Determining the water footprint of tomato and butternut production towards enhanced water security at Nwanedi irrigation scheme

By

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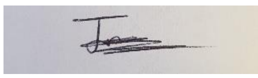
DECLARATION

I, Lebepe Rophinah Tebogo (14014012) hereby declare that this dissertation - **Determining the Water Footprint of Tomato and Butternut Production Towards Enhanced Water Security at Nwanedi Irrigation Scheme -** for Masters in Rural Development (MRDV) degree, submitted to the Institute for Rural Development (IRD) at the University of Venda, has not been submitted previously for any degree at this or another university. It is original in design and in execution, and all reference materials contained herein have been duly acknowledged.

Student:  **Date:** 08/06/2022

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ABSTRACT

Declining underground water, unpredictable rainfall patterns and high temperatures pose a threat to future food and water security. Water security is also threatened by the growing demand for water in the agriculture sector to meet food needs. Knowing the water footprint and total water consumed by major agricultural crops is critical in devising appropriate intervention strategies. This study assessed tomato and butternut water footprint at Nwanedi irrigation scheme in Musina local Municipality, Limpopo Province, South Africa; tomato and butternut are popular horticultural crops grown year round in the region. Data was collected, explored and quantified using a convergent parallel mixed method design. Purposively selected small scale farmers provided data for the study. Quantitative data was analysed descriptively using SPSS version 26 while qualitative data was analysed thematically aided by Atlas Ti version 8.1. The results revealed that tomatoes had less water footprint (134.62 m^3/t) compared to butternuts (393 m^3/t). On the other hand, seeding and maturity stages were observed as using less water, although, a substantial number of farmers believed that all the stages of crop production required the same amount of water. The results further revealed that there were distinct water-saving strategies commonly used in different growth stages for both tomato and butternut and those that were specific to each growth stage and crop. At the seeding stage, for example, nursery, seed soaking, and choice of crop variety were the main methods used. In early growth, flowering, fruit formation, fruit growth and fruit maturity strategies such as mulching, drip irrigation, irrigation monitoring and watering-time optimisation were used variedly and in combination. Given these results, it is recommended that water footprint be calculated for each stage of plant growth to devise appropriate interventions and that farmers with smaller production areas be prioritised in devising water footprint reduction strategies. It is also recommended that farmers practice deficit irrigation to calibrate watering needs for each plant at different growth stages, as part of the strategies to reduce water footprint in vegetable production. There is, therefore, a need for the intensification and adoption of more innovative water reduction strategies at different growth stages for both crops.

Key words: Butternut, climate change, small scale farmers, tomato, water footprint.

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DEDICATION

This study is wholeheartedly dedicated to my beloved late parents - my mother, Morongwa Martha Lebepe and my father, Bethuel Khutso Mohlaloganye. You are forever loved and never forgotten.

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ABBREVIATIONS AND ACRONYMS

CPA	Communal Property Association
IFAD	International Fund for Agriculture Development
MENA	Middle-East and North-Africa
NDP	National Development Plan
NWRS	The South African National Water Resource Strategy
OE	Office of Evaluation and Studies
RCT	Resource Conserving Technology
SDGs	Sustainable Development Goals
UN	United Nations
WASAG	Global Framework on Water Scarcity in Agriculture
WHO	World Health Organization

CHAPTER 1: BACKGROUND TO THE STUDY

1.1 introduction

Water scarcity is one of the major problems faced by many societies across the world. It has an intimate relationship with food security. Over 80% of the global water withdrawn goes to meet the demands of the increasing population and incessant development (Kummu *et al*., 2016). Also, many countries import food to meet their demand and to compensate for water scarcity. Economic activities and human development needs, such as irrigation to meet human food requirements in crop production also compete for water use and contribute to water scarcity. The significance of this understanding lies raising awareness in the population about the need to sustainably and responsibly use water in different sectors, hence, not compromising the water needs for future generations. Current and future human livelihoods greatly depend on the sustainability and efficiency of water resource management (Green *et al*., 2015). Currently, severe water shortages have been reported in some of the world's largest cities and regions across different continents – including California (2011-2017), Beijing (2014), Istanbul (2014), São Paulo (2014-2015) and Cape Town (2017-2018). The situation has significantly impacted several socioeconomic sectors (water availability for human consumption, food, energy production and irrigation), illustrating the gravity and world-wide nature of the challenge (Carley & Christie, 2019). This further shows why it is essential to assess the water footprint of different daily-consumed and highly-demanded horticultural crops, such as tomatoes, to provide a stepping stone for minimizing water usage.

More than two billion people live in highly water-stressed areas, and the pressure on freshwater will inevitably be intensified by population growth, economic development and climate change in the future (Galgano, 2018). Since 1960, available freshwater per capita has dropped by 55%; over 40% of the global population currently live under water scarcity conditions and 11% do not have access to clean and safe water (Kummu *et al*., 2016). Furthermore, global water demand is projected to increase by 50% in 2030, resulting in a 40% gap between water demand and availability (Caldera *et al*., 2016). Moreover, by 2050 an additional 2.3 billion people are expected to be living in areas affected by severe water stress (Caldera *et al*., 2016). Estimates indicate that the total cost of water insecurity to the global economy is nearly US 500 billion/year (Fried *et al*., 2017). The World Health Organization (WHO) (2019) reported that more than 40 % of the global water-stressed population lives in sub-Saharan Africa. In this region, only an estimated 44 % of the urban population and 24% of the rural population have adequate water and sanitation. Given this situation, a fair and wide distribution of water to different needs of the community sectors and saving for the future, cannot be negotiable. This would be important in protecting the future of our environment and human livelihoods. It is, therefore, a necessity for each region to estimate the effect of their major crops on water usage for localized and relevant solutions.

According to Nhamo *et al*. (2018), South Africa is also a water-scarce country and ranks the 30th driest country in the world. It has an average annual rainfall of less than 500 mm, while that of the world is about 850 mm (Landman & Malherbe, 2015). The international average water usage per day is 173 liters, while South Africans use 61. 8% more water than the world average (Friedrich, 2017). It is, therefore, paramount to understand the impact of human activities, such as irrigation in agriculture, on water footprint or use to estimate and adequately deal with water security challenges. This will help in estimating the sustainability of water resources and possibly stimulate interest in finding mitigating measures for reducing water consumption.

Agriculture is one of the important sectors in an economy and particularly, for rural communities; it provides employment and ensures food security. Of all the water usage, agriculture in both animal and crop production, consumes the largest proportion in South Africa (Manyatsi, 2017). Horticultural crop production that provides the food needed all year around, naturally, is expected to impact more on water scarcity, especially through the heavy reliance on irrigated water supply. In South Africa, the production of tomatoes exceeds that of all other vegetables, except potatoes (Moodley & Gubba, 2019). The country's annual tomato production is around 600 000 tonnes (Blando, 2019). Three main types of tomatoes, namely, round tomatoes, those destined for processing, and cherry tomatoes are grown in the country. They take 20 to 30 days to reach maturity from the time they first appear and they begin producing fruits 40 to 50 days after planting (Tilahun, 2019). The wide variations in climate in South Africa allow the planting and production of fresh tomatoes in open fields in various parts of the country all year round, although, tomatoes are generally a warm-season crop (Moodley & Gubba, 2019).

Tomatoes are very sensitive to frost and the ideal temperatures for growth are 20 to 25 ºC, with monthly mean temperatures of between 18 and 27 ºC (Moriyama *et al*., 2020). If temperatures exceed 35 ºC or drop below 12 ºC, this can harm fruit set and quality (Moriyama *et al*., 2020). Hot, dry winds cause excessive flower drops while continuous moist, rainy weather conditions result in the occurrence and spread of leaf diseases (Moriyama *et al*., 2020). It is, therefore, recommended that tomatoes be grown in dry areas under irrigation to produce consistent yields of high-quality tomatoes. Approximately 500 mm of water is required throughout the growing season of tomatoes (Tilahun, 2019). Similarly, butternuts like most other vegetables require an even supply of water throughout the growing season; the amount of water needed to grow butternut is generally 25- 40 mm per week (Botha, 2019).

Just like tomatoes, butternuts are extremely sensitive to frost and long periods of temperatures below 4 ºC can kill the plants (Taghavi *et al*., 2020). According to Milosevic (2020), butternuts are warm climate vegetables, although, the growth period must not experience too many days of temperatures over 35 ºC (this increases the formation of male flowers that do not bear fruit) or temperatures below 12 ºC (this slows or even stops growth and development). Planting, therefore, is concentrated over the spring and early summer months and in South Africa, this is from August to December (Etienne *et al*., 2018). The growing period is normally between 2 and 15 weeks from planting of the seed to the first butternut being ready for harvest (Etienne *et al*., 2018). As with tomatoes, production of butternuts relies on irrigation farming, and it is important to ensure that the soil remains moist. Adequate water in the root zone is essential throughout the growing season for good flowering and fruit set (Granahan, 2018). Literature evidence suggests that; tomatoes and butternut are not only in high demand but have a significant water footprint and usage than other seasonal crops (Tobarra *et al*., 2018). The water footprint concept is described as the direct and indirect volume of freshwater appropriation (consumed and polluted). The water footprint is increasingly recognized as a suitable indicator of human appropriation of freshwater resources and is becoming widely applied to get better understanding of the sustainability of water use (Hoekstra, 2018). Given these facts, it is paramount to explore and estimate the water consumption of various individual crops towards reduced water footprint, to guard against water insecurity.

In the period 1996-2005, agriculture contributed 92% to the total water footprint of humanity (Dolganavo *et al*., 2018). Water footprint theory and its applications in agriculture provide a strategic basis for the rational utilization and sustainable development of water resources (Hoekstra, 2018), therefore, water footprint, which can quantify stress on water resources, is considered a suitable measure for estimating global, regional, national and local water status. It can be applied to a single process step or product or other situations such as economic, political, or geographical delimitations concerning companies, groups of consumers, catchments and countries (Morera *et al*., 2016). The water footprints can be divided into - blue, green and grey. Green and blue water are considered direct consumptive use while grey water is an indirect consumption (Hoekstra, 2018).

The blue water footprint is the volume of freshwater that evaporates from the global blue water resources (surface water and groundwater) to produce goods and services consumed by the individual or community. In crop production, the blue component refers to the water evaporated through crop growth that originates from the surface or groundwater (Rodriguz & Kruse, 2015). On the other end, green water footprint is the volume of water evaporated from the global green water resources (rainwater stored in the soil as moisture) (Mamathashree & Pavithra., 2017). In crop production, the green component refers to the water evaporated through crop growth that originates from soil moisture from rainfall (Hoekstra, 2018). The grey water footprint is the volume of polluted water that is associated with the production of all goods and services for the individual or community. It is quantified as the volume of water required to dilute pollutants to an extent that the quality of the ambient water remains above agreed water quality standards (Agata *et al*., 2017). For crop production, this would be the volume of dilution to reduce, to agreed standards of nitrate and phosphate (fertilizer) levels and pesticide levels leaching from soils. This study, therefore, sought to estimate or determine the water footprint of tomato and butternut based on these three parameters as the measures.

In crop production, water is an essential climatic factor as it affects or determines plant growth and development. Its availability or scarcity can mean either, a successful harvest, diminution in yield, or total failure (Juhola, 2017). Water is the heart of irrigation for most horticultural crops and plays a primary role in crop production (Zaveri & Lobell, 2018). Limpopo is the breadbasket and agricultural engine of South Africa and produces about 60% of all fruit, vegetables, maize, wheat, and cotton, therefore, water must be enough and accessible to farmers in the Province (Maponya & Mpandeli, 2016). Limpopo Province is one of the driest provinces in the country but the largest producer of horticultural products which are heavily reliant on irrigation, however, the registered user of water is 17% of the total water usage in South Africa (Edokpayi *et al*., 2018). Musina Municipality in Vhembe District is usually one of the hardest hit areas by drought. Musina local Municipality is one of the areas in the Province with excessive heat and low rainfall. Reported and forecasted heatwaves in Musina region, threaten water security and crop production (Scheiter *et al*., 2018). Extreme heat conditions and scarce rainfall requires frequent irrigation as the water quickly escapes through both the soil and evapotranspiration, thus, unlike in other regions in the Province, farmers in Musina experience high water loss, hence, there is a need to minimize water loss towards ensuring continued food supply and adequate water supply for crop production. This necessitates an estimation of the water footprint for individual field crops to devise water usage minimization strategies and to maintain an adequate food supply.

The dominant water consumption in the Province is largely by agricultural irrigation, accounting for 63% (Mabhaudhi *et al*., 2018). The current water demand and use are poised to swell amid the growing population's need for more food; population growth means growing demand for water for sanitation, water services, agriculture, mining activities as well as increased urbanisation and land transformation (Hartwell, 2017). As such, it calls for understanding the impact of the current water footprint of individuals' needs for water security. It is against this background that this study determined the water footprint of selected field crops (tomatoes and butternuts). Also, the study investigated the water footprint reduction strategies adopted by horticultural farmers at different stages of crop growth for butternut and tomato.

1.2 Statement of the problem

Water scarcity has received global attention in the last decade as it threatens food and nutrition security, mainly in arid and semi-arid regions. The Middle East and sub-Saharan Africa are the most affected and the situation is worsening due to the impacts of conflict, economic downturn and climate change (Nouri *et al*., 2018). South Africa is not an exception in this regard because it is considered a water scarce country. This is based on physical descriptors like climate conditions and escalating water demands. In provinces such as a Limpopo, water scarcity is a serious threat, hence since 2015, it has been declared a disaster area due to a drought that had affected it and other provinces across the country (Manderson *et al*., 2016).

In Musina Town, most places' water allocation is from groundwater sources with about 97%, amounting to some 10.4 million m³ pa, sourced from 16 abstraction points along the Limpopo River (Zanele, 2018). Due to low rainfall and high temperatures, Musina local Municipality struggles to balance the provision of water to different sectors such as residential, industrial and agriculture. According to Rankoana (2020), water scarcity in the Municipality has negative effects on the agricultural sector, resulting in decrease in agricultural activities; loss of livestock, shortage of drinking water, low yields and shortages of seeds for subsequent cultivation. Rankoana (2020), further stated that the majority of farmers in the area lose a high volume of crops and livestock each year due to shortages of water mainly caused by drought. It was further highlighted by Kom *et al*. (2020), that water shortages in the Municipality also affects the vegetation status. The quality and status of vegetation can be severely impacted by drought periods (Kom *et al*., 2020). This unfortunately produces a range of additional stressors for farmers because poor vegetation often leads to poor grazing. Nwanedi irrigation scheme is dominated by crop production.

The total number of farmers on the Nwanedi irrigation scheme is 300 focusing on the production of crops (Phillip & Mears, 2018). The irrigation scheme covers an area of about 2000 hectares of land in state-owned land and part of it belongs to the Communal Property Association (CPA). It makes up approximately 62% of total horticultural production in the Municipality (Zanele, 2018). The scheme relies on irrigated farming for both winter cropping and to supplement erratic rainfall during the wet season. This trend is set to continue into the foreseeable future amid climate change. It is reported that approximately 1.3-million hectares are under irrigation in South Africa and about 50% of South Africa's water is used for agriculture (Wettstein & Muir, 2017). It is crucial that Nwanedi Irrigation scheme as a supporter of leading crop producers in Musina, should be assessed for its impact on water distribution, in the production of major crops, like butternut and tomato (Maponya & Mpandeli, 2016). It is against this background that the study determined the water footprint for tomato and butternut field crops, as understanding this at the Nwanedi Irrigation scheme would help in finding intervention strategies to manage water use among horticultural farmers.

1.3 Justification of the study

The overuse of groundwater as a resource for food production has serious implications. Agriculture uses about 70 % of the available fresh water on the planet for irrigation (Aliyev, 2018). Water of appropriate quality and quantity is essential to produce crops, livestock, and fisheries, as well as for the processing and preparation of products from them (Whitt, 2018). Understanding how to reduce the water footprint levels in agriculture and taking all the necessary steps to keep that level as low as possible, are essential for mankind. A balance is urgently required because freshwater is vital to humans' daily life, while the supply of fresh water is limited. This study would fill a significant research gap by coming up with sustainable strategies that need to be put in place for reducing water footprint, in crop production. The results help in informing water users, farmers, managers and policymakers about the sustainable use of scarce freshwater resources. Knowing about water usage situation in a region will also enable managers to inform users, timeously to guard against using water in an unsustainable manner, particularly, for the Musina local Municipality in making informed decisions about securing water in the area.

1.4 Objectives of the study

The study aim is to determine the water footprint and farmer perception on water foot print in tomato and butternut production at the Nwanedi Irrigation scheme.

1.4.1 Specific objectives

1. To determine the amount of water used in the production of tomato and butternut at the Nwanedi irrigation scheme;
2. To assess the perceptions of small-scale farmers regarding water footprint at Nwanedi irrigation scheme; and
3. To assess strategies for reducing the water footprint of the selected field crops

1.5 Research questions

To achieve the intended objectives, the study was guided by the following research questions:

I. What is the water footprint for tomato and butternut at the Nwanedi irrigation scheme?
II. What are the perceptions of small-scale farmers regarding the water footprint at the Nwanedi irrigation scheme?
III. Which crops are perceived to consume more water?
IV. How are the farmers coping with the challenges of water scarcity?
V. Which strategies can be used to reduce water footprint on butternut and tomato production?

1.6 Research hypothesis

Ho: Tomato and butternut production influences water footprint at Nwanedi irrigation scheme.

1.7 Definition of key terms

Water security: It is defined as the "capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability” (UN. 2013). A program for saving water in the developing world including South Africa, called Sustainable Water Partnership (2018) explains water security as “the adaptive capacity to safeguard the sustainable availability of, access to, and safe use of an adequate, reliable and resilient quantity and quality of water for health, livelihoods, ecosystems and productive economies” (Sharma *et al.,* 2019). In this study, water security is understood as the ability of rural farmers to safeguard sustainable water access, in adequate quantities, in their farming enterprises.

Water scarcity: Ntibrey & Gyasi (2021), defined the term as "unavailability of water due to physical shortage, or failure of institutions to ensure a regular supply mainly due to a lack of adequate infrastructure". Similarly, White (2014), conceptualised the phrase as "the lack of access to adequate quantities of water for human and environmental uses". In this study, water scarcity, is the lack of adequate available water resources to meet the demands of usage by the horticultural farmers in the Musina region.

Water footprint: According to Vanham & Bidoglio (2013), water footprint refers to the volume of water used for various products and services. Hoekstra *et al*., (2012), add that water footprint is the amount of water utilised in the production or supply of the goods and services used by a person or group. In this study, water footprint, hence, is defined as the amount of water consumed by, used and required in the production of butternuts and tomatoes by horticultural farmers at the Nwanedi irrigation scheme.

1.8 Conceptual framework

There are three types of the water footprint in literature - grey, green and blue. Bluewater footprint refers to the evaporated irrigation water from surface and renewable groundwater sources; green water footprint is the evaporation of water from the rain in crop production; and grey water footprint, on the other hand, is the water pollution that is associated with producing a product. In this study, it is conceptualized that both butternut and tomato affect all three types of water footprints (Figure 1.1). Specifically, the following assumptions are made:

I. Butternut and tomato production affects the evaporation of irrigation water that is supplied from surface production, open water bodies and groundwater.

II. Butternut and tomato production influence the evaporation of water fed through rainfall.

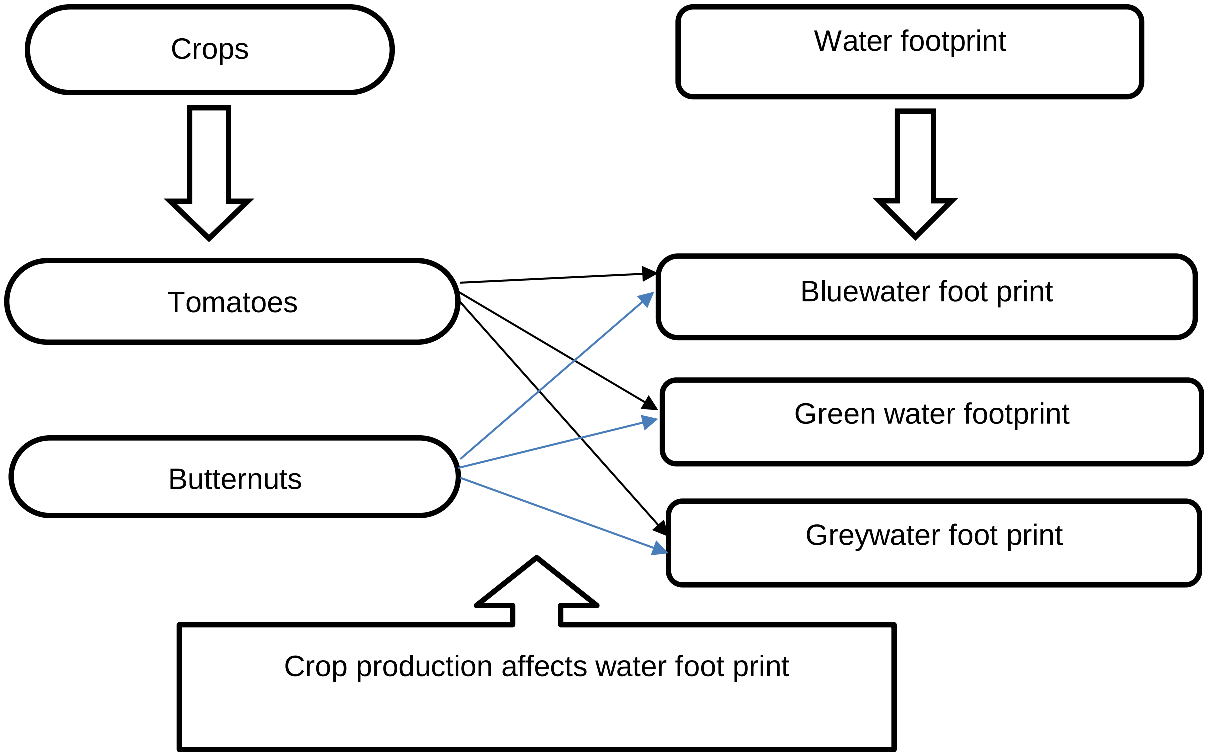

Figure1.1: *Conceptual framework of the study*

1.9 Outline of the dissertation

This dissertation is comprised of 7 chapters. The first chapter outlines the background and the purpose of the study by stating the key specific objectives to be achieved and the research questions. Also, the chapter gives a depiction of the research problem being investigated, a definition of key terms concluding with a conceptual framework. The second chapter discusses scholarly literature guided by the concept of water footprint and related concepts such as water scarcity and security. Specifically, literature on water consumption by horticultural field crops from global, continental and South African perspectives is reviewed in chapter 2. Chapter 3, presents methods and techniques which were used in conducting the study, thus, in the chapter is provided details on - the study area, research design, population and sampling procedures, data collection methods and analysis. In chapters 4, 5 and 6 the research findings are presented per objectives. Each objective forms a chapter and follows a paper structure with title, abstract, introduction, results, discussions and conclusions. Chapter 7 is a synthesis of key study findings, presenting of the general discussion, conclusion and recommendations. In addition, a list of references and appendices forms part of this dissertation.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In this chapter, literature on water security, focusing on the reduction of the water footprint in crop production, is explored. Focus is on the following aspects - frameworks on water scarcity issues, measuring water footprint, perceptions of farmers regarding water conservation and agricultural methods that can be used to reduce water footprint in crop production.

2.2 The global framework on water scarcity in agriculture (WASAG)

The Global Framework on Water Scarcity in Agriculture (WASAG) is an initiative for partners from all fields and backgrounds to collaborate in supporting countries and stakeholders in their commitments and plans related to the 2030 Sustainable Development Agenda, other plans and programs related to agriculture and water (Ardeson *et al.,* 2017). The Framework has been designed to bring together key players across the globe and across sectors to tackle the collective challenge of using water better in agriculture to ensure food security for all (Ardeson *et al.,* 2017). The main focus areas of WASAG are water and migration, drought preparedness, financing mechanisms for sustainable management of water resources, water and nutrition, sustainable agriculture water use and saline agriculture (Nijhoff, 2017). The expected outcomes are to ensure the sustainable management of water for agriculture, thus, the urgency of healthy ecosystems and their services for sustainable agricultural systems are recognized as key points in achieving the Agenda 2030 (Keesstra *et al.,* 2018).

2.3 Sustainable development goals: Water provision

The United Nations Sustainable Development Goals (SDGs) are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity (Paudel, 2017). These 17 Goals build on the successes of the Millennium Development Goals while including new areas such as climate change, economic inequality, innovation, sustainable consumption, peace and justice, among other priorities (Tebbutt & Brodmann, 2018). Goal 6 is one of the 17

Sustainable Development Goals established which calls for clean water and sanitation for all people.

Clean water is crucial for survival, and its absence can negatively impact the health, food security, and livelihoods of families across the world (White, 2017). Drought afflicts some of the world's poorest countries, worsening hunger and malnutrition (Elver, 2018). Floods and other water-related disasters account for 70% of all deaths related to natural disasters (Alexander, 1993). Global goals and national priorities on - reliable energy, economic growth, resilient infrastructure, sustainable industrialization, consumption and production, as well as food security are all inextricably linked to a sustainable supply of clean water (Rasul & Sharma, 2016). It is in this regard that Goal 6 of the SDGs aims to substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity. More efficient use and management of water are critical to addressing the growing demand for water, threats to water security, the increasing frequency and severity of droughts and floods resulting from climate change (Abell *et al*., 2019).

Pathways towards sustainable development goal 6 in agriculture are: (1. Groundwater resources), many areas of sub-Saharan Africa are already facing moderate to severe blue water scarcity for some or all of the year (Serdeczny *et al.,* 2017), therefore, any expansion of irrigation must be planned with caution. Water availability and the protection of aquatic ecosystems, both now and under future climate change scenarios, must be assured before expanding any area for irrigated agriculture (Fader & Shi, 2016). Surface water can be supplemented with deep groundwater resources, yet their sustainable use must be secured with measurement, monitoring and regulation to avoid future negative social, economic and environmental impacts from overuse (Holley & Sinclair, 2018). (2. Crop production and water footprint), assessing crops for their comparative advantage in terms of water footprint from the global perspective and internally in a country would contribute to agriculture projects that benefit people and the ecosystem (Duarte, 2018). Transitioning to crops that fit the local conditions would provide benefits locally and be attractive to businesses reliant on these products in their supply chains.

2.4 The South African National Water Resource Strategy (NWRS2)

South Africa is a water-scarce country and ranks as one of the 30 driest countries in the world with an average rainfall of about 40%, less than the annual world average rainfall (Nkemelang *et al.,* 2018). South Africa has an average annual rainfall of less than 500 mm, while the world average is about 850 mm (Nkemelang *et al.,* 2018). The National Water Resource Strategy (NWRS2) sets out the vision and strategic actions for effective water management which include - the security of water supply, environmental degradation, and pollution of resources. It also outlines the key challenges, constraints and opportunities in water resource management and proposes new approaches to ensure a collective and adequate response for the benefit of all people in South Africa (Foster *et al.,* 2017).

This strategy aims for the achievement and attainment of an inclusive sustainable and equitable economy. The NWRS2, thus, will ensure that the management of national water resources contributes towards achieving South Africa's growth, development and socio-economic priorities, equitably and sustainably (Dickens *et al.,* 2018). The strategy also responds to the priorities set by the government in the National Development Plan (NDP) and the National Water Act of 1998 imperatives that support sustainable development (Dickens *et al.,* 2018).

2.5 Water footprint measurement in agriculture

By measuring the volume and source of water consumed in the production of a product and the volume of water to assimilate pollutants so that water quality standards are met, one can get a picture of how a specific product contributes to the growing concerns of water scarcity and degraded water quality (Hoekstra, 2017). The four major direct factors determining the water footprint are - volume of consumption, consumption patterns, climate (growth conditions), agricultural practices as well as water-use efficiency (Symeonidou & Vagiona, 2017). The volume of freshwater appropriation is measured in terms of water volumes consumed, evaporated or incorporated into a product and/or polluted per unit of time (Symeonidou & Vagiona, 2017).

Crop scientists express and measure water-use efficiency as the ratio of total biomass or grain yield to water supply or evapotranspiration or transpiration on a daily or seasonal basis (Anon, 2017). Biomass yield versus evapotranspiration relations have intercepts on the evapotranspiration axis, which are taken to represent direct evaporation from the soil, and yield can be considered as a linear function of transpiration, provided water-use efficiency does not vary greatly during the seasons (Anon, 2017). Linearity of the yield versus evapotranspiration relation denotes that water-use efficiency would increase with the increase in evapotranspiration as a consequence of increased transpiration/evapotranspiration ratio because the intercept has a constant value. For this reason, water-use efficiency also increases with an increase in the crop water supply up to a certain point. The water footprint can be calculated in the following ways:

2.5.1 Calculating water footprint

The most common use of the water footprint is to calculate the quantity of water used to grow a unit of food or produce a specified weight of a product (Gephart *et al*., 2016). According to the Water Footprint Network's manual, there are two ways to calculate a footprint: the Chain Summation Approach and the Stepwise Accumulative Approach. The former is used for particular cases while the latter is a more generic approach. In the Chain Summation Approach, water footprints associated with the process can be fully attributed to the product. The water footprint is the sum of water consumed by each process that constitutes the production, without double accounting. In the Stepwise Accumulative Approach, the calculation is based on the water footprints of the inputs needed at the last processing step. In other words, if there are several input products, the water footprint of the final product can be calculated by adding up those of the inputs and the processes, therefore, policymakers can use water footprints to decide cropping patterns based on the amount of water available. In this particular study, understanding of the water footprint would be useful for conserving or reducing water loss at each production level of a given crop.

2.5.2 Instruments to measure water footprint

The water footprint can be measured using different instruments such as a water flow meter; this instrument can accurately measure how much water is being used to irrigate (Nam *et al*., 2016). Using the rate from the flow meter, the volume of water used to irrigate for a certain period can be calculated (Nam *et al*., 2016). Secondly, soil sensors' instruments can help farmers understand the condition of roots to suggest when it is time to irrigate or when the plant's thirst is quenched to prevent wasting water, washing nutrients down the soil, and developing a shallow root pattern (Rossel & Bouma, 2018). For example, a tensiometer is an instrument designed to measure the tension or suction that plants' roots must exert to extract water from the soil (Lieth & Oki, 2019). This tension is a direct measure of the availability of water to a plant (Lieth & Oki, 2019).

Tensiometers are most useful when a crop's water requirements are high and when any stress due to water shortage is likely to damage crop potential (Hammam *et al*., 2019). Other devices which can be used for farm monitoring are data loggers. Data loggers are electronic devices that automatically monitor and record environmental parameters over time, allowing conditions to be measured, documented, analysed and validated (Barbaresi *et al*., 2021). Irrigation data loggers, thus, measure, monitor and record soil moisture tension so that water use can be precisely managed and unnecessary watering can be avoided (Henderson *et al*., 2018).

2.6 Farmers' perceptions on water conservation

Applying the right amount of water to grow farm products, careful irrigation and farm water management can help farmers conserve water, improve plant health, and even benefit the quality and quantity of their crops (Porter & Kramer, 2018). The perceptions of farmers are an important part of such decision-making, therefore, it is imperative to understand the perceptions of farmers towards a reduced water footprint; for example, California's farmers invest heavily in efficient water use on their farms. For farmers, maintaining the health of a plant is a strong motivator for efficient water use as for instance, over-watering can damage the plant (Dinar, 2017). According to Niles & Wagner (2017), in California, the impact of water quantity and quality influences access to water, economic returns and the functioning of local ecosystems. Recent good rain years have led to better water availability, however, some farmers felt surface water availability for agriculture was inconsistent even in wet years. To cope, farmers reported that several strategies have been used, including buying crop insurance, fallowing land, growing crops that used less water, purchasing water, cover cropping, monitoring wells and digging new wells (Niles & Wagner, 2017).

In Middle-East and North African countries (MENA) there is a high risk of serious water shortages (Guarin, 2017). To curb this threat water conservation strategies are gaining overall importance and one main focus is targeting farmers' behavior and perspective towards water conservation. As in many MENA countries, Turkey water was and still is a scarce resource (Ide *et al*., 2020). In the central and southern parts of Turkey (the aridest parts of the country) most farmers use groundwater (approximately 75 %) in preference to surface water for irrigation (Al-Saidi *et al*., 2016). A study conducted by Hommes in 2016 revealed that farmers who have wells as a water source, have higher normative dimensions regarding water conservation compared to those who have irrigation canals as a water source. Furthermore, farmers who have wells also had better intentions toward water conservation than those who have irrigation canals. Regarding perceived risk towards a water crisis, farmers who have access to irrigation canals felt more fear than those who had access to wells and springs (Hommes, 2016). There are some indications that if the number of users of a resource was limited, farmers felt more responsible and experienced more pressure towards water conservation and therefore had a better attitude regarding water conservation. Farmers can use a variety of tools to help ensure that plants receive the water they need as a strategy of reducing water footprint in crop production and the tools are as follows:

2.7 Irrigation and crop production

Irrigation is the artificial application of water to land for agricultural production (Zeng *et al*., 2018). Effective irrigation will influence the entire growth process from seedbed preparation, germination, root growth, nutrient utilisation, plant growth and regrowth as well as yield and quality (Zeng *et al.*, 2018). Several irrigation techniques reduce the amount of water applied per unit of crop produced, thus, improving irrigation efficiency regardless of crop type (Rey *et al.,* 2016). For example, drip irrigation systems minimize the amount of water lost due to evaporation and runoff by being buried directly beneath the crop and applying water directly to the root zone, thus, keeping the soil surface dry (Young & Thomson, 2018). This practice causes water to radiate outward from its source point, creating an overlapping wetting pattern beneath the ground. The root zone is kept moist but never saturated with water. The result is that the plant always maintains the ideal balance between water and air (Young & Thomson, 2018). Iran recently has given huge subsidies to develop drip irrigation techniques for farmers, almost 80–100% of the costs were funded by the government (Rizi *et al*., 2019). According to the status of agricultural water use in Iran, it was discovered that drip irrigation used about only 35% of the water used by the surface irrigation systems, thus, giving much higher water-use efficiencies. It was also concluded that low-cost drip systems achieved a water saving of more than 50% compared to surface irrigation systems. A study was conducted in the eastern and southern parts of Iran and the results revealed that affordable smallholders drip systems easily pay for themselves in one growing season, and stimulate shifts to more intensive agricultural practices by small-scale farmers (Chandel, 2016). Implementation of this technology might help improve the livelihoods of individual farmers or small communities in the context of poverty alleviation which is a priority of many sub-Saharan African countries.

2.8 Water use efficiency and plant production

Water efficiency reduces water wastage by measuring the amount of water required for a particular purpose and the amount of water used or delivered (Cheremisinoff, 2019). An example could be a farmer who upgrades his or her irrigation system so that water is more efficiently used by the crop, this would result in producing more saleable, higher-quality crops on roughly the same amount of water. Many sub-Saharan African countries must develop strategies to conserve water to meet future needs as it is anticipated that the need for water may be more than twice the current need (Rollinson *et al*., 2017). For instance, by 2025 cereal production in Ethiopia must be doubled to meet the food needs of its rapidly growing population which in turn escalates the agricultural water demand (Dunkelman *et al*., 2017). 90% of staple food for sub-Saharan Africa comes from rain-fed farming systems, hence, it is recommended that greater emphasis will have to be given to increasing the productivity of global rain-fed agriculture (Zougmore *et al*., 2018). In developing countries, grain yields from rain-fed agriculture are 1.5 t/ha compared to 3.1 t/ha from irrigated agriculture on average (Lathuilliere *et al*., 2018), hence, due attention should be given to better management of water resources in both irrigated and rain-fed agriculture. In this regard, instead of trying to supply the growing demand for water with new sources, improvements in current water-use efficiency should be the main focus in water-management policies (Lathuilliere *et al*., 2018). To increase water-use efficiency, several practices can be adopted; water-saving techniques, advances in irrigation technology and management, leaving crop residues on the soil surface and planting cover crops and adequate tillage practices are considered as potential measures to improve water-use efficiency and adapt to climate change (Florke *et al*., 2018).

2.9 Recycling and recovery in crop production

Farmers are key stakeholders in the reuse of treated recycled water for irrigation, but their position at the end of the water chain means that they are often marginalized in water resource decision-making processes (Saliba *et al*., 2018). Farmers can accept reclaimed water, visible through their decision to irrigate with the resource or reject reclaimed water. The acknowledgment that there is a choice associated with the decision to reuse water makes it imperative to understand the factors and mechanisms at the farm level which make water reuse both acceptable and manageable (Saliba *et al*., 2018). Recycling water allows for reduction of scarcity and easing of pressures on groundwater and other natural water bodies (Schacht *et al*., 2016). For example, Jordan has very limited water resources and has been using recycled water for irrigation for over 40 years as a means to overcome water scarcity (Gude, 2017). Recycled water can contain substantial amounts of plant nutrients, thus reducing the number of chemical fertilizers needed to obtain profitable crop yields (Timsina, 2018). Research conducted by Sharpley in 2017, found that irrigation with reclaimed water on one of the farms of Jordan required additions of potassium and phosphate to meet the crops' demand for these nutrients, although results vary with crop type and cropping intensity.

2.10 Agricultural methods used to reduce water footprint

As the world population grows, so does the demand for food and the need to grow more crops (Long *et al.,* 2016). In many regions of the world, water has become a scarce resource, with supplies affected by climatic changes (Kummu *et al.,* 2016). Not only does water scarcity limit farmers' ability to irrigate their crops, but overdrawing groundwater supplies for irrigation contributes to general water scarcity (Kummu *et al.,* 2016), therefore, reducing the water footprint in crop production helps to secure water. The following are the agricultural methods that can be applied to reduce water footprint in crop production with the view of securing water.

2.10.1 Soil mulching

Mulching is the mixing of wet straw, leaves and loose earth evenly spread on the ground to protect newly-planted trees, shrubs and their roots (Thurston, 2018). Mulching reduces the evaporation from open land surrounding the crops which results in a direct reduction in the green and blue (where irrigation is used) water footprints (Wang *et al.,* 2018). Mulching is considered to be one of the most beneficial practices a farmer can do to keep the farm healthy because the mulch prevents the excess sun from drying out the ground, which would otherwise cause the roots of plants and shrubs to become dry and need continuous watering (Altieri, 2018). Mulching creates a micro-climate for the plant to grow and perform better in a created area that has regulated moisture content, suitable temperature, humidity, carbon dioxide and proper microbial activity within the soil (Bisbis *et al.,* 2017). Mulch saves water because it naturally holds onto moisture and keeps the topsoil moist (Dingfeng *et al.,* 2017).

In China, the application of soil mulching is widely used to improve crop productivity within the semi-arid regions (Wang *et al.,* 2018). For example, a field study was conducted by Zhang *et al*.

(2017) during two consecutive cycles of a wheat cropping system within the Yangling District of Northwest China to evaluate the effects of different mulch cultivation practices on soil water contents, soil temperatures crop yields, and water use efficiency. The results revealed that all mulch treatments significantly improved grain yields of the winter wheat and summer maize. All mulching treatments increased the soil temperature of the crops from the seedling to the greening stages and helped prevent damage. The soil mulching practices, although, it changed the total crop evapotranspiration by a small quantity compared with the non-mulched treatment, the practice tended to reduce non-productive soil evaporation and increase productive plant transpiration (Zhang *et al*., 2017).

2.10.2 Land levelling and zero tillage

Land leveling is a process of flattening or modifying existing slopes or undulations rather than necessarily creating a level surface (Ahmad & Mahdi, 2018). A well-prepared and leveled field, can reduce evaporation, restrict field runoff (which is essential in cases with limited water availability), and optimize fertiliser and pesticide application reducing grey water footprint (Johnson & Mehrvar, 2021). Zero tillage is an agricultural technique way of growing crops or pasture without disturbing the soil through tillage (Busari *et al*., 2016). Zero-tillage increases the amount of water that infiltrates into the soil, the soil's retention of organic matter, and its cycling of nutrients (Busari *et al*., 2016).

Resource-conserving technologies (RCTs) such as zero-tillage and bed planting are beneficial in terms of improving soil health, water use, crop productivity and farmers' income (Rajkumar, 2017). Zero tillage is widely adopted by farmers in the North-western of India, particularly, in areas where rice is harvested late. The findings of a study conducted by Meena, (2016) in the North-Western India revealed that in wheat, zero tillage reduced irrigation requirements compared with conventional-tillage as the former process used residual water more effectively. It has been reported that zero tillage can save $40–50 ha^{-1} input cost, 13–33% water use and 75% fuel consumption. The findings further showed that in terms of land leveling, there was an improvement in water management and it saved up to 50% of irrigation water. Other benefits of land leveling included improved crop stand and crop productivity (up to 30%) and reduced labour requirement for weeding from 21 to 5 d ha^{-1} in rice.

2.10.3 intercropping

Intercropping is the practice of growing a series of dissimilar or different types of crops in the same area in sequenced seasons (Vieira *et al.,* 2018). Intercropping reduces soil erosion, increases soil fertility, helps pests control and improves crop yield. It is a good practice that can either reduce or at least maintain the current level of the grey water footprint of crop production because of the reduced application of pesticides (Schleich *et al.,* 2019). Intercropping can be used as a strategy to save on the applied irrigation water because it could consist of crops with medium to low water requirements.

In Egypt, feeding adequately a population growing at an annual rate of 1.84%, with limited land and water resources, is considered an immense challenge (Ouda, 2017). As a result, there is a large gap between the production of all strategic crops and consumption needs; this has increased the importation of these crops, putting a burden on the country's budget (Ouda, 2017). Agriculture is a vital sector in Egypt's economy, accounting for 14.6% of the Gross Domestic Product (Tanaka, 2018). More than 85% of the water withdrawal from the Nile is used for irrigated agriculture (Tanaka, 2018). Water availability has a direct influence on national food security, thus, sustainable growth in agriculture relies on the use of limited water resources effectively and efficiently. At present, surface irrigation is used in over 80% of Egypt's cultivated land with poor water management by the farmers contributing to a remarkable waste in irrigation water (Singh, 2019). An experiment conducted by Awaad & Naggar (2018), proved that one of the agricultural management practices that could save water on irrigation, in Egypt is the use of intercropping. The technical measures and benefits of intercropping peanut and corn were studied. By adopting comprehensive various water-saving and yield raising measures, the study showed that the practice of intercropping peanut and corn had significant advantages in water-saving.

2.10.4 Irrigation scheduling

Irrigation scheduling is the decision of when and how much water to apply to a field (Chartzoulakis & Berkati, 2015). The irrigation schedule indicates how much irrigation water has to be given to the crop, and how often or when this water is given (Fernandez *et al*., 2020). Its purpose is to maximize irrigation efficiencies by applying the exact amount of water needed to replenish the soil moisture to the desired level (Fernandez *et al*., 2020); this increases irrigation efficiency. A critical element, however, is the accurate measurement of the volume of water applied or the depth of application (Gore & Banning, 2017). A farmer cannot manage water to maximum efficiency without knowing how much was applied. Uniform water distribution across the field is important to achieve the maximum benefits from irrigation scheduling/management (Langridge, 2017). Accurate water application prevents over or under-irrigation. Over-irrigation wastes water, energy and labour, leaches expensive nutrients below the root zone, out of reach of plants, as well as reduce soil aeration, and thus crop yields (Zhou *et al*., 2014). Under-irrigation stresses the plant and causes yield reduction (Zhou *et al*., 2014).

In Europe (EU), irrigation is the largest water-user and exhibits great variability, increasing consumption from the temperate climates of the north to the semi-arid climates of the south (Giannakis *et al*., 2016). The EU's irrigated area is mainly concentrated in the Mediterranean region, accounting for 8.49 million ha or 85% of the total EU irrigated land (Giannakis *et al*., 2016). Irrigation is an indispensable input for Mediterranean agriculture as a large share of the water abstracted is used for this purposes (for example, Greece 88%, Spain 64%) (Molle & Ibor, 2018). Climate change is stressing the limited water resources of the Mediterranean countries, furthermore, the escalating demand for water from other economic sectors is already exerting high pressures on irrigation water uses (Garrote *et al*., 2017), hence, several organizations provide irrigation advice in Europe, either governmentally or commercially (Giannakis *et al*., 2016). "Irrinet" is one of the web-based irrigation scheduling tools that aims to ensure efficient use of water resources in the agricultural sector by providing real-time irrigation scheduling (Pascale *et al*., 2018). In Spain, large investments have been made in irrigation advisory services (Khadra & Sagardoy, 2018). The provincial government in Spain developed an irrigation scheduling service that provides farmers with weekly predictions of crop water requirements tailored to each field (Pascale *et al*., 2018).

2.10.5 Cover crops

A cover crop is a specific plant that is grown primarily for the benefit of the soil rather than its crop yield (Murrell *et al*., 2017). Cover crops are commonly used - to suppress weeds, manage soil erosion, help build and improve soil fertility and quality, control diseases and pests, and promote biodiversity (Altieri *et al*., 2017). Cover crops are usually grasses or legumes but may be comprised of other green plants (Tribouillois *et al*., 2016). Most often, a cover crop is grown in the off-season before the field is needed for growing the cash crop (Blanco-Canqui *et al*., 2015); in essence, a cover crop readies the land for an incoming cash crop. Cover crops reduce the amount of water that drains off a field, protecting waterways and downstream ecosystems from erosion (Blanco-Canqui *et al*., 2015). Each root of the cover crop creates pores in the soil; cover crops allow water to filter deep into the ground, therefore, they help conserve water and prevent soil erosion (Austin *et al*., 2017). In the Mid-Atlantic, USA, region, it was predicted that drought during the cash crop growing season (typically July), would become worse with climate change (Kaye & Quemada, 2017). One management tactic for this type of drought which was adopted, was to use brassica (for example, radish and rapeseed) to cover crop species with deep taproots that breakthrough compacted soil (Kaye & Quemada, 2017). The results showed that after radish or rapeseed cover crops have diminished compaction, maize crops had higher yields due to greater access to deep water, increasing resilience to drought (Kaye & Quemada, 2017).

2.10.6 Organic farming

Organic farming is an agricultural system that uses ecologically-based pest controls and biological fertilizers derived largely from animal and plant wastes and nitrogen-fixing cover crops (Bruggen *et al*., 2016). Organic farming uses fewer pesticides, reduces soil erosion, lowers nitrate leaching into groundwater and surface water, and recycles animal wastes back into the farm (Bai, 2019). Many practices of organic farming include, building soil organic matter, spreading organic mulches, maintaining areas of perennial plants and trees that help the soil absorb and retain water; it also helps recharge underground aquifers (Bai, 2019). The Rodale Institute reports that organic fields hold more water during droughts and that 15-20% more water seeps down to the aquifer under organic fields than does under conventional fields (Bai, 2019). According to a research conducted by the Office of Evaluation and Studies (OE), at the International Fund for Agriculture Development (IFAD), small-scale farmers in Latin America, China, and India can benefit dramatically from organic farming and that will help in alleviating poverty in these countries. Agriculture greatly depends on external factors such as climate, pests, and diseases (Abid *et al*., 2016). While most of the small-scale farmers in these countries are dependent on natural rain for water, in cases of natural calamity, pest or disease attack, or irregular rainfall, or when there is a crop failure, small-scale farmers practicing organic farming suffer less as their investments are low (Abid *et al*., 2016).

2.10.7 Drought-tolerant crops

Drought tolerance is the ability to which a plant maintains its biomass production during arid or drought conditions (Armada & Probanza, 2016). Some plants are naturally adapted to dry conditions, surviving with protective mechanisms such as desiccation tolerance, detoxification, or repair of xylem embolism (Tardieu *et al*., 2018). The United Food and Agriculture Organization's annual Africa Regional Overview of Food Security and Nutrition Report highlighted drought as one of the key factors contributing to the continuing rise in the number of hungry people in sub-Saharan Africa. Smallholder farmers are most affected by drought because many do not have irrigation technology and rely on rainfall for their crops (Fisher *et al*., 2015). With the unpredictability of rainfall patterns, smallholder farmers are no longer able to plan their planting seasons (Fisher *et al*., 2015). Growing drought-tolerant crops can help Africa's smallholder farmers ultimately become drought resilient (Fisher *et al*., 2015). Drought-tolerant crops have many benefits including increasing farm crop yields (Foyer & Lam, 2016). According to Roesch *et al*. (2018), planting climate-resilient maize varieties in most environments leads to 25% more crop yield. This is because these crops are still able to grow in periods when the rains fail. In Zimbabwe, for example, farmers earned USD$240 more per hectare when they planted drought-tolerant maize varieties because of larger yields (Makate & Makate, 2018).

Replacing maize with drought-tolerant crops, such as sorghum, millets, cowpea and green gram is helping farmers overcome the failure of rains and its damaging impact on maize in Busia County in western Kenya (Ochieng *et al*., 2018). To promote drought-tolerant crops like millets and sorghum, farmers have been trained on good agricultural practices, post-harvest handling and value addition, and have been provided with quality seeds of the improved varieties (Kagwiria *et al*., 2018). Capacity building of farmers and agricultural extension workers to promote production and utilization of sorghum, finger millet and groundnuts, has resulted in 62.7 tons of quality seed of the three crops being accessed by farmers in three counties in western Kenya, during the 2016/17 short rainy season (Kagwiria *et al*., 2018).

After reviewing the literature based on the perception of farmers regarding water footprint and agricultural methods that can be used to reduce water footprint a research gap has been discovered. Most of the conducted research did not focus on devising strategies that can be used to reduce water footprint and some of them use secondary data. This shows the significance of this study conducted to determine the water footprints of the selected crops and to devise strategies that can be adopted to reduce water footprint with the view of securing water.

From the reviewed literature, it is evident that water is an essential substances on earth and that there are competing needs for water from residential, industrial and agriculture sectors. In the agriculture sector, there is intense competition for water usage among farmers for plants and animals. It is evident that this condition is set to continue into the foreseeable future if this trend is not changed, therefore, assessing the water footprint of common crops such as tomatoes and butternut in current and future situations is paramount. This means there is a need to measure water consumed by each of the selected crops. Further to that, literature on the perception of farmers on water conservation, and the different tools used by the farmers to reduce water footprint in crop production were assessed to inform the research questions and to compare with the empirical results of this study as stated in Objective 3. Global and national strategies about agriculture and water provision were discussed and these included: The Global Framework on Water Scarcity in Agriculture (WASAG), Sustainable development goals about water provision, and the National Water Resource Strategy (NWRS2). This chapter also discussed the methods of calculating water footprint. Finally, agricultural methods that can be used to reduce water footprint in crop production were outlined. These included: soil mulching, land leveling and zero tillage system, intercropping, irrigation scheduling, cover crops, organic farming and the use of drought-tolerant crops.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

The methodologies adopted for this study are described in this chapter. The chapter presents the site selection and description, research design, target population, sample size and sampling procedure, data collection tools and methods, ethical consideration and data analysis.

3.2 Study area

The study was conducted at Nwanedi Irrigation Scheme, which is in Musina Local Municipality (Figure 3.1) and falls within the Vhembe District Municipality. Vhembe District Municipality is one of the five District Municipalities in Limpopo Province. Vhembe District is made up of four local municipalities - Musina, Makhado, Thulamela and Collins Chabane. Musina local municipality is bounded by Makhado local Municipality to the South; Thulamela local Municipality to the east; bounded in the South West by the local municipality of Blouberg which falls within the Capricorn District Municipality. Musina local Municipality is at the very North of the Limpopo Province, bordering Botswana and Zimbabwe. According to Community Survey 2016, the population of Musina is 132 009; the average annual temperature in Musina is 22.8 °C and it varies by 9.5 °C during the year (Edokpayi *et al*., 2018). The average annual rainfall for the Municipality ranges between 200-400mm and 600 mm (Malungu, 2016).

All Musina's water allocation is from groundwater sources with about 97%, amounting to some 10.4 million m^3 pa, sourced from 16 abstraction points along the Limpopo River (Zanele, 2018). The main rivers including the Matlabas, Mokolo, Lephalale, Mogalakwena, Sand and Nzhelele, together with other smaller tributaries, all flow northwards into the Limpopo River. The area of Musina is comprised of both livestock and crop farmers; currently, the total number of farmers in the Nwanedi irrigation scheme is 300 (Phillip & Mears, 2018); these specifically, grow and harvest crops. The irrigation scheme covers an area of about 2000 hectares, which belongs to the state and part of it belongs to the Communal Property Association (CPA). The area is dominated by vegetable production, and it makes up approximately 62% of the total horticultural production in the Municipality (Zanele, 2018). Vegetable production in the municipality is mainly comprised of tomatoes, potatoes, pumpkins and onions. Tomatoes are the primary vegetables grown in the area, with production taking place on subsistence, small-scale and commercial levels. Tomatoes form a staple supplement to the local diet of maize meals and are, therefore, one of the primary vegetables sold in the informal sector. In terms of commercial production, tomatoes are grown on a contract basis and supplied to producers. Most production is done based on drip irrigation systems (Zanele, 2018).

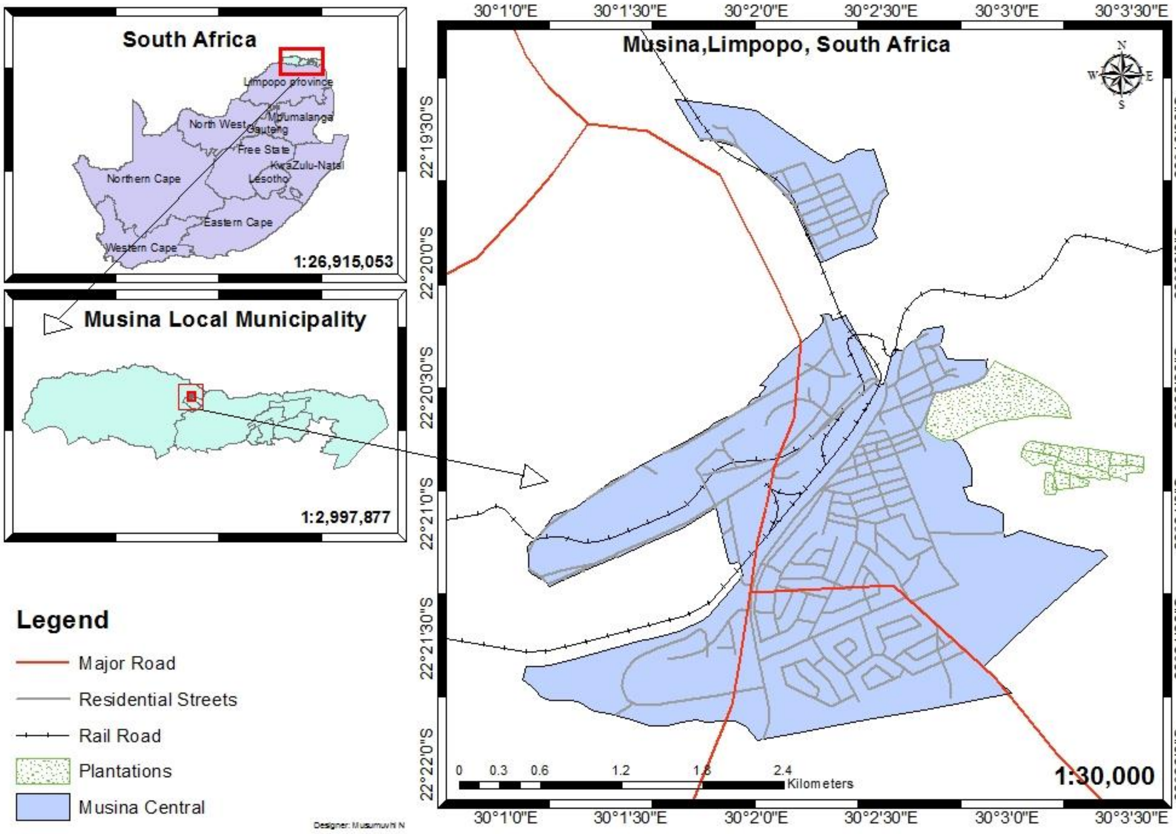

Figure 3.1**:** *Musina local Municipality in Limpopo Province, South Africa*

3.3 Research design

A convergent parallel mixed method design was used in this study, thus, both quantitative and qualitative collection methods were used to solicit data from the participants; both data sets were collected simultaneously. Collected data from the two sets were analysed separately to explain the water footprint situation in the scheme. Research design is the conceptual blueprint within which research is conducted (Cooper *et al*., 2019). A research design is the arrangement of conditions for the collection and analysis of data in a manner that aims to combine relevance to the research purpose with economy and procedural correctness (Wohlin, 2015). Bhardwaj (2018), states that a research design not only anticipates and specifies the seemingly countless decisions connected with carrying out data collection, processing and analysis but it presents a logical basis for these decisions (Neelankavil, 2015). In this study, hence, a parallel mixed method design was used to ensure that the research problem is adequately and logically explained. The design ensured triangulation of data collection on the perceptions and knowledge farmers have about the water footprint of the selected field crops, supported by conducting calculations of the actual water footprint of the selected field crops.

3.4 Population and sampling

The target population for this study is (n = 300) registered small-scale farmers at the Nwanedi irrigation scheme. According to Ryan (2016), a study population refers to the entire population, or group, that an investigator is interested in studying and analysing. In addition, the study population is whom the findings of the study will be generalised (Ames *et al.*, 2019). Due to limited time and resource constraints, it is important to select a representative sample from the total population. This process is called sampling and it is explained in the following section. In this study, purposive sampling technique was utilised to identify the farmers who are involved in tomato and butternut cropping, similarly, purposive sampling was applied to select small-scale farmers with extensive knowledge in water usage and are involved in butternut and tomato production at Nwanedi irrigation scheme. The total number of farmers who participated in this study was 60, which is 20% of the target population.

3.5 Data collection

In the light of Covid-19, qualitative data was telephonically collected, via one-on-one interviews, on the perceptions of small-scale farmers' water usage in different stages of crop growth at the Nwanedi irrigation scheme. Structured questionnaires with open and close-ended questions were utilised to help understand broadly the views of the farmers about crop water usage. In previously conducted studies, it was observed that Nwanedi farmers do not measure water used for crop production, hence, means had to be devised to estimate water used for tomato and butternut production. Quantitative data, therefore, was collected through direct recoding of the water used; for this process, the farmers were asked to estimate the following (Appendix 2).

I. The number of times they irrigated crops at different stages of plant growth,
II. The number of hours taken to irrigate crops at each period,
III. The number of hectares of their farms, and
IV. The number of tonnages they get per growing season from the two crops.

The number of irrigation times was multiplied by the number of hours to obtain the total hours. Thereafter, the size of the pipe (80 cubic meters) used to irrigate was multiplied by total hours to estimate the water use per crop. The water footprint was calculated dividing the total consumption by total yields. The study combined both qualitative and quantitative research methods to ensure the validity and cross triangulation of the results. This was necessary to ensure the reliability and generalisability of the results. According to Johnson (2017), the process of data collection involves collecting raw unprocessed data from all the relevant sources to find answers to the research problem, test the hypothesis and evaluate the outcomes.

3.6 Data analysis

Qualitative data were analysed thematically using Atlas. Ti version 8 software. Major themes emerging from the interview data on water footprint for tomato and butternut crops were analysed using In Vivo and Open Coding. Using the software, In Vivo allows key issues mentioned or identified in the interviews to be immediately converted to a theme. On the other hand, open coding was used to assess issues discussed and code them into key themes. Through the process of coding, and re-coding key themes that describe critical issues in water usage for tomato and butternut production were isolated, for example, the water footprint reduction strategies.

Quantitative data was analysed descriptively to establish trends and present the water footprint of the selected crops. Specifically, means, median, mode, standard deviation, variance, range and percentiles were used to describe the water footprint for tomato and butternut. Moreover, the relationship between tomato total production area, butternut total production area, tomato total yields, butternut total yields, gender, education level, age, tomato and butternut water footprints, as well as total water consumption for tomato and butter were also analysed. To achieve this, Pearson correlation analysis was applied and statistical Package for Social Sciences version 27 was utilised to perform the calculation. Data analysis is a method in which data is processed into meaningful information (Kune *et al*., 2015). Data from various sources was gathered, reviewed, and then analysed to form findings or conclusions. As stated earlier, both qualitative and quantitative data were collected. Qualitative data (perceptions of farmers regarding water footprint) and quantitative data (real experiments) were compared to identify the gap between what farmers think and the true water consumption. Both data sets were merged to devise strategies for addressing water footprint challenges.

3.7 Ethical considerations

Permission was sought from the relevant authorities and farmers, before conducting the research. An ethical clearance certificate was secured from the University of Venda Research Ethics Committee. The participants were assured before and during the telephonic interviews that the study is meant for academic purposes only and that their responses would be treated with the utmost confidentiality. This is because participants should participate because of informed consent. The principle of informed consent involves providing sufficient information and assurances about taking part to allow individuals to understand the implications of their participation so as to reach a fully informed, considered and freely-given decision about whether to do so, without the exercise of any pressure or coercion.

CHAPTER 4: DETERMINING WATER FOOTPRINT OF TOMATO AND BUTTERNUT AT NWANEDI IRRIGATION SCHEME

Abstract

The prevailing unpredictable weather patterns characterized by low rainfall and high temperature are worsening the water problem in semi-arid and arid regions like South Africa. Most of the water is used in agriculture, hence, to ensure sustained water use and guarantee water security, water use patterns and consumption for different crops must be understood. This study determined the value chain water footprint of tomato and butternut production among horticultural farmers at Nwanedi irrigation scheme, Limpopo South Africa. A longitudinal survey design was conducted to observe and record the water consumption of the two selected horticultural crops. The results revealed that tomatoes had the least water footprint (134.62 m^3/t) compared to butternuts (393 m^3/t). For tomato, water footprint ranged from 88 m^3/t to 180 m^3/t while for butternut it ranged from 232 m^3/t to 609 m^3/t. In terms of total water use, flowering and fruit formation growth stages for both plants used the most water. The results further revealed that as the total production area increases, water footprint decreases. Given these results it is recommended that water footprint be calculated for each stage of plant growth to devise appropriate interventions and that farmers with smaller production areas be prioritised in devising water footprint reduction strategies.

Keywords: Butternut, horticulture, tomato, water footprint, water security

4.1 Introduction and background of the study

There are three main uses of water, namely, residential, manufacturing and agriculture; the latter accounts for over 70% of freshwater use (Khokhar, 2017). The 30% is shared among the residential (10%) and industry (20%) use according to the estimates. Many regions globally are currently experiencing a surge in the need or use of freshwater, as frequent and severe water shortages are reported. Population growth and the resultant economic needs are leading to increased water use (Ahuja, 2019) as the increased demand for food exerts a lot of pressure on the already scarce water resources. Semi-arid and arid areas, like South Africa, are severely threatened by adverse effects of water insecurity (Xu & Beekman, 2019) and the prevailing unpredictable weather patterns characterized by low rainfall and high temperatures intensify the problem (Kangalawe & Lyimo, 2013). To provide a balance between various water uses, as well as to ensure future water security, the water consumption of different crops must be investigated so that the right strategies for reducing the water footprint of different crops can be known. This process generates an understanding of how water resources are used and affected by agricultural activities, therefore, this study assessed the water consumption in butternut and tomato production in Limpopo Province of South Africa, using a water footprint indicator.

A water footprint indicator is used to determine the volume of water used, directly and indirectly, in the production chain of a given product or crop (Hoekstra, 2003; Hoekstra *et al*., 2011). Water footprint assessment, thus, is applied to quantify water use, estimate sustainability, and offer information to achieve sustainable, efficient, and equitable water use. In agriculture, direct water use refers to the water consumed by the plant itself during the production stage while indirect use is the water consumed in support of plant growth or complementary products, fertilizers and pesticides (Hadjikakou, Chenoweth & Miller, 2013). There are three sub-indicators, namely, green, grey and blue water footprints used to assess indirect and direct water use. The green water footprint is water from rainfall that is stored or temporarily remains in the soil or plants. The blue water footprint is the ground or surface freshwater that is consumed, evaporated, and directly used in plant production. The grey water footprint is the water that is polluted or contaminated because of activities associated with crop production like pesticide use and post-harvest activities (Hoekstra *et al*., 2011). This study assessed direct water use or blue water footprint (seed germination, early growth flowering, fruit formation, fruit growth and mature fruiting).

Water scarcity is a major challenge globally and has negative effects on food and nutrition security, mainly in arid and semi-arid regions like sub-Saharan Africa; South Africa is semi-arid and water scarce (Nouri *et al*., 2018). A study by Pahlow *et a.,* (2015) found that crop production accounted for over 75% of the total water footprint of national crop production. This indicates that South African water footprint in agriculture is above the global average of 70%. This prompts the need to assess the water footprint of different crops to device strategies to reduce water usage, pollution as well as ensure water security.

Several studies have assessed water footprint in different sectors and crops in South Africa, however, few have been conducted in different areas and municipalities. For example, water footprint has been assessed in citrus production (Munro *et al.,* 2016); dairy products (Owusu-Sekyere *et al.,* 2017); and mine (Ranchod *et al.,* 2015). Also, Myambo & Wakindiki (2015) assessed water footprint in vegetable production (cabbage, tomatoes, spinach, and green beans) and found that different crops had differing water footprints across three provinces (Eastern Cape, KwaZulu-Natal, and Limpopo). There is limited evidence of water footprint assessment in tomato and butter production in Limpopo Province, particularly, in Musina District Municipality where the Nwanedi irrigation scheme is located. This paucity of assessment is despite the severe water shortages and water scarcity in this region; for example, since 2015, the Province has been declared a disaster area together with other provinces across the country (Lombard, 2019). This has led to over-reliance on underground water sources; for instance, most Musina Town's water allocation, comes from groundwater sources (97%) from 16 abstraction points along the Limpopo River (Zanele, 2018). The current spate of climate change is characterized by low rainfall and high temperatures, resulting in difficulties in balancing water provision across different sectors such as residential, industrial, and agriculture. Fanadzo *et al.*(2010), as well as Mnkeni *et al.*(2010), assert that apart from competing uses, a threat to freshwater resources in South Africa is a result of neglect and improper measurement and monitoring of water used in irrigation schemes. It is against this backdrop that this study was conducted to determine the water footprint in selected crops at the Nwanedi irrigation scheme.

4.2 Methods and materials

The study utilised a longitudinal survey study design to observe and record the water used in the production of butternut and tomato. The detailed description of the methods and techniques used is fully outlined in Chapter 3. The results are presented below.

4.3 Results

4.3.1 Demographic profile

Sixty farmers (60) participated in the study, however, 57 accurately completed the data collection process, hence, the latter were used for the analysis. Males 32 (53.3%) and those aged between 43 to 51 years (18; 30%) were the most represented in the study (Table 4.1). Younger people (19 to 25 years) were the least represented among the farmers at the Nwanedi irrigation scheme. Most participants had secondary and matric as their highest levels of education at 16 (26.7%) and 17 (28.3%), respectively.

4.3.2 Farm characteristics

The farming characteristics were assessed before determining the water footprint in butternut and tomato production. All the farmers were involved in tomato production while about 27 of the total also cultivated or alternated with butternut. Table 4.2 shows the total production area in hectares as well as yields and selling price of the crops per tonne. Also, the total number of valid and missing cases is illustrated. The total production area per farmer ranged between 2 to 40 hectares for tomatoes and from 1 and 20 hectares for butternut. On average, farmers had approximately 7.59 and 3.30 hectares under the cultivation of tomato and butternut, respectively. The results show that farmers cultivated butternut and tomatoes once, twice, and thrice a year on an alternative basis (Table 4.3), thus, the frequency of cultivation for each crop depends on the farmers' preferences either for soil management purposes or based on the market needs. Both tomatoes 24 (40%) and butternut 14 (23.3%) were, at most, planted twice per annum. In terms of harvest, the mean yields for tomatoes were 560.09 tonnes and 89.96 tonnes for butternut.

The produce from the farms is sold either to the local, national, and export market or in some combination (Figure 4.1). Most of the produce was sold in the local market (41.7%) followed by those who took their harvest to the local and national markets (31.7%). The results suggest that majority of produce, at the scheme, was sold within South African borders,although, about two-fifths (21.7%) were put on the exports markets. The high local demand and low percentage of exportation suggest the availability of more export-market opportunities for farmers. In terms of the selling price, the price of tomatoes ranged from R1 900.00 to R2 400.00 per tonne; the average selling price was R2 094.74 but most farmers sold their tomatoes for R2 100.00 per ton (Table 4.2).

Table 4.1: Demographic profile of the participants (n = 57)

Item	Category	Frequencies (%)
Gender	Female	28 (46.7%)
	Male	32 (53.3%)
Age	19-25	2 (3.3%)
	26-34	4 (6.7%)
	35-42	11 (18.3%)
	43-51	18 (30%)
	52-59	12 (20.0%)
	≥60	13 (21.7%)
Education Level	No formal schooling	8 (13.3%)
	Primary level	11 (18.3%)
	Secondary level	16 (26.7%)
	Matric Level	17 (28.3%)
	Tertiary level	4 (6.7%)
	Abet	4 (6.7%)

Butternut was sold using standardized measurements of 5 and 10 kilograms. A 5kg bag of butternut was sold for a price ranging between R25.00 to R50.00 while a 10kg was sold between R40.00 to a maximum of R120.00. The quality, size, and market dynamics such as supply and demand influenced the different pricing of both crops. Results also indicate that it is possible to buy 5kg of butternut for R50.00 at one time or buy it for R 25.00 another time depending on demand. In addition, a 10kg of butternut could also sometimes go as low as below the maximum price of 5kg of butternut. Participant number 40, used a "crate" of butternut to sell to customers as opposed to the actual measurement.

Also, the analysis of variance was performed to determine if the crop yields and total production area significantly varied based on gender (Table 4.4). There was no significant variation in total yields and production area for both butternut ($F = 0.595$; $Sig = 0.448$) and tomato ($F = 1.046$; $Sig = 0.311$). This means gender does not influence the land area used for production of both crops as well as in how many tones a farmer produced in a single growing phase, thus, males and females performed fairly the same, for these parameters.

4.3.3 Total water use

The water consumed for each stage of the crops' lifecycles was estimated and calculated in m^3. In both butternut and tomato production, flowering and the start of fruit growth stage had the most cubic centimeter of water used; for example, tomatoes used an estimated amount of 31824.67 m^3/ha of water at the flowering growth stage followed by the fruit growth stage (Table 4.5). Both crops had an average water consumption of 101 995.66 m^3/ha and although the flowering and fruit growth stages had the highest water consumption, flowering consumed the most water for butternut in comparison to tomatoes.

Table 4.2: Farm characteristics

	Total Production Area		Yields		Selling Price
	Tomato	Butternut	Tomato	Butternut	Tomato
Mean	7.59	3.30	560.09	89.96	2094.74
Median	6.00	2.00	425.00	56.00	2100.00
Mode	5	2	300	28[a]	2100
Std. Deviation	5.364	3.891	439.667	116.541	110.875
Variance	28.773	15.140	193307.449	13581.729	12293.233
Range	38	19	3060	580	500
Minimum	2	1	140	20	1900
Maximum	40	20	3200	600	2400

Table 4.3: Frequency of cultivating butternut and tomatoes in Nwanedi irrigation scheme.

	Tomato (n = 57)		**Butternut (n = 27)**	
	Frequency	**Percentage**	**Frequency**	**Percentage**
2 times	24	42.1	14	51.9
3 times	17	29.8	5	18.5
Once	16	28.1	8	29.6

An analysis of variance was performed to determine if the crop yields and total production area significantly varied based on gender (Table 4.4). There was no significant variation in total yields and production area for both butternut ($F = 0.595$; $Sig = 0.448$) and tomato ($F = 1.046$; $Sig = 0.311$). This means gender does not influence the land area used for production by both crops, as well as how many tones a farmer produced in the single growing phase, thus, males and females performed fairly the same, for these parameters.

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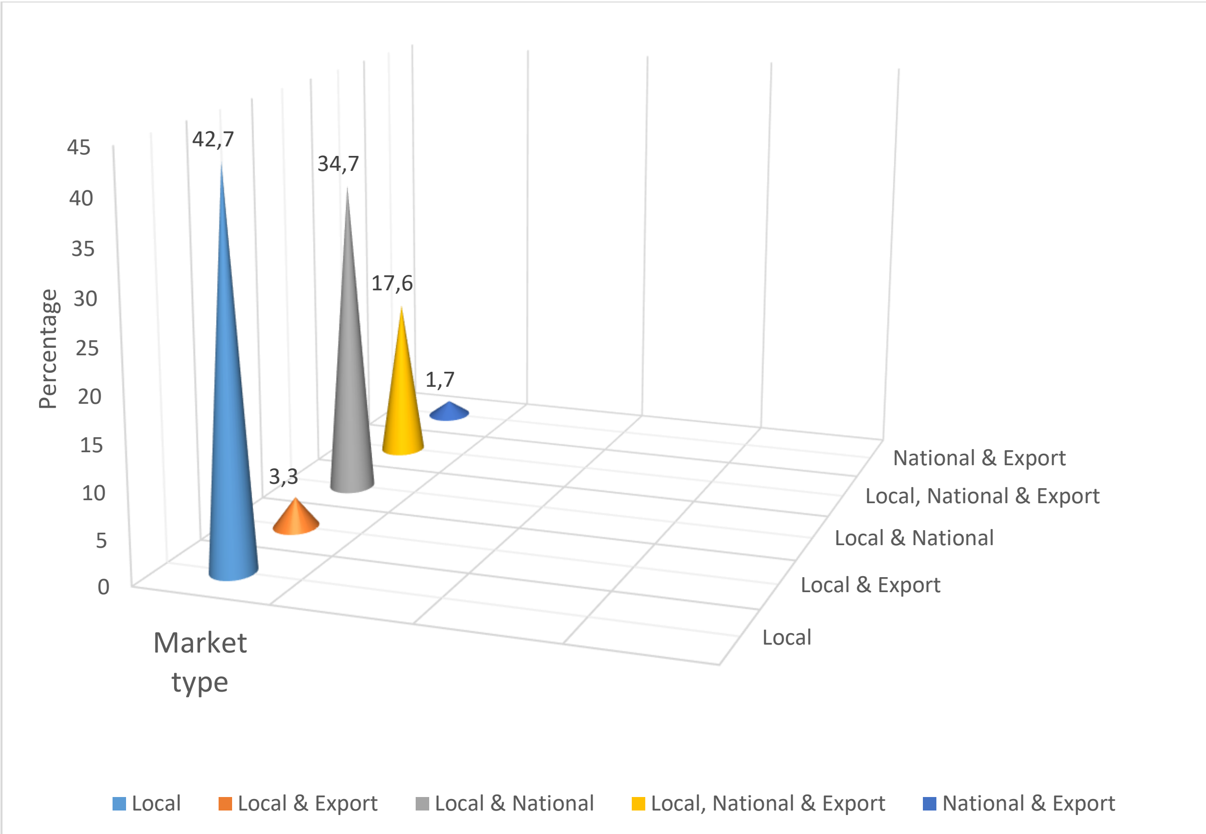

***Figure 4.1**: Common market for farmers in Nwanedi irrigation scheme in Limpopo Province, South Africa*

Table 4.4: Analysis of variance

		Sum of Squares	Df	Mean Square	F	Sig.
Tomato total production area	Between Groups	9.146	1	9.146	.595	.448
	Within Groups	384.484	25	15.379		
	Total	393.630	26			
Butternut total production area	Between Groups	30.059	1	30.059	1.046	.311
	Within Groups	1610.010	56	28.750		
	Total	1640.069	57			
Total tomato Yields	Between Groups	131454.975	1	131454.975	.676	.414
	Within Groups	10887069.594	56	194411.957		
	Total	11018524.569	57			
Total butternut yields	Between Groups	15427.727	1	15427.727	1.142	.295
	Within Groups	337697.236	25	13507.889		
	Total	353124.963	26			

Table 4.5: Water consumption in the life cycle of butternut and tomato production in Nwanedi irrigation scheme **(m³/ha)**

	Tomato					**Butternut**				
	Seed Germination	**Flowering**	**Fruit growth**	**Mature growth**	**Total**	**Seed Germination**	**Flowering**	**Fruit growth**	**Mature growth**	**Total**
Total					393 4326					772347
Mean	4 691.03	31824.67	24 378.95	9 256.55		2103.70	10246.15	12627.69	6866.92	
Mode	3 600	19200	23040	7 200		1280	7200	8640	1600[a]	
Std. Deviation	2 994.665	20453.845	13 894.850	7 760.904		1898.315	9184.388	11565.326	8287.080	
Minimum	960	9600	6 480	2 880		480	3600	4320	1200	
Maximum	19 200	144000	8 6400	57 600		9600	48000	57600	24000	

In general, the data revealed a bell-shaped curve suggesting that for both crops, water consumption increases as the plant reaches flowering and starts bearing fruits. The consumption was found to be lower at the early and late stages of crop growth in both cases. In total, both crops consumed a total of 470 6673 m³/ha (tomato had total water consumption of 393 4326 m³/ha and butternut had 772 347 m³/ha). Butternut had a mean and standard deviation of 70.2 and 45 104.4, respectively, while tomato had a mean and standard deviation of 31 843 .8 nd 30 934.8.

4.3.5 Water footprint

The direct water footprint for tomato and butternut was calculated using the formula below. To calculate the water footprint estimates for each farm, the formula proposed by Hoekstra below was utilized (Hoekstra *et al*., 2011). The formula calculates the total water consumption for the whole area for each farm by dividing it by the total yield. The schedule for total water used, farm size, total yield and total water footprint per farm are presented in Appendix 4.

$WF_{proc,blue} = \frac{CWU\ blue}{Y}$ [m³/tonne]

- WFproc, *blue* is the blue crop water use
- (CWUblue) represents Blue Crop Water Usage measured in m³/ha divided by
- (Y) is the yield measured in Kgs or tonnes/ha

The water footprint for all 57 farms was calculated and estimated. The results showed that the total blue water footprint per farmer for tomato and butternut averaged 134.62 m³/t and 393 m³/t, respectively (Table 4.6). To get this average, the total amount of water footprint per crop was divided by the number of farms as shown below and despite more farmers and more land under cultivation for tomato production, butternut had the highest water footprint.

Average water footprint for tomato

7808 *(Wfp t)* ÷ 58 *(farms)* = 134, 62 m³/t

Average water footprint butternut

10614 *(Wfp b)* ÷ 27 *(farms)* = 393 m³/t

Table 4.6: Bluewater footprint of butternut and tomato production at Nwanedi irrigation scheme

	Tomato (m^3/t)	Butternut (m^3/t)
Mean	134.62	393
Median	135.00	385.50
Mode	123	336
Std. Deviation	20.087	72.534
Minimum	88	232
Maximum	180	609

a. Multiple modes exist. The smallest value is shown

4.3.6 Correlation analysis

Pearson correlational analysis was performed to estimate the relationship between demographics, farm characteristics, and water use variables. Table 4.7 shows that there is a positive significant relationship between total production area and yields for butternut (α = 998; p = 0.00) and tomato (α = 0.990; p = 0.000). This is an expected result that more farming areas will produce higher output. Furthermore, there is a significant relationship between farm cultivation characteristics (total production area and total yields) and water use variables (total water consumption and water footprint). The relationship between farm characteristics and water footprint was negative while total water consumption was positive; for instance, tomato's total water footprint was negative and significantly related to its total production area (α =-.448; p = 0.000). The results mean that as the total production area increases, the water footprint decreases, thus, farmers producing in small farmland areas have a larger water footprint in comparison to those using large tracks of land. To the contrary, the relationship between the total production area is positively related to total water consumption for tomato (α =.970; p = 0.000) and butternut (α = 919; p = 0.000); this was expected that farmland size would be directly related to total water use. Demographic variables such as gender, age, and education levels had no influence or relationship with both farm characteristics and water use variables.

Table 4.7: Correlational analysis for demographic and water use variables for Nwanedi irrigation scheme

		1	2	3	4	5	6	7	8	9	10	11
1. Tomato total production area	Pearson Correlation	1										
	Sig. (2-tailed)											
2. Butternut total production area	Pearson Correlation	.950**	1									
	Sig. (2-tailed)	.000										
3. Tomato Total Yields	Pearson Correlation	.990**	.942**	1								
	Sig. (2-tailed)	.000	.000									
4. Butternut total yields	Pearson Correlation	.956**	.998**	.952**	1							
	Sig. (2-tailed)	.000	.000	.000								
5. Gender	Pearson Correlation	-.135	-.152	-.109	-.209	1						
	Sig. (2-tailed)	.311	.448	.414	.295							
6. Education Level	Pearson Correlation	-.022	-.071	-.046	-.071	-.140	1					
	Sig. (2-tailed)	.871	.725	.731	.724	.287						
7. Age	Pearson Correlation	.029	-.025	.037	-.021	-.102	-.491**	1				
	Sig. (2-tailed)	.827	.902	.781	.916	.437	.000					
8. WFP T	Pearson Correlation	-.448**	-.510**	-.515**	-.515**	.007	.248	-.181	1			
	Sig. (2-tailed)	.000	.009	.000	.008	.956	.061	.175				
9. WFP B	Pearson Correlation	-.572**	-.526**	-.590**	-.552**	.030	-.169	.187	.368	1		
	Sig. (2-tailed)	.003	.006	.002	.004	.883	.410	.359	.077			
10. TWCT	Pearson Correlation	.970**	.899**	.956**	.915**	-.136	.027	.055	-.351**	-.577**	1	
	Sig. (2-tailed)	.000	.000	.000	.000	.298	.840	.678	.007	.002		
11. TWCB	Pearson Correlation	.897**	.919**	.886**	.916**	-.037	.003	-.183	-.415*	-.402*	.834**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.854	.987	.362	.039	.042	.000	

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

WFP T = tomato water footprint; WFP B = butter water footprint; TWCT = tomato total water consumption; TWCB = butternut total water consumption

4.4 Discussion

Farmers produced mainly for the local market, although, they also had a presence in the international market. The results of this study found that the tomato water footprint at the Nwanedi irrigation scheme is 134.6 m^3/t. This result slightly differs from the findings of Nyambo and Wakindiki (2015) in irrigation schemes in other parts of South Africa; the authors established a water footprint of 132 m^3/t for tomatoes. The results show that in the current study area, the blue water footprint is higher than the global average of 63 m^3/t (Mekonnen & Hoekstra, 2011). In comparison, the blue water footprint range from 88m^3/t to 180m^3/t for tomatoes in the Nwanedi irrigation scheme, significantly varies with that of Greece (37m^3/t to 131m^3/t) as reported by Evangelou *et al.*(2016). In Spain, tomato blue water footprint was also reportedly varied (Chico *et al.,* 2010).

Chico *et al.,* (2010) established that water footprint in tomato production mean averages, ranged between 6 m^3/t and 51 m^3/3. Comparatively, results suggest that the lower limit of the water footprint in tomato production of 88 m^3/t at the Nwanedi irrigation scheme is two times higher than 44.6 m^3/t reported by Nyambo and Wakindiki (2015) in South Africa and 37 m^3/t in Greece (Evangelou *et al.,* 2016). These results suggest that, despite using different water footprint measurement methods, the assessment trend is common, therefore, it is concluded that tomato water footprint varies according to geography, agricultural practices adopted, as well as the level of farming knowledge.

The average blue water footprint for butternut ranged from 232 m^3/t to 609 m^3/t and averaged 393 m^3/t. Compared to tomato production in the current study, butternut had the most water footprint. This trend is observed in the literature. The current findings show that the blue water footprint for butternut is higher than for other vegetables. For instance, Mekonnen & Hoekstra (2011) reported 181 m^3/t for cabbage, whereas Nyambo and Wakindiki (2015) reported 1280 m^3/t for green beans. Moreover, a lower water footprint for tomatoes compared to butternut and tomatoes suggest that tomatoes have less water footprint. Similar observations were made by Nyambo and Wakindiki (2015) in South African irrigations schemes, when they compared spinach, potato, cabbage as well as green beans, and found that tomatoes exhibited the lowest amount of blue water with an average of 44.6 m^3/t. These findings point out that water footprint varies, thus, any strategy that sees to reduce the print, must consider the dynamics in each area including the climate, availability of water resources and infrastructure, and farming practices, like the watering methods used.

The result revealed that while the water footprint decreases with an increase in land size, the total water consumption increases with an increase in land size, thus, the results suggest that the total water consumption slope increases at a decreasing rate with land size increase. This could be attributed to the fact that as land size increases, farmers become more conscious about a large amount of water used over a large area, hence, they are likely to attempt to save water voluntarily or involuntarily in the process.

4.5 Conclusions

The result revealed that all farmers were involved in tomato production while a handful also grew or rotated with butternut. Majority, of these farmers produced for the local market and their prices were fixed for tomatoes, however,they varied depending on the quality of the output per harvest and other market forces. The study further revealed that blue water footprint widely varied across the farmers and those with larger farms used less in terms of blue water. Tomato had the lower water footprint compared to butternut and it was also evident from the analysis, demographic variables such as gender, age, and level of education did not influence water footprint. Additionally, results indicated that as the production area for each crop increases, the water footprint decreased, thus, smaller farms have a significantly higher impact on water resources compared to commercial farmers. This result implies that to reduce water footprint and ensure water security in the production of tomatoes and butternut, more effort and attention must be put on water use practices of farmers with smaller land areas. In terms of water use, the results further revealed that most water is used at the flowering and fruit formation stages for both plants, hence, any intervention program or strategy including research activities on water footprint, should focus on flowering and fruit formation stages of plant growth.

CHAPTER 5: FARMERS WATER USE PERCEPTIONS IN BUTTERNUT AND TOMATO PRODUCTION IN LIMPOPO PROVINCE, SOUTH AFRICA

Abstract

This study assessed the water usage perceptions of tomato and butternut farmers in Limpopo Province of South Africa. The main questions addressed in this study were: Which stages of crop production are perceived to consume the most water and why? What are the activities leading to pollution of water resources because of butternut and tomato production? Butternut and tomato crops form part of every meal in most families and are part of the export market in South Africa, hence, it is critical to know the water use experiences of farmers in the production of these crops. A cross-sectional survey study was conducted at the Nwanedi irrigation scheme in Limpopo Province, South Africa. The data was collected through interviews with semi-structured and structured questions to understand and estimate the water use at different growth stages of butternut and tomato. The data was analysed descriptively and thematically using Atlas ti version 8.1 to build themes. The results revealed that most farmers perceived flowering and fruit formation stages as consuming the most water for both butternut and tomato. On the other hand, seeding and maturity stages were observed as using less water, although, a substantial number of farmers believed that all the stages of crop production required the same amount of water. It is recommended that farmers practice deficit irrigation to calibrate watering needs for each plant at different growth stages, as part of the strategies to reduce water footprint in vegetable production.

Keywords: Butternut, irrigation, small scale farmers, tomato, water footprint

5.1 Introduction

The increasing population size globally has put a strain on the available water resources (Fischer & Heilig, 2021). Currently, the population is growing globally at more than twice the rate of population increase in the last century (Fischer & Heilig, 2021). The effects of climate change that manifests in the form of extreme weather conditions such as low rainfall and high temperatures, are a threat to future water availability (Forke *et al*., 2018). The problem is of global concern, however, sub-Saharan Africa is hardest hit by the above factors (Forke, *et al*., 2018). Agriculture uses over 70% of the water compared to other water uses (Chen, 2018), therefore, it is the main area in which strategies and efforts to reduce the water footprint must be intensified. In Africa, most agricultural activities are dependent on rain-fed water making the water supply for the sector a major challenge for most farmers (Dunkelman *et al*., 2018). The problem of water scarcity in Africa is exacerbated by aridity which has been a regular occurrence from droughts and floods that are spread throughout the continent, including South Africa (Dunkelman *et al*., 2018).

The Human Development Report of 2019 predicts that between 24 to 700 million people will be displaced by 2030 due to unliveable conditions associated with loss of water that would permeate the region (United Nations Development Programme, 2019). It is, hence, an urgent matter that countries within the continent intensify efforts to reduce the water footprint of various crops, especially in arid regions and areas such as Limpopo Province in South Africa. This study, as a result, investigated the perceptions of farmers on water use on major horticultural household crops (butternut and tomato) in South Africa. The aim was to establish how water is used by the selected crops at different stages of growth and steps that can be taken to reduce water use.

More than ever before, communities in sub-Saharan Africa need more water than populations in other regions of the world (Santos *et al*., 2019). Africa is disproportionately affected by climate change effects which have worsened water access for many families and South Africa is not an exception. Many industries in South Africa are affected by the shortage of water, which is caused by several factors including population growth, the volatile climate, drought, and aging infrastructure among others (Fitchett, 2021). According to Hendrickson *et al*. (2019), food and Agriculture are the largest consumers of water in the country, for instance, it was found that the Western Cape contributes the most land (269 476 ha) under irrigation, with Limpopo the second largest area under irrigation (218 302 ha). This evidence shows that farmers must get innovative to produce more with less, especially when it comes to freshwater availability. In recent years, the water footprint metric has been employed as a priority tool to make transparent the impact of humanity's consumption and production of global freshwater resources (Upadhyay, 2021).

The water footprint is the amount of water that is consumed (that is, no longer available for immediate reuse) to generate a product or service (Upadhyay, 2021). Mekonnen & Hoekstra (2020), define crop water footprint as the volume of freshwater used to produce a certain crop in all the steps in the production line. Nyambo & Wakindidiki (2015), stated that a water footprint is a critical tool for considering water conservation impacts, from a variety of farm management options, therefore, it is imperative to understand the perception of farmers towards water footprint reduction, in different stages of crop growth. This will help detect if the farmers are aware of water requirements and applications for each crop. This contributes to, improving the practical knowledge on water use and management among farmers in irrigated cropping. It is against this background that this study sought to assess the perceptions of small-scale farmers regarding water footprint at the Nwanedi irrigation scheme.

5.2 Methodology

This study adopted a cross-sectional survey design to assess the lived experiences of farmers on water use in butternut and tomato production. More details of the study area, description of the study area and population, data collection, and how data was analyzed are given in Chapter 3.

5.3 Results

The demographic profile of the participants are presented in chapter 4 Section 4.3.1.

5.3.1 The perceived level of water use in different stages of butternut and tomato production

The participants were asked to state and explain the stages that require more water in the production of each crop. The stages of production are seed germination, early growth, flowering, fruit formation, fruit growth, and maturity (Table 5.1).

Butternut

Majority of the farmers (16) perceived the flowering stage of butternut production as consuming or demanding the most water followed by that of fruit formation (7). Early and fruit growth stages had an equal number of mentions, 3. Maturity and seed germination stages were not mentioned at all by the 27 butternut farmers. Farmers water their plants the most, at the stage of flowering for several reasons. If less water or inadequate water is applied at this stage, the developed flower is likely to fall off, develop prematurely, rot, and be exposed to pest attack. For example, participant number 7 said inadequate water application during the flowering result in,

"… *flowers drop [ping] without producing any fruits*".

Participant number 4 explained that this may also cause the,

"…*plant to abort fruit production*" or have a "*poorly developed fruit*".

Farmers, hence, applied a significant amount of water at this stage to ensure that butternut fruits are fully developed and produce higher kilograms for higher returns at the market, as explained by participant 27. The seed germination and maturity were not mentioned at all as the stages of production that consume the most water. This suggests that both stages consume the least amount of water in comparison to other stages of butternut production.

Tomato

A similar trend of water needs or requirements in butternut production was also observed with tomatoes. The flowering stage was mentioned the most by the farmers. This might indicate that this stage requires a high amount of water for quality fruit development. This is also reflected in the proportions of total responses for both crops constituting majority of the mentions at 30. Part of the reasons why more water had to be applied at this stage was to prepare the plant for fruit production, prevent wilting, mitigate worm attack, attain a higher number of fruits per plant, and stop flowers from falling off the plant.

Lack of or less water application at the flowering stage has negative effects on the number of fruits produced.

"…*flowers drop and only a few fruits develop,*" said participant 26

Participant 20 expanded and said,

" … *For the flowers to produce enough fruits, the plant needs constant watering*"

The results revealed that a significant number of farmers applied more water at the fruit formation stages of tomato production. One of the major reasons for this was to ensure maximum fruit growth and keep the fruit attached to the tree throughout its development. Seed germination and mature fruit development stages were considered the least water-consuming stages in the production of tomatoes.

Table 5.1: The perceived level of water use in different stages of butternut and tomato production in Limpopo Province, South Africa

	BUTTERNUT		**TOMATO**		
PRODUCTION STAGES	**Descriptive statement (quotation)**	**Number of mentions**	**Descriptive statement (quotation)**	**Number of mentions**	**TOTAL**
Seed germination			"*All stages, at each stage if the plant does not get the required amount of water for a long period it dies*" (**Participant 2**)	1	**1**
Early growth	"*Early growth, the plant dies without producing flowers*" (**Respondent 6**)	3	"*Early growth, the plant becomes stunted*" (**Participant 58**)	10	**13**
Flowering	"*Flowering, flowers drop due to water stress*" (**Participant 42**)	16	"*Flowering, the plant wilts and develop worms*" (Respondent 4) "*Flowering, for the flowers to produce enough fruits, the plant needs constant watering*" (**Participant 20**)	30	**46**
Fruit formation	"*Fruit formation, the plant abort the fruit when exposed to water scarcity*" (**Participant 49**)	7	"*Fruit formation, the fruits die without growing*" (**Participant 53**)	11	**18**
Fruit growth	"*Fruit growth, the fruits shrivel and fall off the vine*" (**Participant 43**)	3	"*Fruit growth- maturity, they fall off the plant when exposed to water stress*" (**Participant 52**)	8	**11**
Maturity			"*Fruit growth to maturity, they develop problems like splitting*" (**Participant *16***) "*Maturity stage, the fruits split or wilts*" (**Participant 17**)	10	**10**
TOTAL		**29**		**70**	**99**

5.3.2 Activities leading to water pollution

Apart from direct water use by plant watering, indirect activities of farmers that affect the water footprint in tomato and butternut production were also assessed. Washing of fruits before selling and use of chemicals are the two main causes of water pollution in the Nwanedi irrigation scheme. These included spraying herbicides for weeding and adding fertilizers or chemicals to improve soil fertility (Participants 1, 3, 17, 19, 20, 55). For instance, Participant 6 said,

"…*The use of chemicals for weeds*".

The results show that water contamination by chemicals did not only occur during production but it also was a product of post-harvest activities.

"…*Washing harvested crops directly at rivers or close to water bodies*" (said participant 39).

The results support the need to monitor and observe the entire cycle from production to getting the product to the market to fully comprehend the water footprint.

5.4 Discussion

Most farmers said that the flowering stage followed by that of fruit formation consumed or required the most water during production. Seeding and maturity stages were perceived to use less water. Studies show that different crops are drought-sensitive (Doorenbos & Kassam, 1979; Wang *et al.*, 2011) at certain growth stages and drought-tolerant at other phenological stages (Birhanu & Tilahun 2010; Chen *et al.*, 2015). The findings of the current study concur with earlier (Harmanto *et al.*, 2005) and recent (Nangare *et al.*, 2016) findings that the most sensitive stage to water is the flowering and fruit formation in tomato production. On the contrary, Nuruddin *et al.* (2003) note that water stress imposed at fruit growth and maturity stages reduced tomato marketability. Chen *et al.* (2015), as well as Herrero *et al.* (2001), found that the most water-sensitive period for tomatoes is the fruit maturing stage.

The findings of this study and literature show conflicting results on water sensitivity for different growth stages of tomato growth. This also explains why even farmers have differing perceptions on which stage needs or uses the most water in tomato production. "*At early growth, the plant dies without producing flowers*" (Participant 6). "*not providing enough water during the fruit growth to maturity, results in problems like fruit splitting*" (Participant 16). These differences make it difficult to recommend and develop water management strategies for farmers to reduce scarcity, hence, actual measurements in a longitudinal study are recommended to know the accurate water usage in each stage. Deficit irrigation is increasingly being used in arid and semi-arid regions to minimise the primary constraint for high crop yields (Du & Kang, 2011; Yang *et al*., 2016). In deficit irrigation, a crop is deliberately exposed to a certain extent of water stress to increase water productivity and optimize water use efficiency (Yang *et al*., 2016). This is done either by applying less irrigation water during the whole crop cycle, alternatively, irrigation is withdrawn at different stages, while ensuring that yields are not compromised.

Literature reveals that different growing periods' evapotranspiration and water use efficiency depends on the controlled ranges of soil water content (Kang *et al.,* 2002). Kang *et al.* (2002) found that higher grain yields are subject to mild water deficits at the seedling, regrowth, and stem-elongation stages, followed by soil drying during the period from physiological maturity to harvest. Pulupol *et al*., (1996) had earlier observed that two weeks after transplanting tomatoes, the application of appropriate deficit irrigation increases fruit color intensity, lowers water content, and improves the contents of sucrose, glucose, and fructose of greenhouse-grown tomatoes. The results suggest that farmers should observe different water needs at different stages to be able to apply appropriate deficit irrigation. Farmers are further encouraged to water tomatoes only when there is a need and consider using irrigation scheduling to increase yield and quality. Dorais *et al*., (2001) posit that the nutritional quality, fruit size, and the market demands for tomato are assured by appropriate water and fertilization management. Tomato production consumes a significantly high amount of water, improving its water use, efficiency contributes to positive economic and environmental effects (Cantero-Navarroa *et al.,* 2015).

Like in tomato production, the results also revealed that most farmers perceived the flowering and fruit formation stages to need water most. Moreover, all farmers agreed that at the maturity and seedling stages, less water is required. The results reflect what is known in the literature that most vegetables need more water when they flower and are at the early stages of fruit growth (Bradbury, 2010). The varying views on which growth stage requires the most water, suggest that farmers in the same region and planting similar crops have different levels of water footprint. In some instances, this may lead to farmers applying water uniformly at different stages of butternut production as observed by Fanadzo *et al.* (2010) in South Africa. The authors observed that farmers in the Eastern Cape Province, South Africa, did not consider the crop type and growth stage in irrigation scheduling, instead, farmers observed the condition of the soil and the crops as the basis for irrigation decisions. Lack of knowledge of the appropriate amount of water required at the different stages of butternut production leads to over-irrigation in the early growth stages and under-irrigation in the later growth stages (Fanadzo *et al.*, 2010). This has a negative impact not only on the quality of the crops but also on the water footprint of butternut.

5.5 Conclusions

Most farmers believed that flowering and fruit formation stages for both butternut and tomato consumed or required the most water. On the contrary, maturity and seeding stages were generally perceived by all farmers to require less water,although, there was a significant number of farmers who believed that all stages need the same amount of water. In light of the above, it can be said that most farmers at the Nwanedi irrigation scheme know the amount of water required at different stages of production based on their experience. This implies that the application of this knowledge by farmers will result in water use efficiency and a reduction in crop water footprint. Those farmers who believe that butternut and tomato require the same amount of water regardless of the growth stage are prone to have a significant effect on the water footprint, hence, knowledge on methods, such as deficit irrigation should be transferred and inculcated into farmers to reduce water footprint, thereby, guard against water wastage.

CHAPTER 6: ASSESSING WATER FOOTPRINT REDUCTION STRATEGIES USED IN BUTTERNUT AND TOMATO PRODUCTION IN LIMPOPO PROVINCE, SOUTH AFRICA

Abstract

Increasing population and climate change are forecasted to exacerbate the pressure on the available water resources. Irrigated production has the largest water footprint in crop production, therefore, it is expected that irrigation water requirements would increase by 70–90% by 2050. This threatens the stability of the global water availability and agricultural crop production with negative effects, on present and future global food and nutrition security. The study investigated the water footprint reduction strategies adopted by horticultural farmers at different stages of crop growth for butternut and tomato. A descriptive explorative study was conducted and data were collected from farmers at the Nwanedi irrigation scheme in Limpopo Province, South Africa. Data were analysed thematically based on the crop growth stages. The results revealed that there were distinct water-saving strategies commonly used in different growth stages for both tomato and butternut and those that were specific to each growth stage and crop. At the seeding stage, for example, nursery, seed soaking, and choice of crop variety were the main methods used. In early growth, flowering, fruit formation, fruit growth and fruit maturity used strategies such as mulching, drip irrigation, irrigation monitoring and watering-time optimisation were used variedly and in combination. The study recommends the intensification and adoption of more innovative water reduction strategies, particularly during the flowering and fruit formation stages, on both crops.

Keywords: Butternut, crop production, horticulture, tomato, strategies, water scarcity, water footprint

6.1 Introduction

Water footprint measures humanity's appropriation of fresh water in volumes of water consumed and/or polluted (Hoeskstra & Mekonnen, 2012). The water footprint of a country includes the volume of water needed to produce goods and services. The current and forecasted water challenges prompted the need to understand and establish the best water use practices for efficient water reduction strategies (Rogers *et al*., 2020). Agriculture and horticultural practices consume most water (Spitsov *et al*., 2020), thus, evaluating and developing strategies for reducing the water footprint of different crops are critical to reduce water consumption and ensure sustainable water use. The present study investigated the water footprint reduction strategies used in the production of tomato and butternut vegetables. The results would help farmers and practitioners to identify opportunities and challenges that exist with different water footprint reduction options. In addition, such an evaluation equips governments and organisations with tools and an understanding of water usage in the production processes.

Irrigation is the most preferred water source for many horticultural producers as an alternative to rain-fed water in semi-arid and arid regions like South Africa (Fanadzo & Ncube, 2018), however, there are different irrigation systems, such as flooding, furrow, sprinkler and drip system; all these methods have different water footprints. To alleviate the increasing water scarcity, exploiting available options for exploitation of irrigation and groundwater is necessary. Optimization of field and irrigation management forms part of the critical components of this endeavor.

Drip irrigation, for instance, can reduce water use by 30-70% and raise crop yields by 20-90% (Wang, 2021). As a result, it is the preferred water reduction option by many governments in most countries including sub-Saharan Africa. For example, in Morocco, the government aims to equip 700, 000 hectares or 50% of total irrigated land with drip technology by 2022 (Khan *et al*., 2019). Algeria has attained 300 centimeters which are less than the 500 cu meters' threshold for the UN's definitions of absolute water scarcity (Bouchentouf & Benabdeli, 2021). In 2018, areas using water-saving methods in irrigation grew from 90 000 hectares in the year 2000 to 600 000 hectares (Bouchentouf & Benabdeli, 2021). In addition, precision farming expanded rapidly between 2007 and 2017, and in 2019, 70-80% of new farming equipment used globally contained precision agriculture components (Hamad *et al*., 2020). This shows the level of commitment by international and regional governments in reducing water footprint. Recently farmers are increasingly adopting more innovative technologies such as subsurface drip or variable rate drip irrigation systems, however, their limited use prompts the need for studies on the perceptions of farmers on water saving techniques currently employed.

South Africa faces acute water scarcity due to drought, degradation of surface water resources, and the increasing demand for water for agriculture, which must meet the growing food demands of an increasing population (Crookes *et al*., 2018). Limpopo Province is one of South Africa’s richest agricultural areas; it is a major producer of vegetables. The subtropical climate gives rise to the cultivation of tea, coffee and fruits, especially, tropical fruits (Molekoa, 2021), however, water scarcity is among the major challenges in the province due to aridity conditions like low and unreliable rainfall (Rankoana, 2020). These negatively affect the agricultural sector, resulting in decreased agricultural output. According to Meissner *et al*., (2017), the government in South Africa has established catchment management agencies (CMAs) across the country; these agencies help to develop and implement strategies to protect, control, manage and conserve water resources. Meissner *et al*. (2017), state that both farmers and the processing industry need to get more involved in the management of South Africa's water resources to ensure the overall efficiency of water use. It is against this background that this study intends to propose strategies for reducing water footprint in the production of tomatoes and butternut, at the Nwanedi irrigation scheme.

6.2 Methodology

A descriptive explorative design was followed in this study. The full details of the methods and techniques applied in the present study are discussed in the methodology section, Chapter 3.

6.3 Results

6.3.1 Water footprint reduction strategies

This section presents the strategies used by farmers in different stages of crop production to reduce or minimise water use. The production stages are divided into early plant growth and fruition; under these headings, there are subheadings for each crops' growth stage within a broader category.

Table 6.1 shows that farmers use several strategies to manage and minimise water usage at different stages of butternut and tomato production. At early growth stages (seed germination), techniques such as seed soaking, nursery usage (planting pits), appropriate setup of irrigation equipment, use of drought-resistant seeds and thorough soil preparation were common in the production of tomatoes. In comparison, the use of soluble fertilisers was mentioned as a strategy for water use reduction in butternut production. Methods such as mulching, optimizing watering times, and use of soluble fertilizers, were mentioned for both tomatoes and butternuts.

Table 6.1: Water Reduction steps taken by farmers to reduce water footprint in the seeding and early growth stages of tomato and butternut production

	Tomato		**Butternut**	
	Water-saving practices		Water-saving practices	
Seed Germination	Adequate soil preparation	"Planting seeds on good quality soil because it can hold moisture better" (**Participant 1**).	Mulching.	"Applying chopped leaves around the plant" (**Participant 1**). "Shading the soil with black polythene plastic and irrigating early in the morning" (**Participant 27 & 43**).
	Use of drought-resistant seeds		Watering times optimising	"Irrigating early in the morning, less water is lost to evaporation" (**Participant 9**)
	Seeds soaking	"Soaking the seeds in water before planting, allows them to germinate faster" (**Participant 2**).	Use of soluble fertilisers (**Participants 4)**	
	Setting the drip irrigation appropriately	"Plant the seed close to the drip line" (**Participant 4**)		
	Watering times optimization			
	Mulching	"Using polythene plastic to cover the soil, this keeps the soil moist for a longer period" (**Participant 19**).		
	Use of a nursery	"Creating planting pits for seeding, they trap runoff and increase soil moisture" (**Participants 13**).		

Early growth	Mulching	“*Apply grass clippings around the base of the plant*” (**Participants 17**). "Covering the soil with landscape fabric, it suppresses weeds at every stage and	Mulching	“*Cover the plant with black plastic and irrigate during late hours to minimise water lost to evaporation*” (**Participant 5**). “Cover the young plant with crop residues”
	Watering times optimization	“Shading the soil with black polythene plastic and irrigating early in the morning” (**Participant 50**).	Watering times optimisation	“*Watering early in the morning and removing weeds. Weed removal reduces the competition for water and ultimately reduces consumption*” (**Participant 21**)

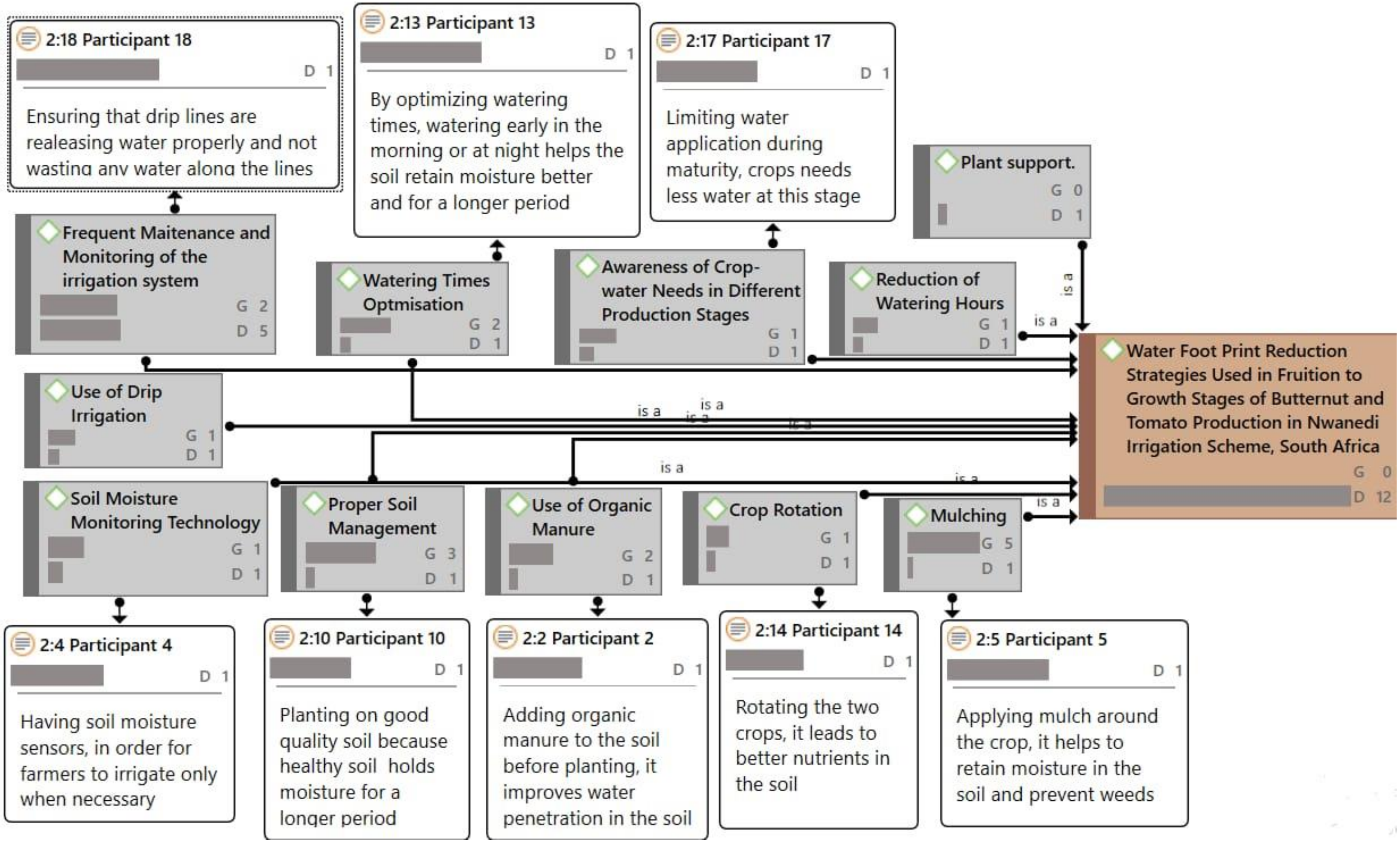

Figure 6.2: Water footprint reduction strategies in Nwanedi irrigation scheme in Limpopo Province, South Africa

The perceived benefits by farmers influenced the methods selection. For example, Respondent 1 said,

"…*Planting seeds on good quality soil because it can hold moisture better.*"

Participant 2 said, "*soaking the seeds in water before planting, allows them to germinate faster*".

Farmers preferred to use a nursery for tomato seed germination, to prevent runoff by trapping water and at the same time increasing soil moisture content for a longer period. Mulching in butternut production involved applying chopped leaves around the plant (Participant 17) and covering the soil with polythene plastic (Participant 27). The results further show that farmers also use different methods in combination as a strategy to achieve maximum water use efficiency and reduce the footprint.

Figure 6.1 shows the Atlas Ti network diagram on the different stages of crop fruition in the production of butternut and tomato using themes and examples of direct quotations from farmers. The results revealed that there were both specific and general methods used at different stages of plant growth to minimise water usage; for example, methods such as frequent maintenance and monitoring of irrigation material, watering times optimisation, knowledge on stage-based crop production water needs, use of organic manure, mulching, and crop rotation were used in most stages of both crops, however, plant support was only relevant to tomato production in all fruition stages. Farmers highlighted that they used strings and stakes to keep the tomato tree straight, thus, allowing them to save water by watering the plant at its base. Apart from the techniques currently used, farmers also said there is a need to consider soil moisture monitoring technology; such technologies help farmers know exactly when each plant needs watering.

Certain water footprint reduction methods and techniques were mentioned for different growth stages of tomato and butternut production and, although these may apply to both butternut and tomato, their mention in each plant or growth stage category might suggest their respective importance.

6.4 Discussion

The results revealed that the flowering and fruit growth stage had the highest water consumption, however, flowering consumed the most water for butternut in comparison to tomatoes. It was revealed that various methods and techniques were used as strategies to reduce the water footprint for butternut and tomato crops.

Farmers relied on irrigation technologies to produce butternut and tomato and the common irrigation technique used was the drip irrigation system. This method is commonly used in most parts of South Africa in irrigation schemes (Mokgatla & Bolton, 2020). These studies show that when the same amount of water is applied using drip irrigation systems, more water is saved and result in better yields compared to furrow and sprinkler systems in vegetable production (Al-Said *et al.*, 2012; Tsakmakis *et al.*, 2017). This suggests that farmers must consider drip irrigation given their circumstances and needs. The adoption of more innovative technologies, such as sub-surface drip or variable rate drip irrigation should be considered given the fact that they further reduce water use compared to a normal drip system (Allen *et al*., 1998). This system achieves maximum crop production as the system supplies the required water that counterbalances evapotranspiration demand.

The results also revealed that knowledge of water requirements for each plant at different stages was effective as a tool for water management and reducing footprint. Such knowledge helps farmers to adopt watering techniques that are suitable for different stages of plant growth, thereby, farmers could schedule and optimise watering times. This practice is linked to deficit irrigation and has the potential to reduce water use per unit of crop yield in comparison to full irrigation strategy (Geerts & Raes 2009; Igbadun *et al*. 2012; Qiu & Meng 2013; Chai *et al*., 2016; Tsakmakis *et al.*, 2017).

The methods and strategies used in Nwanedi also included those commonly used in vegetable production. These included mulching to reduce soil evaporation (Pi *et al.*, 2017); and the use of drip irrigation as ways to increase the fraction of irrigation water reaching the plant (*et al.*, 2001). As the findings of the present study show, farmers at Nwanedi used drought-resistant crops and varieties to reduce vulnerability to water shortages (Hu & Xiong, 2014). Schyns & Hoekstra (2014), as well as Davis *et al.* (2017), show that choosing the right crop or varieties based on the local environmental conditions helps farmers to change spatial cropping patterns. Farmers also interchanged the butternut and tomato with other vegetables to preserve the structure of the soil and enhance its retention. Crop diversification and rotation are reported in the literature as critical in enhancing resilience under water scarcity in the soil (EIP-AGRI, 2016).

The use of an adequate amount of manure was also mentioned as another way in which farmers reduced water use for butternut and tomato production. Over or under-application of manure was perceived to consume more water compared to adhering to the recommended threshold. It was also revealed that organic manure is preferred to synthetic fertilisers as a way to conserve soil moisture. Organic manure is linked to the conservation tillage which is also practiced as a method to improve soil properties and water holding capacity (Azimzadeh, 2012), however, Nouri *et al.* (2019) reveal that the use of organic materials in the surface layer of soil in conservation tillage saves more water than conventional tillage. Chukalla *et al.* (2015) add that organic material provides better conditions for soil aggregation and increases resistance against water and wind erosion, thus, enabling easy moisture infiltration into the soil.

Mulching was another method used by farmers to reduce water loss and it was used in all stages of the production process. Plastic (white or black) and organic material were both techniques used to mulch. Mulching is effective in the production of various crops including vegetables. It significantly improves water storage through shading and leads to warmer soils that hold more water, however, studies show that the use of plastic mulching decreases the content of organic nutrients and has long-term detrimental effects on soil quality (Pi *et al.,* 2017). It was evident from the results that farmers used these strategies variedly and in combination. Combining various methods has the potential to reduce water footprint significantly; for example, Nouri *et al.* (2019) found that mulching reduced the blue water footprint by 3.6% and when combined with drip irrigation, there was an increase of 1.1%. This reflected a saving of about 6.3 million m^3/y on mulching alone and 8.3 million m^3/y in combination.

6.5 Conclusions

The study investigated the strategies used by farmers to reduce water footprint in butternut and tomato production. It emerged that farmers utilised a variety of options to reduce their water footprint in butternut and tomato production. The result revealed that there were methods commonly used in different growth stages for both tomato and butternut, while there were strategies only used for specific growth stages and crop types. At the seeding stage, for example, nursery, seed socking, and choice of crop variety were mentioned as water-saving strategies. Other growth stages, such as early growth, flowering, fruit formation, fruit growth and fruit maturity farmers used strategies such as mulching, drip irrigation, irrigation monitoring and watering time optimisation to reduce water footprint. Based on the result of this study, farmers are required to intensify and adopt innovative water reduction strategies, particularly, during the flowering and fruit formation stages, on both crops.

CHAPTER 7: STUDY SYNTHESIS, CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter presents the study's synthesis of results. It brings together the objectives and shows how the overall aim of the study was achieved. The main objective of the study was to assess the water footprint of butternut and tomatoes in the Nwanedi irrigation scheme in Limpopo Province, South Africa. The key findings per objective are, therefore, presented and discussed in this chapter. Also, the conclusions for the overall study are given before suggesting recommendations.

7.2 Realisation of the study's objectives and questions

The results emerging from each objective/chapter are summarised and presented in the next sections.

7.2.1 To dertermine the water footprint in the production of tomato and butternut at the Nwanedi irrigation scheme

The results revealed that tomatoes had the least water footprint (134.62 m^3/t) compared to butternuts (393 m^3/t). For tomatoes, the water footprint ranged from 88 m^3/t to 180 m^3/t, while for butternut it ranged from 232 m^3/t to 609 m^3/t. In terms of total water use, the flowering and fruit formation growth stages for both plants used the most water. The results further revealed that as the total production area increases water footprint decreases. The total water footprint for each plant must be known to understand the impact of agriculture on water footprint. The prevailing unpredictable weather patterns characterized by low rainfall and high temperatures are worsening the water problem in semi-arid and arid regions like South Africa. Most water is used in agriculture in sub-Saharan African countries. The study contributes to deepening the understanding into the water use patterns in the production of major crops (tomato and butternut). In particular, horticultural farmers with similar and different characteristics to the Nwanedi Irrigation scheme will benefit by gaining knowledge on water use patterns at the different stages of plant growth. Potentially, strategies to safeguard water security and ensure sustained water use, could be realized.

7.2.2 To assess the perceptions of small-scale farmers regarding water use in tomato and butternut different growth stages at the Nwanedi irrigation scheme

The results revealed that most farmers perceived flowering and fruit formation stages to consume the most water for both butternut and tomato, while seeding and maturity stages consumed the least, although, a significant number of farmers said they generally applied the same amount of water from seed germination to maturity. Most butternut farmers (16) said the flowering stage and 7 Participants said the fruit formation stage demanded the most water. Early and fruit growth stages had an equal number of mentions (n =3). Maturity and seed germination stages were not mentioned by any of the 27 butternut farmers. Tomato also exhibited similar trends in water use in terms of farmer perceptions. The flowering stage had the most scores (30 mentions) by farmers. This might indicate that this stage requires a high amount of water for superior fruit and early fruit development. Butternut and tomato crops form part of every meal in most families and are part of the export market in South Africa. Hence, practical water use experiences of farmers in the production of these crops must be established. This is critical in synthesizing the water footprint figures with views of the everyday users of water. In this way, measures to improve water usage and safeguard water security can be developed.

7.2.3 To propose strategies for reducing water use and footprint of tomato and butternut field crops

The results revealed that there were distinct water-saving strategies that could be used in different growth stages for both tomato and butternut. At the seeding stage, for example, nursery, seed soaking, and choice of crop variety were the main methods used. In early growth, flowering, fruit formation, fruit growth and fruit maturity, strategies such as mulching, drip irrigation, irrigation monitoring and watering time optimisation were used variedly and in combination. The perceived benefits by farmers influenced methods' selection. For example, one farmer said "…*Planting seeds on good quality soil because it can hold moisture better*" while another said, "*soaking the seeds in water before planting, it allows them to germinate faster*". Farmers preferred to use a nursery for tomato seed germination because it prevents runoff by trapping water and at the same time retains soil moisture content for a longer period. These findings present options to farmers, scholars and policymakers on how farmers attempt to reduce water use. This means supporting the preferred methods and assessing which combination yields better results would assist the adoption of more innovative water reduction strategies, particularly, during the flowering and fruit formation stages of both crops.

7.3 Discussions

The result revealed that all the selected farmers were involved in tomato production while a handful also grew or rotated with butternut. Limpopo tomato and butternut farmers produced for both the local and international market, however, majority, of these farmers produced for the local market and their prices, were fixed for tomatoes, although, varied depending on the quality of the output per harvest and other market forces.

It emerged that the water footprint at the Nwanedi irrigation scheme was above the world average. It was found that the tomato water footprint at the Nwanedi irrigation scheme is 134.6 m^3/t. The world average water footprint is 63 m^3/t (Mekonnen & Hoekstra, 2011). In South Africa, Nyambo and Wakindiki (2015) studied irrigation schemes and established an average water footprint of 132 m^3/t for tomatoes. The findings revealed that the blue water footprint range from 88m^3/t to 180m^3/t for tomatoes in the Nwanedi irrigation scheme. In Greece, Evangelou *et al.* (2016) reported a range of 37m^3/t to 131m^3/t and even some countries report variations within the same country; for example, in Spain tomatoes' blue water footprint is reportedly varied (Chico *et al.,* 2010), although, these studies utilised different measurement methods. In addition, the blue water footprint widely varied across the farmers and according to farm size. As the production area for each crop increased the water footprint decreased. Tomatoes had the lowest water footprint compared to butternut. Demographic variables such as gender, age, and level of education of farmers did not influence water footprint, although, smallholder farms have a significantly higher impact on water resources compared to commercial farmers. This result implies that to reduce water footprint and ensure water security in the production of tomatoes and butternut, more effort and attention must be paid to water use practices of farmers with smaller land areas.

Some farmers believed that flowering and fruit formation stages for both butternut and tomatoes consumed or required the most water; on the contrary, maturity and seeding stages were generally perceived by all farmers to require less water and there was a significant number of farmers who believed that all stages need the same amount of water. Literature shows different results such as crops being drought-sensitive at certain growth stages (Doorenbos & Kassam, 1979; Wang *et al*., 2011) and drought-tolerant at other phenological stages (Birhanu & Tilahun 2010; Chen *et al*., 2015). The study findings concur with earlier (Harmanto *et al*., 2005) and recent (Nangare *et al*., 2016) findings that the flowering and fruit formation in tomato production is the most sensitive. On the contrary, Nuruddin *et al.* (2003) note that water stress imposed at fruit growth and maturity stages reduced tomato marketability. Chen *et al.* (2015), as well as Herrero *et al.* (2001), found that the most water-sensitive period for tomatoes is the fruit maturing stage. In light of the above, it can be said that most farmers at the Nwanedi irrigation scheme know the amount of water required at different stages of production based on their experience. The application of this knowledge might improve water use efficiency and reduce water footprint. Those who believe that butternut and tomato require the same amount of water regardless of the growth stage are likely to have a significant negative effect on water use in tomato and butternut production. Exploring more options, like deficit irrigation, would contribute to water footprint reduction. Improving tomato and butternut water-use efficiency needs innovative targeted intervention strategies based on direct farmer experiences, justifying why the techniques used by farmers to reduce water footprint in butternut and tomato production were explored in this study.

The farmers utilised a variety of options and strategies to reduce the water footprint in butternut and tomato production. Different methods and combinations were used in different growth stages for both tomato and butternut. There were also those strategies only used for specific growth stages and crop types. At the seeding stage, for example, nursery, seed socking, and choice of crop variety were mentioned as water-saving strategies. Other growth stages such as early growth, flowering, fruit formation, fruit growth and fruit maturity used strategies such as mulching, drip irrigation, irrigation monitoring and watering time optimisation to reduce water footprint. These methods and strategies used in Nwanedi are commonly used in vegetable production. Mulching is one of the common methods used to reduce unproductive soil evaporation (Pi *et al*., 2017); and drip irrigation helps to increase the fraction of irrigation water reaching the plant (Postel *et al*., 2001). Similar, to the current results, the use of drought-resistant crops and varieties to reduce vulnerability to water shortages is common (Hu & Xiong, 2014). Schyns & Hoekstra (2014), as well as Davis *et al*. (2017), show that choosing the right crop or varieties based on the local environmental conditions helps farmers to change spatial cropping patterns. Farmers also interchanged the butternut and tomato with other vegetables to preserve the structure of the soil and enhance its retention. Based on the result of this study, farmers are required to intensify and implement innovative water reduction strategies, particularly, during the flowering and fruit formation stages, on both crops.

7.4 Conclusion

The study assessed the water footprint of tomato and butternut in the Nwanedi irrigation scheme. The results showed that the South African water footprint is above the world average and that tomatoes had a lower footprint compared to butternut. It was evident that as the production land size increased, water footprint started to decline. In terms of water usage, different stages required a varied amount of water as shown by estimates and perceptions. Farmers are, therefore, encouraged to study these results to explore more options of what could work in their situations. It also emerged that farmers employed a different combination of strategies to manage and reduce water used at individual plants' growth stages; some were specific to growth stages and crop type.

7.5 Recommendations

This section presents recommendations to policy and practices based on the implications of the study findings.

I. Farmers are encouraged to study the presented results with the assistance of researchers and extension officers to understand the concept of water footprint and what steps could be taken to minimise water use in vegetable production.
II. Policymakers can use these findings by observing the challenges and water use patterns of farmers, thereby, they can develop systematic policy arrangements that support farmers to remain productive while promoting water-use efficiency. For example, there could be a policy that introductes programs to farmers that would help them achieve efficient water-saving either by new methods or improving the existing ones already understood by farmers.
III. The concept of water footprint is still elusive, hence, more research is still needed to establish the water footprint among the same type of farmers across regions. Also, exploring strategies used elsewhere to save water or reduce water footprint are also recommended.

7.6 Future research work

Conducting similar studies in other regions and areas will assist in better informing relevant stakeholders, farmers and policymakers.

Studies should be conducted to determine user-friendly but efficient ways of measuring water use as farmers determine water-use, user experience and estimations. This should be augmented by farmers training in measuring water use in crop production to support applied research and enhance impact.

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LIST OF APPENDICES

Appendix 1: Research Questionnaire

Determining Water Footprint of Tomato and Butternut Production Towards Enhanced Water Security at Nwanedi Irrigation Scheme

The information provided by participants is strictly confidential. It will be protected and used for research purposes only. The dignity and self-respect of participants will be maintained and the culture for each participant in the community will be upheld to the maximum. Participation in the interview is not compulsory but voluntary.

Section 1: Participants Profile

1.1 General information

Contact details	
Date	

1.2 Socio- Economic Characteristics

1.2.1 Gender

Male	1.	
Female	2.	

1.2.2 Age

<18	1.	
19-25	2.	
26-34	3.	
35-42	4.	
43-51	5.	
52-59	6.	
≥60	7.	

1.2.3 Level of education

No formal	1.	
Primary level	2.	
Secondary level	3.	
Matric Level	4.	

Tertiary level	5.	
Abet	6.	

1.2.4 Years involved in farming

1-5	1.	
6-10	2.	
11-15	3.	
16-20	4.	
21-25	5.	
26-30	6.	
21-35	7.	
36-40	8.	
41-45	9.	
46-50	10.	
51-55	11.	
56-60	12.	
≥61	13.	

1.2.5

Crops	Total area under production	Anticipated Yields
1. Tomato		
2. Butternut		

Section 2: Water footprint of selected field crops

2. To determine the water footprint for tomato and butternut at Nwanedi irrigation scheme

2.1 What is the amount of water consumed in the growth stages of tomato and butternut?

Crop	Amount of water consumed				
	Seed germination	Early growth	Fruit formation	Mature fruiting	Pack house (Sorting and packaging)
Tomato					
Butternut					

2.2 What are the possible water challenges affecting the water needed by tomatoes in the following stages of production and how does it affect crop growth?

Stage	Possible water challenges affecting the water needed by tomato	How development and growth of tomato is affected
Seeding germination		
Early growth		
Fruit formation		
Mature fruiting		

2.3 What are the possible water challenges affecting the water needed by butternut in the following stages of production and how does it affect crop growth?

Stage	Possible water challenges affecting the water needed by butternut	How development and growth of butternut is affected
Seed germination		
Vine growth		
Fruit germination		
Mature fruiting		

2.4 How many times in a year do you often grow tomatoes?

2.5 What is the estimated amount of tomato consumed in your household?

2.6 How many times in a year do you grow butternut?

2.7 What is the estimated amount of butternut consumed in your household?

2.8 Where do you sell your produce?

Crops	1. Farm gate	2. Local	3. National	4. Export market
Tomato				
Butternut				

2.9 How much do you sell each crops for?

Crops	Selling price	Income per year
1. Tomato		
2. Butternut		

Section 3: Farmers perception on water footprint

3. **To assess the perception of small-scale farmers regarding water footprint of tomato and butternut at Nwanedi irrigation scheme**

3.1 Which growth stage of tomato is most sensitive to water and why?

3.2 Which growth stage of butternut is most sensitive to water and why?

3.3 Does the quality of water satisfy the requirements of growing tomato and butternut?

3.4 If not, what are the water quality issues affecting the production of tomato and butternut?

3.5 What can be done to solve the water quality issues?

3.6 Is the amount of available water sufficient for growing your crops?

3.7 If not, what do you think causes insufficiency in terms of the water available to grow your crops?

3.8 What can be done to improve the amount of water available to grow your crops?

3.9 If all these strategies are implemented, do you think your crop yield will increase?

3.10 How can water consumption of tomato and butternut be reduced for enhanced water security?

3.11 Why is it important to minimize water consumption in crop production?

3.12 In your own understanding, how is crop production associated with contamination of water resources?

3.13 Which activities are perceived to contribute significantly to the contamination of water resources in crop production of tomato and butternut?

Section 4: Proposed strategies

4. To propose strategies for reducing water footprint of selected field crops.

4.1 Which strategies can be implemented to reduce water footprint in the following stages of tomato production?

4.1.1	Seeding	
4.1.2	Early growth	
4.1.3	Fruit formation	
4.1.4	Mature fruiting	
4.1.5	Pack house (Sorting, grading and packaging)	

4.2 Which strategies can be implemented to reduce water footprint in the following stages of butternut production?

4.2.1	Seeding	
4.2.2	Early growth	
4.2.3	Fruit formation	
4.2.4	Mature fruiting	
4.2.5	Pack house (Sorting, grading and packaging)	

Appendix *2*: Water Footprint Nwanedi for both butternut and tomato

Hac T	Hac B	YT	YB	WCT S.G	WCT S.G- I	WCT F- F.(	WCT M	WFP T	WCB S.G	WCB S.G-	WCB F- F.(	WCB M	WCB P.H	WFP B
5 h	3 h	300 t	75 t	3600 m3	19200 m3	19200 m3	4800 m3	156 m3/t	1920 m3	10800 m3	12960 m3	4800 m3	600 L	406 m3/t
15 h	10 h	1125 t	280 t	10800 m3	54000 m3	43200 m3	10800 m3	106 m3/t	4800 m3	36 0000m3	43 200 m3	24000 m3	1300 L	308 m3/t
11 h		990 t		7920 m3	39600 m3	31 680 m3	7920 m3	88 m3/t						
5 h	3 h	325 t	66 t	4800 m3	24 000 m3	14400 m3	7200 m3	155 m3/t	1920 m3	10800 m3	12960 m3	1203 m3	306 L	407 m3/t
8 h	6 h	560 t	162 t	5760 m3	28800 m3	23040 m3	11520 m3	123 m3/t	4320 m3	21600 m3	34560 m3	7200 m3	780 L	417 m3/t
3 h	1 h	225 t	25 t	960 m3	10800 m3	6480 m3	4320 m3	101 m3/t	480 m3	3600 m3	4320 m3	1600 m3	240 L	400 m3/t
6h		395 t		2880 m3	28800 m3	17280 m3	8640 m3	146 m3/t						
40 h	20 h	3200 t	600 t	19200 m3	144000m3	86400 m3	57600 m3	96 m3/t	9600m3	48000 m3	57600 m3	24000 m3	2400 L	232 m3/t
12 h	6 h	800 t	168 t	7200 m3	48000 m3	38400 m3	7200 m3	126 m3/t	4320 m3	21600 m3	25920 m3	7200 m3	780 L	351 m3/t
5h	2 h	300 t	50 t	2400 m3	18000 m3	10800 m3	7200 m3	128 m3/t	1440 m3	7200 m3	8640 m3	4800 m3	204 L	441 m3/t
5 h		400t		4800 m3	32000 m3	19 200 m3	4800 m3	152 m3/t						
10 h		1000 t		7200 m3	48000m3	28800 m3	9600 m3	94 m3/t						
6 h	1 h	360 t	23 t	2880 m3	21600 m3	12960 m3	8640 m3	128 m3/t	720 m3	3600 m3	4320 m3	2400 m3	130 L	480 m3/t
4 h		260 t		1920 m3	19200 m3	15360 m3	2880 m3	151 m3/t						
7 h	2 h	560 t	48 t	5040 m3	33600 m3	26880 m3	10080 m3	135 m3/t	1920 m3	7200 m3	8640 m3	2400 m3		420 m3/t
7 h		490 t		3360 m3	25200 m3	20160 m3	10080 m3	120 m3/t						
5h		300 t	26 t	3600 m3	24000 m3	14400 m3	7200 m3	164 m3/t						
5 h	1 h	375 t		3600 m3	24000m3	19200 m3	7200 m3	144 m3/t	1200 m3	4800 m3	5760 m3	1200 m3		498 m3/t
8 h		640 t		3840 m3	38400 m3	23040 m3	11520 m3	120 m3/t						
5 h		400 t		3600 m3	24000m3	19200 m3	7200m3	135 m3/t						
8h	2h	640t	52 t	3840 m3	38400 m3	30720 m3	7680 m3	126 m3/t	2400 m3	7200 m3	8640 m3	1600 m3	284 L	381 m3/t
9h		720 t		6480 m3	43200 m3	51840 m3	8640 m3	153 m3/t						
12 h		960 t		8640 m3	43200 m3	34560 m3	17280 m3	108 m3/t						
9h		765 t		4320 m3	43200 m3	25920 m3	8640 m3	107 m3/t						
5h		350 t		3600 m3	24000 m3	14400 m3	3600 m3	130 m3/t						
6h		450 t		4320 m3	38400 m3	23040 m3	4320 m3	156 m3/t						
10 h	3 h	650 t	75 t	4800 m3	48000 m3	28800 m3	9600 m3	140 m3/t	2400 m3	10800 m3	12960 m3	3600 m3	200 L	396 m3/t
10 h		800 t		7200 m3	48000 m3	28800 m3	14400 m3	123 m3/t						
	2h		50 t						1280 m3	7200 m3	8640 m3	2400 m3	240 L	390 m3/t
5 h		350 t		3600 m3	24000 m3	19200 m3	4800 m3	147 m3/t						
10 h		650 t		7200 m3	38400 m3	38400 m3	9600 m3	144 m3/t						
3 h	2 h	240 t	56 t	2160 m3	11520 m3	11520 m3	4320 m3	123 m3/t	1280 m3	7200 m3	8640 m3	2400 m3	210 L	348 m3/t
15 h		1200 t		10800 m3	57600 m3	43200 m3	21600 m3	111 m3/t						
5 h		350 t		3600 m3	19200 m3	14400 m3	7200m3	127 m3/t						
10 h		700 t		7200 m3	38400 m3	38400 m3	14400 m3	141 m3/t						
3h		180 t		1920 m3	15360 m3	11520 m3	2880 m3	176 m3/t						
	3h		63 t						1920 m3	14400 m3	17280 m3	4800 m3	195 L	609 m3/t
6h	2h	510 t	58 t	5760 m3	30720 m3	23040 m3	5760 m3	128 m3/t	1280 m3	7200 m3	8640 m3	2400 m3	200 L	336 m3/t
10 h		800 t		7200 m3	48000 m3	38400 m3	14400 m3	135 m3/t						
3 h		195 t		1440 m3	11520 m3	11520 m3	4320 m3	147 m3/t						
7 h	1 h	490 t	20 t	3360 m3	33600 m3	20160 m3	6720 m3	130 m3/t	640 m3	3600 m3	4320 m3	1200 m3		488 m3/t
5 h	2 h	300 t	46 t	2400 m3	19200 m3	14400 m3	4800 m3	136 m3/t	1280 m3	7200 m3	8640 m3	2400 m3	180 L	424 m3/t
4 h	1 h	260 t	28 t	1920 m3	15360 m3	11520 m3	3840 m3	126 m3/t	800 m3	3600 m3	4320 m3	1200 m3	102 L	354 m3/t
5 h		375 t		3200 m3	19200 m3	19200 m3	7200 m3	130 m3/t						
5 h		350 t		2400 m3	19200 m3	14400 m3	7200 m3	123 m3/t						
8 h		600 t		3840 m3	30720 m3	23040 m3	11520 m3	115 m3/t						
6 h	1 h	390 t	30 t	4320 m3	23040 m3	17280 m3	8640 m3	137 m3/t	640 m3	4800 m3	5760 m3	1200 m3	102 L	413 m3/t
2 h		140 t		1280 m3	9600 m3	7680 m3	2880 m3	153 m3/t						
3 h	2 h	180 t	58 t	1440 m3	11520 m3	11520 m3	2880 m3	152 m3/t	1280 m3	7200 m3	8640 m3	2400 m3	200 L	336 m3/t
12 h	4 h	960 t	116 t	5760 m3	46080 m3	34560 m3	17280 m3	108 m3/t	3200 m3	14400 m3	17280 m3	6400 m3	300 L	355 m3/t
11 h		770 t		7920 m3	42240 m3	42240 m3	15840 m3	141 m3/t						
7 h	4 h	455 t	112 t	3360 m3	33600 m3	20160 m3	10080 m3	148 m3/t	2560 m3	14400 m3	17280 m3	4800 m3		348 m3/t
4 h		260 t		1920 m3	15360 m3	15360 m3	5760 m3	147 m3/t						
6 h		360 7		3840 m3	30720 m3	23040 m3	5760 m3	176 m3/t						
6 h	2 h	480 t	60 t	4320 m3	28800 m3	23040 m3	8640 m3	135 m3/t	1280 m3	7200 m3	8640 m3	3200 m3	180 L	338 m3/t
15 h		1050 t		7200 m3	72000 m3	57600 m3	21600 m3	151 m3/t						
4 h	1 h	300 t	28 t	1920 m3	15360 m3	15360 m3	5760 m3	128 m3/t	640 m3	3600 m3	4320 m3	1600 m3	100 L	362 m3/t
5 h		300 t		3600 m3	24000 m3	19200 m3	7200 m3	180 m3/t						
8 h		560 t		5760 m3	38400 m3	30720 m3	7680 m3	147 m3/t						
6 h	2h	390 t	54 t	2880 m3	28800 m3	23040 m3	5760 m3	155 m3/t	1280 m3	7200 m3	8640 m3	3200 m3	200 L	376 m3/t

Appendix 3: Ethical Clearance

ETHICS APPROVAL CERTIFICATE

RESEARCH AND INNOVATION
OFFICE OF THE DIRECTOR

NAME OF RESEARCHER/INVESTIGATOR:
Ms RT Lebepe

STUDENT NO:
14014012

PROJECT TITLE: Determining Water Foot Print of Tomato and Butternut production towards Enhanced Water Security at Nwanedi Irrigation Scheme.

ETHICAL CLEARENCE NO: SARDF/20/IRD/ 08/1412

SUPERVISORS/ CO-RESEARCHERS/ CO-INVESTIGATORS

NAME	INSTITUTION & DEPARTMENT	ROLE
Dr M Manjoro - Mwale	University of Venda	Supervisor
Dr S Kativhu	University of Venda	Co-supervisor
Prof B Nkhata	Independent Institute of Education (IIE) Monash	Co-supervisor
Ms. RT Lebepe	University of Venda	Investigator - Student

Type: **Masters Research**
Risk: **Straightforward research without ethical problems**
Approval Period: **December 2020 – December 2022**

The Animal, Environmental and Biosafety Research Ethics Committee (AEBREC) hereby approves your project as indicated above.

General Conditions
While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following.

- The project leader (principal investigator) must report in the prescribed format to the REC:
  - Annually (or as otherwise requested) on the progress of the project, and upon completion of the project
  - Within 48hrs in case of any adverse event (or any matter that interrupts sound ethical principles) during the course of the project.
  - Annually a number of projects may be randomly selected for an external audit.
- The approval applies strictly to the protocol as stipulated in the application form. Would any changes to the protocol be deemed necessary during the course of the project. The project leader must apply for approval of these changes at the REC. Would there be deviated from the project protocol without the necessary approval of such changes, the ethics approval is immediately and automatically forfeited.
- The date of approval indicates the first date that the project may be started. Would the project have to continue after the expiry date; a new application must be made to the REC and new approval received before or on the expiry date.
- In the interest of ethical responsibility, the RECs retains the right to:
  - Request access to any information or data at any time during the course or after completion of the project.
  - To ask further questions; Seek additional information; Require further modification or monitor the conduct of your research or the informed consent process.
  - withdraw or postpone approval if:
  - Any unethical principles or practices of the project are revealed or suspected.
  - It becomes apparent that any relevant information was withheld from the REC or that information has been false or misrepresented.
  - The required annual report and reporting of adverse events was not done timely and accurately.
  - New institutional rules, national legislation or international conventions deem it necessary

ISSUED BY:
UNIVERSITY OF VENDA, RESEARCH ETHICS COMMITTEE
Date Considered: October 2020

Name of the AEBREC Chairperson of the Committee: Prof IEJ Barnhoorn

UNIVERSITY OF VENDA
OFFICE OF THE DIRECTOR
RESEARCH AND INNOVATION
2020 -12- 14
Private Bag X5050
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Signature: ....

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