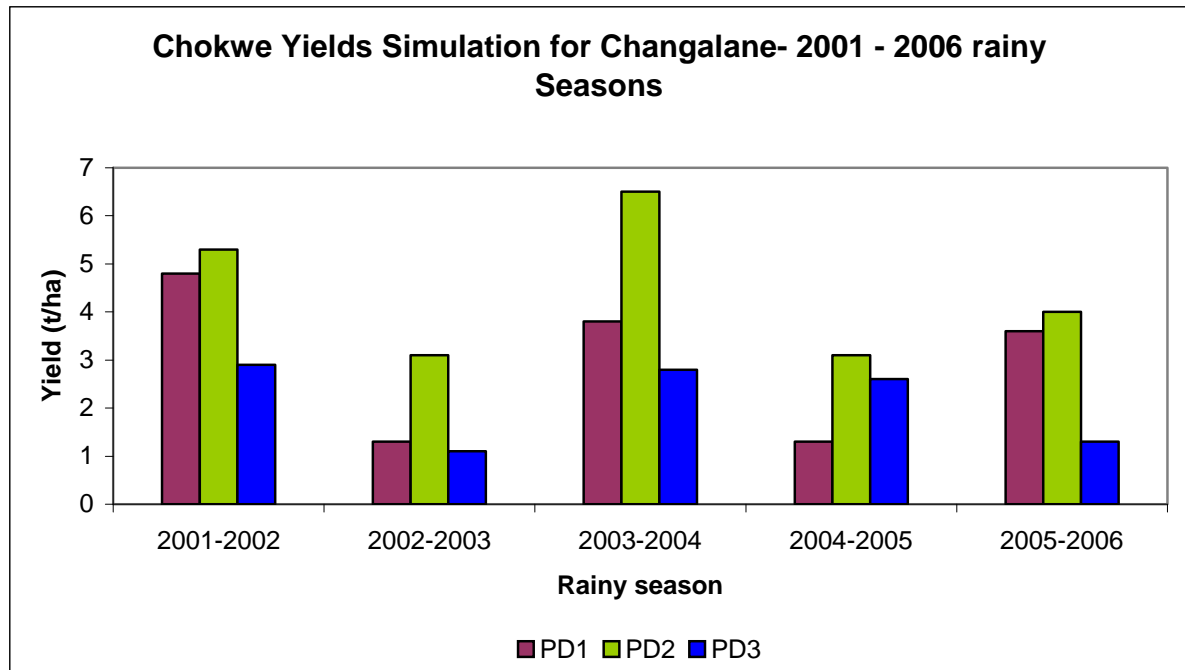


FIGURE G: YIELD SIMULATIONS FOR CHANGALANE (TOP) & TSANGANO (BOTTOM) FOR 2001-2006 RAINY SEASONS AT CHOKWE RESEARCH STATION

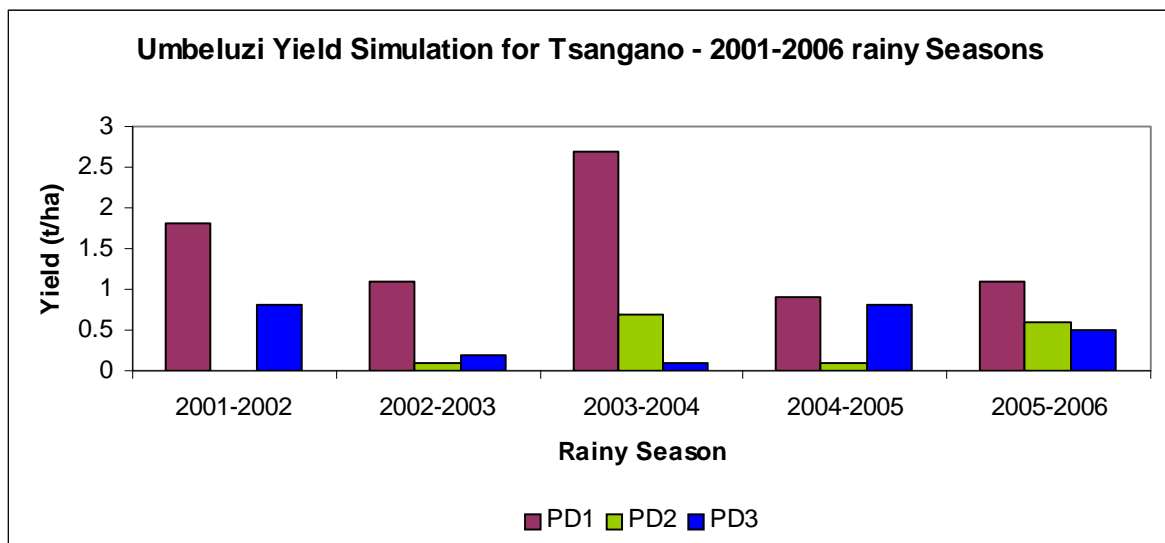
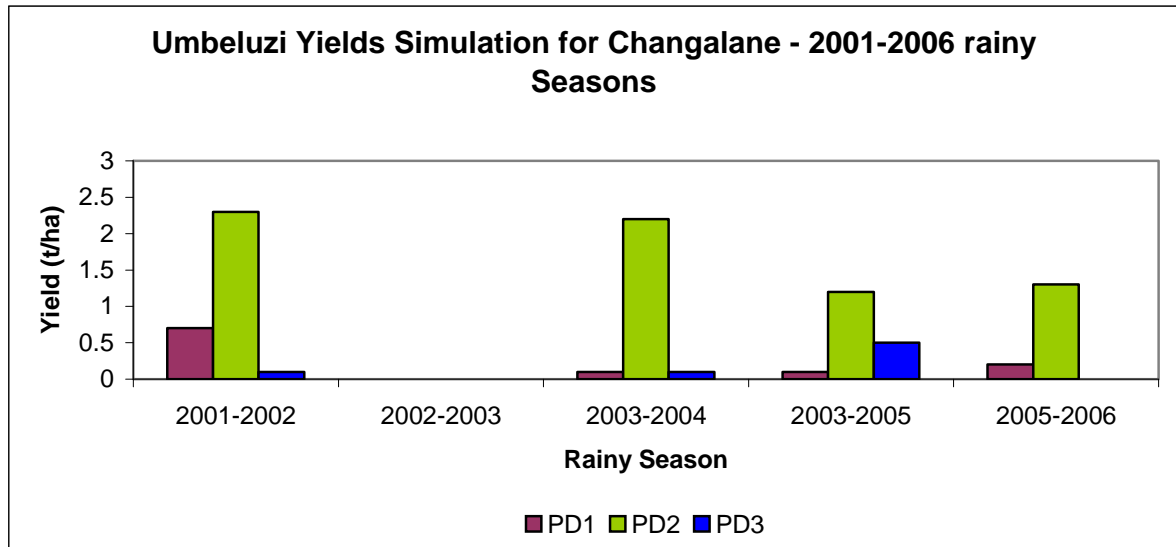


FIGURE H: YIELD SIMULATIONS FOR CHANGALANE (TOP) & TSANGANO (BOTTOM) FOR 2001-2006 RAINY SEASONS AT UMBELUZI RESEARCH STATION

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TABLE I: ANOVA

Yield

Source	DF	Sum of Squares	Mean square	F value	Pr>F
Cultivar	1	0.9446197	0.9446197	14.60	0.012
PD	2	7.1972427	3.5986213	55.63	<-0.0001
Cultivar x PD	2	2.5817537	1.2908768	19.95	0.0115
Block	2	0.42634856	0.2131742	3.30	0.3875
Error	10	0.64689840	0.6468984		
Total	17	11.79686321			
	R ² = 95%	CV = 16%	LSD p<0.05 = 0.55		

1000 seed mass

Source	DF	Sum of Squares	Mean square	F value	Pr>F
Cultivar	1	6094.080	6094.080	9.37	0.012
PD	2	73631.71	36815.855	56.63	<-0.0001
Cultivar x PD	2	9379.30	4689.65	7.21	0.0115
Block	2	1357.46	678.73	0.3875	0.3875
Error	10	6501.56	650.156		
Total	17	96964.120			
	R ² = 93%	CV = 15%	LSD p<0.05 = 0.55		

Total dry matter yield (TDM)

Source	DF	Sum of Squares	Mean square	F value	Pr>F
Cultivar	1	435497.48	435497.48	1.54	0.2432
PD	2	21886426.89	10943213.44	38.64	<0.0001
Cultivar x PD	2	441811.18	220905.59	0.78	0.4844
Block	2	6417491.20	3208745.60	11.33	0.0027
Error	10	2831841.43	283184.14		
Total	17	32013068.18			
	R ² = 91%	CV = 16%	LSD p<0.05 = 0.55		



Leaf area index (LAI)

Source	DF	Sum of Squares	Mean square	F value	Pr>F
Cultivar	1	0.39914	0.39914	0.15	0.71108
PD	2	109.57156	54.785783	19.98	0.0003
Cultivar x PD	2	8.523265	4.2616326	1.55	0.2584
Block	2	22.319079	11.159539	4.07	0.0509
Error	10	27.42374	2.74237		
Total	17	168.23680			
	R ² = 84%	CV = 19%	LSD p<0.05 = 0.55		