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Rainfall is not the most limiting factor to maize (Zea mays L.) production in intermediate rainfall regions of Zambia. Lessons from Choma District

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Abstract

Purpose: This study was based on the following objectives; (1) to investigate the sufficiency of rainfall received in Choma by assessing the differences in the precipitation received (PPT) against the potential evapotranspiration (PET) and actual evapotranspiration (ETa) for maize, and (2) to estimate potential for maize production in Choma under the current rainfall and temperature conditions.

Methodology: The Soil Water Balance (SWB) crop growth model was used to analyze the rainfall-temperature interactions and estimate the maize stress index (SI) for analyses of crop water stress and potential yields (Yp). The relationships involving precipitation, potential and actual evapotranspiration were performed using time series auto regression and Fisher's least significant difference (LSD).

Findings: Choma was not in a state of water deficit as maize water requirements were lower than precipitation. Maize water stress was destructive when it occurred in the mid than late stages of maize development. Mean precipitation (799.29mm) was higher than mean actual evapotranspiration (719.23 mm), though the difference was insignificant ($F = 1.281$; $p = 0.126$). However, potential evapotranspiration for maize in the area was significantly higher than the actual evapotranspiration (mean = 719.23) ($F = 5.621$; $p = 0.012$). Less destructive moderately dry periods seldom occurred during the sensitive initial and mid periods of maize development.

Results: Farmers in Choma can potentially increase their rain-fed maize yields from the current 1.89 t/ha/year to 4.9 t/ha/year by managing limiting factors to maize production such as reduced access to fertilizer, declining of soil nutrients, late delivery of inputs, lack of markets, pests and lack of proper nutrient management. The study also showed that management rather than climatic conditions is responsible for the low yields in Choma area.

Unique contribution to theory, practice and policy: The study established a methodology for simulating potential yields of farmers given existing climatic and soil conditions. Policy should concentrate on improving crop management rather than the current concentration on mitigating impacts of climate change as these are not the factors responsible for observed reduced crop yields.

Keywords: Maize yield, maize stress index, evapotranspiration, smallholder farmers, Soil Water Balance (SWB) model

1.1 INTRODUCTION

Maize productivity among smallholder farmers in Zambia has usually been below the expected and potential for the region. Rainfall is the most important climatic parameter affecting yields for smallholder farmers in sub-Sahara Africa (Vogel 2000). The impacts of climate change on the agriculture sector have been a subject of many researches (Intergovernmental Panel on Climate Change [IPCC] 2007). Researchers have predicted crop yield reductions, especially in Sub-Saharan Africa (SSA) due to expected excessive rainfall, particularly in Central Africa (Usman and Reason 2004) or increased frequency and intensity of droughts and floods. Some studies have also reported increased water stress on crops such as maize (Zea mays L.) in southern Africa which has been detrimental especially when the water stress occur during germination or flowering as it affects crop yields irreversibly (Thornton and Cramer 2012).

The predictions of doom on the agricultural industry have been due to the sector's dependency on climatic parameters. Agriculture in most parts of SSA is rain fed and hence susceptible to impacts of climate change. Availability of water has been a vital limiting factor for yield improvement in water scarce or water excess environments (Sinclair et al. 2004). However, not all areas affected by climate change are expected to be impacted adversely. Alcamo et al. (2007) predicted increased crop productivity of local crop species in northern Europe due to climate change. On the other hand, Usman and Reason (2004) predicted increased rainfall in some parts of SSA such as in Angola, Zambia, Namibia, Mozambique and Malawi. This is likely to increase crop production as a result of climate change. The different climatic studies on agriculture, some of which have contradictory results, bring to the fore the need for site-specific studies that will accurately predict the effects on individual crops in particular sites.

Maize is valued as a staple crop in Zambia. It provides for over half the consumed calories and is a major component in livestock feed. It is cultivated by over 86% of smallholder farmers and is the most marketed crop in the country. Planting dates for maize affects crop yields (Bejiga 1991). The highest maize yields in Zambia are realized when the crop is planted between the 15th and 30th of November. Conservation Farming Unit [CFU] (2007) estimated that with each day that passes after the first planting rains, at least 1.5% of the potential maize yield is lost. The sowing dates are usually the same for all agro-ecological regions (AERs) of Zambia. Zambia is divided into three AERs based on the amount of rainfall and length of growing season characterized in each of the regions (Government of the Republic of Zambia [GRZ] 2007). AER I is the low rainfall region (less than 800mm annual rainfall) with a crop growing season of 80 to 100 days while AER II is the medium rainfall region (800-1000mm annual rainfall) with a crop growing season of 100 to 140 days. AER III is the high rainfall region (over 1000mm annual rainfall) and has a crop growing season of over 140 days. The length of the crop growing season in different AERs determines the type of maize grown in these particular regions. The breeding of maize varieties that are adapted to specific agro-ecological conditions has hinged on the match-up between an area's rainfall characteristics and a cultivar's growing period. Cultivars with a shorter growing period are promoted in the low rainfall regions of AER I while the cultivars with a longer growing period are late maturing and are recommended for the high rainfall regions of AER III. Matching a cultivar's phenological development to its environmental requirements is very important, as it contributes at least 45% to 60% of the yields (Siddique et al. 2003; Shrestha et al. 2006).

Crop simulation models (CSM) have been useful as tools for estimating crop yields as a function of weather conditions, soil conditions, and choice of crop management practices. Expected maize yields were predicted under the current climatic and soil conditions found in Choma under limited financial management style as would be done by smallholder farmers. Characteristics of a typical medium maturing maize variety cultivated in Choma were utilized in the model. The Soil Water Balance (SWB) model was used to compare the potential rain-fed maize yields under current climatic conditions to the actual yields produced by the farmers. The analysis performed for the period 1960 to 2011 would help assess maize water requirements and long-term potential of rain-fed maize production in the region. The accuracy of any yield prediction model is dependent on the accuracy of yield potential and yield reductions. The yield potential is a function of crop growth processes involving leaf area development, interception of light, production of crop biomass and partitioning into grain (Kiniry et al. 2004).

1.2 Objectives

This study was based on the following objectives;

1. To investigate the sufficiency of rainfall received in Choma by assessing the differences in the precipitation received (PPT) against the potential evapotranspiration (PET) and actual evapotranspiration (ETa) for maize, and
2. To assess potential for maize production in Choma under the current rainfall and temperature conditions.

1.3 Problem Statement

Many studies have highlighted climate change as a major contributor to reduced agriculture productivity in Zambia (Chisanga, 2019; Syampaku et al. 2019; Mbewe and Mubanga, 2020). Understandably, climate change as well as various climatic parameters have and are expected to continue posing a big influence on the productivity potential of crops (IPCC, 2014), particularly, rainfed crops among smallholder farmers (Mubanga and Umar, 2014). However, the extent of influence of climatic variables on crop productivity may be overrated in intermediate rainfall regions. For example, GRZ (2016) in the Second National Agricultural Policy stated that over the years, the amount of rainfall has changed across the agro-ecological regions, and this has affected crop productivity across the regions. Further, the World Bank (2019) reported in the Climate-Smart Agriculture Investment Plan for Zambia that observed climatic changes were likely to exacerbate food security challenges through reduced food production. These and more researchers have painted the problem of climate change as the biggest challenge smallholder agriculture is facing that is likely to impact their food production. As such, this study attempted to evaluate the potential for maize production under the current climatic conditions existing in the intermediate rainfall regions of Zambia such as Choma. This was going to help understand whether climatic conditions were the major contributor to reduced crop productivity, or other factors could have contributed more than did climate change. Maize, which is the staple crop for Zambia and the most commonly cultivated crop in the region, was utilized to simulate the productivity under existing climatic conditions. The selection of the crop for study was largely based on the crop's importance to smallholder farmers in that for these farmers, food security entailed having enough stocked maize to last the annual maize production cycle (Mubanga and Ferguson, 2017). As such, this study simulated the possible productivity for maize under the current climatic conditions and compared the results with the reported productivity levels of farmers in the area.

2.0 MATERIALS AND METHODS

2.1 Study area

Choma District lies in southern Zambia between coordinates 16°48' S and 26°59' E (Fig. 1). Its altitude is 1313m above sea level. It is largely an agriculture area with farmers mostly producing maize, cotton, sweet potatoes and groundnuts. Over 70% of the available agricultural land in the area is reserved for maize production making the crop the most important in the region (Tembo and Sitko 2013) [21]. The area receives between 800 mm to 1000 mm of annual rainfall and has a suitable maize growing period of 100 to 140 days. The soils in Choma are mostly sandy clay loam with hilly areas largely being clay (GRZ 2007) [9].

Fig. 1 Location of Choma district in Southern Zambia

2.2 Description of the Soil Water Balance (SWB) model

The SWB model utilized in the current study was a generic crop growth and soil water balance model which can utilize any of two approaches (Jovanovic and Annandale 2000) [11]; (1) a mechanistic crop growth model to calculate crop growth and the soil water balance, and (2) the FAO type crop factor model to calculate the soil water balance, but that does not simulate dry matter production mechanistically (Annandale et al. 1999) [2]. The SWB growth model follows a generic crop approach and can predict yields and water use requirements for various crops, using a database of crop-specific model parameters

(Jovanovic et al. 2000) [11]. It utilized weather, soil and crop input units to predict crop growth and the water balance systematically. The crop growth model of SWB was utilized to assess maize response to different growing conditions.

The input weather data was used to calculate crop growth and phenology (temperature dependent), vapour pressure deficit (kPa), estimate actual evapotranspiration, Penman-Monteith reference evapotranspiration (mm/day) and potential evapotranspiration (mm/day). The model estimated both dry matter accumulation proportionally to transpiration as well as radiation limited growth on a daily time step, and uses the least of the two values. The calculated dry matter represents the whole plant biomass, including the harvested biomass. Dry matter partitioned into roots, stems, leaves and grain was dependent on the calculated phenology with thermal time and was modified by water stress. In the absence of crop-specific model parameters, the FAO basal crop factor model can be used to estimate crop water use (but not dry matter production).

SWB calculates canopy radiant interception from the leaf area index (LAI) and canopy extinction coefficient (kc) (Annandale et al. 2000) [3]. The fractional intercepted radiation was used to estimate potential evapotranspiration, which was divided into potential transpiration and evaporation from the soil surface (Jovanovic et al. 2000) [12]. When the actual evapotranspiration was less than the potential, crops can be stressed and assimilate partitioning changes, resulting in a smaller plant canopy (LAI). Crop water stress index (SI) for maize was calculated by the soil unit of SWB as the ratio of the actual transpiration to the potential (T/PT). If the calculated daily water SI was lower than a specified threshold, this was interpreted as the crop being under moisture stress. For maize, a stress index threshold of 0.95 was used. The calculated crop LAI determines the amount of solar radiation intercepted and used for crop growth estimation as a function of radiation use efficiency (Sinclair et al. 2014) [18]. Hence, the daily total dry matter production was a function of the LAI, incident solar radiation and amount of soil water available. The harvested dry matter was the proportion of the total dry matter accounting for the harvest index (Ghanem et al. 2015) [8].

Input soil data was needed to predict water movement in the soil and estimate its availability to plants. The model uses a multiple soil layer component system in simulating infiltration and water uptake (Table 1). This presents a realistic impression of the actual soil layers. Considering the nature of soil in the region, the water extraction depth in the soil was set at 100 cm, which was the root depth limit throughout the growing season. This was set as the final depth of soil water extraction, while the actual depth at any time was influenced by the crop phenology, the actual crop root depth capacity or even physical barriers such as hard pans in the soil. The field capacity (FC), the initial water content (WC), the permanent wilting point (PWP) and the bulk density (BD) were more variable in the upper soil zone as compared to lower layers. This was due to the availability of water in the lower soil layers since data was collected during the rainy season.

Table 1 Input soil characteristics for different soil layers.

Layer No.	Zone (m)	Field Capacity FC (mm)	Initial Water Content WC (m/m)	Permanent Wilting Point PWP (m/m)	Bulk density BD (Mg/m3)
1	0.15	0.3	0.25	0.17	1500
2	0.3	0.22	0.22	0.1	1400
3	0.45	0.22	0.22	0.1	1400
4	0.6	0.22	0.22	0.1	1400
5	0.75	0.22	0.22	0.1	1400
6	0.9	0.22	0.22	0.1	1400
7	1.05	0.22	0.22	0.1	1400
8	1.2	0.22	0.22	0.1	1400
9	1.35	0.22	0.22	0.1	1400
10	1.5	0.22	0.22	0.1	1400
11	1.65	0.22	0.22	0.1	1400

Since the model integrates processes in the soil-plant-atmosphere continuum, the evaporation and transpiration processes will only proceed at potential rates as dictated by atmospheric demand and soil water supply. Soil water supply may be limiting, as may be the plant root system.

2.3 Model inputs: weather, soil and crop parameters

The model required daily inputs of weather variables, soil characteristics of the area as well as the characteristics of the maize variety whose yields were simulated (Singels et al. 2010) [19]. The daily weather data included daily minimum and maximum temperatures, solar radiation, relative humidity and rainfall. In the absence of complete weather data, at least daily minimum and maximum temperature, and rainfall are required while the missing weather parameters are mechanistically estimated according to FAO 56 (Trajkovic et al. 2011) [23]. The daily weather data from 1960 to 2011 was obtained from the Zambia Meteorological Department data base. The data set was screened for errors before inputting into the model to ensure accuracy.

A fixed planting date of 23rd of November was used for running the simulations. The date represented the mid-point in the planting period and falls within the actual planting period used by farmers in Choma. The rainy season in Zambia runs from November to April and planting of maize usually occurs between 15th and 30th November of every year, depending on the arrival of the planting rains (CFU 2007) [5]. The specific soil input data required by the model was not readily available for all locations of the study area. However, general soil information for the area was extracted from the digital soils map of Zambia. Furthermore, the 1991 soils map of Zambia obtained from the Ministry of Agriculture and Livestock (MAL) also provided the necessary details for soils in Choma. Ferric acrisols were the dominant soil type in the area with some parts having ferric luvisols. These soils have layers of clay accumulation and are usually acidic. Parameters for aggregate soils for Choma were used due to a lack of site specific soil information for various locations. Nonetheless, location dependent verification could be conducted in cases of site specific data availability in which case better site specific simulations could be conducted.

The maize cultivated in the three agro-ecological regions of Zambia was differentiated in terms of their phenological characteristics. Medium maturing maize varieties (e.g. MM 604, MM 603 and MRI 634) are the most commonly cultivated in Choma. These varieties, which flower later than the early maturing ones (e.g. ZMS402, PAN413, SC403, MRI455), but earlier than the late varieties (e.g. SC715, SC704) are moderately drought tolerant. They were recommended for Choma area due to their ability to mature within a period of 100-140 days. Actual long-term maize yields for Choma were obtained from the Central Statistics Office (CSO) data base which contains countrywide post-harvest yields for various crops.

The model utilizes four development stages namely; initial, development, mid and late stages of crop growth. Each stage of plant development was defined in thermal time requirements necessary to complete each developmental stage from crop-specific parameters (Soltani and Sinclair 2012) [20]. SWB calculates cumulative growing degree days (GDD) for each developmental stage as well as for the whole plant growth period (Equation 1).

$$GDD = (T_{avg} - T_b) \times 1 \text{ day} \qquad (1)$$

Where T_{avg}= mean daily temperature and T_b=base temperature, both in ^oC

Depending on the actual daily temperatures, the period (in days) of particular plant stages of development might be longer or shorter for a particular crop. Hence, the model requires minimum and maximum daily temperatures as these affect crop developments. On average the thermal time requirement for maize for the whole period of growth was 1711 degree-days/growth cycle (about 139 calendar days). The simulated development stages of the maize varieties indicated a shorter initial development period and a longer late development stage (Table 2).

Table 2 Thermal time requirements for each phenological development stage.

Development stage	**Mean calendar days**	**Cumulative Degree Days (°C days)**
Initial	19	212
Development	25	316
Mid	34	397
Late	61	786

Total	139	1711

2.4 Structured interviews with farmers

Data on smallholder farmers' perceptions of factors contributing to the observed maize yields was collected using structured interviews administered to 322 respondents in Choma's Singani, Mbabala and Batoka areas. The use of interviews enabled the researcher to probe for more detailed information whenever necessary. The period of data collection was from November 2014 to October 2015. The farmers were randomly sampled using village registers collected from the chief (for Singani) and headmen (for Mbabala and Batoka) Names in the village registers were assigned numbers, then using the 'RANDBETWEEN' function of Microsoft Excel, random numbers were generated, which corresponded to the required number of respondents. Mbabala had 112 selected respondents, Singani had 109, while in Batoka 101 farmers were interviewed.

2.5 Statistical analyses

When assessing relationships involving potential evapotranspiration (PET), actual evapotranspiration (ETa) and precipitation (PPT) in Choma, between 1960 and 2011, we used AREG (Cochrane-Orcutt estimation method in SPSS) to estimate time series regression analysis taking into account autocorrelation errors. In order to compare between these water related variables, a parametric Analysis of Variance (ANOVA) was firstly performed to see if a significant difference exist, taking into account the Levene's test of homogeneity of variances. When the significant difference among PPT, PET and ETa) were established, a post hoc test, Fisher's least significant difference (LSD) test were used to compare significant differences between PPT, PET and ETa.

3.0 RESULTS AND DISCUSSION

3.1 Precipitation, potential evapotranspiration and actual evapotranspiration

The annual amount of rainfall received in Choma between 1960 and 2011 has not significantly changed ($r = 0.01$; $p = 0.944$) even though the area has been experiencing a temperature increase over the same period at an annual rate of 0.037 °C/year (Fig 2). The rate of warming was significant ($r = 0.824$; $p = 0.001$) and contributed to the increase in crop water requirements, of which actual maize evapotranspiration in the area has been significantly increasing at an annual rate of 9.01 mm/year ($r = 0.522$; $p = 0.001$).

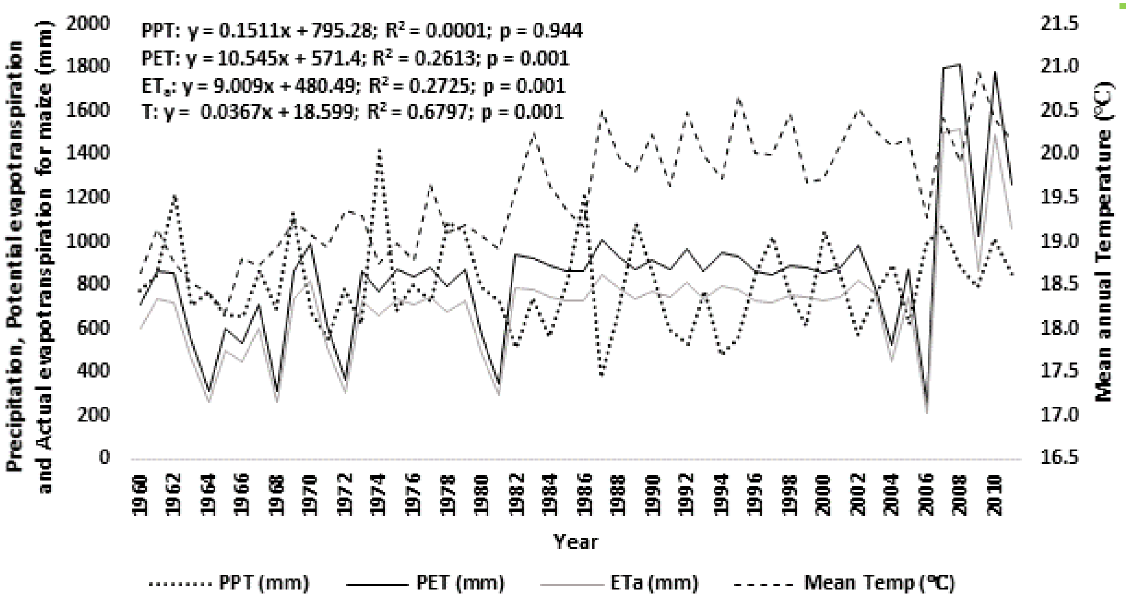

Fig 2. Mean annual temperature and precipitation, potential and actual evapotranspiration in Choma District, Zambia, 1960 to 2011

The parametric ANOVA conducted on PPT, PET and ET_a in Choma over the period 1960 to 2011 showed significant differences in rainfall received and water use requirements for maize (F = 3.247; p = 0.042) (Fig, 3). The Levene's test for homogeneity of variance was not significant (F = 0.321; p = 0.726). The potential evapotranspiration (mean =850.83mm) for maize in Choma was higher than the amount of rainfall received (mean = 799.29), however, the difference was not statistically significant (F = 2.471; p = 0.324). Similarly, while PPT was higher than ET_a, the difference was not statistically significant (F = 1.281; p = 0.126). On the other hand, the potential evapotranspiration for maize in the area was significantly higher than the actual evapotranspiration (mean = 719.23) (F = 5.621; p = 0.012).

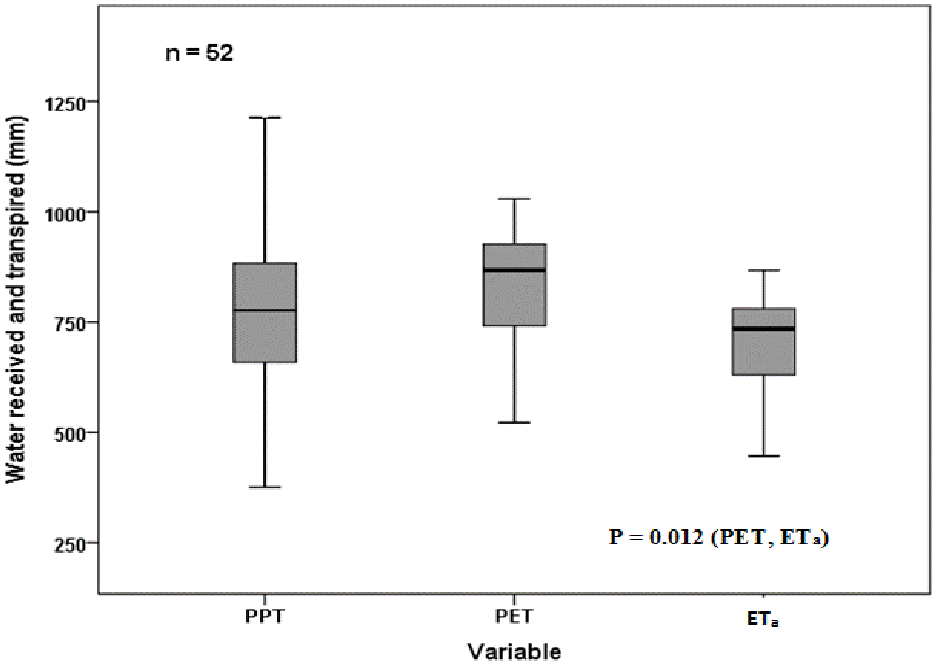

Fig. 3 Comparison between precipitation, potential evapotranspiration and actual evapotranspiration in Choma District between 1960 and 2011

3.2 Crop water stress analysis

Results from the SWB model suggest that maize in Choma experienced the highest number of stress days/year between 1960 and 2004 (13.2 days/year) (Fig. 4). Most of these stress days occurred between 2000 and 2004 when an annual average of 21.8 water stress days/year for maize was recorded (Table 3). The years thereafter (2006-2009) had the lowest stress days/year (once every year).

Table 3 Frequency of crop water stress in Choma, 1960 to 2011.

Number	Period	Frequency of crop stress	Stress days/ season
1	Nov.1960-Apr.1970	66 days in 10 years	6.6
2	Nov.1970-Apr.1980	75 days in 10 years	7.5
3	Nov.1980-Apr.1990	188 days in 10 years	18.8
4	Nov.1990-Apr.2000	164 days in 10 year	16.4
5	Nov.2000-Apr.2004	87 days in 4 years	21.8
6	Nov.2006-Apr.2009	3 days in 3 years	1
7	Nov.2009-Apr.2011	10 days in 2 years	5

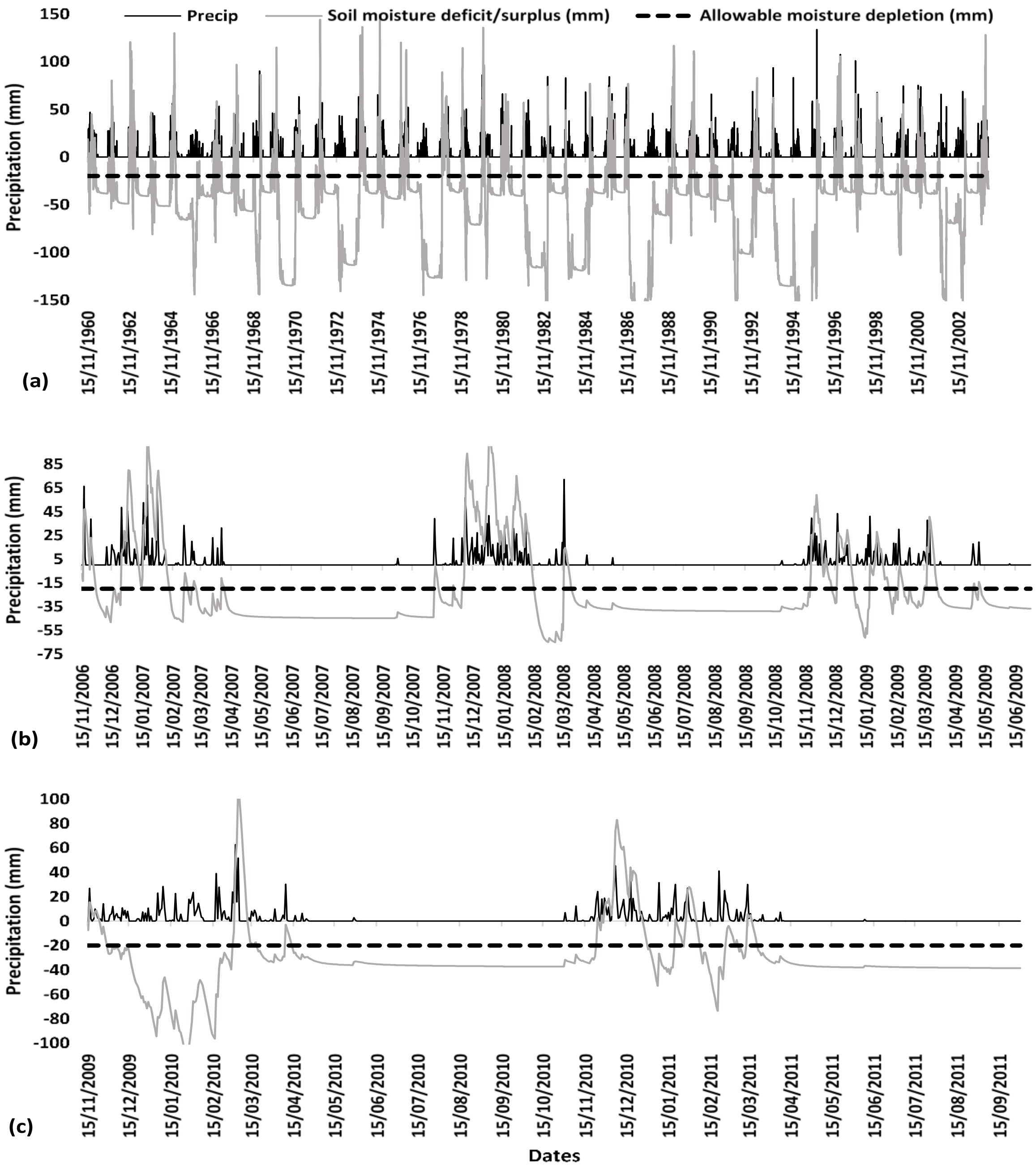

Fig. 4 An SWB model output showing precipitation, soil moisture deficit (crop stress periods) and surplus for (a) November 1960 to April 2006 (b) November 2006 to May 2009, and (c) November 2009 to Apr 2011 for Choma, Zambia. Allowable moisture depletion (-20 mm) was the zone where plants would still survive despite the depleting moisture.

Most of the simulated stress days in Choma occurred during the mid-period of crop development (Fig. 4 and Table 4). There were 31 years which experienced crop water stress during the mid-period of plant development. Extended duration and frequency of crop water stress was detrimental to crop yields. When water stress occurred during the late stages, crop yields where not severely affected. In fact, all the years which recorded the highest ratio of actual to potential yield (1977, 1981, 1986, 1987 and 1988) had experienced water stress during the late stage of crop development (Tables 4). The fact that high actual yields were recorded during the period when the area had the highest number of stress days per year (13.2 days/ year from 1960 to 2004) and yet the period with low stress days/year (2006 to 2011) had consistently declining yields could indicate other factors affecting maize production other than water content in the soil.

Table 4 Distribution of stress years across stages of crop development, 1960-2011.

Stage	**Initial**	**Development**		**Mid**			**Late**		
Month	Nov	Dec		Jan	Feb		Mar		Apr
Years affected	1970, 1989, 2009, 2011	1966, 1969, 1976, 1992, 2003	1968, 1972, 1987, 1999,	1965,1966, 1967,1970, 1974,1977, 1978,1982, 1984,1985, 1989,1991, 2001,2002	1967, 1973, 1981, 1983, 1987, 1993, 1995, 2001, 2010	1970, 1977, 1982, 1986, 1991, 1994, 1999, 2002,	1967, 1971, 1977, 1980, 1982, 1984, 1987, 1991, 2001	1970, 1973, 1979, 1981, 1983, 1986, 1988, 1994,	1971, 1979, 1980, 1986, 1994
Total number of years	4	9		31			22		

When water stress affected yields, the severe stress usually occurred in January and February which coincided with the mid period of crop development. For example, some of the worst affected yields occurred in the years 1991, 1999, 2001, 2002, and 2010 when severe water stress was recorded in January and February (Tables 4).

3.3 Actual vs. potential rain-fed maize yields

The lowest actual maize yields recorded in Choma was in 1992 when the area recorded an average yield of 0.1 ton/ha (Fig. 5). In 1987 the actual yields came close to the potential when farmers harvested 1.59 ton/ha instead of the potential 2 ton/ha (Table 5) for that year. Since 2007, the potential for increasing yields has been trending upwards, even though the potential yields per hectare over the period 1976 to 2014 have not significantly changed ($r = 0.073$; $p = 0.672$). However, the actual yields have significantly decreased over the same period ($r = 0.316$; $p = 0.049$). Since 1989, the actual maize yields recorded in Choma have been less than half the potential (Fig. 5).

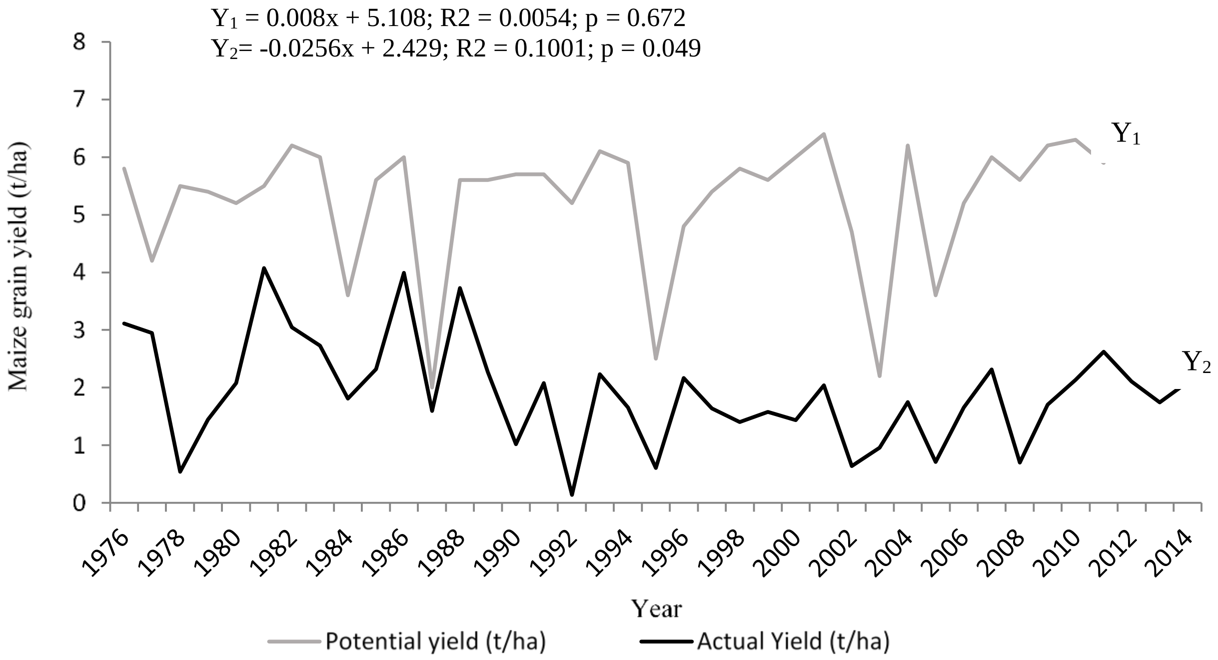

Fig. 5 Actual vs. potential rain-fed maize production per hectare for Choma, 1976-2014

3.4 Relating maize yields to water use requirements

Choma received an average of 792 mm of annual rainfall, ranging from 376 mm to 1224 mm, over the period 1976 to 2010 (Table 5). Plants acquire most of this water from the soil water reserves. As such the process of evapotranspiration was important in determining the rate of water uptake from the soil. The water for potential evapotranspiration (PET) ranged from 788 to 992 mm (Table 5). Maize in Choma required an average of 550.5 mm of annual rainfall (ranging from 415 mm to 686 mm depending on the rate of evapotranspiration). This is well below the average annual rainfall received in the region (792 mm). Only the years 1987 (376 mm) and 1994 (482 mm) recorded total rainfall amounts below the seasonal rainfall requirement for maize.

The mean actual yield for Choma over the study period was 1.89 ton/ha/year (Table 5). The yield classification column in Table 5 gives an indication of the attainable yield (Y_{at}) level achieved, which was the ratio of the actual yields to the potential. When the attainable yields were greater or equal to 70% of the potential for a particular season, the yields were classified as ‘good’.

Table 5 Rainfall, evapotranspiration and yield parameters per growing season (1976-

2010).

Year	**Rainfall**	**ET$_a$**	**PET**	**Y$_a$**	**Y$_p$**	**Y$_p$-Y$_a$**	**Y$_{at}$**	**Yield Classification**
1976	804	605	828	3.11	5.80	2.69	0.54	Not good
1977	723	479	909	2.95	4.20	1.25	**0.70**	Good
1978	1087	625	805	0.54	5.50	4.96^{*}	0.10	Not good
1979	1046	560	893	1.45	5.40	3.95	0.27	Not good
1980	796	659	857	2.08	5.20	3.12	0.40	Not good
1981	724	545	941	4.07^{*}	5.50	1.43	**0.74**	Good
1982	511	430	950	3.05	6.20	3.15	0.49	Not good
1983	738	536	910	2.73	6.00	3.27	0.45	Not good
1984	563	605	846	1.81	3.60	1.79	0.50	Not good
1985	829	667	856	2.32	5.60	3.28	0.41	Not good
1986	1224^{*}	455	992^{*}	3.99	6.00	2.01	**0.70**	Good
1987	$376^{\#}$	570	949	1.59	$2.00^{\#}$	$0.41^{\#}$	**0.80**	Good
1988	668	526	847	3.73	5.60	1.87	**0.70**	Good
1989	1079	526	927	2.27	5.60	3.33	0.41	Not good
1990	851	538	901	1.02	5.70	4.68	0.18	Not good
1991	594	497	967	2.08	5.70	3.62	0.37	Not good
1992	527	578	854	$0.14^{\#}$	5.20	-	0.03	Not good
1993	774	529	924	2.23	6.10	3.87	0.37	Not good
1994	482	$415^{\#}$	966	1.66	5.90	4.24	0.28	Not good
1995	551	556	862	0.61	2.50	1.89	0.24	Not good
1996	859	604	835	2.17	4.80	2.63	0.45	Not good
1997	1021	527	902	1.64	5.40	3.76	0.30	Not good
1998	764	531	856	1.40	5.80	4.40	0.24	Not good
1999	611	659	875	1.58	5.60	4.02	0.28	Not good
2000	1049	686^{*}	878	1.43	6.00	4.57	0.24	Not good
2001	837	608	967	2.04	6.40^{*}	4.36	0.32	Not good
2002	572	528	933	0.64	4.70	4.06	0.14	Not good
2003	747	621	872	0.96	2.20	1.24	0.43	Not good
2006	990	585	841	1.75	6.20	4.45	0.28	Not good
2007	1070	591	866	0.71	3.60	2.89	0.20	Not good
2008	874	509	881	1.65	5.20	3.55	0.32	Not good
2009	793	609	$788^{\#}$	2.31	6.00	3.69	0.39	Not good
2010	1010	663	888	0.70	5.60	4.90	0.13	Not good
1976/2010	792	564	890	1.89	5.18	3.28	0.37	Not good

*Maximum; $^{\#}$Minimum; ET$_a$=Actual evapotranspiration under rain-fed conditions (mm/day); PET=potential evapotranspiration (mm/day); Y$_a$ = actual harvested yield (t/ha); Y$_p$ = potential rain-fed yield (t/ha); Y_p-Y_a=potential for yield increase; Y_{at}= attainable yields.

Under these ratings, only five seasons had recorded good yields, with four of these occurring in the 1980s (Table 5). Since 1988, farmers in Choma had not produced yields greater than 70% of the potential. This suggested that farming in Choma had been operating below its potential, considering the existing weather and soil conditions. The difference between the potential and the actual yields represents the potential for yield increase (Y_p-Y_a). Under the current weather and soil conditions, the potential for maize increase in Choma ranged from 0.4 t/ha, in a year with limited rainfall and high mean temperatures (1987) to over 4.9 t/ha/year in years with high annual rainfall (1978, 2010). This represented an increase in maize production of about 2.6 times the current rate of 1.89 t/ha/year of maize produced by smallholder farmers.

3.5 Factors affecting maize yields-farmers' perspectives

Ninety-six percent of farmers interviewed felt that their limited access to inputs such as fertilizer and seed was their biggest challenge (Fig. 6). Late delivery of inputs (53%) and lack of markets (19%) were also major challenges faced by farmers. Climatic challenges such as droughts and floods were not considered major challenges as the region received sufficient rainfall for the crops cultivated.

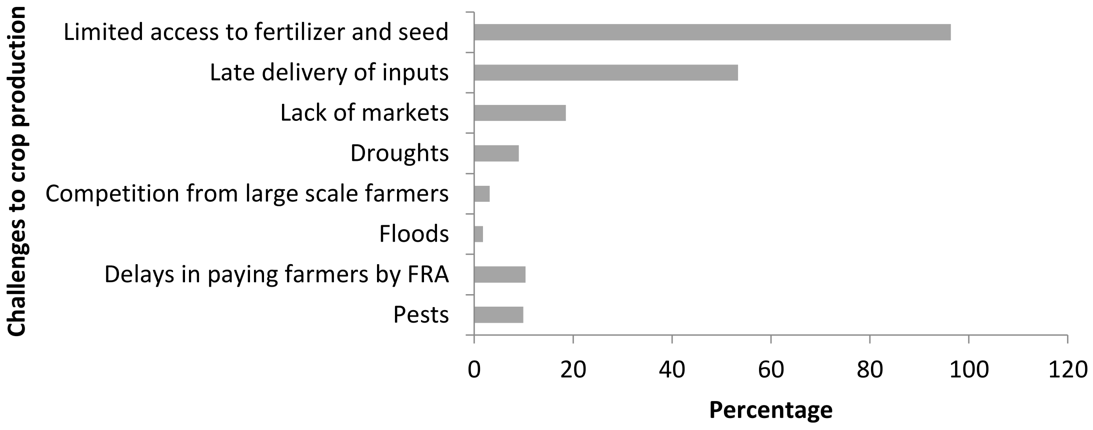

Fig. 6 Factors affecting smallholder farmers' maize production in Choma District.

Farmers felt the inputs received under the Farmers' Input Support Program (FISP) - a government funded subsidy program, were not enough for their cultivated area. A respondent whose problem was limited access to fertilizer said the following:

> *"We get four bags of fertilizer from the cooperatives (2 x 50kg basal and 2 x 50kg top dressing) and that's if you are fortunate. Otherwise most of the time we are given 2 bags (1 x 50 kg basal and 1 x 50kg top dressing). This is not enough for our fields. Besides, we can't afford to buy fertilizer from agro-shops.*

> *It's too expensive."*

During the period of data collection, a 50 kg bag of either NPK (1:2:1) or N fertilizer was costing USD $30.4, while the subsidized FISP fertilizer was costing USD $13.5. Farmers could only get a maximum of four bags at the subsidized price and any extra required had to be bought from the local agro-shops at the current market price. Hence access to both subsidized fertilizer (due to the restriction on the number of bags available) and unsubsidized fertilizers (high cost) affected the amount of maize produced in Choma.

Farmers also faced challenges regarding time of input delivery in the area. They complained that inputs were usually only available by December or January (instead of November), which was late for maize production. One respondent explained their predicament as follows:

> *"Fertilizer has usually been delivered in January. Sometimes by the time we receive fertilizer our crops would have been stunted and our yields lost. It would be better if we could receive the fertilizer by September or October."*

The planting time for maize in Choma cultivated under rain-fed conditions should be between 15th and 30th November under current climatic conditions, at which time NPK fertilizer should be applied. If farmers receive fertilizer in January, it would be too late to maximize the effect of the nitrogen at such a late stage in the plant's development. Availability of fertilizer also helps farmers plan for the area and type of crops to be cultivated. Such planning usually takes place at the beginning of the season.

3.6 Water effects on maize yields

SWB crop growth model was used to estimate day-to-day crop water stress over the study period. Most of the intra-seasonal droughts occurring between November and January might occur in the form of late onset of rainfall. While this affects crop production, farmers may choose to either dry plant or delay planting until the planting rains have come. If the rains come before the end of the normal planting period (15th to 30th of November for maize) overall crop yields will probably not be severely affected. Intra-seasonal droughts occurring just after plant germination are more detrimental to plants, particularly if they have a longer duration. Maize was also very sensitive to drought in the flowering to grain filling (reproductive) stages of development.

The seasonal water use requirements for maize in Choma region ranged from 415 mm to 686 mm. While there are no studies which have been done in the area to provide comparisons, Du Pleissis (2003) [6] reported that maize requires an average of 400 mm of well distributed rainfall while FAO reported a 500-800 mm range of rainfall requirements for a medium-maturing maize variety. This range of rainfall requirements varied depending on actual local climatic conditions. Choma's mean annual rainfall (792 mm) for the study period was above the maximum water use requirement for medium maturing maize varieties (686 mm). While the effect of limited water on maize was considerable, simulations suggest that Choma was not in a state of significant water deficit over the period 1976 to 2010. This implied that while overall water availability might not be such a challenge in the area, spatial distribution of rainfall as well as input availability could prove to be more limiting factors to achieving optimum maize yields in the area.

Climatic factors such as the interaction of rainfall and temperature through evapotranspiration have not been major factors in the low maize yields produced in Choma. While water stress has occurred in some years, and has at times contributed to the observed low yields, it has generally not been the main limiting factor resulting in the low yields observed in Choma. This was because despite some years experiencing limited rainfall, even such rainfall amounts were usually above the water use requirements for maize. Furthermore, a considerable number of stress days which could have affected maize yields occurred during the late stages of maize growth when the grain yields was seldom affected by water stress. Occurrence of high stress days during the first period when Choma recorded high actual yields also indicate that these stress days had less effects on yields as compared to non-water quantity related factors which resulted in the declining actual yield trends in the second and third periods of simulation. The medium maturing maize varieties cultivated in Choma take about 100 to 140 days to mature. The stress days which occurred after February rarely affected maize yields, especially for farmers who planted early. Yet, the actual yields in the area had consistently been declining since the 1970s.

The study is vital to policy and policy makers as it helps with highlighting areas that may be cardinal in improving the agricultural performance of maize among smallholder farmers. Since water stress was not the major limiting factor in the low yields, other factors which could be social, economic, political or institutional could have been at play. Factors such as limited access to fertilizer and seed, late delivery of inputs and delayed payments by the Food Reserve Agency for maize sold by farmers contributed to the reduced yields. Furthermore, a lack of proper input management, unsustainable farming systems, declining nutrient levels, a maize mono-cropping culture among farmers and land degradation have been identified as limitations to smallholder agriculture in the area (Umar et al. 2012) [24]. However, this was an area that would require further research in order to conclusively determine the major factors responsible for the observed low yields in the area.

4.0 CONCLUSIONS

With regard to maize water use requirements, Choma area was generally not in a water deficit situation. The seasonal maize crop water requirements were usually below the available water for use for most of the years, with the exception of two years (1987 and 1992), when the area experienced severe rainfall shortages. As such, there was high potential to increase maize production under the current climatic and soil conditions from the current actual yield average of 1.89 t/ha/year recorded by farmers over the period 1960 to 2014 to about 4.9 t/ha/year, which was the calculated rain-fed potential yield for the study area.

The SI analysis in SWB showed that water stress was not the major limiting factor in maize production in Choma. The highest yields recorded over the period 1960 to 2011 coincided with the period of high-water stress for the region (13.2 days/year) while the periods with a less number of water stress days/year had declining actual maize yields. The declining yields over time could have been an indication of declining soil nutrient levels, land degradation, unsustainable farming practices or even inadequate management of crop nutrients due to late fertilizer delivery by the government. Further research into these could determine the most important limiting factors in the region.

5.0 RECOMMENDATIONS

Based on the results of the study, the following recommendations were made:

1. For optimum maize productivity of the crop cultivated under rainfed conditions, smallholder farmers in intermediate rainfall areas of Zambia should plant between the 15th and 30th of November at which time NPK fertilizer should be applied.
2. The government should distribute fertilizer to farmers by October of each year in preparation for planting and application of the fertilizer by November at the time of planting. Early distribution of fertilizer also helps farmers plan for the area and type of crops to be cultivated as such planning usually takes place at the beginning of the season.
3. Since water stress was not the major limiting factor in the low yields, it is recommended that studies in other factors which could contribute to low yields in intermediate rainfall regions be conducted. The studies could relate to social, economic, political or institutional factors that could contribute to reduced productivity on maize

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