

**RESPONSES OF ORANGE FLESHED SWEET POTATO (*Ipomoea batatas L.Lam*)
VARIETIES TO DEFICIT IRRIGATION IN TANZANIA**

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**A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
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EXTENDED ABSTRACT

Climate change has put a strain on water resources in most parts of the world. Water, on the other hand, is a critical input for agricultural production and plays a critical role in food security. As a result, the risk of various forms of malnutrition has increased, potentially leading to under nutrition as well as overweight and obesity, which is likely to worsen further due to the health and socioeconomic effects of Covid-19. Thus, the importance of producing food to improve nutrition security is obvious, as it is a promising approach to combating malnutrition. However, improving food production is faced with the challenge of water scarcity, especially in sub-Saharan Africa. Methods that enhance efficiency in water use are promoted to improve food production. Deficit irrigation (DI) strategies in pressurized irrigation systems are beneficial in reducing applied irrigation water and nutrient loss through leaching, as well as crop vegetative vigour. This strategy is useful for dealing with water scarcity and improving water productivity. This study used field experimentation to assess the effects of deficit irrigation on orange-fleshed sweet potato storage root yield, water productivity, and nutritional water productivity, as well as the financial implications in Tanzania. Orange fleshed sweet potato (OFSP) varieties are documented to offer a balanced nutritional composition, mature early and can withstand marginal conditions where other crops fail.

To achieve the intended goal, three irrigation rates were used for scheduling: 100 per cent (Full irrigation (FI)), 60 per cent (60 DI), and 30 per cent (30 DI) of total available water (TAW) in a factorial arrangement of treatments laid out in a randomized complete block design (RCBD), with Naspot-13 and Jewel of orange-fleshed sweet potato crop as test varieties. A 3 x 2 factorial design with three replications was used. When 20 per cent of the total available water (TAW) was depleted, the FI treatment was irrigated to 100 per cent field capacity, whereas the 60 DI and 30 DI treatments received 60 per cent and 30 per cent of the amount applied in the FI treatment, respectively. A drip irrigation system was used to apply irrigation water using a continued deficit irrigation strategy. The strategy was implemented eight days after the plants were planted. Analysis of Variance was performed on response variables data and treatment means separated using Tukey's multiple range test at $p < 0.05$.

The first goal was to evaluate the yield, water productivity, harvest index, and dry matter content of OFSP varieties subjected to deficit irrigation. The fresh yields were harvested 120 days after planting then weighed and weight converted to tons per hectare. In this

study, only marketable storage roots were considered. Marketable storage roots were defined as storage roots weighing 100 g or more and free of defects caused by diseases or mechanical damage. The dry matter content of the test varieties was determined by drying peeled and sliced OFSP in a solar drier for 48 hours at a temperature of 62.4 °C.

The second goal was to evaluate the nutritional root quality parameters and nutritional water productivity of OFSP varieties in response to deficit irrigation. To obtain an analytical sample, four medium-sized orange-fleshed sweet potato varieties were homogenized in a food processor. The analytical sample was extracted for 1 minute with methanol: tetrahydrofuran (THF) (1:1) and then filtered into petroleum ether (PE), as described by Rodriguez-Amaya and Kimura (2004). An Atomic Absorption Spectrophotometer (ASS) was used to determine the iron and zinc micronutrient content of a portion of the analytical sample, as described by AOAC (2002).

The third goal was to evaluate the production economics of drip-irrigated OFSP varieties subjected to deficit irrigation. The benefit-cost ratio (BCR) analysis is a financial measure of the value of a project. The economic return analyses of the production system of OFSP varieties under each irrigation regime were calculated using BCR in this study. However, BCR components including the capital cost of a drip irrigation system and the gross and net return of each irrigation regime were estimated assuming a field area of one hectare and flat land.

According to the results of the first objective, the Naspot-13 variety demonstrated a high yielding ability to water stress, recording 17 t/ha, whereas the Jewel variety recorded 9 t/ha of storage root yield. The Jewel variety produced the most storage root yield, with the highest at 25 t/ha during the first season, while the Naspot-13 variety performed poorly. This could be attributed to the rain effect that occurred during the first season. Under deficit irrigation, the varieties' water productivity (WP) and harvest index (HI) increased. The varieties' WP ranged from 1.8 to 11.0 kg/m³, and their HI ranged from 52 to 58 per cent. Both varieties' dry matter content ranged from 23 to 31 per cent and was statistically similar. The fresh above-ground biomass decreased significantly as the amount of water applied decreased. According to the findings of the study, the Naspot-13 variety can be strategically used as a feasible crop for producing more food with less water.

In the second objective, it was discovered that the beta-carotene content of the Jewel cultivar was 27 per cent higher than that of the Naspot-13 cultivar. Iron and zinc concentrations in both cultivars were found to be sufficient and minimal respectively. Otherwise, when deficit irrigation was compared to full irrigation, neither cultivar's root

quality changed. All the same, a typical serving (125g) of test OFSP varieties provides more than 100% of the vitamin A, sufficient iron, and minimal zinc dietary requirements for 4-8-year-old children and 10-50-year-old pregnant women. In general, the nutritional water productivity of root quality parameters increased as water application decreased. Finally, a positive water-food-nutrition nexus was established under the Naspot-13 variety, which is capable of alleviating Vitamin A, and iron as well as minimising zinc deficiency health-related problems, particularly in children and pregnant women living in areas with limited water resources.

The results of the third objective show that a net positive return using the benefit-cost ratio (BCR) was observed, with the highest net financial return (6516 US \$ per ha) observed for the Naspot-13 variety at the 60 DI deficit strategy. As a result, for Naspot-13 cultivation using drip irrigation in sandy-clay soils, the 60 DI strategy is a more cost-effective option than full irrigation. However, in the case of water-limiting situations, the highest net financial return was observed under Jewel variety at 30DI treatment (8404 US \$). In summary, the findings in this study indicated that the production of OFSP for deficit irrigation is economically feasible.

DECLARATION

I, MAKAMA ARNOLD OSORE, do hereby declare to the senate of Sokoine University of Agriculture that this dissertation is my original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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Date

The above declaration is confirmed by;

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Prof. Nganga I. Kihupi

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Date

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Dr. Winfred B. Mbungu

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Date

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Above all, praise be to the Almighty God.

DEDICATION

To my late father, Terah Osore, “for the support, passion and dream of seeing his children excel” “Aluta continua.”

To my daughter, Bernice, “you are the salt that flavours my strides”.

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LIST OF ABBREVIATIONS AND SYMBOLS

AOAC	Association Official Analytical Chemists
BCR	Benefit-Cost Ratio
CIP	International Centre Potato
EAC	East African Community
FAO	Food and Agricultural Organization
IFAD	International Fund for Agricultural Development
KFW	Kreditanstalt Fur Wiederaufbau
OFSP	Orange Fleshed Sweet Potato
RAE	Retinol Activity Equivalent
RCBD	Randomized Complete Block Design
SDGs	Sustainable Development Goals
SUGECO	Sokoine University Graduate Entrepreneurs Cooperative
TAW	Total Available Water
TMA	Tanzania meteorological Authority
UNESCO	United Nations Educational Scientific and Cultural Organization
UNICEF	United Nation's Children Fund
USDA	United States Department of Agriculture
WFP	World Food Programme
WHO	World Health Organization

CHAPTER ONE

1.0 Introduction

Sweet potatoes are one of the world's most important food crops, particularly in Sub-Saharan Africa, parts of Asia, and the Pacific Islands (CIP, 2021). Sweet potatoes can grow from sea level to 2500 meters in altitude. They require fewer inputs and labour than other crops and can withstand adverse growing conditions such as dry spells and poor soils (CIP, 2021; HKI, 2012).

Orange fleshed sweet potato (OFSP) varieties have been bred to withstand drought impacts (Agili *et al.*, 2012), and their importance as a food crop and income generator is rapidly growing, even though their short shelf-life limits marketing thrive (Flores and Cruz, 2017). The crop has the potential to alleviate most forms of malnutrition, including vitamin A deficiency, particularly in children, as well as zinc deficiency and iron deficiency in adolescent girls and pregnant women (Neela and Fanta, 2019).

According to WHO (2002), nutrition is defined as the intake of an adequate amount of energy nutrients to the body's needs for normal growth, development, and active and healthy life. Many agricultural interventions fail to achieve nutrition outcomes because agricultural research programs and policies place little emphasis on maximizing nutrition output from farming systems (Berti *et al.*, 2004).

Climate change has put a strain on water resources in most parts of the world (Consoli *et al.*, 2016). On the other hand, water is a critical input for agricultural production and plays a critical role in food security (Anandhi *et al.*, 2016). Therefore, due to water scarcity and climate change, sustainable food production has gained attention to ensure more nutrition per water drop, giving rise to the nutritional water productivity concept (Chibarabada *et al.*, 2017). According to Chibarabada *et al.* (2017), nutritional water productivity is a measure of a crop's yield and nutritional performance per unit of water consumed. In addition, since water productivity is a powerful indicator of land use productivity under limited water resources, deficit irrigation strategies have been recommended to improve water productivity as reported by Ben-Gal *et al.* (2021) in their study albeit two olive oils cultivars. However, studies on the orange-fleshed sweet potato to deficit irrigation strategies in the wake of climate change are limited.

Furthermore, profitability analysis of sweet potato production conducted in Odisha, India by Prakash *et al.* (2016) revealed that sweet potato farmers profited. Therefore, economic analyses of crops grown in areas with limited land and water resources provide policymakers with information for better irrigation management planning (Ali *et al.*, 2007). However, few studies on the economic return of OFSP to deficit irrigation have been conducted. As a result, this study used field experimentation to assess the effects of deficit irrigation on OFSP storage root yield, water productivity, and nutritional water productivity, as well as the crop production financial implications in Tanzania.

1.1 Justification

Malnutrition in all its forms is a global problem, with the worst effects felt in developing countries. The significance of food production in improving nutrition security is obvious, as it is a promising approach to combat malnutrition. The purpose of this study was to add to the current body of knowledge about the importance of using water productivity and nutritional water productivity in prioritizing limited water resources in agriculture in order to save water and provide more nutrition per water drop. The data gathered will be used to provide informed advice to smallholder farmers who have access to irrigation, as well as to lay the groundwork for policy planning regarding irrigation management in order to maximize net financial returns from limited land and water resources.

1.2 Objectives

1.2.1 Main objective

The main objectives of this study were to evaluate the responses of orange-fleshed sweet potato varieties and the production economic analysis of drip-irrigated orange-fleshed sweet potatoes under deficit irrigation strategies.

1.2.2 Specific objectives

The specific objectives of the study were, to:

- i). Assess the yield, harvest index and dry matter content of the OFSP varieties under deficit irrigation.
- ii). Evaluate the nutritional root quality parameters and nutritional water productivity of OFSP varieties under deficit irrigation.
- iii). Evaluate the economic analysis of drip-irrigated OFSP production under deficit irrigation.

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CHAPTER TWO

2.0 Water productivity response of orange fleshed sweet potato (*Ipomoea batatas* L.Lam) varieties to deficit irrigation

2.1 Abstract

Continued deficit irrigation (CDI) is beneficial in reducing applied irrigation water and nutrient loss through leaching, as well as excessive vegetative vitality. This strategy is useful when dealing with water scarcity and improving water productivity. A study was conducted to assess the water productivity of drip-irrigated orange-fleshed sweet potato varieties to deficit irrigation. The purpose of this study was to i) assess the hydraulic performance of the drip irrigation system, and ii) evaluate the effect on the yield of orange-fleshed sweet potato and their water productivity under deficit irrigation (DI). Three irrigation rates were used for scheduling: 100% (full irrigation), 60% (60 DI), and 30% (30 DI) of total available water (TAW). A factorial arrangement of treatments was laid out in a randomized complete block design (RCBD), with Naspot-13 and Jewel as test varieties. The hydraulic parameters evaluated were the emission uniformity (EU), coefficient of variation (CV), emission flow variation (EFV), and coefficient of uniformity (CU). The results show values of EU, CV, EFV, and CU of 92%, 0.02, 12% and 99.76%, respectively, and were found to be acceptable under the ASABE standard. Both varieties' dry matter content ranged between 23 and 31% and was statistically similar. The results of yield for the Naspot-13 variety were statistically similar in both seasons at all levels of water application. The Jewel variety produced two times more yield in season 1 than in season 2 at all levels of water application. Generally, the water productivity and harvest index of the test varieties increased under deficit irrigation. Similarly, the amount of fresh above-ground biomass was significantly reduced with a decrease in water application. According to the study findings, the Naspot-13 variety can strategically be used as a feasible crop for producing more food from fewer water resources in areas prone to water scarcity.

Keywords: Deficit irrigation, Naspot-13, Jewel, water productivity, Drip irrigation

2.2 Introduction

Water is a critical input for agricultural production and significantly plays a pivotal role in food security. However, in recent times, there has been a growing awareness that the competition for water resources is expected to increase due to population growth,

urbanization and climate change, with a particular impact on agriculture (Anandhi *et al.*, 2016; Chartzoulakis and Bertaki, 2015). Predictions suggest that the world population might exceed nine billion people by 2050, requiring 70% more food and 80% more water to meet its basic needs (Albrecht *et al.*, 2018). Therefore, the need to improve agricultural productivity and develop sustainable water management techniques is paramount (Anandhi *et al.*, 2016).

According to Consoli *et al.* (2016) increased variability of rainfall, high temperatures and associated extreme weather events such as droughts and floods are the most immediate products of climate change which have an impact on the water for agriculture. Hence, the need for water productivity (WP) and irrigation to be meticulously linked to boost productivity and improve food quality is crucial. This approach is vital, especially for areas prone to water shortages (Du *et al.*, 2015).

Studies, albeit on different crops have shown that deficit irrigation strategies successfully reduce irrigation water applied at the expense of relatively small yield reductions while improving crop fruit or root quality and efficiently managing limited water resources in arid and semi-arid regions (Ben-Gal *et al.*, 2021; Lipan *et al.*, 2019). Therefore, increasing water productivity is gaining popularity as a solution to the problem of rising food demand in the face of limited water resources. The United Nations Sustainable Development Goals (SDGs) acknowledge this by stating that agricultural output should be doubled by 2030 (SDG 2.3) and water productivity should be significantly improved (SDG 6.4) (Mul *et al.*, 2020).

Sweet potato is the sixth most important food crop after rice, wheat, potatoes, maize, and cassava with more than 105 million metric tons produced globally each year (CIP, 2021). Moreover, the crop has the potential to generate income; however, its marketing is limited due to the crop's short shelf-life (Flores and Cruz, 2017). Furthermore, realizing the rewarding benefits of sweet potato is difficult due to a lack of processed product markets, storage facilities, and effective postharvest handling technologies for storing and processing OFSP (Kangile *et al.*, 2020).

However, orange-fleshed sweet potato (OFSP) varieties have been reported to tolerate marginal growing conditions and are a useful disaster recovery crop that often succeeds

when other crops fail as well as having consistent production in short periods (Trancoso-Reyes *et al.*, 2016). Furthermore, orange-fleshed sweet potato has a well-balanced nutritional profile because it is high in beta-carotene, a precursor to vitamin A (Neela and Fanta, 2019).

Tanzania is the leading producer of sweet potatoes in Africa, with an annual production of 4.2 million metric tons, accounting for 3.8 per cent of global sweet potato production (FAO, 2020). The production data for the years 2008 to 2019 show a clear upward trend in sweet potato production and area under cultivation in Tanzania (NBS, 2021). However, as Low *et al.* (2020) report, the achievable yield remains low. Water scarcity is one of the major challenges causing the realization of the intended yield. According to Hatfield *et al.* (2011) in their study, there is an opportunity to enhance water use efficiency through crop selection and cultural practices to offset the impact of a changing climate. Hence, the need for water management in orange-fleshed sweet potato production to make use as well as improve the area under cultivation. Therefore, to understand water productivity in sweet potato production in the face of climate change, the present study aimed at evaluating the response of selected orange-fleshed sweet potato varieties to deficit irrigation in Tanzania to lay the basis for policy planning regarding irrigation management.

2.3 Materials and methods

2.3.1 Study area

2.3.1.1 Location

The field experiment was conducted at the School of Engineering and Technology (SoET) research field in Morogoro, Tanzania (grid zone: 350213.19 E, 9243788.94 N, 37M; 512 m above sea level) (Fig. 2.1).

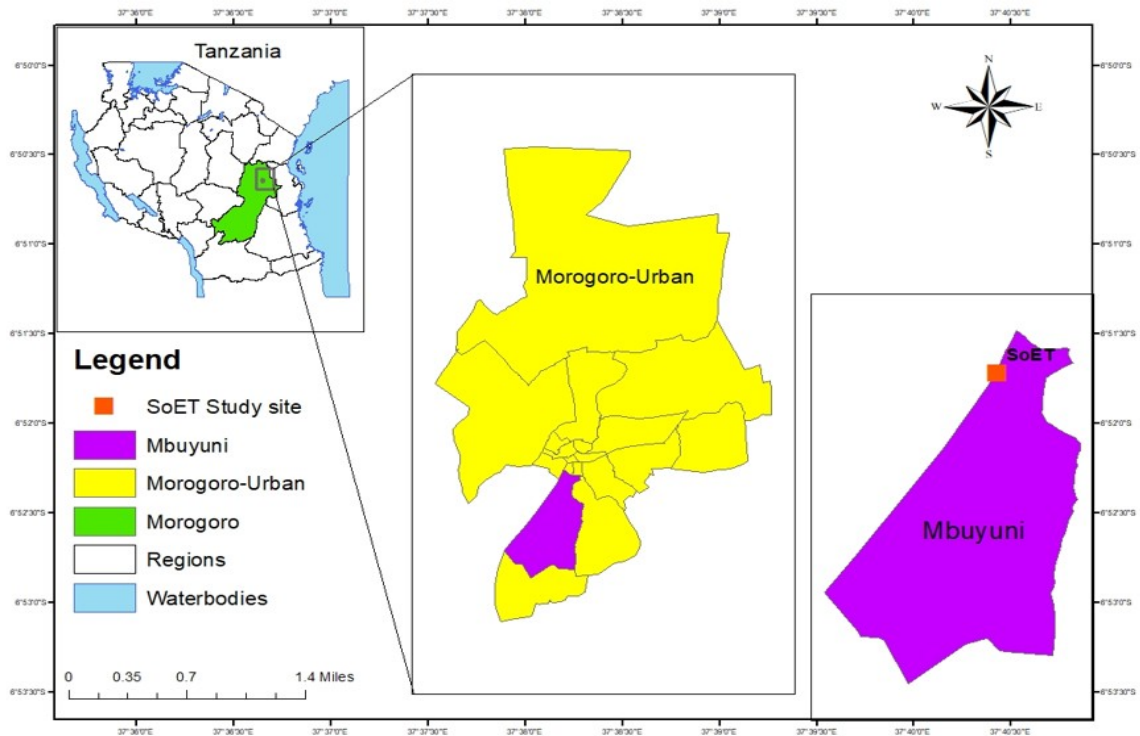


Figure 2.1: Location of study area in Morogoro Region, Tanzania

2.3.1.2 Topography

Morogoro Urban District is bordered by the Uluguru Mountains on the south eastern side and Mindu and Nguru ya Ndege hills on the western side. The district comprises a larger part of plains of various forms and extents. Rainfall in river valleys and basins ranges from 600 mm to 1400 mm per year. Temperatures in this zone are high due to its lowland location, with an average of 30 °C. The zone is densely populated in the upper valleys but less so in the lower valleys.

2.3.1.3 Climate

The distribution of rainfall within the Morogoro urban area is bimodal, with long rains between March and May and short rains between October and December. Fig. 2.2 shows the Morogoro monthly average rainfall frequency for 60 years under normal conditions. The long rains (*Masika*) on average amount to 411.1 mm annually, whereas the short rains (*Vuli*) average 149.8 mm annually (Fig. 2.2). Table 2.1 shows the mean monthly weather data for Morogoro Urban District, Tanzania for 6 years.

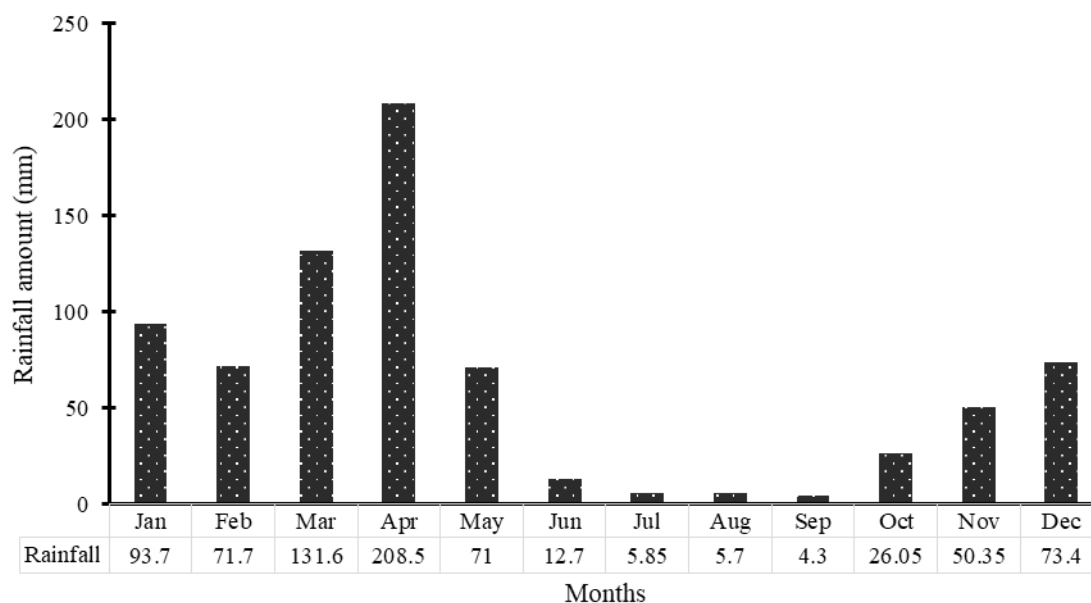


Figure 2.2: Mean monthly rainfall (mm) at Morogoro (1961-2020) (Source: TMA Meteorological Station, 2021)

Table 2.1: Mean monthly weather data within Morogoro Urban (2015-2020)

Month	3 pm RH (%)	Wind (Km/day)	Temperature (°C)		Radiation (MJ/m ²)
			Maximum	Minimum	
JAN	64.1	181.2	32.1	22.1	19.8
FEB	68.2	159.0	32.7	22.2	21.0
MAR	66.3	85.4	32.3	22.0	18.5
APR	75.9	49.4	29.6	21.5	15.2
MAY	72.9	39.9	28.2	19.9	13.9
JUN	64.1	48.2	28.2	16.9	15.4
JUL	64.9	61.7	27.9	16.1	15.2
AUG	53.8	83.7	28.8	17.2	16.4
SEP	50.7	109.7	30.6	17.7	18.2
OCT	51.8	118.7	31.5	19.5	18.2
NOV	57.5	144.9	31.7	21.2	19.7
DEC	58.3	173.5	32.6	22.2	20.0

(Source: TMA Meteorological Station, 2021)

2.3.1.4 Soils

Soils in the Morogoro Region vary according to topology and agro ecological zones. In USDA soil taxonomy, the soil in the experimental area is classified as Ultisol, and in FAO-UNESCO classification, it is classified as Acrisol (Msanya *et al.*, 2003). The

physical and chemical properties of the soil for the top 300 mm layer are shown in Table 2.2. The soil texture is sandy clay, and the clay content in the upper 300 mm of the soil sample profile was 53 per cent. The soil's field capacity was 333 mm/m and the permanent wilting point was 208 mm/m.

Table 2.2: Physical and chemical properties of the topsoil layer (0 - 300 mm) at the experiment site SUA, Morogoro Region

Soil parameters	Unit	Range per 300 mm	Remarks
Soil pH (H ₂ O)		5.19 – 5.96	weak acidic soils
Electrical Conductivity ^a	μS/cm	117 – 207	non saline
TN-Kjeld ^c	mg kg ⁻¹	900 – 1300	Low
Ext. Phosphorous(PBry-1) ^b	mg kg ⁻¹	0.58 – 1.43	Low
Zinc ^d	mg kg ⁻¹	0.21 – 0.86	Low
Iron ^d	mg kg ⁻¹	17.06 – 22.07	High
Clay ^e	%	54.48 – 53.48	
Silt ^e	%	0.32 – 1.68	
Sand ^e	%	43.84 – 46.20	

The range represents different sampling points within the experiment field

^a1:2:5 w/v method (Ayers and Westcot, 1985)

^bBray 1 method (FAO, 2021)

^cKjeldahl method (Bremner, 1960)

^dDTPA extraction method (Lindsay and Norvell, 1978)

^eSieve and pipette method

2.3.2 Experimental setup, treatments, randomisation

2.3.2.1 Experimental setup

The experimental schematic layout of the irrigation system network is shown in Fig. 2.3. The experiment was conducted over two seasons, i.e., the 2020/21 and 2021 seasons. A factorial arrangement of treatments was laid out in a randomized complete block design.

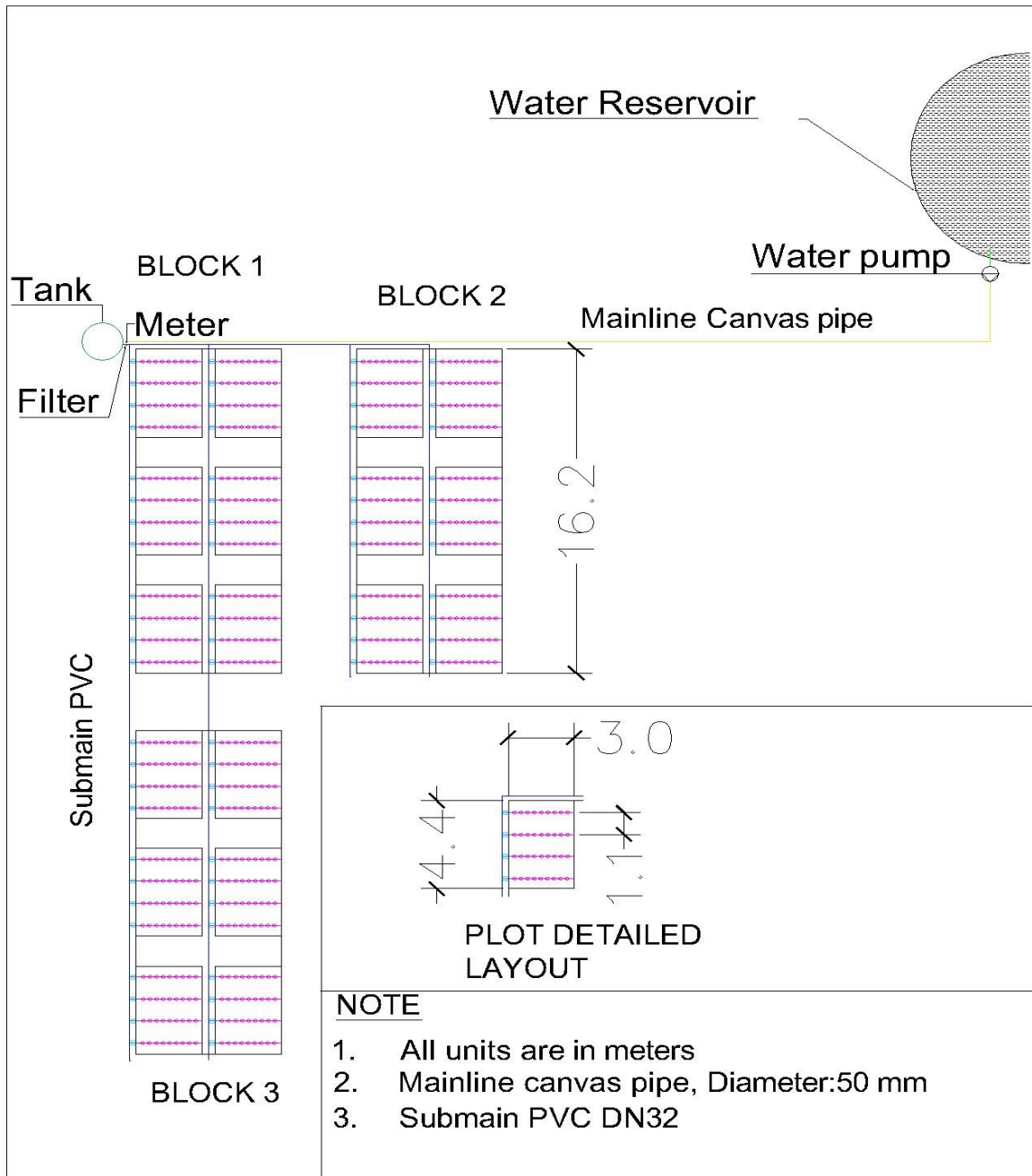


Figure 2.3: Experimental schematic layout of the irrigation system network

2.3.2.2 Treatments

The test varieties were Naspot-13 and Jewel of the orange-fleshed sweet potato crop. The water application regimes were 100 per cent (Full irrigation (FI)), 60 per cent (60 DI), and 30 per cent (30 DI) of total available water (Laurie *et al.*, 2012). A 3 x 2 factorial with three replications was applied. When 20 per cent of the total available water (TAW) was depleted, the FI treatment was irrigated 100 per cent to field capacity, whereas the 60 DI and 30 DI treatments received 60 per cent and 30 per cent of the amount applied in the FI treatment, respectively.

2.3.2.3 Randomisation

Fig. 2.4 shows the experimental arrangement of treatment combinations per replication. Each plot measured 3 m by 4.4 m with a plant spacing of 0.3 m within a row and 1.1 m between rows laid out in ridges (36 plants per plot).

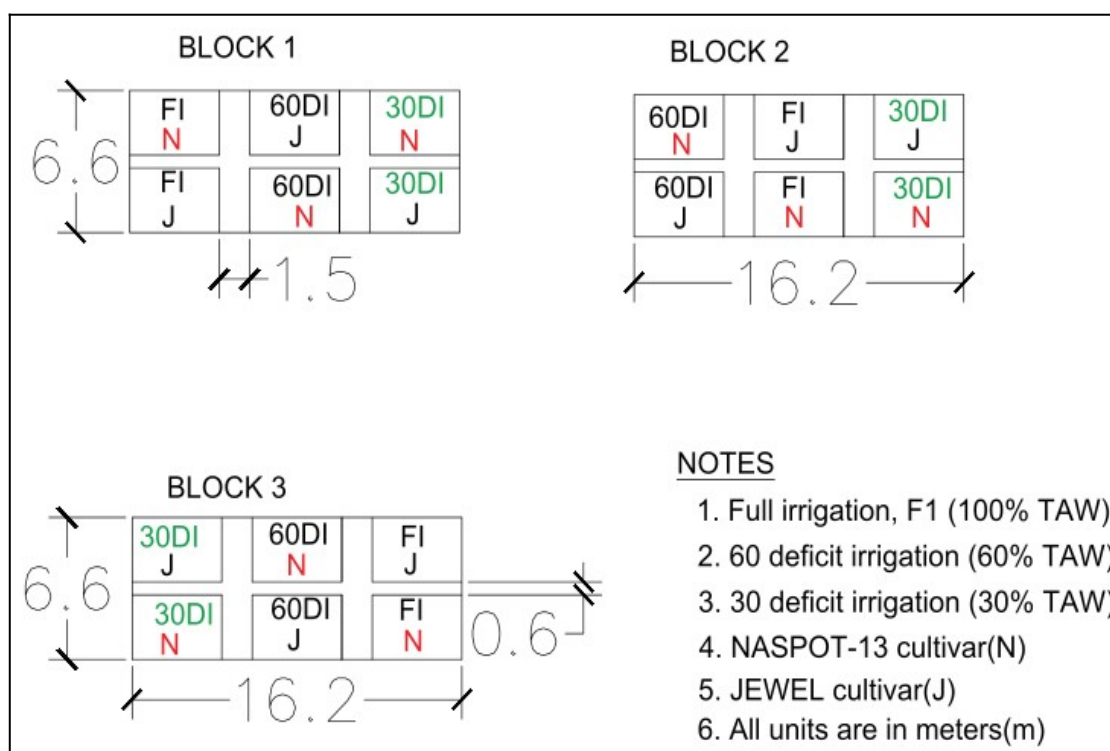


Figure 2.4: Experimental arrangement of treatment combinations per replication

2.3.3 Agronomic practices, irrigation water quality and fertilizer application

2.3.3.1 Agronomic practices

Agronomic practices were followed, including manual weeding regularly and earthing-up when necessary. An insecticide spray was applied during the growth period to control pests. For both seasons, continued deficit irrigation was imposed days after planting.

2.3.3.2 Irrigation water quality and application

The source of water for irrigation was a reservoir. Water samples were collected as described by the U.S. Geological Survey (2006). Water quality parameters were analysed at the Soil and Geological Sciences laboratory, Sokoine University of Agriculture. The irrigation water was slightly alkaline (7.86) and had an electrical conductivity of 1015 $\mu\text{S/cm}$, 0.03 mg/l total nitrogen, 0.04 mg/l phosphorus, and a trace amount of

micronutrients. A drip irrigation system with pressure compensating emitters of 2 lph discharge rate was used to deliver irrigation water.

2.3.3.3 Fertilizer application

Based on the analysis of the experimental site soils, 252.5 kg/ha of NPK fertilizer was applied once during the crop development stage to provide nitrogen, phosphorous, and potassium elements to improve yield (Laurie *et al.*, 2012).

2.3.4 Hydraulic performance evaluation and crop water requirements determination

2.3.4.1 Hydraulic performance evaluation

A sample of 26 emitters was selected randomly from the entire experimental setup for data collection. The volumetric method was used to measure the discharge of emitters. Measuring tools, including graduated measuring cylinders, catch cans, and a stopwatch, were used during the experiment. A supply water tank with a capacity of 1000 litres was placed on a stand 3 m above the ground at the experimental site to provide the required head for the drip system.

2.3.4.2 Crop water requirements

Reference evapotranspiration (ET_0) was determined by the Penman-Monteith equation (Allen *et al.*, 1998) with the aid of Instat+ software version 3.33 (Wass, 1998).

Table 2.3: Crop water requirement for orange fleshed sweet potato growth stages in Morogoro region

Season	Variables	Initial	Crop development	Mid-season	Late	Total
Season 1	K_c	0.4	0.4	1.15	0.58	
	DAYS	14	29	48	29	
	ET_0 (mm/day)	6	6	5.8	4.7	
	ET_c (mm/day)	34	70	320	79	502
Season 2	K_c	0.55	0.55	1.15	0.61	
	DAYS	14	29	48	29	
	ET_0 (mm/day)	3.4	3.4	3.7	4.5	
	ET_c (mm/day)	26	54	204	80	364

K_c is crop co-efficient, ET_0 is reference evapotranspiration and ET_c is crop evapotranspiration

2.3.5 Data collection

2.3.5.1 Soil moisture content and rainfall measurement

A moisture meter, type HH2 connected to an ML2X Theta probe was used to measure the volumetric soil moisture per water application treatment for each replication on a daily basis throughout the growing seasons (Matula *et al.*, 2016; Gaskin and Miller, 1996). The readings were taken at 30 cm depth horizontally. Rainfall was recorded at the site using a manual rain gauge with a funnel diameter of 8.2 cm.

2.3.5.2 Yield and above-ground biomass

Harvesting was done 120 days after planting. The two outer rows in each plot, and the two extreme plants on both sides of the inner rows, were left out during harvesting. The two inner rows, with a net plot size of 3.3 m², were used for data collection. The fresh yields were weighed and the weight was converted to tons per hectare. Marketable storage roots were considered in this study. Marketable storage roots, were defined as those weighing 100 g or more and having no defects due to diseases or mechanical damage. Similarly, harvesting of the fresh above-ground biomass occurred after 120 days.

2.3.5.3 Dry matter content

Three medium-sized sweet potatoes were taken from every plot in all blocks. The unprocessed samples were taken to the Sokoine University Graduate Entrepreneurs Cooperative (SUGECO) centre for preparation and drying. The fresh weight after cleaning was recorded, and chopped into small pieces. The chopped samples were placed on the top tray in a solar drier for 48 hours at 62.4 °C (Missana *et al.*, 2020). The dry weight was then measured and the dry matter content expressed as the ratio of dry weight to fresh root weight of selected OFSP varieties.

2.3.6 Data analysis

Hydraulic performance evaluation was analysed using MS Excel 2013. Analysis of Variance was performed using GenStat 16th Edition (VSN International Ltd, UK) software to determine if any significant differences existed between individual factors, that is the varieties and water regimes treatment effects and their interactions in terms of storage root yield, above-ground biomass, harvest index, dry matter content and water productivity parameters of the two cultivars. Treatment means were separated using

Tukey's multiple range test at $p < 0.05$. Table 2.4 shows the equations used in computing the selected parameters in this study.

Table 2.4: Equations used to calculate the selected parameters

No	Equations	Descriptions	References
1	$ET_C = ET_0 * K_C$	ET_C is crop evapotranspiration (mm), ET_0 is reference evapotranspiration (mm), K_C is crop coefficient	Allen <i>et al.</i> (1998)
2	$ET_a = I + P \pm \Delta W$	ET_a is actual evapotranspiration (mm), I is irrigation amount (mm), P is precipitation (mm), ΔW is the change in soil water content (mm)	Nyathi <i>et al.</i> (2019)
3	$HI = [(Y_{TSR}) / (Y_{TSR} + AGB)]$	HI is Harvest index (%), Y_{STR} is storage root yield (t/ha), AGB is above ground biomass (t/ha)	Nyathi <i>et al.</i> (2019)
4	$WP = Y_{STR} / ET_a$	WP is water productivity for root yield (Kg/m^3), Y_{STR} (kg/ha), ET_a (mm)	Mul <i>et al.</i> (2020)
5	$EU = (q_n / q_a) * 100$	EU is Emission uniformity, q_n is average rate of discharge of the lowest one fourth of the field data of emitter discharge reading, q_a is average discharge rate of all the emitters checked in field.	Lamm <i>et al.</i> (1997)
6	$CV = (SD / q_{avg})$	CV is coefficient of variation, q_{avg} is average discharge in the same lateral lines, and SD is standard deviation of emitter discharge.	Lamm <i>et al.</i> (1997)
7	$EFV = [1 - Q_{min} / Q_{max}] * 100$	EFV is emission flow variation, Q_{min} is minimum emitter discharge rate in the system, Q_{max} is maximum emitter discharge rate in the system	Lamm <i>et al.</i> (1997)
8	$CU = (1 - (\sum \Delta q / (q * n)) * 100$	CU is coefficient of uniformity, Δq is average deviation of individual emitters discharge, q is average discharge and n is number of observations.	Lamm <i>et al.</i> (1997)

2.4 Results and Discussion

2.4.1 Irrigation water and Rainfall

Seasonal irrigation water use, rainfall totals, seasonal water applied and crop evapotranspiration for orange-fleshed sweet potato varieties over the two growing periods are summarized in Table 2.5. During the first season, it rained from the onset of the mid-season stage of the OFSP until harvest, whereas drought prevailed in the second season. Water applied to the crop is best reflected in season 2 due to the absence of rainfall compared to season 1, which had a substantial amount of rain. Crop evapotranspiration was greater in season 1 than in season 2. The total water applied under the full irrigation treatment for season one was nearly three times ET_C , with much of it wasted as deep percolation.

Table 2.5: Summary of seasonal irrigation water use, rainfall totals, and seasonal water applied and crop evapotranspiration (ET) to OFSP varieties for the growing seasons

Seasons	Irrigation water use (mm)			Rain (mm)	Seasonal water applied (mm)			ET _c (mm)
	FI	60DI	30DI		FI	60DI	30DI	
S1 (2020/2021)	128	77	38	1297	1425	1374	1335	502
S2 (2021)	409	245	123	negligible	409	245	123	364

The 100% (Full irrigation) treatment was irrigated to field capacity when 20% of the total available water (TAW) was depleted whereas the 60% (60 deficit irrigation) and 30% (30 deficit irrigation) treatments received 60% and 30% of the amount applied in the 100% treatment respectively

2.4.2 Hydraulic performance evaluation of the drip system

Table 2.6 displays the hydraulic performance of the drip system installed at the experimental site. The hydraulic parameters assessed included coefficient of uniformity (CU), emission uniformity (EU), coefficient of variation (CV), and emission flow variation (EFV). The CV value demonstrates a high level of flow variation. High coefficients of uniformity of at least 85 per cent and emission uniformity of more than 90 per cent, according to Ab Razak and Sharu (2020), indicate a well-designed drip irrigation system. Therefore, the CU and EU in the current study show that the drip system operates efficiently when both parameters are excellent. The result of EFV is 12 per cent, which is considered acceptable. However, the hydraulic parameters were within the allowable ranges following the ASABE standards.

Table 2.6: Performance parameters for drip system and their respective performance indicators

	Emission Uniformity (EU)	Coefficient of Variation (CV)	Emission flow variation (EFV)	Coefficient of Uniformity (CU)
Results	92%	0.02	12%	99.76%
Performance indicator	≥ 90% Excellent	< 0.05 Excellent	≤ 10% Desirable	≥ 90% Excellent
	80-90% Good	0.05-0.07 Average	10-20% Acceptable	80-90% Good
	70-80% Fair	0.07-0.11 Marginal	> 25% Unacceptable	70-80% Fair
	≤ 70% Poor	0.11-0.15 Poor		60-70% Poor
		> 0.15 Unacceptable		< 60% Unacceptable
Reference	Lamm <i>et al.</i> (1997)	Lamm <i>et al.</i> (1997)	Lamm <i>et al.</i> (1997)	Lamm <i>et al.</i> (1997)

2.4.3 Soil moisture profile

Fig. 2.5 depicts soil moisture profiles for soil moisture content at 30 cm depth for various levels of water application during the second season. Soil moisture measurements were taken on a regular basis to track the moisture profile status after and before an irrigation dose was applied. The spikes above the field capacity were caused by rain showers after irrigation was applied.

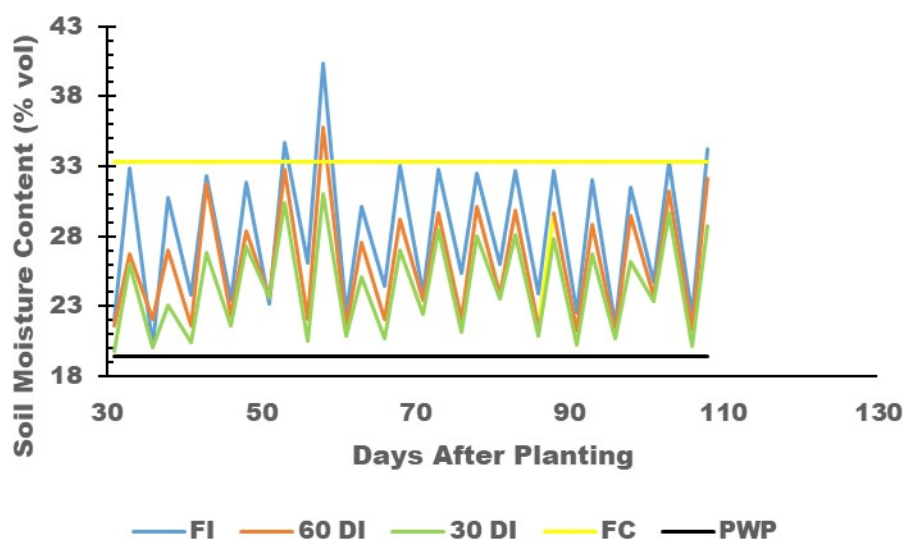


Figure 2.5: Season 2 soil moisture profiles of the field experiment

2.4.4 Effect of deficit irrigation on dry matter content, yield, and water productivity of OFSP varieties

Table 2.7 shows that the three-way interactions between water application regime, variety, and season were insignificant ($p > 0.05$). Except for water productivity, there was a significant difference ($p < 0.05$) between the varieties in terms of dry matter content and yield. There was a significant ($p < 0.01$) interaction between variety and season for root yield and water productivity. The treatment combination had a significant effect on the water productivity of both varieties ($p < 0.01$). Furthermore, seasons significantly influenced the OFSP's water productivity ($p < 0.001$) (Table 2.7). The substantial rain received in season 1 detrimentally affected the water productivity of the test varieties in the present study.

Table 2.7: Significance levels from the analysis of variance results for the effect of treatment and season on DMC, yield and WP of Jewel and Naspot-13 varieties.

Source of Variation	Dry matter content(DMC)	Yield	Water productivity(WP)
Treatment (Water application regimes)	ns	ns	**
Variety	*	***	ns
Seasons	ns	ns	***
Treatment*Variety	ns	ns	ns
Treatment*Season	ns	ns	**
Variety*Season	ns	***	**
Treatment*Variety*Season	ns	ns	ns

*, **, *** indicates significance at $p < 0.05$, $p < 0.01$, $p < 0.001$ respectively and ns indicate non-significant at $p > 0.05$

2.4.4.1 Dry matter content

The Jewel variety did not fare so well during season 2, ranging from 19-20 per cent of dry matter content when conditions were dry. The finding suggests that the Jewel cultivar is sensitive to weather conditions concerning dry matter accumulation. On the other hand, the Naspot-13 cultivar showed no variation in dry matter accumulation with either season or water regime, which makes it more robust. In general, water stress did not affect the dry matter content of both OFSP varieties (Fig. 2.6a). The findings in this study on the Naspot-13 cultivar were comparable to the range of 26.7–34.1 per cent dry matter content obtained for the Naspot-13 cultivar (Mwanga *et al.*, 2016; Tumwegamire *et al.*, 2014). However, the dry matter content was statistically similar between the seasons across all water levels (Fig. 2.6b).

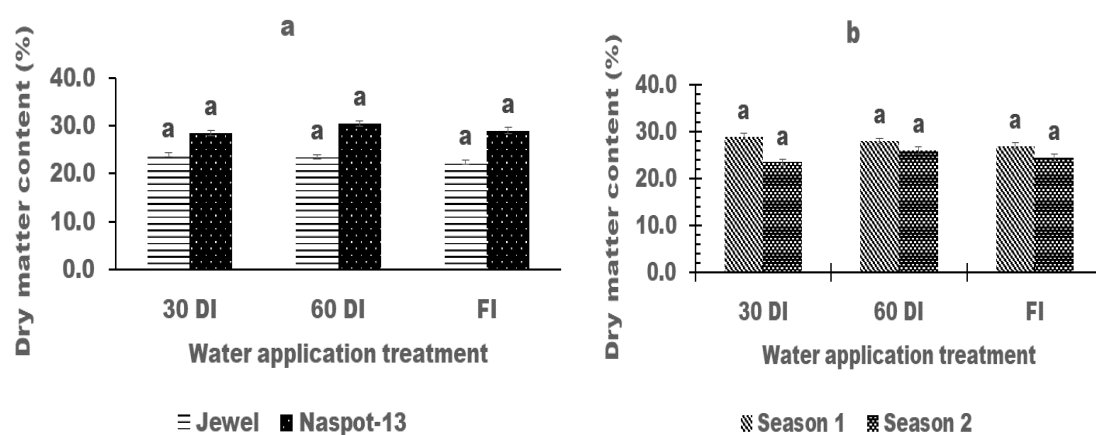


Figure 2.6: Effect of water application regimes on dry matter content as influenced by variety (a) and season (b)

2.4.4.2 Yield

The Jewel cultivar outperformed the Naspot-13 variety in season 1, whose mean yields were statistically different, as shown in Fig. 2.7. The yielding ability of the Naspot-13 cultivar during season 2 improved tremendously, though the means were statistically similar ($p > 0.05$) between the varieties.

In terms of yield, the two varieties tend to give opposite results during season 1. Whereas the Jewel cultivar gave higher yields at all water stress levels during season 1, the Naspot-13 cultivar had the lowest yields (Fig. 2.7). The root yield of the Naspot-13 cultivar appeared to improve with increasing water stress, as shown for season 2 (Fig. 2.7). These results for the Naspot-13 cultivar defy widely held views that deficit irrigation strategies accompany yield decreases (Ben-Gal *et al.*, 2021; Van Heerden and Laurie, 2008).

The yield of the Jewel cultivar between water application regimes in seasons 1 and 2 was statistically different ($p < 0.05$) except under the 60 DI strategy (Fig. 2.7). The results suggest that the Jewel cultivar is a water-loving variety. Similarly, the Naspot-13 cultivar performed poorly under wet conditions. It would appear that under ample water supplies, the Naspot-13 cultivar made more above-ground biomass accumulation at the expense of storage root yield in the case of the Naspot-13 cultivar. This observation is in tandem with Gajanayake *et al.* (2014) in their study, which investigated the impact of early-season soil moisture deficit on growth, developmental and physiological responses of sweet potato cultivars.

Generally, the yielding ability of neither variety responded significantly to water application regimes for both seasons. Correspondingly, in the case of almonds, the yield has been observed not to decrease with deficit irrigation (Lipan *et al.*, 2019). Therefore, the Naspot-13 cultivar can strategically alleviate food insecurity in drought-prone regions and other arid and semi-arid areas where farmers have access to limited irrigation water.

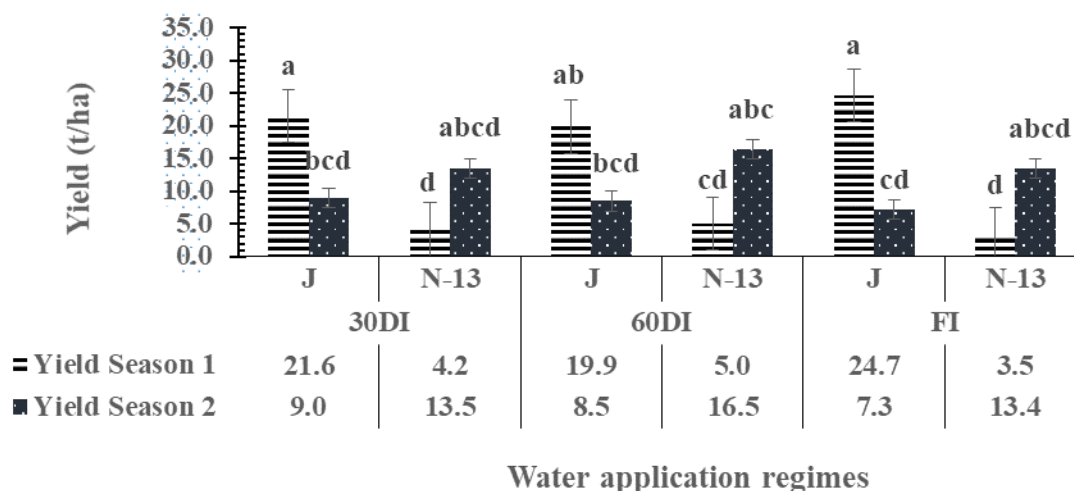


Figure 2.7: Effect of water application regimes on yield as influenced by variety and season

2.4.4.3 Water productivity

In the case of the Naspot-13 variety during season 2, water application regimes were significantly different ($p < 0.05$) for water productivity (Fig. 2.8). This result showed that a reduction in water application increases the Naspot-13 variety's water productivity. This finding was in line with Basso and Ritchie (2018), who reported, albeit, on maize (*Zea mays* L.), that productivity can increase with no change in water use rate with an increase in water productivity. This result was consistent with the findings of Laurie *et al.* (2012), who found that the water productivity of two OFSP varieties increased with increasing water stress. As evidenced by its water productivity, the Naspot-13 variety produced a higher yield with less water.

On the other hand, there was no significant difference between water application regimes for the Jewel variety in both seasons. However, the consistent rise in the water productivity during season 2 for both cultivars indicates variety tolerance to drought. These results for both varieties were comparable to the water productivity values reported by Laurie *et al.* (2012) and Nyathi *et al.* (2019) in their studies on different OFSP varieties, respectively.

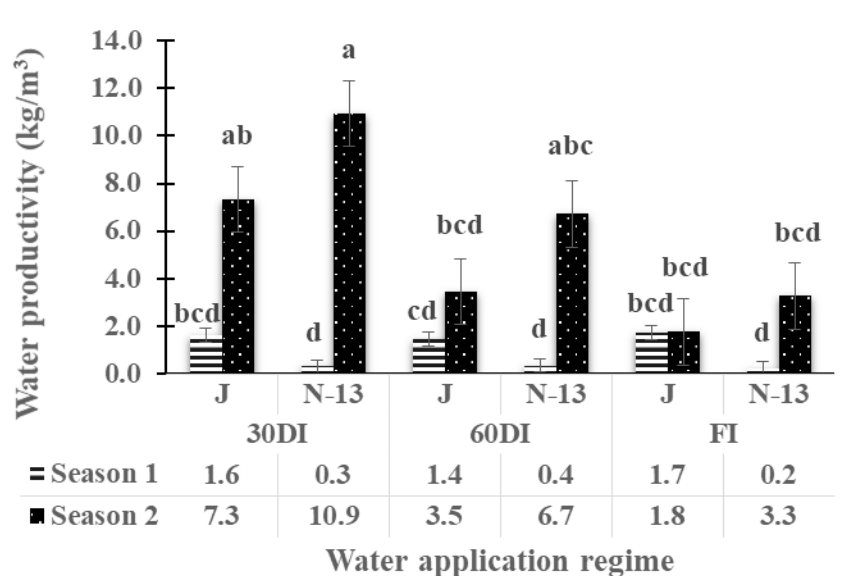


Figure 2.8: Effect of water application regimes on water productivity as influenced by variety and season

2.4.5 Effect of deficit irrigation on the fresh above ground biomass, and harvest index of orange fleshed sweet potatoes

The three-way interactions between water application regime, variety, and season were not significant ($p > 0.05$) (Table 2.8). The effects of cultivar and season were significant ($p < 0.001$) for fresh above-ground biomass (AGB) and harvest index (HI). There was a significant difference ($P < 0.05$) between the water application regimes for fresh AGB except for HI. Furthermore, there was a significant ($p < 0.01$) interaction between variety and season for fresh AGB, and HI.

Table 2.8: Significance levels from the analysis of variance results for the effect of treatment and season on AGB, and HI of Jewel and Naspot-13 varieties

Source of Variation	Above ground biomass (AGB) (t/ha)	Harvest Index (HI) (%)
Treatment (water application regime)	*	ns
Variety	***	***
Seasons	***	***
Treatment*Variety	ns	ns
Treatment*Season	ns	ns
Variety*Season	***	***
Treatment*Variety*Season	ns	ns

*, **, *** indicates significance at, $p < 0.01$, $p < 0.001$ respectively and ns indicate non-significant at $p > 0.05$

2.4.5.1 Fresh above ground biomass

The fresh above-ground biomass (AGB) was statistically similar between the water levels for both varieties in both seasons (Fig. 2.9). However, the consistent decline in the AGB with a degree of water deficit by the cultivars in both seasons indicated sensitivity to water stress. The Naspot-13 cultivar had more AGB than the Jewel cultivar in both seasons, illustrating the vigorous vegetative nature of the Naspot-13 cultivar. Season 1 exhibited superior AGB for both varieties compared to season 2. The findings in this study for both cultivars agree with Nyathi *et al.* (2019), who observed an increase in total above-ground biomass with an increase in applied water.

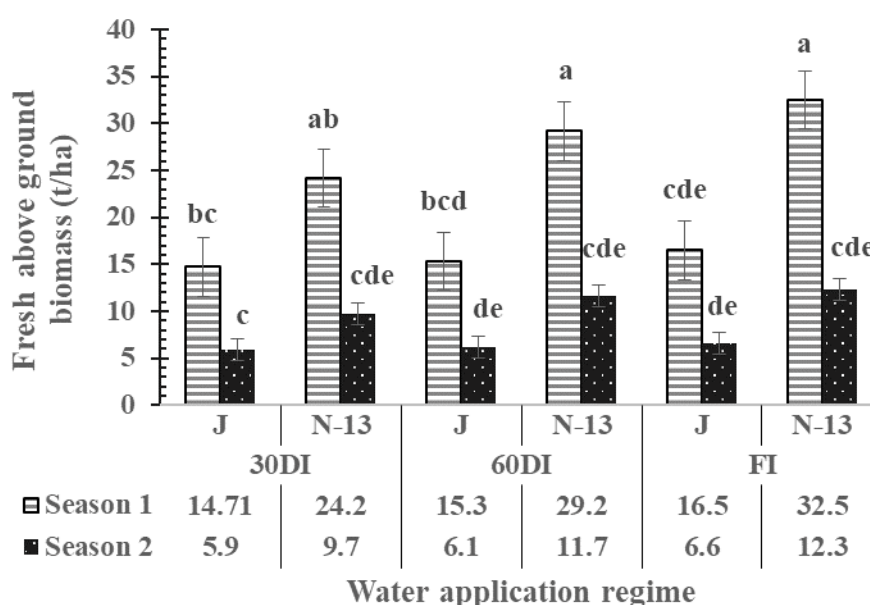


Figure 2.9: Effect of water application regimes on fresh above ground biomass as influenced by variety and season

2.4.5.2 Harvest index

The harvest index for the Jewel variety was statistically similar between the water levels in both seasons. A similar trend occurred between the seasons at all water levels. On the other hand, in the case of the Naspot-13 variety, the harvest index was statistically similar between the water levels in both seasons. However, the harvest index for the Naspot-13 cultivar was statistically different between seasons at all water levels. The reduction in vegetative growth observed in the second season provided the pathway for improving the harvest index for the Naspot-13 cultivar. Thus, there is a need for further investigation into genetic improvement to crop management practices to reduce the vegetative vigour of OFSP to improve harvest index. The Jewel variety in this study indicates a similar

proportion in the accumulation of assimilates to root during wet and dry conditions. However, the Naspot-13 cultivar showed a higher proportion of accumulated assimilates during the dry conditions when compared to the wet conditions.

The harvest index values for the Jewel variety in both seasons and season 2 for the Naspot-13 cultivar were comparable to those reported by Makunde *et al.* (2017). On the contrary, the values in this study were relatively low compared to the harvest index values reported by Nyathi *et al.* (2019). The difference could be due to the low vegetative vigour of the Bophelo variety (Nyathi *et al.*, 2019).

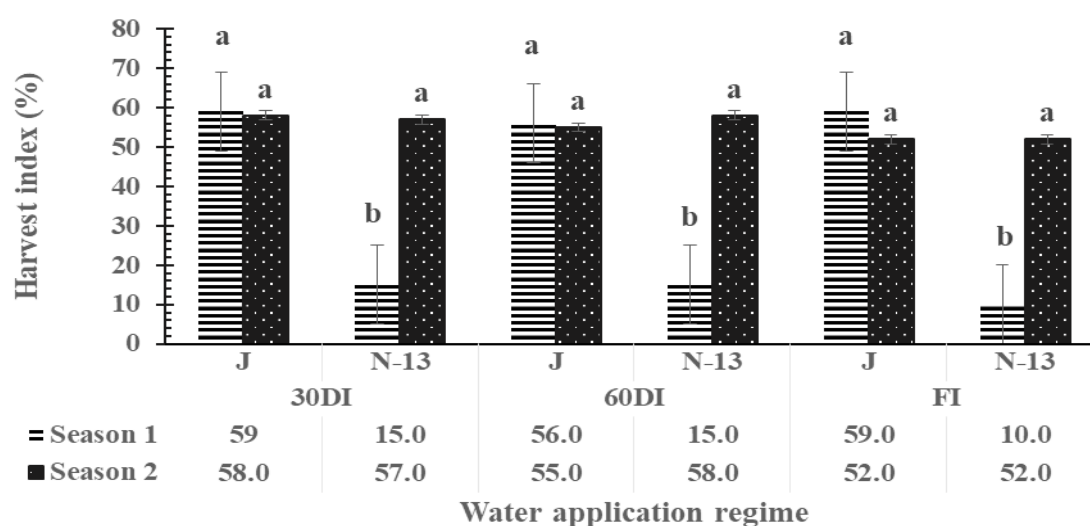


Figure 2.10: Effect of water application regimes on harvest index as influenced by variety and season

Pearson correlation between response variables

There was a positive and statistically significant correlation between the harvest index and yield ($r = 0.74$, $p < 0.001$). The correlation between harvest index and above-ground biomass was strongly negative and statistically significant ($r = -0.82$, $p < 0.001$).

Table 2.9: Correlation between studied response variables of orange fleshed sweet potato varieties

Y_{TSR} (t/ha)	1	-			
WP (kg/m ³)	2	0.2711	-		
AGB (t/ha)	3	-0.2863	-0.5219	-	
HI (%)	4	0.7399	0.5715	-0.8230	-
		1	2	3	4

Y_{TSR} is storage root yield, WP is water productivity, AGB is fresh above ground biomass and HI is harvest index

2.5 Conclusion

The values for the coefficient of uniformity and emission uniformity have more than 92 per cent efficiency. The coefficient of variation is 0.02, which is considered excellent. Thus, the hydraulic parameters were efficient per the ASABE classification. The emission flow variation was acceptable at 12 per cent. The results concluded that the hydraulic parameters evaluated were within allowable ranges following the ASABE standard under the 4 m operating head.

The dry matter content for both varieties was statistically similar in both seasons and at different levels of water application. The Jewel variety gave higher yields in the first season due to the significant amount of rain received than in the second season. In contrast, the Naspot-13 cultivar produced statistically similar root yields for both seasons at all levels of water application.

The Naspot-13 variety demonstrated that productivity increases under deficit irrigation strategies and simultaneously increases water productivity. Season 2 exhibited superior water productivity values to season 1 for the Naspot-13 variety. Hence, the present study shows that the Naspot-13 cultivar can be a feasible crop for producing more food from fewer water resources.

The fresh above-ground biomass reduced significantly with decreasing water application for both varieties. Superior values occurred in the first season, ranging from 15 to 33 t/ha, and in the second season, they varied from 6 to 12 t/ha. The results of the harvest index in this study concluded that the Jewel variety has a high proportion of accumulated assimilates to roots under both wet and dry conditions. The values varied from 52 to 59 per cent for both seasons. On the other hand, the results of the harvest index implied that the Naspot-13 variety has a high proportion of assimilates to roots during dry conditions. The values ranged between 10 to 15 per cent in season 1 and 52 to 58 per cent in season 2.

The findings of this study have shown that there is a need to further carry out preliminary studies on drought-tolerant OFSP varieties under different deficit irrigation methods to improve water management in small-scale producer systems. Similarly, further investigation into genetic improvement to crop management practices will be vital in reducing the vegetative vigour of the OFSP crop to improve the harvest index.

2.6 References

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CHAPTER THREE

3.0 Nutrition quality response of orange fleshed sweet potato (*Ipomoea Batatas* L.Lam) varieties to deficit irrigation in Tanzania

3.1 Abstract

Malnutrition in all its forms is a global problem, with the worst effects felt in developing countries. The importance of producing food to improve nutrition security is self-evidently a promising approach to combating malnutrition. The present study assessed the nutritional quality response of orange-fleshed sweet potato (OFSP) varieties to deficit irrigation. The study's specific objectives were to i) evaluate yield and root quality and (ii) assess the nutritional root yield and nutritional water productivity of selected OFSP varieties under full and deficit irrigation (DI). Beta-carotene, iron, and zinc were the root quality parameters studied. A factorial arrangement of treatments was laid out in a randomized complete block design (RCBD). The irrigation rates used for scheduling were 100 per cent (full irrigation), 60 per cent (60 (DI)), and 30 per cent (30 (DI)) of total available water (TAW). The test varieties were Naspot-13 and Jewel of the orange-fleshed sweet potato crop. The beta-carotene content of the Jewel cultivar was 27 per cent higher than that of the Naspot-13 cultivar. However, neither cultivar's root quality changed under the deficit irrigation. The results show that serving 125 g of boiled OFSP varieties provides more than 100% of vitamin A, sufficient iron, and minimal zinc dietary requirements for 4–8-year-old children and 10–50-year-old pregnant women. In general, the nutritional water productivity of root quality parameters increased with a decrease in water application. In conclusion, a positive water-food-nutrition nexus was established under the Naspot-13 variety, suggesting a capacity for alleviating Vitamin A, iron, and zinc deficiency health-related problems, particularly in children and pregnant women in regions with limited water resources.

Keywords: Nutritional water productivity, Vitamin A, Iron, Zinc, Food security, Malnutrition

3.2 Introduction

Malnutrition is a significant challenge facing humankind globally. Estimates by FAO (2020) for the year 2019 indicate that 21.3 per cent of children globally under five years of age were stunted, 6.9 per cent wasted, and 5.6 per cent overweight. The report further predicts the deterioration of the nutritional status of the highly vulnerable population

groups due to the health and socioeconomic impacts of COVID-19. The East African region has the highest prevalence of malnutrition in Africa at 34.2 per cent and the second-highest worldwide (FAO, 2020). According to the Ministry of Health, Community Development, Gender, Elderly, and Children (MoHCDGEC, 2019), stunting was estimated to be 31.8 per cent in Tanzania in 2018, with the prevalence of underweight estimated to be 14.6 per cent.

A review conducted in Ethiopia, Kenya, Nigeria and South Africa by Harika *et al.* (2017) showed that the prevalence of anaemia and iron deficiency, as well as vitamin A, zinc, iodine and folate nutrition in pregnant women and adolescent girls, was a concern by the World Health Organisation criteria (WHO, 2012). Malnutrition is attributed to limited resources in Sub-Saharan Africa and the need to enhance human development, with nutrition as a focus (UNICEF, 2019). More so, more focus on agricultural research programs and policies is being directed to maximise nutrition output from farming systems for the success of agricultural interventions (Berti *et al.*, 2004).

Orange-fleshed sweet potatoes (OFSP) have been regarded as vital in improving health despite being labelled a resource-poor farmer's choice (Mitra, 2012). The International Potato Centre (CIP) and its partners, breed and promote orange-fleshed sweet potatoes as an important root crop. Growing evidence of the importance of orange-fleshed sweet potatoes in improving their nutritional value has been reported and, to date, more than 42 OFSP varieties have been bred in Africa (Tanumihardjo *et al.*, 2017; Low *et al.*, 2017). According to Busse *et al.* (2017), the importance of Vitamin A as a micronutrient for proper growth and development in children and pregnant women has been highlighted. According to Low *et al.* (2017), OFSP is rich in beta-carotene, which is beneficial during the critical growth period of children when the intake of vitamin A is high. Children are susceptible to vitamin A deficiency (VAD) during this period.

OFSP provides dietary fibre, antioxidants, specific minerals, and various vitamins (Laurie *et al.*, 2012b; Rodrigues *et al.*, 2016). The crop is also rich in nutritive constituents with anticarcinogenic and cardiovascular disease-inhibiting properties (Chandrasekara and Josheph Kumar, 2016) as well as starch content (Rodrigues *et al.*, 2016). Furthermore, the crop has received scientific recognition for its role in bakery, snack, and confectionery foods (Chen *et al.*, 2003). On the other hand, OFSP varieties

withstand marginal conditions where other crops fail, have balanced nutrition composition, have consistent productivity in short periods, and withstand natural disasters where other crops fail (Trancoso-Reyes *et al.*, 2016).

Climate change, impending water scarcity, and the need to develop sustainable water management techniques have disrupted the fight against malnutrition (Anandhi *et al.*, 2016). Despite this, the need for sustainable food production due to limited water resources has gained attention in making sure more nutrition per water drop is attained, leading to the nutritional water productivity concept (Chibarabada *et al.*, 2017). Chibarabada *et al.* (2017) define nutritional water productivity as a measure of the yield and nutritional performance of a crop per unit of water consumed.

The call for climate-smart nutrition-sensitive food systems is a reality the world cannot afford to ignore. There is an urgent need for research that provides more evidence and action linking climate-smart agricultural approaches to diets and nutrition (Fanzo *et al.*, 2017). However, little scientific on-farm research on OFSP storage root yields and their subsequent nutritional composition in sub-Saharan Africa is available (Low *et al.*, 2020; Nyathi *et al.*, 2019). Therefore, this study aimed to assess how deficit irrigation affects yield, root quality, and nutritional water productivity in selected orange-fleshed sweet potato varieties.

3.3 Materials and methods

3.3.1 Study area

3.3.1.1 Location

The field experiment was conducted at the School of Engineering and Technology (SoET) research field in Morogoro, Tanzania (grid zone: 350213.19 E, 9243788.94 N, 37M; 512 m above sea level) (Fig. 3.1).

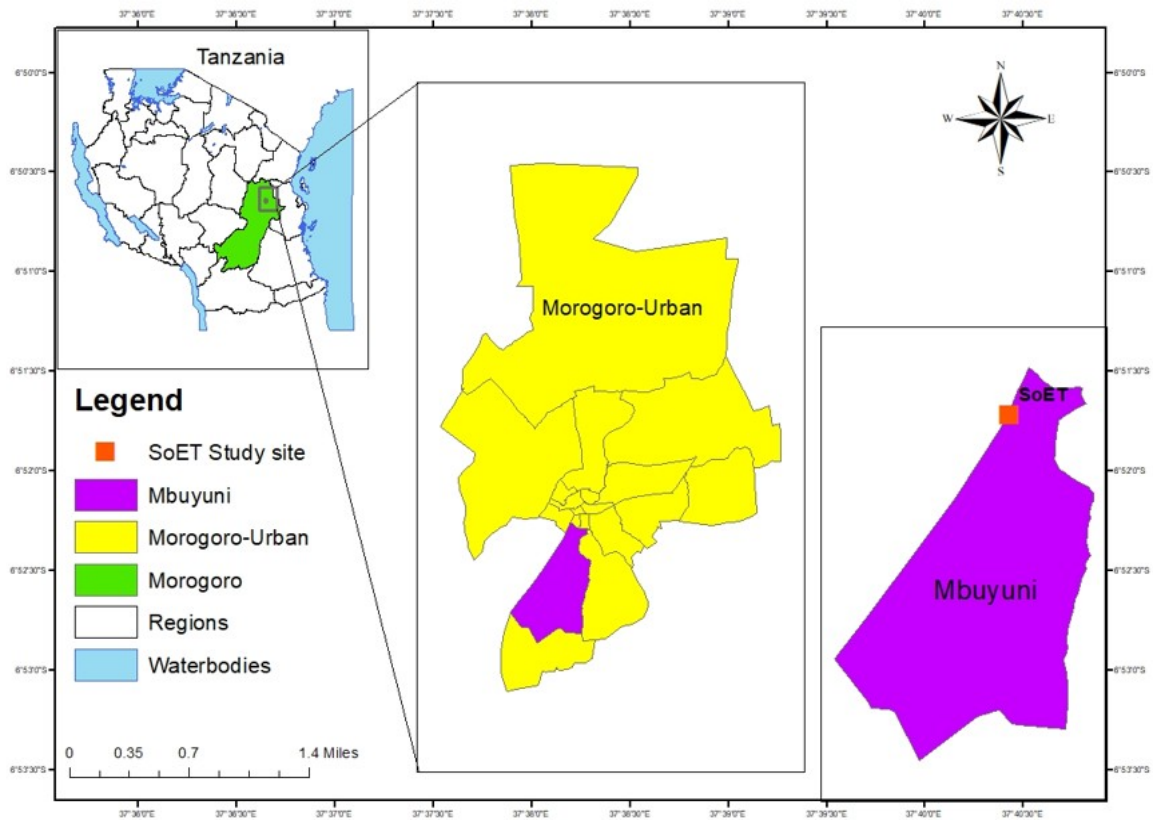


Figure 3.1: Location of study area in Morogoro Region, Tanzania

3.3.1.2 Topography

Morogoro Urban District is bordered by Uluguru Mountains on the south eastern side and Mindu and Nguru ya Ndege hills on the western side. The district comprises of a bigger part of plains of various forms and extent. Rainfall in river valleys and basins ranges from 600 mm to 1400 mm per year. Temperatures in this zone are high due to its lowland location, with an average of 30 °C. The zone is densely populated in the upper valleys, but less so in the lower valleys.

3.3.1.3 Climate

The distribution of rainfall within the Morogoro urban area is bimodal, with long rains between March and May and short rains between October and December. Fig. 3.2 shows the Morogoro monthly average rainfall frequency for 60 years under normal conditions. The long rains (*Masika*) on average amount to 411.1 mm annually, whereas the short rains (*Vuli*) average 149.8 mm annually (Fig. 3.2). Table 3.1 shows the mean monthly weather data for Morogoro Urban District, Tanzania for 6 years

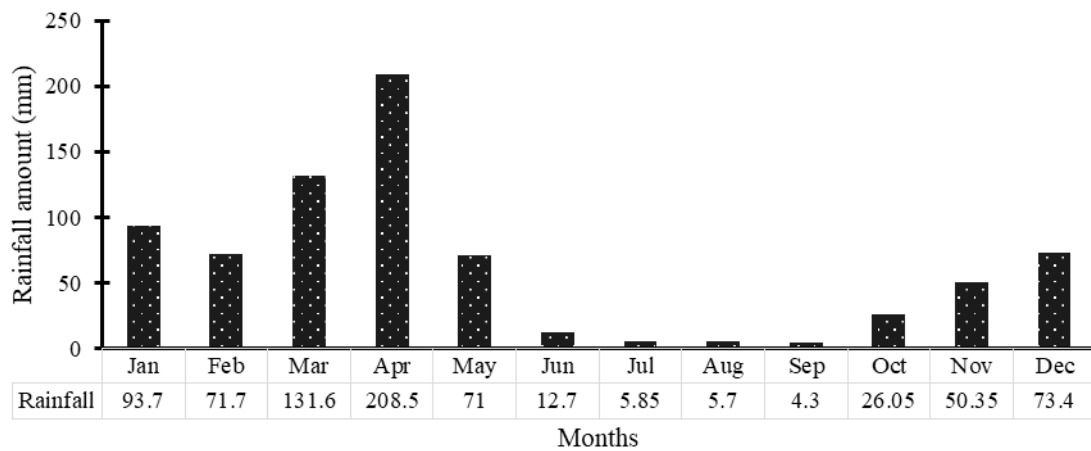


Figure 3.2: Mean monthly rainfall (mm) at Morogoro (1961-2020) (Source: TMA Meteorological Station, 2021)

Table 3.1: Mean monthly weather data within Morogoro Urban (2015-2020)

Month	3 pm RH (%)	Wind (Km/day)	Temperature (°C)		Radiation (MJ/m ²)
			Maximum	Minimum	
JAN	64.1	181.2	32.1	22.1	19.8
FEB	68.2	159.0	32.7	22.2	21.0
MAR	66.3	85.4	32.3	22.0	18.5
APR	75.9	49.4	29.6	21.5	15.2
MAY	72.9	39.9	28.2	19.9	13.9
JUN	64.1	48.2	28.2	16.9	15.4
JUL	64.9	61.7	27.9	16.1	15.2
AUG	53.8	83.7	28.8	17.2	16.4
SEP	50.7	109.7	30.6	17.7	18.2
OCT	51.8	118.7	31.5	19.5	18.2
NOV	57.5	144.9	31.7	21.2	19.7
DEC	58.3	173.5	32.6	22.2	20.0

(Source: TMA Meteorological Station, 2021)

3.3.1.4 Soils

Soils in the Morogoro Region vary according to topology and agro ecological zones. In USDA soil taxonomy, the soil in the experimental area is classified as Ultisol, and in FAO-UNESCO classification, it is classified as Acrisol (Msanya *et al.*, 2003). The physical and chemical properties of the soil for the top 300 mm layer are shown in Table 3.2. The soil texture is sandy clay, and the clay content in the upper 300 mm of the soil

sample profile was 53 per cent. The soil's field capacity was 333 mm/m and the permanent wilting point was 208 mm/m.

Table 3.2: Physical and chemical properties of the topsoil layer (0 - 300 mm) at the experiment site, SUA, Morogoro Region

Soil parameters	Unit	Range per 300 mm	Remarks
Soil pH (H ₂ O)		5.19 – 5.96	weak acidic soils
Electrical Conductivity ^a	µS/cm	117 – 207	non saline
TN-Kjeld ^c	mg kg ⁻¹	900 – 1300	Low
Ext. Phosphorous(PBry-1) ^b	mg kg ⁻¹	0.58 – 1.43	Low
Zinc ^d	mg kg ⁻¹	0.21 – 0.86	Low
Iron ^d	mg kg ⁻¹	17.06 – 22.07	High
Clay ^e	%	54.48 – 53.48	
Silt ^e	%	0.32 – 1.68	
Sand ^e	%	43.84 – 46.20	

The range represents different sampling points within the experiment field

^a1:2:5 w/v method (Ayers and Westcot, 1985)

^bBray 1 method (FAO, 2021)

^cKjeldahl method (Bremner, 1960)

^dDTPA extraction method (Lindsay and Norvell, 1978)

^eSieve and pipette method

3.3.2 Experimental setup, treatments, replications

3.3.2.1 Experimental setup

The experimental schematic layout of the irrigation system network is shown in Fig. 3.3. The experiment was conducted over two seasons, i.e., the 2020/21 and 2021 seasons. A factorial arrangement of treatments was laid out in a randomized complete block design.

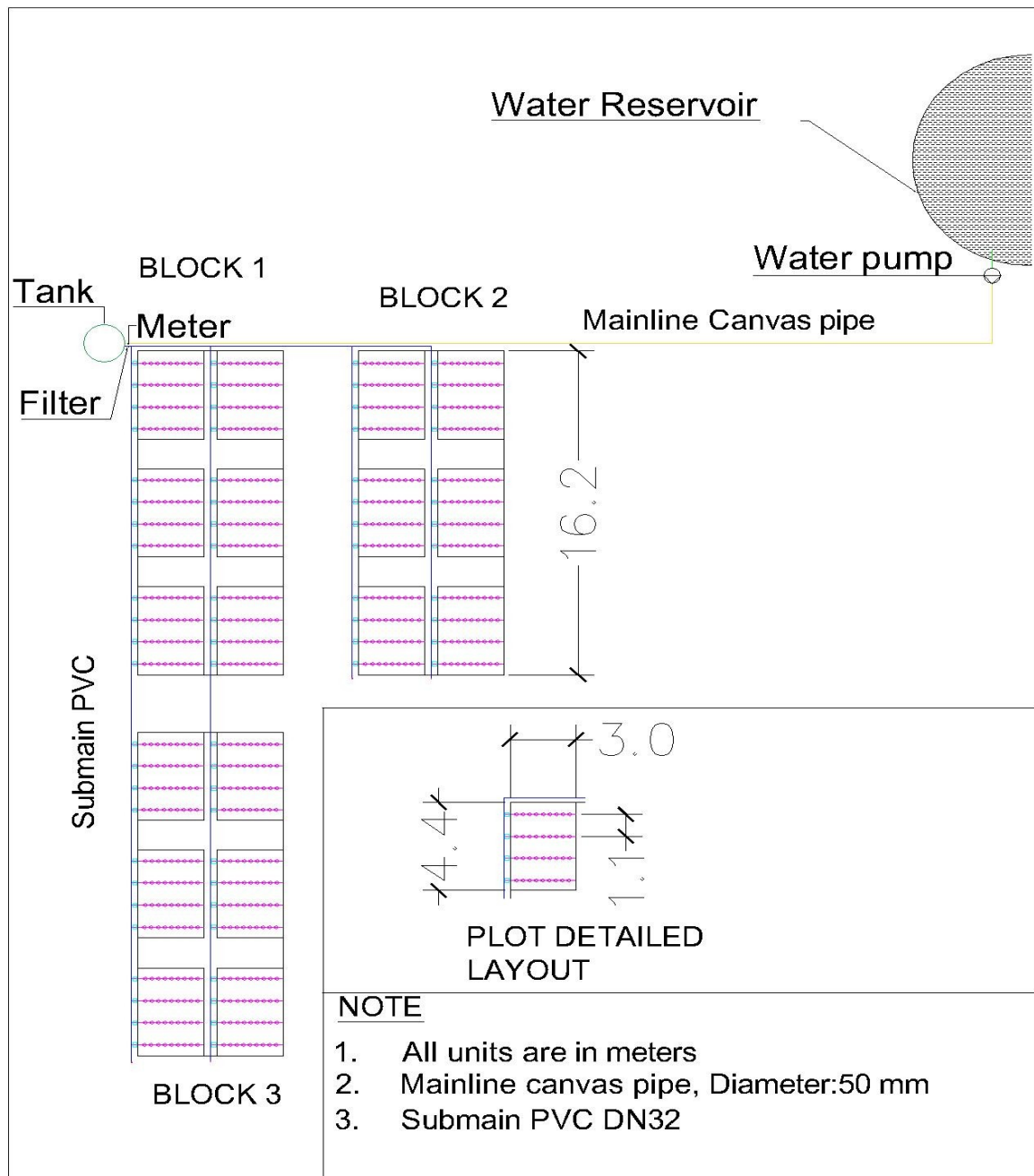


Figure 3.3: Experimental schematic layout of the irrigation network

3.3.2.2 Treatments

The test varieties were Naspot-13 and Jewel of the orange-fleshed sweet potato crop. The water application regimes were 100 per cent (Full irrigation (FI)), 60 per cent (60 DI), and 30 per cent (30 DI) of total available water (Laurie *et al.*, 2012a). A 3 x 2 factorial with three replications was applied. When 20 per cent of the total available water (TAW) was depleted, the FI treatment was irrigated 100 per cent to field capacity, whereas the 60 DI and 30 DI treatments received 60 per cent and 30 per cent of the amount applied in the FI treatment, respectively.

3.3.2.3 Replications

Fig. 3.4 shows the experimental arrangement of treatment combinations per replication. Each plot measured 3 m by 4.4 m with a plant spacing of 0.3 m within a row and 1.1 m between rows laid out in ridges (36 plants per plot).

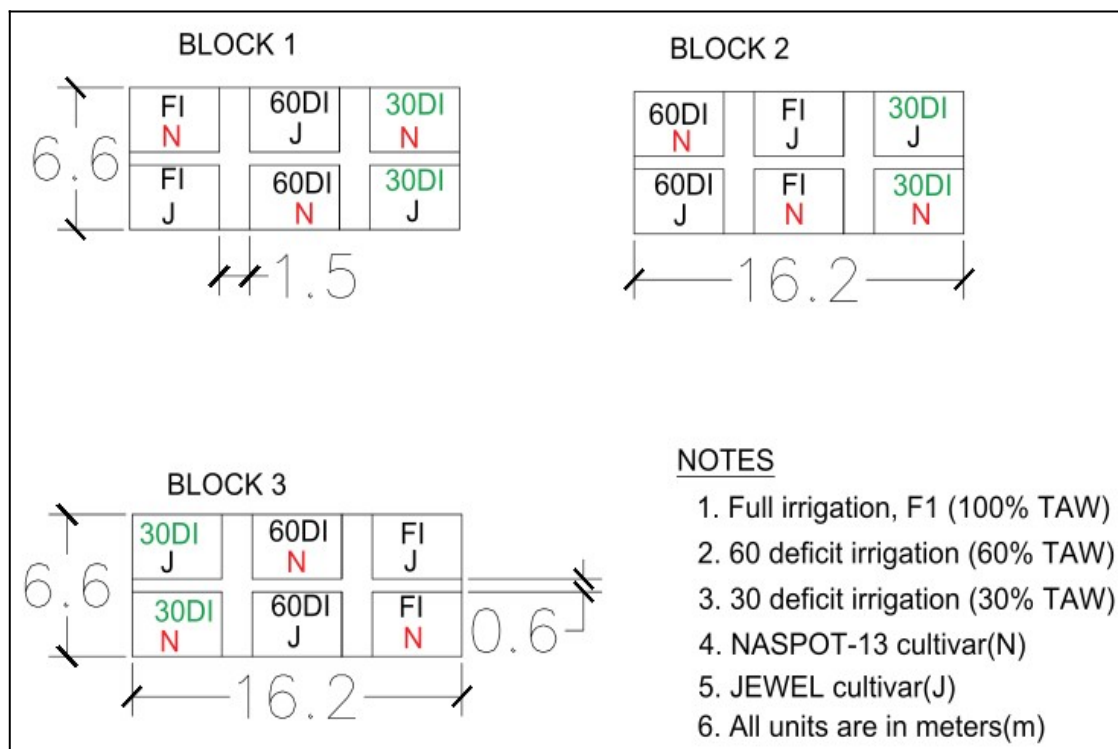


Figure 3.4: Experimental arrangement of treatment combinations per replication

3.3.3 Agronomic practices, irrigation water quality and soil fertilisation

3.3.3.1 Agronomic practices

Normal agronomic practices were followed, including manual weeding on a regular basis and earthing-up when necessary. Insecticide spray was applied during the growth period to control pests. For both seasons, continued deficit irrigation was imposed after 8 days of planting.

3.3.3.2 Irrigation water quality and application

The source of water for irrigation was a reservoir. To determine the chemical properties, a sample of water was collected from the reservoir as described by the U.S. Geological Survey (2006) and quality parameters were analysed at the Soil and Geological Sciences laboratory, Sokoine University of Agriculture. The irrigation water was slightly alkaline (7.86), had an electrical conductivity of 1015 $\mu\text{S}/\text{cm}$, 0.03 mg/l total nitrogen, and 0.04

mg/l phosphorus and trace amounts of micronutrients. Irrigation water was applied by use of a drip irrigation system with pressure compensating emitters with a discharge of 2 lph.

3.3.3.3 Soil fertilisation

Based on soil analysis of the experimental site soils, 252.5 kg/ha of NPK fertilizer was applied once during the crop development stage to provide nitrogen, phosphorous, and potassium elements to improve yield (Laurie *et al.*, 2012a).

3.3.4 Data collection

3.3.4.1 Yield and rainfall amount

Harvesting was done 120 days after planting. The two outer rows in each plot, and the two extreme plants on both sides of the inner rows, were left out during harvesting. The two inner rows, with a net plot size of 3.3 m², were used for data collection. The fresh yields were weighed and the weight was converted to tons per hectare. Marketable storage roots were considered in this study. Marketable storage roots, were defined as those weighing 100 g or more and having no defects due to diseases or mechanical damage. Similarly, harvesting of the fresh above-ground biomass occurred after 120 days.

3.3.4.2 Storage root nutrient quality determination

β- Carotene assay

Four medium-sized OFSPs were picked from every plot (treatment combination) in all blocks. The unprocessed samples were packed in disposable food paper bags and transported to the Sokoine University of Agriculture's Food Science Laboratory for preparation and analysis. Four medium-sized sweet potatoes were homogenized in a food processor to obtain the analytical sample. Duplicate samples with weights ranging from 1.5 g to 3.0 g were extracted from the analytical sample for each treatment. This was done solely to ensure that the sample was representative of the population. The analytical sample was extracted for 1 minute with methanol: tetrahydrofuran (THF) (1:1) and then filtered into petroleum ether (PE), as described by Rodriguez-Amaya and Kimura (2004). Measurements of the absorbance of beta-carotene occurred on a visible wavelength detector set at 450 nm. Equation 1 aided in computing the total carotenoid content.

$$TCC = [(A*V*104)/ (A_{1cm}^{1\%} *Ws)]..... (1)$$

Where: TCC is total carotenoid content ($\mu\text{g/g}$), A is absorbance, V is total volume of extract (ml), $A_{1\text{cm}}^{1\%}$ is absorption co-efficient of β -carotene in petroleum ether, W is sample weight (g) (Rodriguez-Amaya and Kimura, 2004).

Iron and zinc assay

A portion of the analytical sample was taken to the Soil and Geological Sciences Laboratory, Sokoine University of Agriculture, for analysis. The determination of iron and zinc happened using an Atomic Absorption Spectrophotometer (ASS), as described by AOAC (2002).

3.3.4.3 Nutritional yield and Nutritional water productivity determination

Nutritional yield, nutritional water productivity and water productivity were obtained using Equations 2, and 3 respectively.

$$NY_{\text{TSR}} = [(Y_{\text{TSR}} * \text{MC}) / 100] \dots \dots \dots (2)$$

Where: NY_{TSR} is storage root nutritional yield (g/ha) of β -carotene (β), iron (Fe), zinc (Zn), Y_{STR} is storage root yield (t/ha), MC is mass concentration (mg/m^3) of β , Fe and Zn (Nyathi *et al.*, 2019)

$$NWP_{\text{TSR}} = WP_{\text{TSR}} * \text{MC} * 10 \dots \dots \dots (3)$$

Where: NWP_{TSR} is Nutritional water productivity (mg/m^3) of the total storage roots, WP_{TSR} (kg/m^3), MC (mg/m^3) of β , Fe and Zn (Nyathi *et al.*, 2019)

3.3.5 Statistical analysis

The yield, root quality, nutritional yield, and nutritional water productivity results were subjected to analysis of variance (ANOVA) using GenStat 16th Edition (VSN International Ltd, UK) software. The Tukey's Multiple Range Test was used as the treatment mean separation test. A Pearson correlation coefficient analysis established the association between the studied parameters.

3.4 Results and Discussion

3.4.1 Seasonal water inputs and crop evapotranspiration

During the first season (2020/21), rain fell from the on-set of the mid-season stage of the OFSP test varieties until harvest, whereas negligible rainfall fell in the second season (Table 3.3). The total amount of water applied to the crop was best reflected in season 2

due to the absence of rainfall compared to season 1, which had a substantial amount of rain. Crop evapotranspiration was higher during season 1 compared to season 2 (Table 3.3). For season 1, the total water applied under the full irrigation treatment was almost three times the ETC, much of it wasted as deep percolation. However, for season 2, the total water applied under the full irrigation treatment was just slightly above that required by the crop (Table 3.3).

Table 3.3: Summary of seasonal water inputs and crop evapotranspiration (ET) for OFSP varieties for the growing seasons 1 and 2

Seasons	Irrigation Water			Rain	Total water applied			ET
	FI	60DI	30DI		FI	60DI	30DI	
S1 (2020/2021)	128	77	38	1297	1425	1374	1335	502
S2 (2021)	409	245	123	negligible	409	245	123	364

The 100% (Full irrigation) treatment was irrigated to field capacity when 20% of the total available water (TAW) was depleted whereas the 60% (60 deficit irrigation) and 30% (30 deficit irrigation) treatments received 60% and 30% of the amount applied in the 100% treatment respectively

3.4.2 Effect of deficit irrigation on OFSP yield, and its nutrient content

The yield and β -carotene content were significantly different ($p < 0.001$) among the varieties at all levels of water application (Table 3.4). Table 3.4 shows that the seasons significantly influenced the β -carotene, Fe, and Zn concentration of the OFSP varieties ($p < 0.01$). This was attributed to environmental factors like the rainfall during the first season. The two-way interaction between water application regime and variety significantly influenced the Zn concentration parameter ($p < 0.05$). Similarly, the two-way interaction between variety and season significantly influenced the yield and β -carotene concentration ($p < 0.05$). However, the three-way interactions between the water application regimes, variety, and season were not significant ($p > 0.05$) (Table 3.4).

Table 3.4: Significance levels from the analysis of variance results for the main and interaction effects on OFSP yield, and its nutrient content under deficit irrigation

Water Regimes	Response Variable	T	V	S	T*V	T*S	V*S	T*V*S
30DI	Y _{TSR}	ns	***	ns	ns	ns	***	ns
	NC-β	ns	***	***	ns	ns	*	ns
	NC-Zn	ns	ns	***	*	ns	ns	ns
	NC-Fe	ns	ns	**	ns	ns	ns	ns
60DI	Y _{TSR}	ns	***	ns	ns	ns	***	ns
	NC-β	ns	***	***	ns	ns	*	ns
	NC-Zn	ns	ns	***	*	ns	ns	ns
	NC-Fe	ns	ns	**	ns	ns	ns	ns
FI	Y _{TSR}	ns	***	ns	ns	ns	***	ns
	NC-β	ns	***	***	ns	ns	*	ns
	NC-Zn	ns	ns	***	*	ns	ns	ns
	NC-Fe	ns	ns	**	ns	ns	ns	ns

*, **, *** indicates significance at $P < 0.05$, $P < 0.01$, $P < 0.001$ respectively and ns indicate non-significant at $p > 0.05$. Similar letters indicate statistically similar means at $p > 0.05$, Y_{TSR} is storage root yield (t/ha), NC is Nutrient content of beta-carotene, β (μg/g), zinc, Zn (mg/kg) and iron, Fe (mg/kg), T is water application treatment, V is variety, S is season, FI is Full irrigation treatment, 60DI is 60 deficit irrigation treatment and 30DI is 30 deficit irrigation treatment

3.4.2.1 Yield

There was a significant difference ($p < 0.001$) in yield between varieties. The watering regime did not affect the yield of either cultivar statistically ($p > 0.05$). In this context, it is reasonable to conclude that the adopted deficit irrigation strategy did not affect the yield of the OFSP varieties studied. For comparison, albeit on a different crop, Lipan *et al.* (2019) found that regulated deficit irrigation did not affect almond yield in a study conducted in Seville, Spain. The Jewel cultivar outperformed the Naspot-13 variety in yielding ability by 81 per cent during season 1, whereas the difference was 43 per cent during the second season. Season 2 yield of the Jewel cultivar, averaging 8 t/ha, was significantly lower than season 1 yield, averaging 22 t/ha among the treatment combinations (Table 3.4 and Fig. 3.5). This finding was consistent with Van Heerden and Laurie (2008), who observed a decrease in yield as water stress increased. According to

the results of this study, the Jewel cultivar seems to be a water-loving variety, and the Naspot-13 cultivar is a drought-tolerant variety.

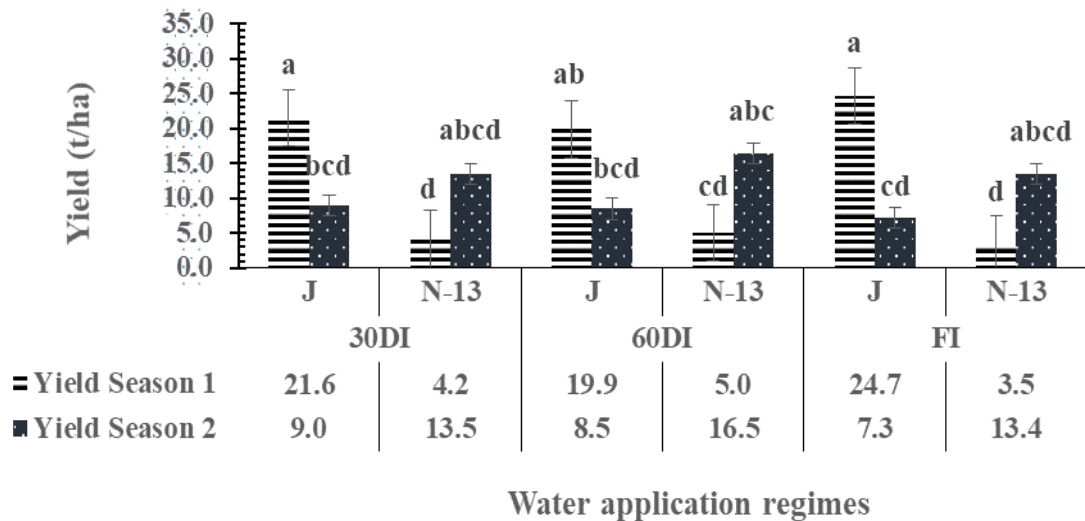


Figure 3.5: Yield of selected OFSP varieties as influenced by deficit irrigation

3.4.2.2 Zinc micronutrient

Table 3.4 and Fig. 3.6 summarize the zinc micronutrient content results. The difference in mean zinc content between seasons was highly significant ($p < 0.001$). The rain observed in season 1 influenced the zinc concentration in the OFSP varieties. Generally, the studied continued deficit irrigation strategy did not affect the zinc content of the orange-fleshed sweet potato varieties. These findings are consistent with those of Lipan *et al.* (2019), who found that the studied deficit irrigation strategies did not affect the quality of almond fruit. Furthermore, the findings in this study were insufficient to meet the 5 mg/100g recommended dietary allowance for zinc micronutrients. These findings were comparable to the range of 2.4 to 13 mg/kg reported by Neela and Fanta (2019) in their review study.

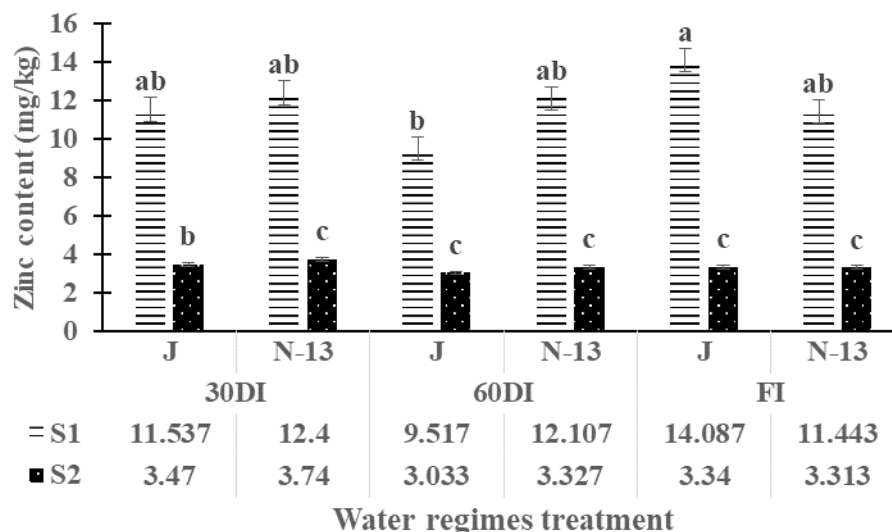


Figure 3.6: Zinc concentrations of OFSP varieties as influenced by deficit irrigation

3.4.2.3 Iron micronutrient

The iron micronutrient content varied significantly ($p < 0.01$) between seasons (Table 3.4). However, there was no significant difference ($p > 0.05$) in the mean iron content between varieties for both seasons (Fig. 3.7). The mean iron content was higher during season 2 when compared to season 1. The findings reported in this study were higher than those by Burgos *et al.* (2021), who found iron content ranging from 2.6 to 4.8 mg/kg for six varieties of OFSP investigated at different locations in the Yauli district in Peru. Therefore, acidic soils promote iron accumulation (Burgos *et al.*, 2021).

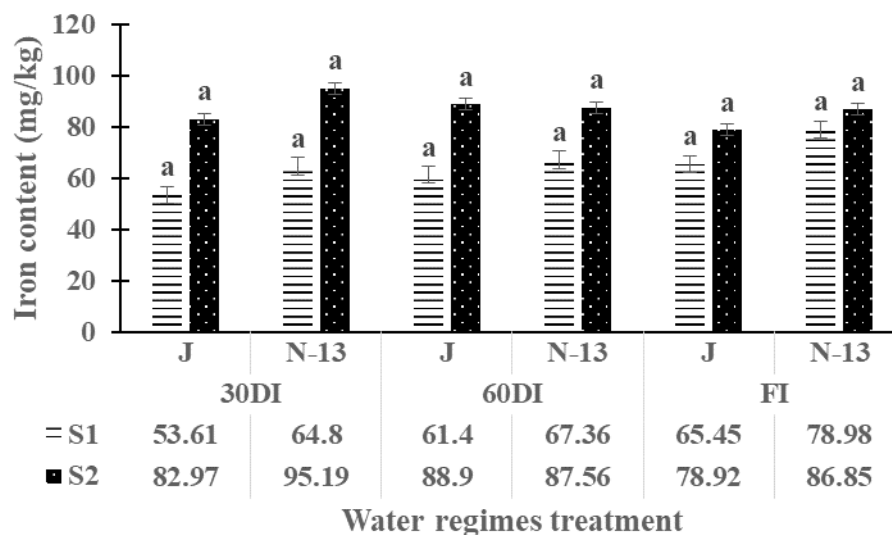


Figure 3.7: Iron concentrations of OFSP varieties as influenced by deficit irrigation

3.4.2.4 Beta-carotene nutrient

As shown in Fig. 3.8, total carotenoid content increased by 57 per cent during season 2 compared to season 1 since there was a significant interaction ($p < 0.01$) between variety and season. The considerable amount of rain that fell during season 1 appears to have reduced the total carotenoid content in orange-fleshed sweet potato varieties. These findings are consistent with Laurie *et al.* (2012a), who observed that beta-carotene tends to concentrate in the storage roots at lower moisture contents. In both seasons, the Jewel cultivar had higher levels of beta-carotene than the Naspot-13 cultivar by 31 per cent and 27 per cent for seasons 1 and 2, respectively (Fig. 3.8). The values obtained in this study

were relatively low compared to the beta-carotene content of several orange-fleshed sweet potato varieties reported by most researchers. However, there is high variability in the reported data. A review by Mwanga *et al.* (2016) presented a range of 89 to 129.8 $\mu\text{g/g}$ for the Naspot-13 cultivar. Nyathi *et al.* (2019) reported an average of 2015 to 2415 $\mu\text{g/g}$ for the Bophelo variety studied under various conditions. Furthermore, under rainout shelter, Rautenbach *et al.* (2010) and Laurie *et al.* (2012a) reported a range of 143 to 182 $\mu\text{g/g}$ for the W-119 cultivar and an average of 174 to 215 $\mu\text{g/g}$ for the Resisto cultivar. The difference between the present study results and those reported elsewhere ascribes to soil type, the interaction between genotype and environment, and other environmental factors.

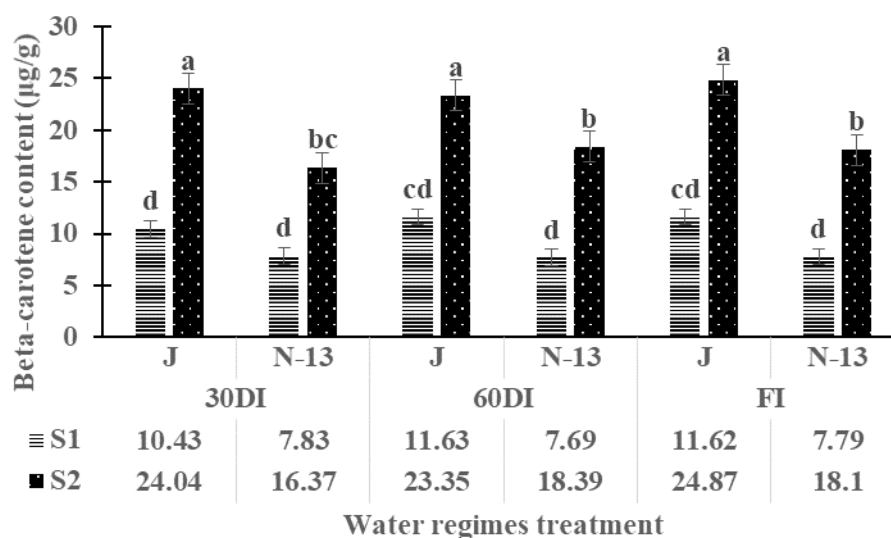


Figure 3.8: β -carotene concentrations of OFSP varieties as influenced by deficit irrigation

3.4.2.5 Nutritional contribution to dietary requirements

Despite the low beta-carotene concentration shown in season 1, notably for the Naspot-13 variety, an average amount (125g) of orange-fleshed sweet potatoes provides more than 100% of the RDA for 4-8-year-old children and 10–50-year-old pregnant women (Table 3.5). The second season provided twice the needed vitamin A for children and pregnant women compared to season one.

The potential contribution of the test OFSP varieties to iron mineral dietary requirements is adequate (Table 3.5) for both children and pregnant women in each life stage group. The second season of the Naspot-13 variety contributes the most, accounting for more

than 100 per cent of the RDA for 4–8-year-old children. Furthermore, for pregnant women aged 10 to 50, both varieties provided more than 20% of the RDA. The potential contribution of the test OFSP cultivars to zinc mineral dietary requirements is minimal (Table 3.5), with season 2 indicating less than 10% of the RDA for children and pregnant women. However, during season 1, both varieties contributed the most, accounting for more than 20% of the RDA for children aged 4 to 8 years.

Table 3.5: Nutrients provided by 125g fresh roots of orange fleshed sweetpotato varieties when boiled (calculated using the USDA retention factors)

Nutrient	RDA/AI		Unit	OFSP varieties			
	Children (4-8 yrs.)	Pregnant women (10-50 yrs.)		Jewel		Naspot-13	
				S1	S2	S1	S2
			µg RAE/125g fresh ^a	1375.0	2950.0	950.0	2150.0
Vitamin A	400	770	µg when boiled ^b	1168.8	2507.5	807.5	1827.5
			%RDA Children ^c	292.2	626.9	201.9	456.9
			%RDA Pregnant women ^c	151.8	325.6	104.9	237.3
			mg/125g fresh	7.5	10.5	8.8	11.2
Iron	10	27	mg when boiled ^b	7.1	9.9	8.4	10.7
			%RDA Children ^c	71.5	99.3	83.6	106.8
			%RDA Pregnant women ^c	26.5	36.8	31.0	39.5
			mg/125g fresh	1.5	0.4	1.5	0.4
Zinc	5	11	mg when boiled ^b	1.4	0.4	1.4	0.4
			%RDA Children ^c	27.8	7.8	28.5	8.1
			%RDA Pregnant women ^c	12.6	3.6	13.0	3.7

^a RAE is retinol activity equivalent, 1 RAE = 12 µg trans-β-carotene. Amount of trans-β-carotene is 98% of total β-carotene content

^b Nutrient content in boiled roots obtained in the present study; 95% for minerals and 85% for β-carotene (USDA, 2007)

^c RDA is recommended dietary allowance, AI is adequate intake (Institute of medicine, 2001)

3.4.3 Nutritional yield and nutritional water productivity of selected micronutrients as influenced by deficit irrigation

3.4.3.1 Beta-carotene

Beta-carotene yield varied significantly ($p < 0.001$) across varieties and seasons (Table 3.6). The Jewel variety produced the highest beta-carotene yield (287 g/ha), even though the means were statistically similar ($p > 0.05$) among the treatment combinations in both seasons. On the other hand, the Naspot-13 variety produced the highest beta-carotene yield (294 g/ha) during season 2, while season 1 gave the lowest beta-carotene yield (Table 3.7). The correlation between root yield and beta-carotene yield of either variety was positive and statistically significant ($r = 0.844$, $p < 0.001$). Therefore, an increase in the storage root yield of orange-fleshed sweet potatoes leads to a higher beta-carotene yield.

Table 3.6: Significance levels from the analysis of variance results for the effect of treatment combination and season on nutritional yield (NY) and nutritional water productivity (NWP) of selected micronutrients of orange fleshed sweet potato varieties

Source of Variation	β -NY	Fe-NY	Zn-NY	β -NWP	Fe-NWP	Zn-NWP
Treatment	ns	ns	ns	**	**	**
Variety	***	ns	***	ns	ns	ns
Seasons	***	ns	***	***	***	**
Treatment*Variety	ns	ns	**	ns	ns	ns
Treatment*Season	ns	ns	*	**	**	***
Variety*Season	***	***	***	ns	**	***
Treatment*Variety*Season	ns	ns	**	ns	ns	ns

*, **, *** indicates significance at $p < 0.05$, $p < 0.01$ and $p < 0.001$ respectively, ns indicate non-significant at $p > 0.05$, β is beta-carotene, Zn is zinc and Fe is iron

The nutritional water productivity of beta-carotene was significantly affected by the interaction between treatment combination and season ($p < 0.01$) (Table 3.6). For comparison, the findings reported in this study (Table 3.7) were lower than the nutritional water productivity values of the Bophelo variety by Nyathi *et al.* (2019). The correlation between water productivity and beta-carotene nutritional water productivity was positive and statistically significant ($r = 0.954$, $p < 0.001$).

Table 3.7: Beta-carotene yield and nutritional water productivity of orange-fleshed sweet potato varieties at three water application treatments

Water Regime	Variable	Jewel		Naspot-13	
		S1	S2	S1	S2
30 DI	β -carotene yield (g/ha)	224abc	220abc	33cd	211abcd
	β -carotene NWP (mg/m ³)	17bc	179a	2c	171a
60 DI	β -carotene yield (g/ha)	229ab	197abcd	39bcd	294a
	β -carotene NWP (mg/m ³)	17bc	80abc	3c	120ab
FI	β -carotene yield (g/ha)	287a	178abcd	26d	243a
	β -carotene NWP (mg/m ³)	20bc	44bc	2c	59bc

Similar letters indicate means not significantly different at 5% level of significance

3.4.3.2 Iron and zinc

The nutritional yield of iron was significantly affected by the interaction between variety and season ($p < 0.001$) (Table 3.9). During season 1, the iron yield of the Jewel cultivar was higher and significantly different ($p < 0.05$) from that of season 2, whereas the opposite occurred for the Naspot-13 cultivar (Fig. 3.9).

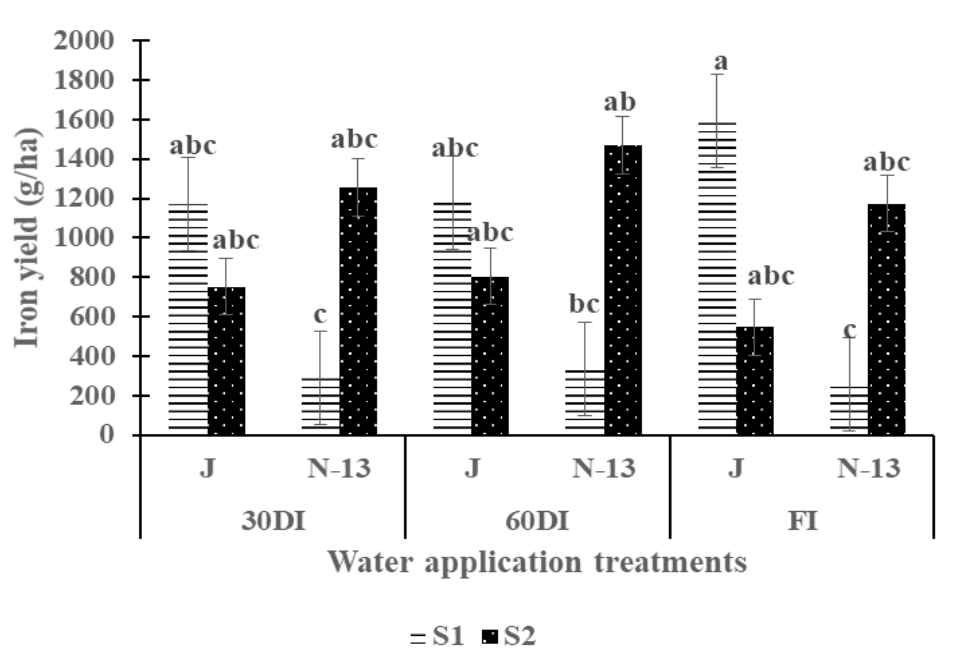


Figure 3.9: Nutrient yield of iron as influenced by full irrigation and irrigation deficit.

In the case of zinc, the three-way interaction between treatment combination, variety, and season was significant ($p < 0.01$) (Table 3.10). Furthermore, the Jewel cultivar had the highest zinc yield in season 1 under FI treatment, which was statistically different ($p < 0.01$). Zinc yield significantly decreased in season 2 (Fig. 3.10).

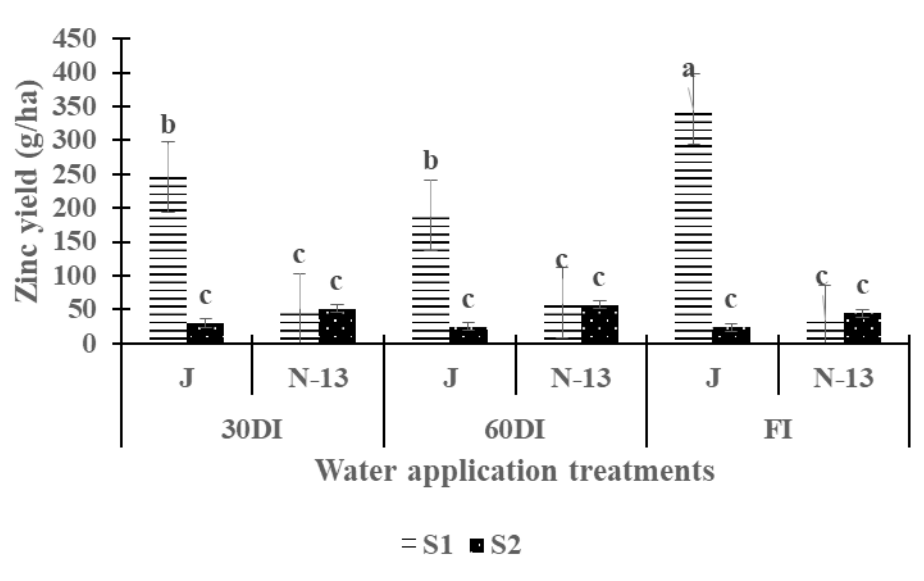


Figure 3.10: Nutrient yield of Zinc as influenced by full irrigation and irrigation deficit

As shown in Fig. 3.11, season 2 significantly ($p < 0.001$) outperformed season 1 iron nutritional water productivity for both varieties. The experience during season 1. The nutrient water productivity of iron differed significantly ($p < 0.01$) among water application regimes. There was a significant interaction between the water application regime and the season. Similarly, there was a significant interaction between variety and season at $p < 0.01$ (Table 3.11). During season 2, the nutritional water productivity of iron increased significantly ($p < 0.05$) with decreasing water application for the Naspot-13 cultivar.

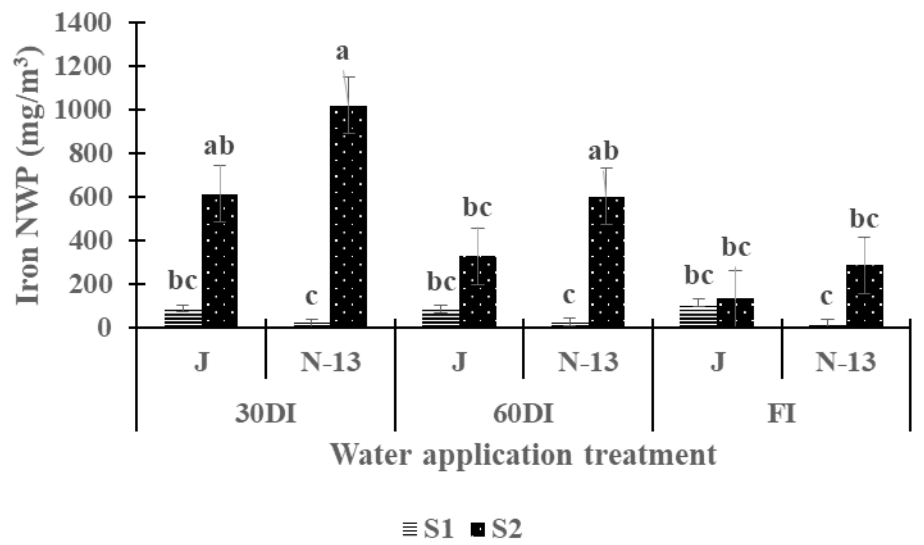


Figure 3.11: Nutritional water productivity of Iron as influenced by full irrigation and irrigation deficit

Similarly, the correlation between water productivity and nutritional water productivity of zinc was positive and statistically significant ($r = 0.873$, $p < 0.001$). The nutritional water productivity of zinc followed the same pattern as the nutritional water productivity of iron. These findings, however, are consistent with the observation that the nutritional water productivity of iron and zinc increases as water stress increases (Nyathi *et al.*, 2016, 2019; Wenhold *et al.*, 2012).

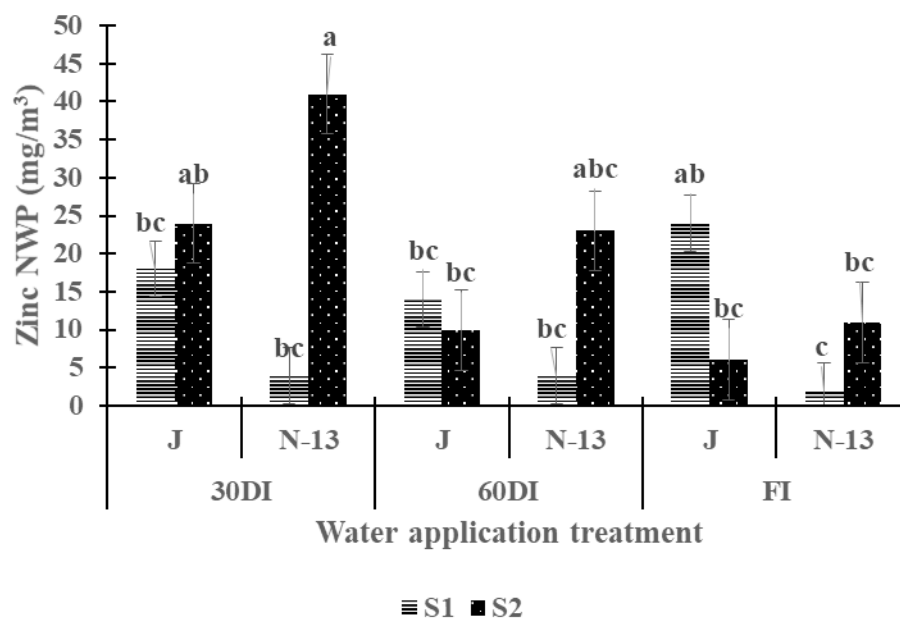


Figure 3.12: Nutritional water productivity Zinc as influenced by full irrigation and irrigation deficit

3.5 Conclusion

In conclusion, the Naspot-13 variety produced more yield with less water, as indicated by water productivity, which was 10 kg of root yield per unit m³ of water under the 30 deficit irrigation treatment. According to the findings of this study, the Jewel variety is a water-loving crop, whereas the Naspot-13 cultivar is a drought-tolerant crop. The quality of beta-carotene, iron, and zinc content did not change under the adopted deficit irrigation strategy. Furthermore, there was a significant improvement in beta-carotene and iron nutrient content for both varieties among seasons.

An average serving (125g) of boiled OFSP for both varieties provides more than 100 per cent of the recommended dietary requirement for vitamin A. Furthermore, both cultivars contributed an adequate iron mineral dietary requirement with a minimal amount of zinc mineral dietary requirement. Jewel cultivar root yield, iron, and zinc nutritional yields increased as water application increased. The Naspot-13 cultivar's root yield, iron, and zinc nutrient yields decreased as water application increased.

Based on the findings of this study, it is reasonable to conclude that the Naspot-13 variety is a suitable variety for use as a food security crop that can be grown in areas with limited water resources. Neither cultivar contained adequate nutrient content in beta-carotene, iron, or zinc. However, the findings were still sufficient for managing malnutrition, iron, and zinc deficiency complications.

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CHAPTER FOUR

4.0 Economic analysis of drip-irrigated orange fleshed sweet potato (*Ipomoea batatas* L.Lam) production in Tanzania

4.1 Abstract

To compare the economic feasibility of deficit irrigation strategies versus full irrigation, the economics of drip-irrigated orange-fleshed sweet potato production under deficit irrigation were worked out. The study aimed to assess the economics of drip-irrigated orange-fleshed sweet potato production to deficit irrigation. The field data on yield values, production costs, water costs, and commodity prices were collected. The data helped calculate the indicators for net financial return and benefit-cost ratio of orange-fleshed sweet potato production. The results indicate a positive net financial return under water-limiting conditions with a benefit-cost ratio greater than one for all studied water application levels. The highest benefit-cost ratio of 1.6 was observed for the Naspot-13 variety under the 60 DI deficit strategy for water-limiting situations.

Keywords: Naspot-13, Jewel, Drip irrigation, Economic viability, Benefit-Cost Ratio

4.2 Introduction

Drip irrigation is regarded as one of the most efficient types of irrigation. The high rate of drip irrigation adoption is due to its positive impact on water saving, productivity, and product quality output in many crops, including orange-fleshed sweet potatoes (Fereres *et al.*, 2003).

Deficit irrigation is an optimization strategy in which irrigation water is applied in amounts below the crop water demand and can be applied at certain stages during the plant's growing season or throughout its growing season (Fereres and Rabanales, 2007). Deficit irrigation strategies have been reported by researchers, which include: regulated deficit irrigation (RDI), sustained deficit irrigation (SDI), and partial root-zone drying irrigation (PRD) (Ben-Gal *et al.*, 2021; Consoli *et al.*, 2016; Lipan *et al.*, 2019). PRD simultaneously maintains both a wet and dry portion of the root zone, whereas RDI strategies create a moisture deficit throughout the root zone (Shahnazari *et al.*, 2008). When the irrigation water volumes are required for leaching, then it is considered a sustainable strategy (Du *et al.*, 2015). Deficit irrigation provides a promising approach to

efficiently saving water while ensuring that the agricultural water productivity of several crops is improved. Therefore, there is a need to conduct an impact analysis on crop yield and the economic evaluation of deficit irrigation (DI) techniques on the crop from the farmer's perspective.

According to Nabay *et al.* (2020), sweet potato trading investments had a net positive return using the benefit-cost ratio (BCR). On the other hand, Prakash *et al.* (2016) conducted a profitability analysis of sweet potato production in Odisha, India, and observed that sweet potato farmers made a profit. Similarly, Yusuf and Wuyah (2015) found that sweet potato production was profitable in Kaduna State, Nigeria.

Interestingly, even though OFSP processing has been reported to be economically viable, few studies have looked into the economic performance of deficit irrigation on the OFSP crop (Kangile *et al.*, 2020). Therefore, the current study aimed to evaluate the production economics of a drip-irrigated OFSP crop.

4.3 Materials and methods

4.3.1 Study area description

4.3.1.1 Location and topography

The field experiment was conducted at the School of Engineering and Technology (SoET) research field in Morogoro, Tanzania (grid zone: 350213.19 E, 9243788.94 N, 37M; 512 m above sea level) (Fig. 4.1) located in Morogoro Urban. Morogoro Urban District is bordered by the Uluguru Mountains on the south eastern side and Mindu and Nguru ya Ndege hills on the western side. The district comprises a larger part of plains of various forms and extents. Rainfall in river valleys and basins ranges from 600 mm to 1400 mm per year. Temperatures in this zone are high due to its lowland location, with an average of 30 °C. The zone is densely populated in the upper valleys but less so in the lower valleys.

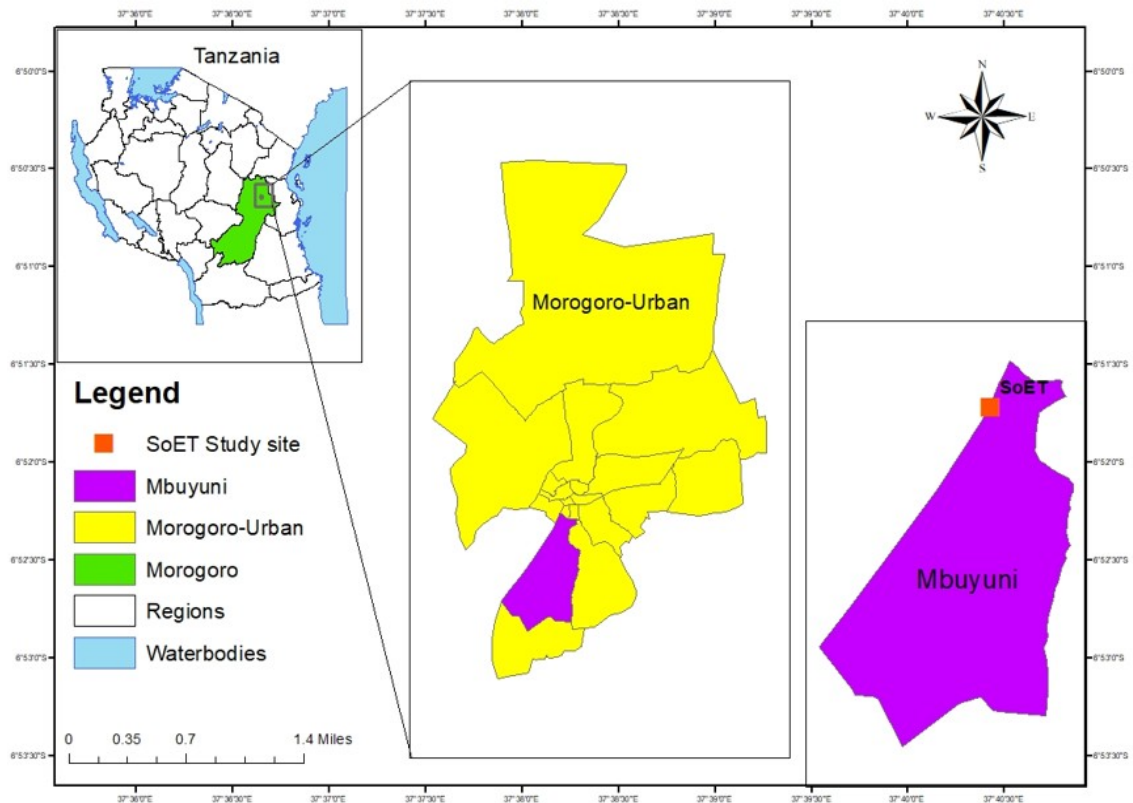


Figure 4.1: Location of study area in Morogoro region, Tanzania

4.3.1.2 Climate

The distribution of rainfall within the Morogoro urban area is bimodal, with long rains between March and May and short rains between October and December. Fig. 4.2 shows the Morogoro monthly average rainfall frequency for 60 years under normal conditions. The long rains (*Masika*) on average amount to 411.1 mm annually, whereas the short rains (*Vuli*) average 149.8 mm annually (Fig. 4.2). Table 4.1 shows the mean monthly weather data for Morogoro Urban District, Tanzania for 6 years

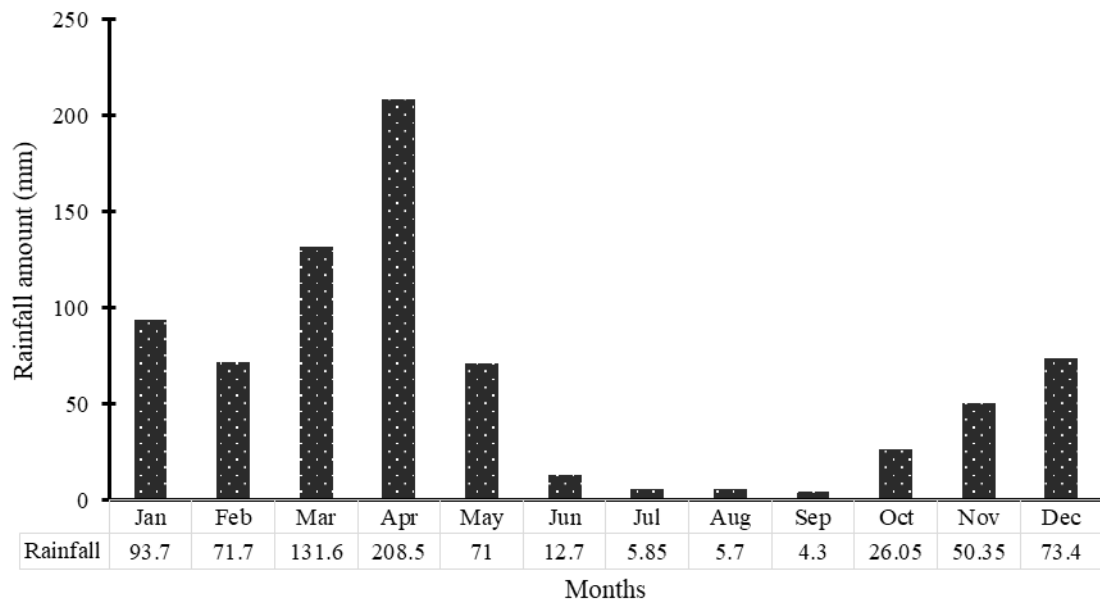


Figure 4.2: Mean monthly rainfall (mm) at Morogoro (1961-2020) (Source: TMA Meteorological Station, 2021)

Table 4.1: Mean monthly weather data within Morogoro Urban (2015-2020)

Month	3 pm RH (%)	Wind (Km/day)	Temperature (°C)		Radiation (MJ/m ²)
			Maximum	Minimum	
JAN	64.1	181.2	32.1	22.1	19.8
FEB	68.2	159.0	32.7	22.2	21.0
MAR	66.3	85.4	32.3	22.0	18.5
APR	75.9	49.4	29.6	21.5	15.2
MAY	72.9	39.9	28.2	19.9	13.9
JUN	64.1	48.2	28.2	16.9	15.4
JUL	64.9	61.7	27.9	16.1	15.2
AUG	53.8	83.7	28.8	17.2	16.4
SEP	50.7	109.7	30.6	17.7	18.2
OCT	51.8	118.7	31.5	19.5	18.2
NOV	57.5	144.9	31.7	21.2	19.7
DEC	58.3	173.5	32.6	22.2	20.0

(Source: TMA Meteorological Station, 2021)

4.3.1.3 Soils

Soils in the Morogoro Region vary according to topology and agro ecological zones. In USDA soil taxonomy, the soil in the experimental area is classified as Ultisol, and in FAO-UNESCO classification, it is classified as Acrisol (Msanya *et al.*, 2003). The

physical and chemical properties of the soil for the top 300 mm layer are shown in Table 4.2. The soil texture is sandy clay, and the clay content in the upper 300 mm of the soil sample profile was 53 per cent. The soil's field capacity was 333 mm/m and the permanent wilting point was 208 mm/m.

Table 4.2: Physical and chemical properties of the topsoil layer (0 - 300 mm) at the experiment site, SUA, Morogoro Region

Soil parameters	Unit	Range per 300 mm	Remarks
Soil pH (H ₂ O)		5.19 – 5.96	weak acidic soils
Electrical Conductivity ^a	μS/cm	117 – 207	non saline
TN-Kjeld ^c	mg kg ⁻¹	900 – 1300	Low
Ext. Phosphorous(PBry-1) ^b	mg kg ⁻¹	0.58 – 1.43	Low
Zinc ^d	mg kg ⁻¹	0.21 – 0.86	Low
Iron ^d	mg kg ⁻¹	17.06 – 22.07	High
Clay ^e	%	54.48 – 53.48	
Silt ^e	%	0.32 – 1.68	
Sand ^e	%	43.84 – 46.20	

The range represents different sampling points within the experiment field

^a1:2:5 w/v method (Ayers and Westcot, 1985)

^bBray 1 method (FAO, 2021)

^cKjeldahl method (Bremner, 1960)

^dDTPA extraction method (Lindsay and Norvell, 1978)

^eSieve and pipette method

4.3.2 Experimental setup, treatments, replications

The experimental schematic layout of the irrigation system network is shown in Fig. 4.3. The experiment was conducted over two seasons, i.e., the 2020/21 and 2021 seasons. A factorial arrangement of treatments was laid out in a randomized complete block design. The test varieties were Naspot-13 and Jewel of orange fleshed sweet potato crop. The water application regimes were 100 percent (Full irrigation (FI)), 60 percent (60 DI), and 30 percent (30 DI) of total available water (Laurie *et al.*, 2012). A 3 x 2 factorial with three replications was applied. When 20% of the total available water (TAW) was depleted, the FI treatment was irrigated 100% to field capacity, whereas the 60 DI and 30 DI treatments received 60% and 30% of the amount applied in the FI treatment, respectively.

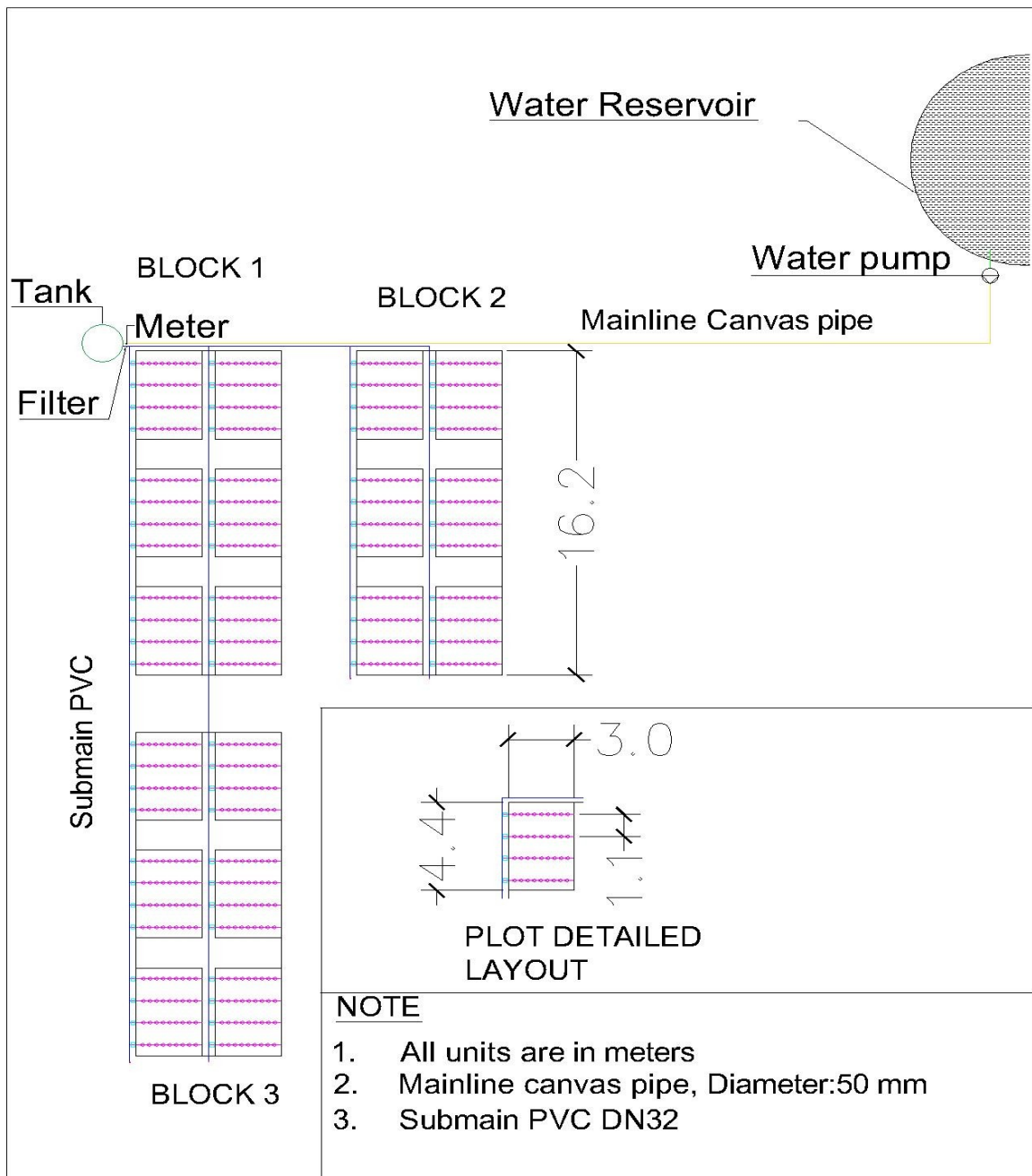


Figure 4.3: Experimental schematic layout of the irrigation network

Fig. 4.4 shows the experimental arrangement of treatment combinations per replication. Each plot measured 3 m by 4.4 m with a plant spacing of 0.3 m within a row and 1.1 m between rows laid out in ridges (36 plants per plot).

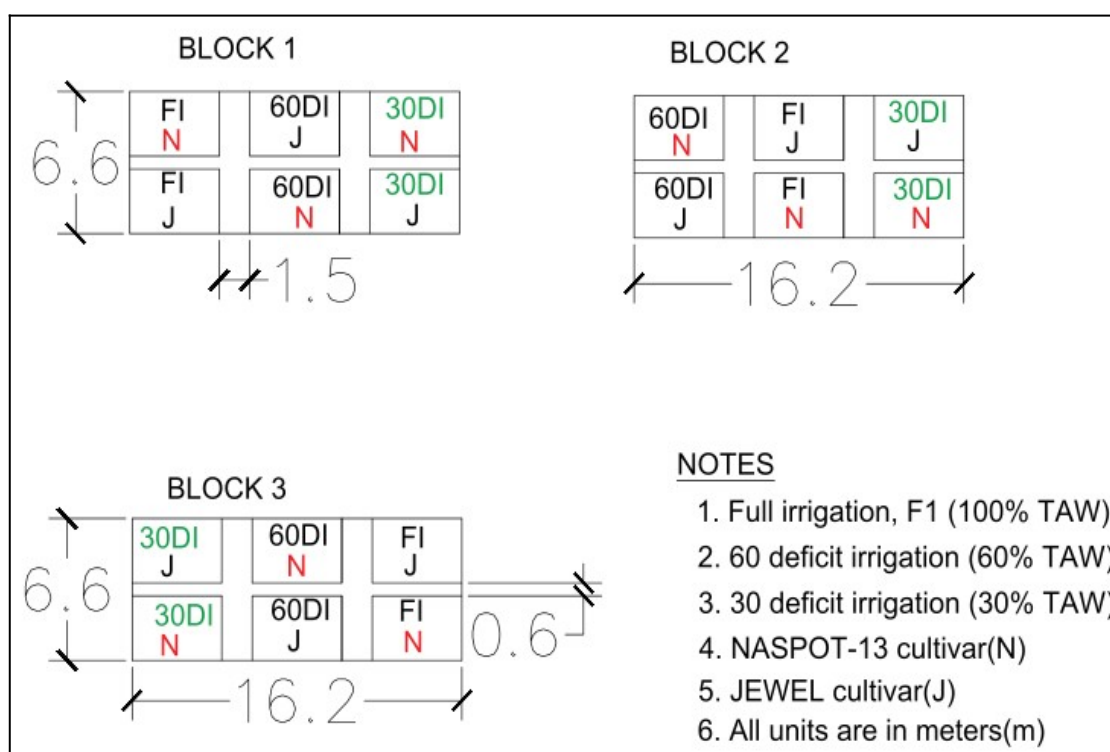


Figure 4.4: Experimental arrangement of treatment combinations per replication

4.3.3 Economic Analysis

Deficit irrigation was the main focus of this study, though economic analysis of both land-limiting and water-limiting situations was investigated as described by Ali *et al.* (2007). Furthermore, quoting Ali *et al.* (2007), "under some circumstances, available land for cultivation may be limited, but the available water is abundant, this is a land-limiting case. An area with limited water and abundant land and the farm in question have an opportunity to irrigate additional land if water becomes available. It is a water-limited case".

4.3.3.1 Land-limiting condition

Benefit-cost ratio (BCR) analysis is a financial measure of project usefulness. In this study, economic return analyses of the production systems of OFSP varieties under each irrigation regime were calculated using BCR (Panigrahi *et al.*, 2013). However, BCR components, including the capital cost of the drip irrigation system, as shown (Table 4.3), and the gross and net return of the irrigation regimes were estimated assuming that the area of the field was 1 hectare and the land was flat. The total cost of production incorporated the summation of operation cost, land use cost on a seasonal basis per year and the interest amount on the operating capital cost.

Operating costs consisted of fertilizer cost, cost of tillage, seedlings cost, irrigation costs (water and energy cost), insecticide cost, and human labour cost. Operating capital cost was considered as an average operating cost over the growing period with interest being charged at a rate of 10% per year (Ali *et al.*, 2007). The gross return was obtained as the product of marketable storage root yield and above-ground biomass with their respective prevailing market prices. The net financial return was determined as the difference between total cost and gross return. Finally, BCR was determined as the ratio of gross return to the total cost of production.

Table 4.3: Capital cost of the drip irrigation system

S/NO	Item	Technical		Unit Cost	Total Cost (US \$)
		Specification	Quantity		
1	Drip line and emitter	2 lph PC	8 No	174	1388
2	Laterals	16mm blind pipe	27 m	0.65	18
3	Main pipe	Canvass	100 m		52
4	Sub main pipe	32mm PE 100	100 m	0.43	43
5	Control valves		1 No		5
6	Filter and Water meter	Screen filter			43
7	Drip accessories	PVC			98
8	Water pump	5hp	1 No		126
TOTAL					1773

US \$ is US dollars [1 US \$ = 2305 Tanzanian Shilling)

4.3.3.2 Water limiting condition

In this case, the amount of water used is less than the actual amount, and the saved water can be used to expand the production land. The maximum increase in farm income from increased area coverage due to saved water is an irrigation water opportunity cost (Ali *et al.*, 2007; Mila *et al.*, 2017). The computation of total production cost and gross return followed the same procedure discussed under the land-limiting condition.

4.3.4 Data analysis

The analytical tools utilized to capture the objective of this study are:

- i). Total production cost function

The total production cost = Total operation cost + land use cost + Interest amount on the operating capital cost (1)

Operation cost = Fertilizer cost + Tillage cost + Seedlings cost + irrigation costs + insecticide cost + human labour cost..... (2)

The price of fertilizer as per the prevailing market price was 40, 000 Tanzania shilling (TSh.) per 50kg in the study area. The unit cost per seedling was TSh. 50. The cost of water was TSh. 1250 per cubic meter. The average wage rate was put at TSh. 10 000 per man day.

ii). The net return function

The net return = (Marketable storage root + above ground biomass) * Market prices..... (3)

The prevailing market price for the marketable storage root of OFSP was TSh. 800 whereas for the biomass was TSh. 200 per kilogram in the study area.

iii). Benefit-Cost Ratio (BCR)

BCR = Gross return/Total cost of production..... (4)

Computations were done by use of electronic spreadsheets (XLSTAT and Excel)

4.4 Results and Discussion

4.4.1 Economic implications of the OFSP varieties under land-limiting condition

The cost of irrigation water and the associated energy cost influenced the overall cost of irrigation of orange-fleshed sweet potatoes. The revenue from OFSP varieties and by-products varied according to variety and water application regime. The highest gross return was observed under full irrigation for Jewel and under a 60 DI deficit strategy for the Naspot-13 cultivar (Table 4.4). The 30 DI deficit strategy produced the highest net return for the Jewel cultivar. The rain effect in season 1 increased yield. The 60 DI deficit strategy yielded the highest net return for the Naspot-13 cultivar. The BCR was more than one in all treatments, with the highest value at the 60 DI deficit strategy for the Naspot-13 cultivar.

Table 4.4: Economics of orange fleshed sweet potato production using drip irrigation under land-limiting condition in 2020-2021

Variety	Treatment	Gross return (US \$)	Total operating cost (US \$)	Interest on Operating capital	Land use cost (US \$)	Total cost (US \$)	Net return (US \$)	BCR
JEWEL	FI	16110	10254	513	43	10810	5300	1.5
	60DI	14622	9295	465	43	9803	4819	1.5
	30DI	15088	9006	450	43	9499	5588	1.6
NASPOT-13	FI	15586	10254	513	43	10810	4775	1.4
	60DI	16320	9295	465	43	9803	6516	1.7
	30DI	13486	9006	450	43	9499	3987	1.4

4.4.2 Economic implications of OFSP production under water-limiting condition

The gross return from both varieties of OFSP and their respective vines increased in the deficit irrigation treatments than in the full irrigation treatments (Table 4.5). The reason is an increase in the amount of land under cultivation as a result of the saved water. The 30 DI treatment yielded the highest gross return because 70% of irrigation water was saved with a nearly double-fold increase in area coverage.

A similar trend occurred in total production costs, which were higher under deficit irrigation than under full irrigation. The 30DI treatment had the greatest total production cost, which was more than 1.5 times higher than full irrigation. This is because the amount of land under cultivation increased, which in turn increased the operating costs. The operating costs included the capital cost of the drip irrigation system; tillage costs, insecticide costs, irrigation costs, labour costs, fertilizer costs, and seedling costs. The net return of the Jewel variety was high under the 30DI treatment. Similarly, the net return of the Naspot-13 variety was high under the 60 DI treatment. The findings were consistent with those reported by Ali *et al.* (2007) and Mila *et al.* (2017), even though they looked at the economics of deficit irrigation on wheat and sunflower, respectively.

The benefit-cost ratio (BCR) of the studied deficit irrigation strategies was more than one (Table 4.3), indicating that producing OFSP under drip irrigation in sandy-clay soils is economically viable.

Table 4.5: Economics of orange fleshed sweet potato production using drip irrigation under water-limiting condition in 2020-2021

Variety	Treatment	Land under irrigation (ha)	Gross return (US \$)	Total operating cost (US \$)	Interest on Operating capital	Land use cost (US \$)	Total cost (US \$)	Net return (US \$)	BCR
	FI	1	16110	10254	513	43	10810	5300	1.5
JEWEL	60DI	1.4	20471	13740	687	61	14487	5984	1.4
	30DI	1.7	25649	16354	818	74	17245	8404	1.5
	FI	1	15586	10254	513	43	10810	4775	1.4
NASPOT-13	60DI	1.4	22847	13740	687	61	14487	8360	1.6
	30DI	1.7	22926	16354	818	74	17245	5681	1.3

The findings of this study imply that with limited water resources, there is an opportunity to increase net farm income by employing the 60 DI deficit strategy with the Naspot-13 cultivar. As a result, adopting the 60 DI strategy is a cost-effective option than full irrigation for Naspot-13 cultivation using drip irrigation in sandy-clay soils. Similarly, adopting full irrigation is an economically viable option in regions with sufficient water resources for the Jewel variety.

4.5 Conclusions

The findings of this study show that it is economically viable to engage in orange-fleshed sweet potato production using drip irrigation in sandy clay soil in regions prone to limited water resources. A net positive return using BCR was observed between the water application regimes. The highest net financial return (6516 US dollars per ha) materialized under the Naspot-13 variety at 60 DI treatment in the case of the land-limiting condition. However, in the case of water-limiting situations, the highest net financial return was under the Jewel variety at 30DI treatment (8404 US dollars). Therefore, it implies that a strategy would be more likely in light of the findings of this study. The results of the economic analysis under land and water resource situations provide information to policymakers for formulating improved planning regarding irrigation management practices. The result would help adopt a deficit irrigation strategy to enhance net financial returns. Nevertheless, there is a need to conduct further preliminary studies on the economic returns of orange-fleshed sweet potato production under different deficit irrigation methods.

4.6 References

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CHAPTER FIVE

5.0 Conclusion and Recommendations

5.1 Conclusion

Based on the findings of this study, the following conclusions were drawn: In terms of yielding ability, the Naspot-13 variety performs well under limited water resources, whereas the Jewel variety performs well under abundant water resources. The amount of water used had no effect on the dry matter content of either cultivar. The water productivity and harvest index of the varieties increased under deficit irrigation. Many opportunities exist to increase net farm income with the Naspot-13 variety in sandy clay soils with limited water resources using a drip irrigation system.

Vitamin A, iron, and zinc concentrations ranging from 628 to 2031 RAE/Kg, 54 to 95 mg/Kg, and 3 to 14 mg/Kg, respectively, were adequate in meeting the recommended dietary allowance. The Jewel variety had superior nutrient qualities to the Naspot-13 cultivar. Furthermore, both cultivars show that beta-carotene content increased with a decrease in the seasonal amount of water applied. Also, zinc micronutrient content decreased while iron micronutrient content remained statistically similar. The nutritional water productivity of beta-carotene, iron, and zinc increased for both varieties with a reduction in water application.

5.2 Recommendations

Based on the findings of this study, the following recommendations can be made: The Naspot-13 variety can strategically be used as a viable crop for producing more nutritionally dense food in areas prone to water scarcity and highly vulnerable to malnutrition. Further research can be conducted to compare the response of OFSP varieties using different deficit irrigation methods to improve water management in small scale producer systems.