WATER MANAGEMENT PRACTICE FOR MAIZE PRODUCTION IN CHINCHIMANE, ZAMBEZI REGION, NAMIBIA

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WATER MANAGEMENT PRACTICE FOR MAIZE PRODUCTION IN CHINCHIMANE, ZAMBEZI REGION, NAMIBIA

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Abstract

Agriculture is the greatest water consumer in Namibia and the world at large, it is thus necessary to know the water needs of the irrigated crops for better water management. However, there is little scientific literature on crop water and irrigation requirements in Namibia. Therefore, this study intended to contribute to the body of knowledge on water needs for crops in general and maize in particular, since maize is a staple crop in the selected study area. CROPWAT, a software which uses the Penman-Monteith approach to compute reference evapotranspiration, crop water needs and irrigation requirements, was employed in this study to estimate the water needs of maize in the Chinchimane area of the Zambezi region. Subsequently, a maize irrigation schedule was simulated in CROPWAT based on soil and long-term meteorological data. The study found the minimum and maximum daily crop water requirements for irrigated maize in the study area to be 1.74 mm and 7.49 mm, respectively. In contrast to the seasonal crop water requirement, which was found to be 679.2 mm, the seasonal irrigation requirement was found to be 628.8 mm. Furthermore, the study's estimates of the water requirements for maize fall within the range of values that were reported by some earlier studies in other locations. Additionally, the simulated maize irrigation schedule suggested eight irrigation events in contrast to watering every day. This study's findings can thus assist maize irrigators in Chinchimane to conserve water and reduce unnecessary expenditure while still meeting agricultural water needs, because knowing the water needs of irrigated crops and adhering to an optimized irrigation schedule ensures that water resources are used sustainably, and irrigation water demand is managed.

Key Words: CROPWAT**,** Penman-Monteith approach, reference evapotranspiration, crop water requirement, irrigation requirement, irrigation schedule.

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List of Abbreviations and/or Acronyms

CWR	Crop Water Requirement
Ea	Water application efficiency
e_a	Actual Vapour Pressure
e_s	Saturation Vapour Pressure
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization
FAO-24	Food and Agriculture Organization Irrigation and Drainage Paper No.24
FAO-33	Food and Agriculture Organization Irrigation and Drainage Paper No.33
FAO-56	Food and Agriculture Organization Irrigation and Drainage Paper No.56
G	Soil Heat Flux Density
GIR	Gross Irrigation Requirement
IR	Irrigation Requirement
Kc	Crop Coefficient
Ky	Yield Response Factor
l/hr	Litres per hour
l/s/ha	Litres per second per hour
NIR	Net Irrigation Requirement

P	Precipitation
Pe	Effective Precipitation
R_n	Net Radiation
SASSCAL	The Southern African Science Services Centre for Climate Change and Adaptive Land Management
T	Mean Daily Air Temperature
U_2	Wind Speed
USDA	United States Department of Agriculture
ZGCF	Zambezi Green Commercial Farm

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Dedication

To my mother, Miss Mary- Clare Nanvula Libana.

To the late Prof. Frank Paul Kavishe

Declarations

I, Lisa Nalufu Lisho, hereby declare that this study is my own work and is a true reflection of my research, and that this work, or any part thereof has not been submitted for a degree at any other institution.

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CHAPTER 1: INTRODUCTION

1.1. Orientation of the Study

Globally, rising water demand is a growing concern, particularly in arid and semi- arid countries like Namibia. This developing water challenge necessitates the proper allocation of water to competing users as well as water conservation in agricultural production, which consumes most water. For the conservation and better management of water in irrigated agriculture to be possible, crop water and irrigation requirements for the irrigated crops must be known (Aghdasi, Sharifi & Van der Tols, 2011). Thus, the role of crop water and irrigation water requirement estimation in the agricultural sector is critical because each crop requires a different amount of water depending on the local conditions.

Namibia is a water-stressed country, mainly due to its arid climate. It is associated with rainfall that is low and unpredictable, and high evaporation rates – due to high temperatures. In addition to that, the country's only perennial rivers (Zambezi, Chobe, Okavango, Kunene, and Orange River) are trans-boundary (Mapani et al., 2023). As a result, Namibia is primarily reliant on groundwater resources, which are also hampered by low rates of recharge from precipitation and/or floods (Government of the Republic of Namibia, 2004). Considering this, it is essential to utilise the country's water resources, which are already scarce, in a sustainable way.

Agriculture consumes approximately 70% of the water in Namibia and accounts for most of the water use globally (Government of the Republic of Namibia, 2004; Aghdasi, Sharifi & Van der Tols, 2011). In 2008, crop land irrigation consumed approximately 135 million cubic meters of water, which is equivalent to approximately 40% of total water demand in Namibia ("Agricultural Use - Kunene River Awareness Kit," n.d.). Therefore, knowing the water requirements of irrigated crops is critical for

managing irrigation water demand.

CROPWAT software, which was developed by the Food and Agriculture Organization (FAO), has been useful in agricultural water management. It was developed for irrigation water investigations and the design and management of irrigation schemes (Smith, 1992). Furthermore, researchers from different parts of the world have used the CROPWAT model to calculate crop evapotranspiration (ETc) or crop water requirements (CWR) and irrigation requirements (IR), and to generate irrigation schedules (Elkiran & Abdullahi, 2017; Song, Oeurng & Hornbuckle, 2016; Bhausaheb, Khose & Mandage, 2021).

1.2. Statement of the Problem

Maize farming is common in the Zambezi Region (Mendelsohn et al., 2009). However, there is little scholarly literature available on crop water and irrigation requirements in the region. According to the literature search, only one study (which was conducted in the Kabbe North Constituency) attempted to estimate the crop water and irrigation requirement of maize within the region (Mwazi, 2017). Given that crop water requirements are locality-specific, there is a need to determine the water requirements of maize and/or the irrigated crops in various localities within the region. Therefore, this study seeks to contribute to the available literature on maize crop water requirements.

1.3. Aim and Objectives of the Study

1.3.1. Aim

The aim of this study was to improve on agricultural water use efficiency within the Zambezi Green Commercial Farm (ZGCF).

1.3.2. Objectives

1. To estimate the crop water requirement of maize in the study area by using

CROPWAT,

2. To compute the irrigation requirement of maize in the study area by using CROPWAT, and

3. To simulate the irrigation schedule within ZGCF.

1.4. Significance of the Study

This work will contribute to the body of knowledge on agricultural water management in the Zambezi region. Furthermore, the findings can assist the ZGCF and other maize farmers in Chinchimane in saving water and reducing unnecessary costs while meeting agricultural water needs.

1.5. Limitation of the Study

The study's limitation is that the lack of resources (both financial and time) prevented the researcher from advancing this work by field- testing the CROPWAT-simulated irrigation schedule.

1.6. Delimitation of the Study

The study's methodology was limited to using the FAO-56 approach/CROPWAT model to calculate the crop's water needs and to create an irrigation schedule using crop, soil, and climate information obtained from both primary (field observations, a soil survey, and interviews) and secondary sources (literature). Also, the study was limited to maize grown under drip irrigation in sandy loam soil and the local climate of Chinchimane. It is therefore impossible to simply generalise the study's findings to the entire constituency or region.

CHAPTER 2: LITERATURE REVIEW

2.0. Introduction

This chapter gives a general overview of irrigation and focuses on some key agricultural or irrigation water management concepts, such as crop water and irrigation requirements and irrigation scheduling. Furthermore, the chapter draws attention to the use of the FAO Penman-Monteith method and the CROPWAT model for calculating crop water requirements, irrigation requirements, and scheduling irrigation. It also provides an overview of earlier studies that used the methodology mentioned above.

2.1. Irrigated Agriculture

Applying water to the soil in addition to what is received through rainfall to promote plant growth and yield is known as irrigation (Sojka et al., 2002). Worldwide, irrigation has been used for thousands of years; and in use today are several irrigation techniques. Globally, surface irrigation, sprinkler irrigation, and drip irrigation are the three techniques that are most frequently used (Orlina & Schaldach, 2018). Irrigated agriculture has been beneficial in meeting the rising demand for food (Orlina & Schaldach, 2018) and it offers the chance to grow food in nations where crop production may be constrained by environmental factors such as drought or dry spells (Postel, 1998; Sharmasarkar et al., 2001; Bannayan et al., 2008). Although agro-irrigation has the potential to boost food production, most of Africa's cultivated land is rainfed - and only 6% is irrigated. However, the state of irrigation in Africa varies among countries or subregions. For instance, Southern Africa (where Namibia lies) irrigates 4.2% of its farmland, while Central Africa, Sub-Saharan Africa and Northern Africa irrigate 0.7%, 4% and 28%, respectively. The lack of adequate policies that promote agro-irrigation is one of the reasons why irrigation is not widely implemented in Africa (You et al., 2011), but Namibia has a policy that supports this. Through its

"green scheme" policy, the government of Namibia has made investments in agro-irrigation projects (Hansen & Kathora, 2013). This program aims to improve the welfare of communities, achieve national social development goals, and build skills and capacity both nationally and within the irrigation sub- sector, which are key steps in achieving the nation's food self-sufficiency. It does this by providing leasehold land and input subsidies to farmers (commercial and communal) to encourage them to grow field crops, vegetables, and fruit crops. However, Namibia’s irrigation sector does not only comprise of beneficiaries of the green scheme initiative; there are other small and medium scale farmers outside the scheme who engage in agro-irrigation (Haidula, 2016). Although irrigation is beneficial, it is crucial to use irrigation techniques that are appropriate for the local environmental circumstances and irrigation that can increase yield, limit the waste of limited resources, and require few inputs (Imtiyaz et al., 2000). The use of highly efficient irrigation techniques such as drip irrigation can help in this regard, especially in regions where water scarcity is experienced. In drip irrigation, water is delivered directly onto the root zone of crops, thus wastage of water is reduced. This method of irrigation is becoming extensively used due to this water conservation ability, while maintaining or enhancing yield and optimizing fertilizer use (Hanson et al., 2012). Furthermore, knowledge of evapotranspiration and crop water requirements in general aids in the design of the most appropriate irrigation system (Gu et al., 2020).

2.2. Crop Water Requirements

According to Doorenbos and Pruitt (1977), crop water requirement refers to the quantity of water needed to replace the water lost through evapotranspiration from crop fields. The crop water requirement is determined by multiplying the reference evapotranspiration by the crop coefficient, which is the ratio of crop evapotranspiration

(ETc) to reference evapotranspiration (ETo) (Sarukkalige & Jones, 2017). To estimate the reference evapotranspiration (ETo), the FAO CROPWAT model requires climatic information on maximum and minimum temperatures, relative humidity, wind speed, and sunshine hours. The crop water requirement is given by CROPWAT 8.0 on a decade (10-day) basis and daily basis. The model calculates ETc using the Penman-Monteith equation below:

$$ETc = ETo \times Kc$$

Where ETc = crop evapotranspiration in mm/day, ETo = reference evapotranspiration in mm/day, Kc = crop coefficient (the ratio of ETc to ETo, which expresses the variation in evapotranspiration between the cropped area and the reference grass surface).

The crop's planting dates, crop coefficients (Kc) at various growth stages, length of the growing season (in days), crop rooting depth, permissible soil moisture depletion levels, and yield response factors (Ky) must all be entered into the model (Doorenbos & Kassam, 1979).

2.3. Irrigation Requirements

When the rainfall is insufficient to make up for the water lost through evapotranspiration, irrigation is necessary (supplemental irrigation), but irrigation can also be applied during the full growth period (full irrigation). Applying water in the proper amount and at the proper time is the main goal of irrigation. The frequency and depth of upcoming irrigations can be planned by calculating the soil water balance of the root zone daily. The crop's evapotranspiration under typical conditions and the effective rainfall contributions over the same time step determine the irrigation requirement, which is computed over a given period and expressed in millimetres. The percentage of the crop's water requirement that must be met by irrigation contributions

to ensure the crop's ideal growing conditions is known as the irrigation requirement (Kumari, 2017). The net depth of water to be applied in the effective root zone is known as the net irrigation requirement. On the other hand, the amount that must be applied to ensure that sufficient water enters the soil and is stored within the plant root zone to meet crop needs is known as the gross irrigation requirement. Not all the irrigation water applied to the field enters and gets retained in the root zone of the plants. In other words, there are unavoidable water losses brought about by uneven water application across the field, deep percolation beneath the plant root zone, surface runoff, and evaporation from the soil surface from flowing and stagnant water (Allen et al., 1998).

2.4. Irrigation Scheduling

A field's irrigation schedule determines when and how much water should be applied. To maximize production and reduce negative environmental effects, good scheduling will apply water at the appropriate time and in the appropriate quantity. Water is consistently made available to plants through irrigation scheduling, which also ensures that it is applied in accordance with crop needs. Irrigation scheduling can be done using CROPWAT based on different management conditions (Kumari, 2017). For example, irrigation at critical depletion, irrigation at fixed depletion, irrigation at user-defined intervals, or irrigation at fixed intervals per stage (Shar & Suryanarayana, 2016). The scheduling of irrigation aids in lowering farmers' costs of water and labour by requiring less irrigation, maximizing the use of soil moisture storage, lowering fertilizer costs by limiting deep percolation or leaching, increasing net returns by increasing crop yields and quality, and minimizing water-logging issues by lowering the drainage requirements (Kumari, 2017). Irrigation scheduling is crucial in coping with water stress in arid regions to ensure optimum yield and water-use-efficiency as proven by

Li et al. (2020).

2.5. The Use of Models to Estimate Crop Water Needs and Schedule Irrigation

Crop water needs are often not known because of the difficulty of getting reliable field data, while crop water need data is sometimes required under limited time and resources. To address this need, FAO published guidelines (FAO Irrigation and Drainage Paper No. 24) for predicting crop water and irrigation requirements under various climatic and agronomic conditions (Doorenbos & Pruitt, 1977). Since the publication of FAO-24 which has been a milestone in the field of crop water requirements and irrigation scheduling, many models have been proposed. For example, BUDGET, ISAREG, AQUACROP, OSIRI, DAISY, SWB, CIDSS, WISE, CRITERIA-1D, SIMETAW, SALTMED, PILOTE, MOPECO, swbEWARELREG, and SIMDualKc were developed; but the CROPWAT model has been extensively used because it includes a database of crop and soil data from FAO manuals, a supplemental CLIMWAT weather database, a reference evapotranspiration calculator, and a water balance computational tool that can recommend an irrigation scheduling calendar for the crop, soil, and field that have been chosen. After the release of FAO-56 (FAO Irrigation and Drainage Paper No. 56), the model underwent a series of updates. Recently, CROPWAT 8.0 was made available (Pereira et al., 2020). In recent years, soil moisture sensors and remote sensing technologies have been applied in addition to simulation models, weather-based indices such as the Penman-Monteith equation or simple look and feel methods (Zhang et al., 2020). In terms of irrigation scheduling methods, other techniques exist besides the use of weather-based simulation modules such as CROPWAT. One of the common techniques is the use of soil moisture sensors that provide real-time information about soil moisture levels, enabling farmers to initiate irrigation when the soil reaches a specific limit (Munoz-Hernandez et al.,

2015). Furthermore, some irrigators use weather forecasts and climatic data to estimate crop water needs and in turn decide the timing of irrigation (Snyder et al., 2005).

2.6. The FAO Penman-Monteith Method and CROPWAT Model

Researchers have developed several techniques over time for calculating crop water requirements. Crop evapotranspiration can be calculated using direct or indirect methods and meteorological data. Examples of crop evapotranspiration estimation methods include the energy balance method, mass transfer method, lysimeters, scintillometers, pan evaporation method, FAO Penman-Monteith method, and remote sensing (Allen et al., 1998). After comparative studies, scientists came to a consensus that the Penman-Monteith equation is the best approach for calculating crop evapotranspiration, and this is the approach used by the CROPWAT model (Smith, 1992). Penman (1948) combined the energy balance with the mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatological records of sunshine, temperature, humidity, and wind speed. This so-called combination method was further developed by many researchers and extended to cropped surfaces by introducing resistance factors (Kumari, 2017). According to Allen et al. (1998), the Penman-Monteith form of the equation is given by:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where:

ET_o is reference evapotranspiration (mm day-1),

R_n is net radiation at the crop surface (MJ m-2 day-1), G is soil heat flux density (MJ m-2 day-1),

T is mean daily air temperature at 2 m height (°C), U_2 is wind speed at 2 m height (m

s-1),

e_s is saturation vapour pressure (kPa),

e_a is actual vapour pressure (kPa),

$e_s - e_a$ is saturation vapour pressure deficit (kPa),

Δ is slope vapour pressure curve (kPa °C-1), and γ is psychrometric constant (kPa °C-1)

The direct measurement of crop evapotranspiration is an expensive and tedious task. The Penman-Monteith equation can therefore be used in CROPWAT to calculate evapotranspiration (Bhat et al., 2017). CROPWAT is intended to be a useful tool for performing standard calculations for reference evapotranspiration, crop water requirements, irrigation requirements, irrigation scheduling, and more particularly the design and management of irrigation schemes. In addition to planning irrigation schedules under various water supply conditions, it also enables the development of recommendations for better irrigation practices and the evaluation of production under deficit irrigation or rain-fed conditions (Kumari, 2017). To determine reference evapotranspiration, crop water needs, and irrigation scheduling, CROPWAT applies the FAO Penman-Monteith method by using soil, crop, rainfall, and other climate data (Elkiran & Abdullahi, 2017).

2.7. Previous Studies

The CROPWAT model has been applied in various regions of the world to determine the crop water and irrigation needs for various plant types under both irrigated and rain-fed conditions, as well as under various climatic and soil conditions (Muhammad, 2009). In Namibia, Mwazi (2006) used the CROPWAT model to calculate the crop water needs for rain-fed maize, sorghum, pearl millet, and cowpeas at the Excelsior Resettlement Project in the Oshikoto Region and discovered that maize had a 518 mm

crop water requirement for a 130-day growth period. Another study by Mwazi (2017) determined the crop water needs for rain-fed maize between the 2004/2005 and 2015/2016 growing seasons in the Kwalala non-flooded landscape unit of the Kabbe North constituency in the Zambezi Region of Namibia. The observed maize crop water requirement ranged from 1.25 to 5.59 mm/day between the 2004/2005 and 2015/2016 seasons.

The CROPWAT model has also been used to conduct studies on the crop water and irrigation requirements of maize in other parts of the world apart from Namibia. For instance, Ahmad et al. (2019) applied the CROPWAT model and reported that 520 mm is the optimum level of irrigation for the entire growing season in semi-arid regions, and that a 20% reduction in irrigation doesn't significantly affect maize yield based on simulation model. Other examples of such studies conducted outside Namibia are summarized in Table 1.

Table 1: Some case studies from different parts of the world (and different climates) where CROPWAT was used to estimate crop water and irrigation requirements of maize in recent years (2017 – 2021).

Source	**Location & Climate**	**Seasonal CWR (mm)**	**Seasonal IR (mm)**
Yirga, Mamo, and Mengesha (2018)	Ethiopia (sub-humid)	423	101
Thazin (2019)	Myanmar (semi-arid)	467.3	611
Mebrahtu et al. (2021)	Ethiopia (Semi-arid)	457.8	335.7

Herbha, Vora, and Kunapara (2017)	India (Sub-tropical)	477.4	431.7
Gabr and Fattouh (2021)	Egypt (semi-arid and arid)	576.2 - 1319	576.2 - 1319
Bhat et al. (2017)	India (temperate)	304	288.2
Onyancha, Gachene, and Kironchi (2017)	Kenya (temperate highland tropical)	674.90	611.70

In addition to maize, estimations of the crop water requirements for other crops, trees or shrubs, and vegetables have also been done. For instance, Aydin (2022) used the CROPWAT model to estimate the water requirements of some important crops (pistachio, olive, almond, and grape) in Turkey under a semi-arid climate. This study further developed irrigation schedules for the plants under consideration using the same model. The crop water requirements for wheat, barley, white corn, and tomatoes were calculated in another study using the CROPWAT simulation tool and the CLIMWAT 2.0 tool for the Dhi-Qar Province in Southern Iraq (Ewaid, Abed Al-Ansari, 2019). In the semi-arid Ahmednagar district of India, Bhausaheb, Khose and Mandage (2021) estimated the crop water requirements for Kharif and Rabi crops. Using the CROPWAT 8.0 program, irrigation scheduling was also completed for cotton, wheat, bajra, and sorghum. In the Bina command area of India's Sagar district, CROPWAT was used to calculate the crop water and irrigation needs for the Rabi crops (mustard, wheat, and gram-pulses) (Gangwar et al., 2017).

CHAPTER 3: METHODOLOGY

3.0. Introduction

This chapter provides a description of the study area and details the tools and techniques adopted in this study to calculate the crop water and irrigation requirements and produce an irrigation schedule for maize grown under drip irrigation within Zambezi Green Commercial Farm, Namibia.

3.1. Study Area

Namibia is known for rainfall which typically decreases from the east to the west and from the north to the west, and the Zambezi Region is one of the regions that receive the highest rainfall in the country, making it one of the most fortunate regions in terms of maize production. This part of the country has a semi-tropical climate with rainfall that typically falls between October and March and ranges from 650 to 900 millimetres annually. May to September is the dry season, and the annual gross evaporation rate ranges from 1680 mm/year to 1820 mm/year. Its elevation is roughly 950 m above sea level, and it is distinguished by its uniform terrain. The most common type of soil is sandy loam (Mendelsohn et al., 2009; Mendelsohn, Roberts, & Hines, 1998).

According to the 2011 census, the Zambezi region has a total of 90 756 inhabitants, an area of 14 785 km^2, and a population density of 6.20 persons/km^2: with the rural population consisting of predominantly subsistence farmers. Most of the rural population engages in small-scale crop and animal production (Namibia Statistics Agency, 2011). Maize is one of the high-yielding crops grown there for both subsistence and commercial purposes (Mendelsohn et al., 2009).

Zambezi Green Commercial Farm was selected as the study site. It was chosen because maize is grown there under irrigation, there is a weather station (Sachinga) in the constituency where it is located, and the farm owner was willing to be interviewed and

to avail the site for research. The study site is situated between 17°58'59.79" S and 24° 6'51.18" E in Namibia's Chinchimane area of the Zambezi Region, in Sibbinda Constituency. The site is owned by the proprietor of ZGCF, which was started in 2017 as a trial gardening project. After receiving funding from Agribank in 2018, the project was turned into a commercial farm and began supplying local wholesalers (such as Pick 'n Pay and Spar) with seasonal fresh produce. ZGCF grows tomatoes, watermelons, spinach, sweet potatoes, okra, cabbage, and butternuts using drip irrigation. Green maize, a hybrid with a very quick maturation period of 121 to 125 days, is also grown there. Groundwater (boreholes) serves as the main source of water. A visual representation of the study area is shown in Figure 1 (map) and Figure 2 (satellite image).

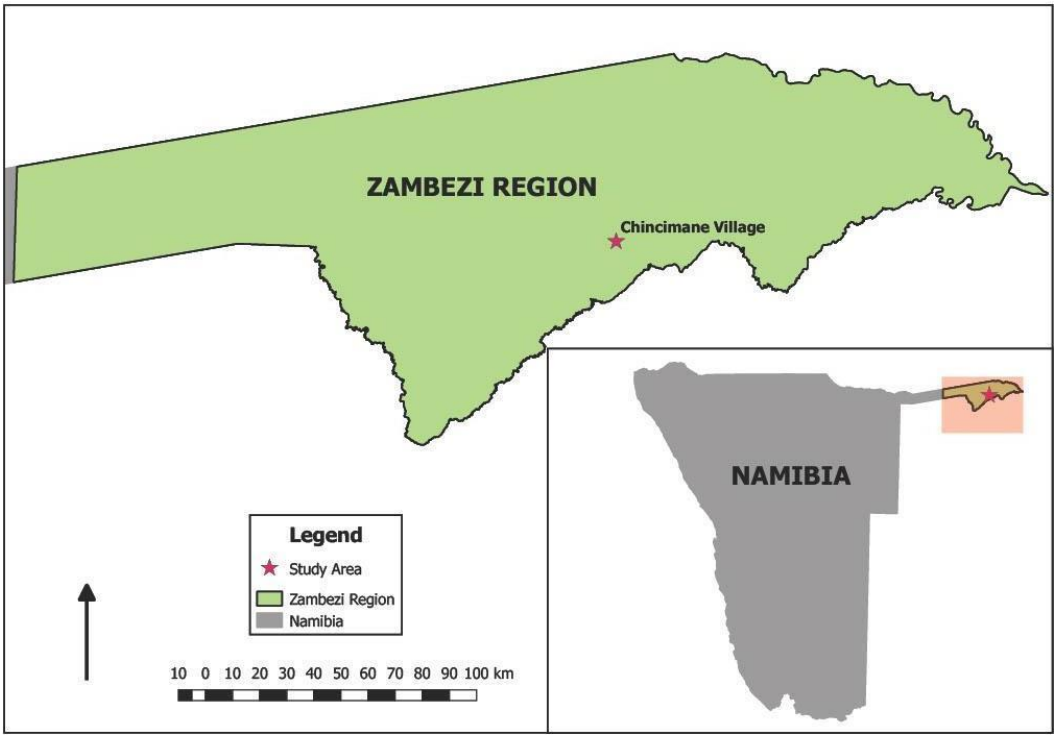

Figure 1: Study area map

Figure 2: A satellite image of the study site

3.2. Research Design

This study featured both the quantitative and qualitative research designs. CROPWAT was the quantitative model used, with data acquired through interviews, field observations (including a soil survey), and a review of literature. Additionally, interviews produced some qualitative information, for example, crop type, irrigation technique, and water source.

3.3. Estimating Crop Water and Irrigation Requirements of Maize

The FAO CROPWAT model was selected in this study for the estimation of crop water and irrigation requirements and irrigation scheduling for maize grown under drip irrigation. As mentioned under the limitation of the study, time and money were limiting factors. Therefore, the researcher opted for computer model-based estimation of water requirements, as it is cheaper and even less tedious in contrast to direct measurement of crop evapotranspiration. The CROPWAT model was specifically chosen because it has a database of standard crop and soil data, which can be used when it is not possible to obtain these data through field work or when there is no local

data available (Bhat et al., 2017). For instance, after soil sampling and using a simple jar test to determine the soil texture the rest of the soil data were adopted from the FAO soil database in CROPWAT. The selected model uses the Penman-Monteith method for estimating reference evapotranspiration, and the single crop coefficient approach for estimating crop water requirements. To determine the crop water and irrigation needs and develop an irrigation schedule for maize in the study area, the CROPWAT model required the following themes of input data: (1) climatic data, (2) crop data, and (3) soil data.

3.3.1. Data Collection

Climatic Data:

The study was initiated by collecting historical climatic data for the study area, encompassing variables such as minimum and maximum temperatures (°C), relative humidity (%), wind speed (km/day), sunshine hours (h), and rainfall (mm). This data was sourced from SASSCAL WeatherNet and the Climate Data Portal. Due to a lack of data or inadequate data before 2014 for the selected station (Sachinga), the study's climatic data only dates to 2014. The collected meteorological data covers an eight-year period from 2014 to 2021.

Crop Data:

The required crop data included crop coefficients representing water use at various growth stages, the duration of each growth stage in terms of days, rooting depth (in meters), critical depletion fraction, yield response factor, and crop height (in meters). These parameters were sourced primarily from FAO manuals (No.24, No. 33, No. 56) and supplemented with interviews with ZGCF staff.

Soil Data:

Soil data collection involved conducting a soil survey. A total of 10 soil samples were

collected randomly within the study site, at a depth of 30 cm using a spade. The collected soil samples were carefully mixed and homogenized in a bucket to draw a representative composite sample for the entire study area. A jar test was conducted to determine the sand, silt, and clay composition, which led to soil texture classification according to the USDA textural triangle. Furthermore, supplementary soil data specific to the identified soil type was obtained from the FAO-56 manual.

3.3.2. Data Analysis

To estimate the crop water requirement and compute the irrigation requirement for maize, the collected data was captured in the FAO CROPWAT model. The process begins by entering the geographical information of the weather station and then the meteorological data (minimum and maximum temperature, humidity, wind speed, and sunshine hours) is entered to calculate ETo, using the Penman-Monteith method. Radiation is subsequently computed along with the ETo. The second step is entering the monthly rainfall values, to compute the effective rainfall. In this study, the USDA Soil Service Conservation Method for calculating effective rainfall was chosen, as recommended in FAO's guide on soil texture. The USDA Soil Service Conservation method is represented by the equations below:

For P less than or equal to $250/3$ mm, $Pe = ((P \text{ x } (125 - 0.2 \text{ x } 3 * P)) / 125$

$Pe = 125/3 + 0.1 * P$, for P more than $250/3$ mm

Where: Pe is the effective precipitation measured in millimetres and P is the total precipitation measured in millimetres during the local area's crop-growing season. This was followed by entering maize crop data (crop coefficients, length of crop growth stages, rooting depth, critical depletion fraction, yield response factor, crop height, and planting and harvest dates). The Kc values for each growth stage were adopted from Allen et al. (1998) and Pereira et al. (2021). Additionally, the soil data (soil texture,

total available soil moisture, initial soil moisture depletion, maximum rooting depth and maximum rain infiltration rate) were entered. With all these inputs, CROPWAT calculated the crop's water requirements at various growth stages using the crop coefficient approach or Penman-Monteith equation below:

$$ETc = ETo \times Kc$$

ETo is the reference evapotranspiration (mm), Kc is the crop factor, and ETc is the crop evapotranspiration (mm).

Furthermore, the software calculates the irrigation requirement by considering the difference between the crop's water requirement and the effective rainfall. If effective rainfall is insufficient to meet the crop's water needs, CROPWAT quantifies the deficit that must be addressed through irrigation. The following equation was used to determine the irrigation requirement:

$$NIR = ETc - Pe$$

NIR stands for net irrigation water requirement (mm), ETc for crop water requirement (mm) and Pe for effective rainfall (mm).

The following formula was used to calculate the gross irrigation requirement:

$$GIR = NIR/Ea$$

Where: GIR stands for gross irrigation requirement, NIR for net irrigation water requirement, and Ea for water application efficiency.

3.4. Irrigation Scheduling

CROPWAT can also assist in irrigation scheduling by providing guidance on when and how much irrigation water should be applied. Factors such as the crop's growth stage, soil moisture levels, and the availability of water for irrigation are considered in making these recommendations. In CROPWAT, irrigation Scheduling can be carried out using the following management conditions: (i) irrigation at critical depletion, (ii)

irrigation at fixed depletion, (iii) irrigation at user defined intervals and (iv) irrigation at fixed interval per stage. Some studies (Vashisht & Satpute, 2015; Shah & Suryanarayana, 2016) revealed that using the critical depletion criteria for irrigation scheduling is the best as the yield reduction is negligible. Therefore, this study used the critical depletion scenario (irrigation at critical depletion and refilling soil to 100% field capacity). The default field efficiency in CROPWAT (70%) was used. Finally, CROPWAT generates reports and graphs that convey the crop's water requirements, irrigation needs, and suggested irrigation schedules.

3.5. Assumptions

In this study, certain assumptions were made while utilizing CROPWAT. It was assumed that the meteorological data collected accurately represented the study area, and that climatic conditions and soil characteristics remained consistent throughout the study duration. The crop coefficients sourced from existing literature were assumed to be suitable for maize cultivation under local conditions, assuming uniform soil characteristics across the study area. Additionally, it was assumed that rainfall was evenly distributed and effectively replenished soil moisture. The meteorological data from the nearest weather station, Sachinga station, was assumed to be a dependable proxy for the ZGCF's weather conditions. Furthermore, the irrigation schedule generated by CROPWAT was assumed to effectively maintain soil moisture at desired levels.

3.6. Research Ethics

Throughout the study, the researcher's goal was to uphold the beneficence and non-malfeasance principles. This was made possible by informing the participants of the study's goal, the intended use of the data collected, and their right to refuse to participate or to withdraw altogether. As a result, the respondents gave their informed

consent to being interviewed (Appendix 2). Additionally, the researcher respected the respondents' right to anonymity**.**

CHAPTER 4: RESULTS

4.0. Introduction

This chapter presents the findings of crop water and irrigation requirements estimation and irrigation scheduling for optimal maize production within ZGCF. The primary and secondary data that was gathered and analysed to accomplish the objectives of this study is presented. The data includes the study site's soil properties, maize crop characteristics, and meteorological variables (minimum and maximum temperatures, relative humidity, sunshine hours, wind speed, and rainfall).

4.1. Estimation of Input Data Used in CROPWAT

4.1.1. Climatic Data

An analysis of an eight-year (2014–2021) meteorological data set for the study area yielded monthly mean values for the climate variables needed to calculate crop water requirements, which include monthly averages for minimum and maximum temperatures, relative humidity, wind speed, sunshine hours, and rainfall (Table 2).

Table 2: Monthly mean climate data for Sachinga station between 2014 and 2021.

Month	Min. Temp (°C)	Max. Temp (°C)	Humidity (%)	Wind Speed (km/day)	Sunshine (hours)	Rainfall (mm)
January	16.6	36.5	69.1	295.9	7.0	145.4
February	15.8	35.2	71.2	280.8	6.0	90.6
March	15.0	34.8	74.3	275.4	8.0	100.6
April	9.8	34.2	60.3	289.4	9.0	32.6
May	5.0	33.0	59.5	285.1	10.0	0.1

June	1.2	31.2	53.4	300.2	10.0	0.1
July	1.0	30.9	47.5	305.6	9.0	0.0
August	2.7	35.3	34.9	349.9	9.0	0.0
September	6.1	38.1	27.0	387.7	8.0	0.6
October	10.8	40.4	28.1	384.5	7.0	3.1
November	14.2	39.6	45.6	381.2	7.0	49.8
December	17.4	37.1	55.1	320.8	6.0	100.7

Data source: SASSCAL WeatherNet, 2022; Climate Data Portal, 2022

According to the data presented, the study area experiences hot summers with an average maximum temperature of 40.4 °C and October is the hottest month. The winters are mild, with July being the coolest month with an average minimum temperature of 1°C**.** Average monthly relative humidity for the study area from 2014 to 2021 was highest in March (74.3%) and lowest in September (27%). The highest average wind speed was 387.7 km/day in September. The lowest average wind speed was in March (275.4 km/day). More hours of sunshine (9 to 10 hours per day) are experienced during the winter months of May to July, but fewer hours of sunshine are experienced during the summer months of October to February (between 6 and 7 hours per day). The monthly mean rainfall for the study area between 2014 and 2021. The highest average rainfall was received in January (145.4 mm). Typically, there is little to no rainfall received from May to September (0 - 0.6 mm). The average annual rainfall for the period 2014 – 2021 was 523.6 mm.

4.1.2. Crop Characteristics

Figure 3 shows the crop characteristics for maize that were used as input in CROPWAT to estimate the crop's water needs. Most of the values were adopted from Allen et al. (1998); except the Kc values for the mid-season and late season which were obtained from Pereira et al. (2021), since these values have been updated recently; the lengths of crop growth stages which were obtained from Doorenbos and Pruitt (1977); and yield response factor which was obtained from Doorenbos and Kassam (1979).

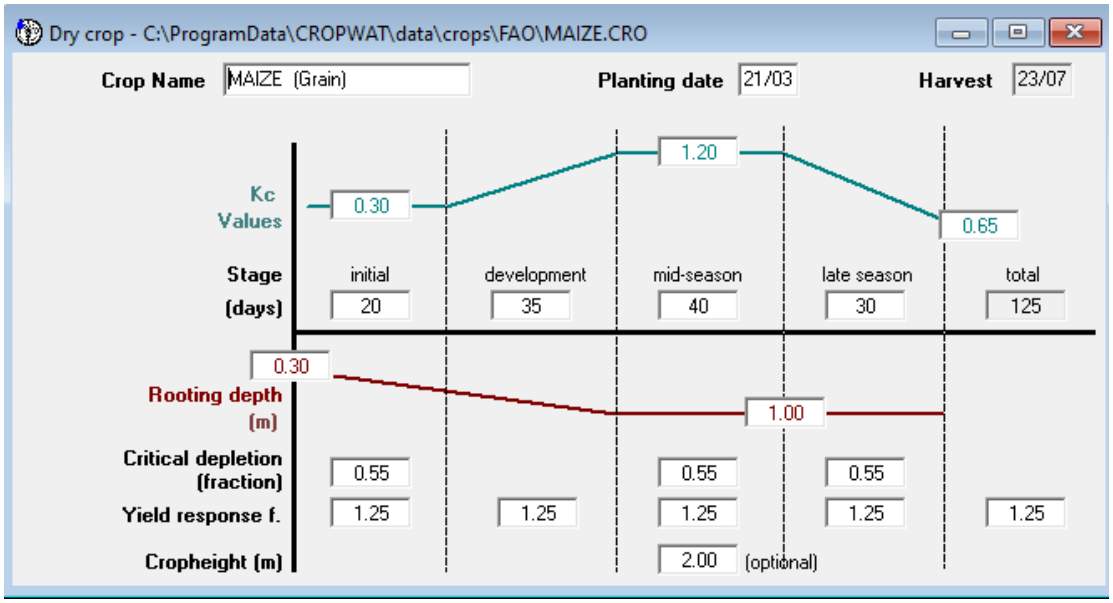

Figure 3: Maize crop characteristics (screenshot from CROPWAT 8.0)

4.1.3. Soil Properties

The soil within the study site was classified as sandy loam according to the USDA soil textural triangle; as it is made up of 76% sand, 17% silt, and 7% clay. As a result, the FAO general soil properties stored in the CROPWAT model that match the type of soil within the study site were adopted. As shown in Figure 4, sandy loam soil has total available moisture (TAM) of 140 mm/m. The maximum infiltration rate is 30 mm per day, and the maximum rooting depth is 900 cm. The initial soil moisture depletion as % TAM is zero, and the initial soil moisture availability is 140 mm/m.

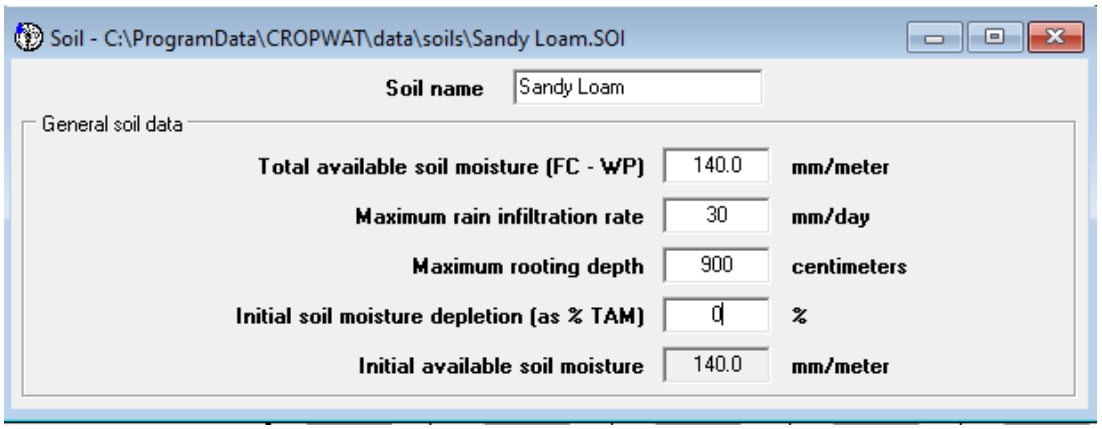

Figure 4: Study site soil properties (screenshot from CROPWAT 8.0*)*

4.2. Determination of Crop Water and Irrigation Requirements

The calculation of the reference evapotranspiration, radiation and effective rainfall are prerequisites to computing crop water requirements in CROPWAT. Thus, the CROPWAT model computed the reference evapotranspiration and radiation of the study area are shown in Table 3, and the effective rainfall is shown in Table 6**.** The findings reveal that the lowest ETo was observed in June (5.41 mm/day) due to low temperature and the highest in October (9.85 mm/day) due to high temperature, whereas the lowest radiation was observed in June and the highest in January. The average effective rainfall was found to be 438.5 mm/year for the period 2014 – 2021 (Table 4), and only 55.4 mm is for March to July which is the period in which maize is grown under drip irrigation (Table 5).

Table 5 reveals that ETc varied from 1.74 mm/day (March) to 7.49 mm/day (May). Immediately after planting is when the ETc is at its lowest. It rises until mid-season, when it reaches its peak, and then it begins to decline until harvest. The irrigation requirement also fluctuates with the crop water requirement (as shown in Table 5); and the seasonal IR was found to be 628.8 mm while the seasonal ETc was 679.2 mm. Since maize is grown towards the end of the rainy season and is harvested in winter, the effective rainfall during this growing period (March to July) is very low (55.4 mm),

as expected. This study's estimates of crop water and irrigation requirements for maize during the dry season are closest to those of Gabr and Fattouh (2021) and Onyancha, Gachene and Kironchi (2017), which were found to be 582 - 812 mm/season (CWR) and 576 - 810 mm/season (IR) and 674.90 mm/season (CWR) and 611.70 mm/season (IR), respectively.

Table 3: CROPWAT computed radiation and reference evapotranspiration.

Month	Rad MJ/m²/day	ETo mm/day
January	21.5	6.38
February	19.5	5.69
March	21.3	5.66
April	20.5	6.06
May	19.3	5.59
June	17.9	5.41
July	17.3	5.56
August	19.4	7.56
September	20.4	9.24
October	20.6	9.85
November	21.3	8.83
Average	19.9	6.91

Table 4: Effective rainfall in the study area

Month	Rain mm	Effective rainfall mm
January	145.4	111.6
February	90.6	77.5
March	100.6	84.4
April	32.6	30.9
May	0.1	0.1
June	0.1	0.1
July	0	0
August	0	0
September	0.6	0.6
October	3.1	3.1
November	49.8	45.8
December	100.7	84.5
Total	523.6	438.5

Table 5: CROPWAT simulated crop water and irrigation requirements

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Pe mm/dec	IR mm/dec
Mar	3	Init	0.3	1.74	19.1	24.1	0
Apr	1	Deve	0.3	1.8	18	15.5	2.4
Apr	2	Deve	0.5	3	30	9.2	20.8

Apr	3	Deve	0.8	4.7	47	6.2	40.9
May	1	Deve	1.1	6.31	63.1	0.2	62.9
May	2	Mid	1.33	7.47	74.7	0	74.7
May	3	Mid	1.35	7.49	82.4	0	82.3
Jun	1	Mid	1.35	7.41	74.1	0	74
Jun	2	Mid	1.35	7.32	73.2	0	73.2
Jun	3	Late	1.3	7.11	71.1	0	71.1
Jul	1	Late	1.13	6.06	60.6	0	60.6
Jul	2	Late	0.95	5.07	50.7	0	50.7
Jul	3	Late	0.83	5.05	15.2	0	15.2
					679.2	**55.4**	**628.8**

Note: dec = decade. A decade is a period of 10 days.

4.3. Simulation of Irrigation Schedule

In the ZGCF, it is a norm to irrigate maize from 6:00 a.m. to 10:00 a.m. and then from 16:00 p.m. to 22:00 p.m. every day, at a flow rate of 2 litres per hour. From planting to harvest (which is a period of 125 days), the drip irrigation system is used for 6 hours per day. In contrast, CROPWAT suggests eight irrigation events (which start 39 days after sowing) using the critical depletion scenario (Table 6), with a flow rate of 0.26–1.24 l/s over an area of 1ha. According to the irrigation schedule from CROPWAT, the gross irrigation requirement and net irrigation requirement is 893.9 millimetres and 625.7 millimetres, respectively.

Table 6: CROPWAT simulated irrigation schedule for maize in the study area

Date	Day	Stage	Rain mm	Ks fract.	Eta %	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
28-Apr	39	Dev	0	1	100	55	61.6	0	0	88	0.26
11-May	52	Dev	0	1	100	59	79.8	0	0	114	1.01
22-May	63	Mid	0	1	100	59	82.2	0	0	117.4	1.24
02-Jun	74	Mid	0	1	100	59	82.2	0	0	117.4	1.24
13-Jun	85	Mid	0	1	100	58	81.2	0	0	116	1.22
24-Jun	96	End	0	1	100	57	79.7	0	0	113.9	1.2
06-Jul	108	End	0	1	100	56	79	0	0	112.9	1.09
21-Jul	123	End	0	1	100	57	80	0	0	114.3	0.88
23-Jul	End	End	0	1	0	4					

Note: l/s/ha = litres per second over an area of 1 hectare. This is the unit of flow used in CROPWAT.

CHAPTER 5: DISCUSSION

5.0. Introduction

This chapter discusses the findings of crop water and irrigation requirements estimation and irrigation scheduling for optimal maize production within ZGCF.

5.1. Crop Water and Irrigation Requirements

One of the key parameters in determining crop water requirements is ETo, as it indicates the rate at which water is evaporated and transpired by a reference crop under standard conditions (Allen et al., 1998). The study revealed that ETo exhibited significant seasonal variation. For instance, the lowest ETo was recorded in June, at 5.41 mm/day (Table 3). This lower rate can be attributed to the relatively cooler temperatures during that time. Conversely, the highest ETo was observed in October, reaching 9.85 mm/day (Table 3). This peak is linked to the warmer temperatures prevalent during that month. These findings highlight the influence of temperature on evapotranspiration rates, which is crucial information for planning irrigation schedules (Allen et al., 1998). In addition to ETo, the study also investigated radiation, which is another key factor impacting crop water requirements (Maidment, 1993). The study noted that radiation exhibited seasonal variations as well, with the lowest values occurring in June and the highest values in January (Table 3). These variations are associated with the changing solar radiation patterns throughout the year (Maidment, 1993). Effective rainfall, as determined by the study, also plays a significant role in meeting the water needs of crops (Smith, 1992). It represents the portion of rainfall that is effectively utilized by crops, accounting for losses due to runoff and deep percolation. The study found that the average effective rainfall for the period spanning 2014 to 2021 was 438.5 mm/year (Table 4). However, only 55.4 mm of this effective rainfall was available during the critical growing period for maize, which is from

March to July (dry season). This indicates a potential water deficit during this crucial season and emphasizes the necessity of irrigation to supplement the water requirements of maize crops (Smith, 1992).

The crop water requirement (ETc) varied throughout the growing season. It was lowest in March at 1.74 mm/day (Table 5), immediately after planting, and gradually increased, peaking during mid-season in May at 7.49 mm/day (Table 5). Subsequently, ETc started to decline, reaching its lowest levels again at harvest. This pattern aligns with the typical growth stages and water needs of maize crops, with higher water demand during the critical growth stages (Doorenbos & Pruitt, 1977). Furthermore, the irrigation requirement (IR) fluctuated with the crop water requirement (ETc), as expected (Doorenbos & Pruitt, 1977). The study calculated a seasonal IR of 628.8 mm, whereas the seasonal ETc was 679.2 mm (Table 5). This suggests that irrigation is vital to fulfil the water needs of maize crops, particularly during the dry season when effective rainfall is scarce, as confirmed by the low effective rainfall of 55.4 mm during the March to July growing period (Smith, 1992). Comparing this study's results with those from other studies reveals variations in estimations of crop water and irrigation requirements. For instance, Yirga, et al. (2018), Thazin (2019), Mebrahtu et al. (2021), and Herbha et al. (2017) reported lower values of CWR; thus, highlighting the relevance of considering local conditions and context when determining crop water and irrigation requirements for specific regions. However, Gabr and Fattouh (2021) and Onyancha et al. (2017) reported CWR values which closely align with those of this study, which were found to be 582 - 812 mm/season (CWR) and 576 - 810 mm/season (IR), and 674.90 mm/season (CWR) and 611.70 mm/season (IR), respectively.

5.2. Irrigation Schedule

The current irrigation practice at the ZGCF involves a specific schedule. As revealed by the interviews conducted with ZGCF staff, irrigation is performed twice daily, from 6:00 a.m. to 10:00 a.m. and then from 16:00 p.m. to 22:00 p.m., totalling 6 hours of irrigation per day. This irrigation is executed at a consistent flow rate of 2 litres per hour throughout the entire 125-day period, from planting to harvest. In contrast, the CROPWAT model, which factors in reference evapotranspiration (ETo), radiation, and effective rainfall, suggests an alternative irrigation schedule. According to CROPWAT, irrigation should commence 39 days after sowing, following the critical depletion scenario (Table 6). The model recommends a total gross irrigation requirement of 893.9 millimetres and a net irrigation requirement of 625.7 millimetres for the entire growing period. Although the CROPWAT simulated schedule was not validated by field trials in this study, using CROPWAT as a guiding tool for irrigation scheduling is commendable because the use of CROPWAT to generate the irrigation schedule can promote water savings by tailoring irrigation to the crop's actual water requirements and soil moisture levels, thus minimizing water wastage. In addition, it maximizes crop yields by ensuring that the irrigation schedule aligns with the crop's growth stages and water needs, thereby avoiding over-irrigation or under-irrigation that can negatively impact productivity. This was proven by some studies whereby CROPWAT- based irrigation practice was compared with farmers' practice. The results revealed that the farmers' practice used more water than the CROPWAT schedule, by 14.7 – 27.9% (Adamtie & Mitku, 2021; Adamtie et al., 2022).

CHAPTER 6: CONCLUSION

The FAO CROPWAT 8.0 model was used to determine the crop water demand of maize grown in Chinchimane under drip irrigation, in sandy loam soil. For the dry season, irrigation scheduling and calculation of crop water and irrigation requirements were performed. The findings showed that the crop demands a lot of water during the growing period (March – July) due to the insufficiency of precipitation, so irrigation would be primarily required to satisfy the crop's water needs. In addition to that, the values of ETc and IR varied with respect to the soil moisture and weather variations that changed over the course of the maize crop's growth cycle. The minimum and maximum daily crop water requirements were found to be 1.74 mm and 7.49 mm, respectively. In contrast to the seasonal crop water requirement, which was found to be 679.2 mm, the seasonal irrigation requirement was found to be 628.8 mm. Additionally, the simulated maize irrigation schedule suggested eight irrigation events in contrast to watering every day (at a flow rate of 2 litres per hour for 6 hours a day). This demonstrates the need for research-based planning and management of irrigation. Using these findings, crop production from irrigation-based agriculture in ZGCF/Chinchimane can be enhanced by more effectively controlling irrigation water application rates.

CHAPTER 7: RECOMMENDATIONS

To determine the total irrigation water demand for a specific irrigation scheme, future studies should estimate the water needs of all crops grown within that scheme per cycle. Additionally, CROPWAT-simulated irrigation schedules should be validated by field trials.

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APPENDICES

Appendix 1: Ethical Clearance Certificate

UNAM
UNIVERSITY OF NAMIBIA

ETHICAL CLEARANCE CERTIFICATE

Ethical Clearance Reference Number: JED0122 **Date: 19 April 2022**

This Ethical Clearance Certificate is issued by the University of Namibia Ethics Committee (REC) in accordance with the University of Namibia's Research Ethics Policy and Guidelines. Ethical approval is given in respect of undertakings contained in the Research Project outlined below. This Certificate is issued on the recommendations of the ethical evaluation done by the ethics committee.

Title of Project: Water Management Practice for Maize Production Within Zambezi Green Commercial Farm, Namibia
Principal researchers: Ms. Lisa Lisho

~~**Staff Number/**~~ **Student number**: 201206804

Remarks:

Centre for Research Services

Take note of the following:

1. Any significant changes in the conditions or undertakings outlined in the approved Proposal must be communicated to the ethics committee. An application to make amendments may be necessary.
2. Any breaches of ethical undertakings or practices that have an impact on ethical conduct of the research must be reported to the ethics committee
3. The Principal Researcher must report issues of ethical compliance to the ethics committee (through the Chairperson) at the end of the Project or as may be requested by the ethics committee
4. The ethics committee retains the right to:

i) Withdraw or amend this Ethical Clearance if any unethical practices (as outlined in the Research Ethics Policy) have been detected or suspected,
ii) Request for an ethical compliance report at any point during the course of the research.

The ethics committee wishes you the best in your research.

Dr. Erasmus Shaanika (Chairperson Decentralized Ethics Committee)

Prof. Davis Mumbengegwi (Head, Multidisciplinary Research)

Appendix 2: Participant Information Leaflet and Consent Form

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT: Water Management Practice for Maize Production in Chinchimane, Zambezi Region, Namibia

REFERENCE NUMBER:

PRINCIPAL INVESTIGATOR: Lisa Nalufu Lisho

ADDRESS:

CONTACT NUMBER:

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or doctor any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary**, and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the Research Ethics Committee at The University of Namibia and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and Namibian National Research Ethics Guidelines.

a) What is this research study all about?

The study will be conducted at Zambezi Green Commercial Farm, Chinchimane, Zambezi Region; and the site manager will be recruited as a participant for the interview. Additionally, willing agricultural extension officers from this part of the region will form part of the interviewees.

The project aims to find out how much water the maize crop grown at Zambezi Green Commercial Farm uses throughout the season, how much water it needs from the irrigation system, and if the crop is currently receiving the right amount of water at the right time. This project is being done for educational purposes as it is a requirement from the university, for the researcher to be able to complete their studies.

A computer program called CROPWAT will be used to estimate the crop water requirement and irrigation requirement, and generate an irrigation schedule for maize from weather, soil, and crop data that will be acquired from interviews with Zambezi Green Commercial Farm staff and agricultural extension officers, field observations (including a soil survey), and online sources.

b) Why have you been invited to participate?

The site manager at the farm and agricultural extension officers are invited to participate in the study because they will be able to provide reliable information regarding irrigation practices on site, planting, and harvest dates for maize, and other relevant crop data.

c) What will your responsibilities be?

The participants will be asked to assist the researcher by responding to questions presented by the researcher.
Both the site manager and agricultural extension officer/s will be expected to participate in a 30-minute interview which will be once off. However, the site manager might be needed to explain some things telephonically or during field visits as the need arises.

d) Will you benefit from taking part in this research?

There will be no incentives provided for participating. However, the farm management will have access to the results of this study.

e) Are there in risks involved in your taking part in this research?

Participating in this research does not come with any risks.

f) What will happen in the unlikely event of some form injury occurring as a direct result of your taking part in this research study?

There will be no expected injuries as participation only involves talking.

g) Will you be paid to take part in this study and are there any costs involved?

There will be no incentives or payment offered for participating in this study and there will be no costs to be covered by the participants.

Is there anything else that you should know or do?

You can contact the Centre for Research and Publications at +264 061 2063061; pclaassen@unam.na **if you have any concerns or complaints that have not been adequately addressed by the investigator.**
You will receive a copy of this information and consent form for your own records.

- **Declaration by participant**

By signing below, I …….. agree to take part in a research study entitled **Water Management Practice for Maize Production Chinchimane, Zambezi Region, Namibia**

I declare that:

a) I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.

b) I have had a chance to ask questions and all my questions have been adequately answered.

c) I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.

d) I may choose to leave the study at any time and will not be penalised or prejudiced in any way.

e) I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ……..…… on (*date*) ……..…… 2021.

…… ……

Signature of participant **Signature of witness**

- **Declaration by investigator**

I *(name)* declare that:

1. I explained the information in this document to ……
2. I encouraged him/her to ask questions and took adequate time to answer them.
3. I am satisfied that he/she adequately understands all aspects of the research, as discussed above.
4. I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.*

Signed at (*place*) .....…..……. on (*date*) ……...…….. 2021.

.....	.....
Signature of investigator	**Signature of witness**

1. Declaration by interpreter

I *(name)*declare that:

a) I assisted the investigator (*name*) ……. to explain the information in this document to (*name of participant*) ……. using the language medium of (Oshiwambo, Otjiherero, Afrikaans, etc.)

Appendix 3: Questionnaire

QUESTIONNAIRE

Dear Participant

1. My name is **Lisa Lisho**, student number **201206804**. I am studying towards a **Master of Science (Water Resources Management)** degree at the University of Namibia (UNAM), and I am conducting a survey about **Water Management Practice for Maize Production in Chinchimane, Zambezi Region, Namibia**.
2. I have selected you to participate in my study, because you belong to the group of people I want to include for my research. I would therefore like to invite you to complete this questionnaire.
3. The research I am conducting has been approved by the UNAM Research Ethics Committee. I would appreciate it very much if you would complete this questionnaire, and I would like to assure you of the following:
    a. You do not have to fill in this questionnaire if you do not want to.
    b. You can stop filling in the questionnaire and stop participating at any time if you want to, and there will be no negative consequences for you.
    c. Your participation is completely anonymous. This means that, even if I ask information that might identify you or if I know you, I am not allowed to make your identity known to anyone. When I report on my questionnaires' data and results, I will not mention any personal information about participants that might identify them.
    d. All completed questionnaires and data will be stored in a safe and secure place, and only authorised University officials, my supervisor and I will have access to it. After five years, all the questionnaires and data will be destroyed in an environmentally friendly way.
4. If you have any questions about this questionnaire, or if you do not understand anything, please feel free to ask me, and I will be happy to explain it to you.
5. If you want to know more about the research I am doing, please feel free to ask me, and I will be happy to tell you more.
6. It should take about **15 minutes** for you to complete the questionnaire.
7. You can reach me on my cell phone at ……., or send an e-mail to …….
8. If you want more information about the study you can contact Lisa Lisho at lisahlsh962@gmail.com or Centre for Research & Services at kmbulu@unam.na if you have any further queries about the study or **if** you have any concerns or complaints that have not been adequately addressed by the research team.
9. Thank you very much for your willingness to participate in this research!

Please detach this page and keep it.

Please turn over to start filling in the questionnaire.

IRRIGATOR'S QUESTIONNAIRE

WATER MANAGEMENT PRACTICE FOR MAIZE PRODUCTION IN CHINCHIMANE, ZAMBEZI REGION, NAMIBIA

Date of interview: _____

Position of respondent: _____

Farm Information:

Farm name:	
Location:	Elevation:
	Farm size:
Latitude:	Longitude:

Part A

Q: How long have you lived in Chinchimane area?

A: _____

Q: How long have you been working at Zambezi Green Commercial Farm?

A: _____

Q: Did you receive any training on Maize production and/or irrigation (e.g. irrigation system design/installation/maintenance, irrigation scheduling, etc.)? [If yes, please specify the type of training and who provided the training]

A: _____

_____

Part B

Q: What is the size of the land under irrigation?

A: _____

Q: What is the size of the plot currently under irrigated maize production?

A: _____

Q: What is the source of water?

A: during wet season _____ during dry season_____

Q: What type of irrigation system do you use?

A: _____

Q: What is the distance between the main water source and the maize plot?

A: _____

Q: How is water transported from the source to the plot?

A: _____

Q: How is the irrigation regime determined? (E.g. you wait for crops to show signs of water stress/ irrigate when the soil is dry/irrigate everyday/follow a pre-determined schedule)

A: _____

Q: Who determines the irrigation schedule?

A: _____

Q: Do you pay for the water you use for irrigation? [If yes, indicate how much and how often you pay]

A: _____

Q: What is the main objective for irrigation?

A: _____

Q: Are there any water-related challenges faced on farm?

A: _____

Part C

Maize production statistics for the last two seasons

	Season:	Season:
Planting date		
Harvest date		
Irrigation interval:		
Irrigation time:		
Discharge rate:		
Plot area:		