INVESTIGATING THE EFFECTS OF MUNICIPAL TREATED WASTEWATER IRRIGATION MANAGEMENT ON GROWTH AND YIELD PARAMETERS OF MADUMBE (*Colocasia esculenta*) AND RICE *(Oryza sativa L.)* USING ANAEROBIC BAFFLED REACTOR (ABR) EFFLUENTS

IT Busari
216076978

SEMINAR

Submitted in partial fulfilment of the requirements for the degree of PhD (Engineering)

Bioresources Engineering
School of Engineering
University of KwaZulu-Natal
Pietermaritzburg
November 2017

PREFACE

I, Isiaka Toyin Busari declare that:

(i) This literature review and proposal, except where otherwise indicated, is my original work.

(ii) This literature review and proposal has not been submitted for any degree or examination at any other university.

(iii) This literature review and proposal does n or other information, unless specifically acknowledged as being sourced from other persons.

(iv) This literature review and proposal does ting, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

(a) Their words have been re-written but the general information attributed to them has been referenced;

(b) Where their exact words have been used, their writing has been placed inside quotation marks, and referenced.

(v) Where I have reproduced a publication of which I am an author, co-author or editor, I have indicated in detail which part of the publication was written by myself alone and have fully referenced such publications.

(vi) This literature review and proposal does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the document and in the References sections.

Signed:

Supervisor:

Co-supervisor:

ABSTRACT

The discharge of treated wastewater (TWW) in decentralized wastewater treatment systems (DEWATS) of urban and peri-urban (UP) environments from anaerobic baffled reactor (ABR) effluents can cause pollution. Usage and management of treated wastewater for irrigation have the possibility of using up nitrogen (N) and phosphorous (P) and increasing production of crop per household in urban and peri-urban settings, as well as reducing the hazards of environmental contamination. Therefore, the broad objective of this study is to evaluate the effects of treated wastewater irrigation management approaches and intercropping on the growth and yield of flood irrigated madumbe and rice (water and nutrients loving crops) using ABR effluents. It is expected that treated wastewater irrigation management and intercropping do have an effect on the agronomic performance of madumbe and rice. A field trial using basin (flood) irrigation with ABR effluent and pot planting inside a tunnel house for zero effective rainfall will be conducted simultaneously with the same treatments at Pollution Research Group (PRG) farm, Newlands, Durban. The treatments consist of alternate wetting and drying - AWD, conventional flooding irrigation - CFI and continuous wetting without flooding - WWF) and cropping systems madumbe, rice and madumbe and rice. The treatments with WWF and CFI will serve as controls at both field and pot trials for madumbe and rice respectively. Each of the treatments is replicated three times in a randomized complete block design. Water and nutrient balance analyses would be carried out as a proper monitoring tool. Data will be collected on the growth and yield parameters of the crops. Irrigating crops with ABR effluent is expected to decrease the quantity of water that needs to be extracted from expensive municipal water supply or natural water sources. Consequently, treated municipal wastewater may be a valuable water source for reusing and recycling.

TABLE OF CONTENTS

page

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Water is a very valuable resource yet, it is a strictly insufficient resource in many nations (Rusan *et al.*, 2007). Hence, the need to preserve, protect and conserve fresh water and access lower quality water for irrigation (Al-Rashed and Sherif, 2000). Water is a natural asset critical for the survival of human beings. Different human activities, which include disposal of effluent into both surface and ground water resources, coupled with increasing population have made appropriate management of water resources a very complex requirement throughout the world. Essentially, an increase in the water demands by the urban populations is reducing the water availabile for agricultural purposes with a rise in associated costs. To counter the continually growing food and fibre requirements of an increasing populace, it is imperative to enhance irrigation water efficiency to guarantee sustainable agriculture (Hari *et al.*, 2016).

Globally, fast urbanization is tantamount to rapid increase in urban poverty and urban food insecurity. The developing countries of Africa, Asia and Latin America will be home to some 75% of all urban dwellers in 2020 because of the productive reuse of wastewater for irrigation, where crops of high value can be raised due to amount of nutrients in the wastewater and where the demand for tap water is more (de Zeeuw and Drechsel, 2015). In the next 25 years, Africa may face declining food security in the metropolises due to fast urbanisation because above one-third of the populace will live in cities. The growing demand for fresh and consumable agricultural crops in the major cities is driving the development of non-seasonal urban and peri-urban irrigation (UPI) requiring year-round production, dependent on irrigation (Sonou, 2001).

According to Renner (2012), surface irrigation is the application of water to the surface of the field. The entire field might be flooded (basin irrigation), the water might be fed into minor channels (furrows) or strips of land (borders). It is the most common irrigation method. It is usually applied when conditions such as sufficient or abundant supply of water are favourable, mild slopes, soil type is clayey-loam with medium to low infiltration rate. Basins are surrounded by low bunds. The bunds avert water from moving to the end-to-end fields (Renner, 2012).

Recycling of wastewater for irrigation is becoming a common practice (Alghobar and Suresha, 2016). Recycling of urban wastewater in agriculture has become public practice for a number of reasons, part of it begin water scarcity, nutrient worth and environmental safety (Tamoutsidis *et al.*, 2009). The need for irrigation, since rainfall is not readily available throughout a season, and the need for water are constantly growing; therefore, water of higher quality is conserved for domestic use while that of lesser quality is suggested for irrigation purposes (Nafchi, 2016). Musazura *et al.* (2015) found that closely inhabited peri-urban settlements in developing nations like South Africa need cost effective solution systems called decentralized waste water treatment systems (DEWATS) to be developed which comprises the use of anaerobic baffled reactors (ABR). The need for DEWATS is because of the rate of expansion of the peri-urban populace and the implication of connecting it to the main central sewers. Wang *et al.* (2004) defined ABR as a series of baffles which allow wastewater to flow under and over them from inlet to outlet in the absence of oxygen. It is based on physical treatment that involves settling of sludge and biological treatment that involves anaerobic digestion.

An attempt to introduce mono-cropping systems to the environment, a tradition of farmers in the humid and sub-humid tropics, has failed because intercropping is almost synonymous with peasant agriculture (Njoku and Muoneke, 2008). Intercropping suppresses weeds, reduces pest disease infestation and gives yield advantage. It encourages higher nutrient uptake than in mono-cropping and water use efficiency is high. It enhances high soil fertility maintenance particularly where legumes are used as a component crop (Ibeawuchi, 2007). According to Ouma and Jeruto (2010), two or more crops grown together should have enough spacing to exploit cooperation and avoid competition among them.

Madumbe (*Colocasia esculenta*), being one of the food security crops, is a marginalized tuber food crop, with wide distribution in the tropics. The neglect of madumbe as an indigenous crop is one of the causes of food insecurity; therefore, production of indigenous crops will play a critical role in contributing to food security (Kamwendo and Kamwendo, 2014). It is the 14th most consumed vegetable worldwide (Lebot and Aradhya, 1991; Singh *et al.*, 2008; Tumuhimbise, 2015). All parts of the plant can be used for human consumption; nonetheless its starch-rich corm is by far the most frequently used part. The corms provide easily digestible starch and the leaves provide nutritious spinach-like vegetable, which is rich in minerals and vitamins. Despite its importance as a food and vegetable crop, it has received very limited research attention from agricultural, academic and development institutions and is therefore classified as a neglected and an underutilized crop species (Tumuhimbise, 2015).

Madumbe (an indigenous crop) is one of the food security crops but scientific research on it is scarce in South Africa (Sibiya, 2015; Tumuhimbise, 2015; Mabhaudhi and Modi, 2016). Cocoyam (corms and cormels) is "*an underexploited food and feed resource"* (Owusu-Darko *et al.*, 2014).

Rice (*Oryza sativa L.)* is a main food for more than half of worldwide, plus thousands of families in Sub-Saharan Africa (SSA). Rice is grown in almost 115 nations in the world and is only next to wheat in terms of production globally (Carriger and Vallee, 2007). Approximately 40% of the rice consumed in Africa is imported. Africa is, therefore, seriously exposed to global market shocks with sometimes weighty consequences on food security and political stability as shown by events of 2008 food crisis (Seck *et al.*, 2010). Luckily, Africa is blessed with an abundant source of natural resources which can support an enormous expansion in food, specifically precisely rice production (Balasubramanian *et al.*, 2007).

There has not been any reported study carried out to investigate the effect of treated wastewater such as ABR effluent with regards to wastewater irrigation management approaches through flood irrigation. There is also no report of an intercrop of Madumbe with rice using flood irrigation in the presence of an abundant treated wastewater. Madumbe production is synonymous with food and income security, hence, the need to carry out this study because it is expected to make madumbe available throughout the year, if the knowledge is adopted.

Having presented the general introduction and preamble to the research topic, it is pertinent to discuss in detail wastewater and agriculture (Chapter 2) which include its effect, guidelines, benefits, potential risks, public concern and how to overcome wastewater reuse problems. Chapter 3 deals with the wastewater irrigation management and intercropping while Chapter 4 details the two crops (madumbe and rice) and previous studies on madumbe. Discussion and conclusion of literature review were discussed in Chapter 5. Chapter 6 explains the details about the research proposal and finally Chapter 7 lists the various references cited and consulted.

2. WASTEWATER AND AGRICULTURE

Urban wastewater is less expensive and considered an attractive source for irrigation. Any source of water which might be used carefully and efficiently should be considered to promote further development. Inadequate water supplies require careful management for effective agricultural production (Kiziloglu *et al.*, 2008). The growing necessity for water in the world, inclusive of Sub-Saharan Africa, has resulted in the development of application of wastewater for farming and landscaping. The only potential source of water that will rise as the population increases and the demand for freshwater rises, is wastewater (Heidarpour *et al.*, 2007).

Sustainable techniques for wastewater disposal in a way that enhances crop production will ease water shortages and recycling of nutrients also necessitates the use of treated wastewater for irrigating crops (Pedrero *et al.*, 2010). According to Tabatabaei *et al.* (2017), the deteriorating water resources, ever growing drying time and increasing irrigated land, lead to deficit irrigated production which is not based on full water requirement.

The attention to recycling wastewater for irrigation is growing rapidly in most countries. Moreover, irrigation with communal wastewater is considered an environmentally sound wastewater dumping practice that helps to reduce the effluence of the ecosystem subjected to pollution by direct disposal of wastewater into surface or groundwater. Furthermore, wastewater is a valuable source for plant nutrients and organic matter needed for preserving fertility and productivity of soils. Nevertheless, the reuse of wastewater for irrigation may possibly create environmental problems if not suitably treated and managed (Kiziloglu *et al.*, 2008).

ABR is made up of a tank and discontinuous hanging baffles (Wang *et al.*, 2004) that separate the reactors and force domestic waste to move from one partition to another, permitting improved contact among the fresh wastewater (influents) entering the container, the residual (sludge) and the effluents leaving the reactor. According to Bame *et al.* (2014), ABR as a high rate digester (anaerobically), involves different hanging and vertical baffles premeditated for wastewater treatment. The ABR is an appropriate method for medium or short-term hygiene solutions in low-income societies (Foxon *et al.*, 2004).

2.1 Effects of Recycled Wastewater

The recycling of wastewater for irrigation use is becoming a widespread practice. Irrigation with wastewater has two distinct levels of consequences: may change the physico-chemical properties and microbiological content of the soil. The former may disturb soil productivity and fertility; the latter may pose severe dangers to human and environmental health (Alghobar and Suresha, 2016). Unnecessary build-up of large amounts of nutrients in the soil may cause adverse effects on productivity and quality of crops, if wastewater is used as the only source of irrigation water for field crops. Accordingly, use of irrigation with wastewater should take into consideration the nutrient content in relation to the specific crop requirements and the concentrations in the soil, and other soil fertility parameters.

According to Musazura *et al.* (2015), the ABR effluent comprises mineral elements (phosphorus and nitrogen) which are significant for growth of crops. Eutrophication and death of aquatic life can occur if the effluent is discharged into water bodies. It is expected under normal situations that users have no direct contact with either the influent or effluent because they contain high levels of pathogens. Both the influent and effluent produce odour and care must be taken in planning and establishing the ABR plant facilities to minimize odour troubles to the nearby inhabitants (Tilley *et al.*, 2014). Generally, effluents from ABR have been proven to constantly meet the standard requirements for irrigation with regard to the removal of organics such as BOD or COD for reuse in agriculture, but not for disposal to surface waters. The high contents of nutrients, ammonia and phosphorous in the effluents may be viewed as a valuable resource from an agricultural perspective. Obviously, an important function of a system that produces effluent coming from raw wastewater should display removal of adequate pathogens to reduce the likelihood of infecting the public with waterborne pathogens (Foxon *et al.*, 2004). Introduction of wastewater below the surface of soil could reduce the surface microbiological contamination meaningfully (Najafi and Tabatabaei, 2008).

Irrigating with grey water produced statistically significant higher yields and general growth of plant for spinach, peppers and onion than was attained with the use of hydroponic nutrient solution (Kanawade, 2015). Use of wastewater also increased dry and wet forage yield (Nafchi, 2016). Irrigating with wastewater significantly affected the plant height (Alghobar and Suresha, 2016). The cause of the improvement in yield is not immediately clear and neither are possible harmful effects of greywater on plant growth.

2.2 Effects of Treated Wastewater on Physico-chemical Properties of Soils

Several studies evaluated the effects of using treated wastewater on soil physico-chemical properties. Bedbabis *et al.* (2014) reported no significant effect of treated wastewater on various soil properties such as electrical conductivity (EC), sodium adsorption ratio (SAR), pH, organic matter (OM), soluble cations, chloride (Cl) and infiltration rate of the soils. Musazura *et al.* (2015) also reported no significant changes of soil physical and chemical properties over three seasons following irrigation with ABR effluent. However, Bhardwaj *et al.* (2008) reported that treated wastewater improved hydraulic properties and structural formation (stability) of soils. The use of treated wastewater was also reported to contribute additional organic C and N to the soil, and to result in peak available P levels which are above the optimal available P level in the soil (Mandal *et al.*, 2008b). The use of wastewater increased organic matter, soil salinity, exchangeable K, Na, Mg Ca, plant available P and microelements but decreased soil pH (Kiziloglu *et al.*, 2008). Irrigating with K-rich wastewaters was also seen as valuable to overall soil fertility, though its long-term use could affect physical and chemical properties of soil (Myburgh and Howell, 2014). Mandal *et al.* (2008a), in their study, reported that regardless of aggregate slaking, irrigating with treated wastewater possessed steadily degrading effect on hydraulic conductivity, runoff and soil loss.

The degradation in hydraulic properties of soils (Bhardwaj *et al.*, 2008) may be due to use of treated wastewater for irrigating semiarid and arid soils, but the extent of degradation may depend on the kind of irrigation system.

2.3 Reuse of Wastewater

Pedrero *et al.* (2010) reported that about 70% of world water use (i.e. water abstracted from rivers and exploited from underground) is used for irrigation. According to Toze (2006), there is a growing need more for effective use of water resources in urban and rural environments. The increasing effectiveness in crop administration and the continuing rise in crop production have increased demands on water resources for irrigation purposes. The reuse of water that once would have been ejected into the environment after use is a major practice to achieve greater efficiencies. The recycling of water for irrigation is often observed as a helpful means of reusing water due to the likely large volumes of water that can be used. The recycling of treated urban wastewater for purposes such as agricultural and landscape irrigation decreases the quantity of water that requires to be removed from natural water sources as well as reducing the release of wastewater to the environment. Accordingly, treated public wastewater is a valuable water source for reusing. The quality of treated wastewater relies to a great level on the quality of the metropolitan water supply, nature of the wastes added during use, and the extent of treatment the wastewater has received.

Used water can have the benefit of being a continuous, dependable water source and decreases the amount of water removed from the environment. Treatment requirements in some cases may be less than for water used in a municipal environment due to reduced possible human contact. However, concerns and unknowns are raised about the effect of the quality of the recycled water on the crop itself and on the end users of the crops. Water quality issues that can generate actual or supposed difficulties in agriculture include nutrient, sodium concentrations, heavy metals, and the presence of pollutants such as human and animal pathogens, pharmaceuticals and endocrine disruptors (Toze, 2006).

2.4 Guidelines for Interpretation of Water Quality for Irrigation

Rutkowski *et al.* (2007), in his critique, described wastewater irrigation that has emerged as a focus of study in the developing countries where its use by municipal and peri-urban farming societies is progressively becoming a livelihood reality. Poor wastewater facilities on the one hand resulting in contamination of otherwise clean irrigation water sources, and increasing water scarcities on the other, have shaped the conditions under which farmers turn towards wastewater as a reliable source of irrigation. Table 2.1 is the standard guidelines for interpretation of water quality for irrigation.

Table 2.1 Guidelines for interpretation of water quality for irrigation (Pedrero *et al.*, 2010)

Potential irrigation problem	Units	Degree of restriction on use		
		None	Moderate	Severe
EC_w	$dS.m^{-1}$	≤0.7	0.7–3.0	≥3.0
TDS	$mg.l^{-1}$	450	450–2000	2000
Permeability (effects on infiltration rate of water into the soil. Evaluate using EC_w and SAR together)	SAR=0–3	EC_w ≥0.7	EC_w 0.7–0.2	EC_w ≤0.2
	SAR=3–6	EC_w ≥1.2	EC_w 1.2–0.3	EC_w ≤0.3
	SAR=6–12	EC_w ≥1.9	EC_w 1.9–0.5	EC_w ≤0.5
	SAR=12–20	EC_w ≥2.9	EC_w 2.9–1.3	EC_w ≤1.3
	SAR=20–40	EC_w ≥5.0	EC_w 5.0–2.9	EC_w ≤2.9
Specific ion toxicity, Sodium, Na (Surface Irrigation)	$mg.l^{-1}$	≤3	3–9	≥9
Specific ion toxicity, Sodium, Na (Sprinkler Irrigation)	$mg.l^{-1}$	≤70	>70	
Specific ion toxicity, Chloride, Cl (Surface Irrigation)	$mg.l^{-1}$	≤140	140–350	≥350
Specific ion toxicity, Sodium, Na (Sprinkler Irrigation)	$mg.l^{-1}$	≤100	>100	
Specific ion toxicity, Boron, B (Surface–sprinkler irrigation)	$mg.l^{-1}$	≤0.7	0.7–3	≥3
Miscellaneous effects, Nitrogen	$mg.l^{-1}$	≤5	5–30	≥30
Miscellaneous effects, (Total N) Bicarbonate	$mg.l^{-1}$	≤90	90–500	≥500
(Overhead sprinkling only) Residual chlorine	$mg.l^{-1}$	≤1	1–5	≥5
(Overhead sprinkler only) Ph	Normal range 6.5–8.4			

2.5 Potential Risks from Using Recycled Water

As reported by Toze (2006), a few risk factors have been identified for using recycled waters for purposes of agricultural irrigation. The use of wastewater can result in a number of complications such as pathogenic contamination and accumulation of heavy metals in soil and crops to toxic levels (Alghobar and Suresha, 2016). Some of the risk are short term and differ in impact depending on the potential for human, animal or environmental contact (e.g., microbial pathogens), while others have long term effects and increase with continued use of recycled water (e.g., saline effects on soil). The common human microbial pathogens found in reused water are enteric in origin and they enter the environment through faeces of infected hosts and can enter water bodies directly by defecation into the water, contamination by sewage or by run-off from soils and other land surfaces. They include viruses, bacteria, protozoa and helminths. The risk of water-borne contamination from any of these pathogens can be dependent on an array of factors plus pathogen numbers and dispersal in water (Toze, 2006).

Alghobar and Suresha (2016) found out that the advantage derived from using wastewater was adversely affected by heavy metals presence such as Lead and Mercury. They are carried by untreated wastewater and become deposited in the soil. The harmful consequence of heavy metal toxicity outweighs the importance of presence of organic nutrients (Alghobar and Suresha, 2016). Wastewater irrigation offers N and P plus organic matter to the soils, nevertheless, there is a worry about the accumulation of possibly toxic elements such as Cd, Cu, Fe, Mn, Pb and Zn from domestic and industrial sources (Kiziloglu *et al.*, 2008). Wastewater irrigation of vegetables and fodder may serve as the carrier for heavy metals in the human food chain (Scott *et al.*, 2008). Heavy metals in wastewater can pose a health threat (Carr *et al.*, 2008).

Toze (2006), however, said heavy metals are simply and efficiently eliminated during common treatment processes and the majority of concentrations in raw sewage end up in the sludge settlement fraction. This leads to very low heavy metal concentrations in the treated effluents. Consequently, heavy metals are of less concern for irrigation when using treated effluents. If the source is from an industrial source, then the influence of heavy metals need to be considered. Heavy metals from effluents used for irrigation tried to accumulate in the soils with a potential that they can become bioavailable for crops (Toze, 2006). The tolerance of plants to heavy metals from wastewater varies with type of plant and this must be considered when irrigating with treated wastewater to avoid toxicities (Pedrero et al., 2010).

2.6 Public Concern

Hartley (2003), explored the understanding of public perception and participation on reuse of treated wastewater in the United States and discovered that most people tend to become less favourable towards recycled water as it physically comes closer to them. However, they are very supportive of the irrigation of municipal open spaces in some ill-defined region, but hesitate at the use of reused water in the household or when the chance of individual physical contact increases. The extent of public disquiet about water reuse also hangs on the type of reused water and treatment levels, e.g. people have much less anxiety about using untreated arrested storm water than they have about highly treated sewage effluent.

2.7 Overcoming Water Reuse Problems

Peasey *et al.* (2000), recommended pre-treatment of the recycled water to overcome any problem relating to reusing water for irrigation of crops. The risk from microbial pathogens is appreciably reduced with the treatment of water. Salt and other cations and anions are the major contaminants difficult to eliminate from used water. The only active treatment mechanism to eradicate salt molecules and ions is reverse osmosis membrane filtration. The treatment may be expensive to be economically feasible for irrigation of crops.

The discussion in the next chapter is centered on wastewater irrigation management and intercropping which are the main factors and treatments to be investigated in the research. Different wastewater applications such as alternate wetting and drying, conventional continuous ponding and continuous wetting without ponding are also discussed.

3. WASTEWATER IRRIGATION MANAGEMENT AND INTERCROPPING

Due to growing shortage of freshwater resources obtainable for irrigated agriculture and rising need of food in the world, it is paramount to make available more food with little water. The management of wastewater irrigation must consider wastewater nutrient content, nutrient requirements of crop and soil nutrient content (Mohammad and Mazahreh, 2003). The usage of treated domestic wastewater in nations that are poor in water resources is cheap and taken as an attractive irrigation water source.

3.1 Wastewater Irrigation Management

The reuse of wastewater for irrigation is rapidly growing in most countries (Rusan *et al.*, 2007). Therefore, the wastewater reuse for irrigation is extremely encouraged (Al Salem, 1996; Mohammad and Mazahreh, 2003). The use of treated domestic wastewater as irrigation is agreed to be environmentally sound as compared with disposal directly to water bodies (Mohammad and Mazahreh, 2003). Wastewater is also a treasured source of nutrients for crops required for sustaining fertility levels in the soil (Weber *et al.*, 1996). However, wastewater may comprise unwanted chemical elements and pathogens that cause harmful environmental and health effects (Rusan *et al.*, 2007). Wastewater irrigation mismanagement can also lead to environmental and health complications to both ecosystem and human beings (Mohammad and Ayadi, 2004).

The continuous use of wastewater as the only irrigation water for crops leads to unnecessary addition of nutrients and toxic elements to the soil-plant system. It results in damaging effects on productivity and yield quality of crops and soil (Vazquez-Montiel *et al.*, 1996).

The International Rice Research Institute (IRRI) with its National Agricultural Research and Extension System (NARES) associates joined together to create an
wetting and drying” (AWD) techniquessing of wat
inaccessibility of water for agriculture. AWD is a management practice in irrigated lowland rice that saves water while maintaining yields. The practice is defined by periodic drying and re-flooding of the rice field (Lampayan *et al.*, 2015). Due to growing shortage of freshwater

resources obtainable for irrigated agriculture and rising need of food in the world, it is paramount to make available more food with little water.

Farmers have accepted AWD method of irrigation to handle scarcity of water in the production of rice. The practice uses aerobic respiration instead of the rice being continuously under anaerobic soil conditions (Cabangon *et al.*, 2011). It has generally been accepted to substitute continuous flooding irrigation (CFI) for managing water and increasing productivity of water in irrigated rice systems (Ye *et al.*, 2013). The practice increases grain yield of rice when compared with continuously submerged conditions (Zhang *et al.*, 2010). Shao *et al.* (2013) showed that irrigation water was reduced under AWD without a substantial impact on yield and it increased average productivity of water by 16.9 % when equated with conventional flood irrigation.

Liang *et al.* (2013), said AWD management was an active approach to save water, reduce N and losses through runoff from rice fields, and preserve yields. Kang *et al.* (1998), showed that when the root zones were alternatively exposed to drying and wet soil of field capacity above 55% or 65%, water use was reduced by 35%, while total biomass production was only reduced by an average of 8%, if compared with the well-irrigated plants. Alternative wetting and modest drying of soil improves yield of rice grain (Yang *et al.*, 2009). AWD irrigation in rice is a developed skill that saves water by 15-30% without falling yields (Lampayan *et al.*, 2009). The controlled alternate partial root-zone irrigation (CAPRI) is a new technique of irrigation that may enhance water productivity without Substantial reduction in yield (Kang and Zhang, 2004). The WWF is a well-watered conditions with 100% water holding capacity (Ruíz-Sánchez *et al.*, 2011). WWF is maintained at 100% field capacity of soil (Farooq *et al.*, 2008).

3.2 Water balance

Water balance of an irrigated field refers to the equilibrium between incoming water from irrigation and/or precipitation and water leaving the field by evapotranspiration, groundwater recharge and run-off (Jasrotia *et al.*, 2009). According to Fereres and Connor (2004), crop water need is met in many agricultural zones of the universe by precipitation and when it is insufficient, irrigation is the option to meet the water requirement of crops during the growing period.

The water balance over an irrigated field during and after irrigation is demonstrated in Figure 3.1. Applied water (precipitation or irrigation) is lost in four ways; transpiration, evaporation, surface run-off and deep percolation beyond the root zone of the crop. A water balance equation can be derived from Figure 3.1 affirming that the input water either alters the water content in the root zone or must exit the field.

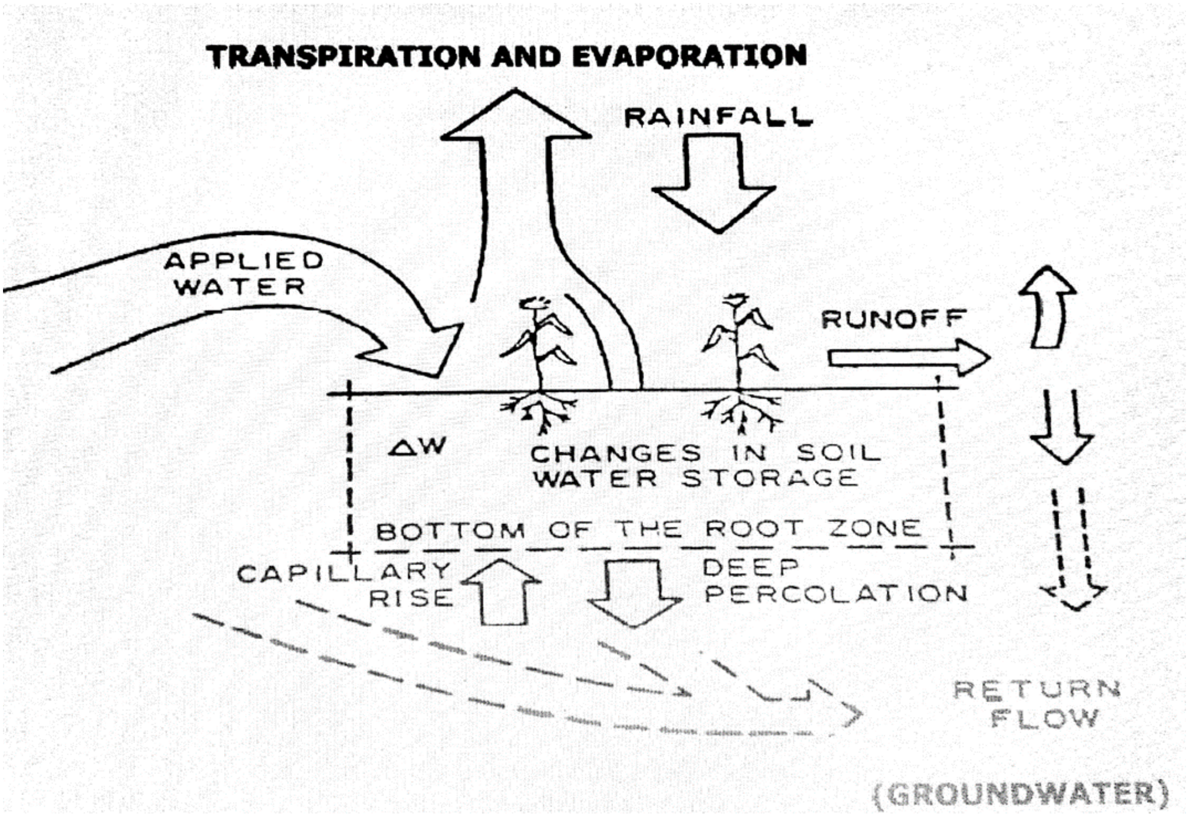


Figure 3.1 The water balance of an irrigated field (Fereres and Connor, 2004)

Mathematically, water balance of an irrigated field is given as Equation 3.1,

$$IR + P = ET + R +/- D + W \qquad 3.1$$

where IR = applied irrigation water (mm),

P = precipitation (mm),

ET = evaporation + transpiration (mm),

R = run-off (mm),

D = drainage below the root zone (deep percolation; it may be negative if capillary rise occurs) (mm), and

W = changes in soil water content in the crop root zone (mm).

Equation 3.1 is as seen by both irrigation engineers and hydrologists. The farmer's concern is as expressed in Equation 3.2,

$$IR = ET - Pe + IL \qquad 3.2$$

where IR = applied irrigation water (mm),
Pe = effective precipitation (mm), and
IL = the irrigation losses from the combination of R and D, which are majorly inevitable during irrigation (mm).

3.3 Intercropping and its Effect

Intercropping is the growing of two or more crop species simultaneously in the same field during a growing season (Ofori and Stern, 1987). Intercropping enhances land use maximization, steadiness in yield and profit (Erhabor and Filson, 1999). According to Hauggaard-Nielsen *et al.* (2001), intercropping is the concurrent growing of two or more crop species in the same plot. According to Ibeawuchi (2007), intercropping is practiced by most farmers in the tropical and subtropical areas of the world and most of the food from markets in these areas are produced by these set of farmers. Intercropping boosts high nutrient uptake compared to mono cropping systems and water use efficiency (WUE) is also high because of the interface between the intercrops. It promotes high soil fertility maintenance particularly when legumes are included as component crops. The legumes in the intercropping systems also offer continuous soil cover that prevents direct impact of raindrops that causes erosion. It is an inexpensive method of food production as one input like manure can be introduced once and consumed by the entire crop components on the farm thereby conserving time for the farmer. It decreases hazard of crop failure and safegu
farmer enhances best and highest use of the land at any cropping season. Factors such as spatial arrangement, plant density, maturity dates of the crops grown, plant architecture should be considered to avoid competition (Ouma and Jeruto, 2010).

3.4 Intercropped Productivity

Ibeawuchi (2007) presented that one of the utmost significant motives of raising two or more crops together is to increase productivity per unit of land. Scholars have designed numerous methods for evaluating intracrop performance as compared to pure stand, and the land equivalent ratio (LER) has become usual exercise in intercropping studies, because of its comparatively simple concept. LER may be well-defined as the relative land area under mono crops that is needed to produce the same yields as realised by intercropping. Usually, the of management" must be the same for intercropping and mono cropping. In this regard, Intercrop and sole crop must be at their optimal populations as variations in population disturbs yield responses. Therefore, the LER can be used as a degree of relative yield advantage. The LER is calculated as in Equation 3.3.

$$LER = L_A + L_B + \cdots L_N = \frac{Y_A}{S_A} + \frac{Y_B}{S_B} + \cdots \frac{Y_N}{S_N} = \sum_{I=1}^{N} \frac{Y_N}{S_N}$$

where

L_A, L_B…. L_N is the LER for the individual crops,

Y_A, Y_B…. Y_N are the individual crop yields in intercropping, and

S_A, S_B…. S_N is their yields as sole crops.

When LER is greater than 1 or more it signals yield advantage, and a ratio of less than 1 is a yield disadvantage.

3.5 Types of Intercropping

There are several types of intercropping according to Ouma and Jeruto (2010). Row intercropping is the planting of two or more crops at the same time but with at least one planted in rows. Cultivating two or more crops in strips that are wide enough to separate crop production with machines, yet sufficiently close to interact is strip intercropping. Mixed cropping is planting together two or more crops in no separate row planning. Planting a second crop into an existing crop at a time when the standing plant is at reproductive stage but before harvesting is called relay intercropping. Planting two or more crops concurrently during certain part of growing season of each have more benefits over strip intercropping (Parajulee *et al.*, 1997). Relay intercropping method is worth considering utilizing resources (Homma *et al.*, 2008). It is a better way of enriching the soil-crop arrangement with nitrogen and improving weed control (Jeranyama *et al.*, 2000; Singh *et al.*, 2007; Amossé *et al.*, 2013). Relay intercropping, especially with commercial crops increases the productivity of existing natural resources and biomass which can be used as fodder without reducing the yield of the main crop (Anil *et al.*, 1998; Jeranyama *et al.*, 2000; Baldé *et al.*, 2011).

Madumbe and rice which are crops to be used are discussed in the next chapter. Also reviewed in the next chapter are relevant previous studies on Madumbe to explore the research gaps.

4. MADUMBE AND RICE PRODUCTION

The two crops to be considered are madumbe and rice. Their distribution, origin and production level are reviewed.

4.1 Origin and Distribution of Madumbe

DAFF (2011) gave the following description and discussion on madumbe. It (*Amadumbe, Amadombie, Amadombi, Mufhongwe,* and *Taro*) is referred to as “po (*Colocasia esculenta*), found globally in subtropical areas and is cooked much like a yam. It is also called cocoyam (English) in some parts of West Africa. Edible aroids (family *Araceae*) encompass many underground food crops grown in numerous tropical and subtropical nations. They are called *amadumbes* in many parts of the world, particularly in Africa. It originated from Oceania and South-East Asia and the American tropics. It is held that madumbe has been cultivated for over 6 000 years. It came to West Africa through America, which is now the foremost producer.

4.1.1 Production level of madumbe in South Africa

Since it is usually produced by rural farming localities for sustenance and not for trading, the level of production of madumbe in South Africa is not known**.** Madumbe has been planted by villagers in KwaZulu-Natal for many generations, and is now considered as an indigenous food crop. Mpumalanga and Eastern Cape also cultivated Madumbe. There are no cultivars developed in South Africa to date so far (DAFF, 2011).

4.1.2 Production level of madumbe in Africa

The production of madumbe is largely confined to the “yam zone of Africa” that comprises countries such as Cameroon, Nigeria, Benin, Togo, Ghana, and Côte d’I about 80% of the world’s production takes place in this zone

4.1.3 International production level of madumbe

Its limited worth in terms of total production of root and tuber crops has made it difficult to estimate data on world production and trade of madumbe. The entire world production area of madumbe alone was valued to be about 0.9 million ha in 1983, with 80% in Africa. The remaining 20% is what other continents contributed with Asia being the largest. The global production of Madumbe then was 5.6 million tons, with Africa producing about 61.33% and Asia about 38.67%. The world production increased to 37.5 million tons in 2000 with nearly 4 million ha of land and 96% of the production from Africa. The principal producer was Nigeria with 26 million tons, trailed by Ghana with 2.9 million tons. More than 69% of the whole area (4 million ha) was in Nigeria. The average yield was approximately 10 $t.ha^{-1}$ (DAFF, 2011).

4.2 Description of Madumbe

Madumbe is a wetland perennial plant which grow up to about 2 m high. It is a tube-shaped root or corm. The corm is molded like a top with rough ridges, lumps and spindly roots and usually weighs around 0.5 to 0.9 kg, but rarely as much as 3.6 kg. The covering is brown but the flesh is white or pink depending on species. There are some varieties of madumbe that yield smaller tubers called *eddos*, which grow off the sides of the main corm. The *eddos* are usually around 2 to 4 g. It produces heart-shaped leaves which are 0.6 to 0.9 m long. Its flowers sprout between the leaves. Madumbe is propagated from full tubers or carvings from corms. It possesses a central corm from which leaves grow upwards and roots grow downwards but cormels, daughter corms and runners grow laterally (Sibiya, 2015).

4.2.1 Growth cycle and development stages

The developmental stages of madumbe depend largely on the species (Mare, 2009). The rate of development is sluggish after planting but advances rapidly after 1 to 2 months. The size and shape (corm quality) are determined at various growth stages. A typical madumbe has three different growth stages; establishment, vegetative growth, and corm initiation and bulking through maturation.

4.2.2 Climatic requirements

The parameters required to produce Madumbe are described (DAFF, 2011) and presented in Table 4.1.

Table 4.1 Production parameters for madumbe (DAFF, 2011)

S/N	Parameters	Description
1	Temperature	It does great in partial shade, nonetheless endures full sun if it gets plenty of water. An ideal temperature for growth is 24° C. Madumbe enjoys warm conditions because it does not survive in freezing temperatures. It grows best in the tropics at 1 500 m above sea level.
2	Water requirement	Madumbe can be grown under both wetland and dry land conditions and some species perform well under both conditions. It can tolerate high-rainfall areas, if there is good drainage, but does not withstand water logging. An ideal rainfall is 1 400 – 2 000 mm for the growing season.
3	Soil requirements	Madumbe thrives well in moist, heavy, well-aerated soils with good moisture holding capacity. It requires a pH value of 5.5 to 7.8. It tolerates a pH value as low as 4.8 with high yields. It also flourishes in a slightly acidic, moist or wet soil, rich in organic material.
4	Soil preparation	The land is cleared, ploughed and harrowed at 5 to 7-day intervals. Heaps or ridges can be done at 1 x 1 m apart.
5	Field layout and design	The planting row distance in commercial farming is 1.3 m apart and 40 to 50 cm between plants in a row. Planting can be done in embankments spaced at 1 x 1 m or 1.3 x 1.3 m in small farms. Plant on the apex of the heaps or ridges at 1 m apart on rows.
6	Planting	Planting is either done manually or mechanically with the help of a tractor-pulled planter. Planting depth is 15 to 20 cm deep. The root depth is within 40 cm. The safest planting period is between December and April, but plantings can be done any time during the year provided moisture is adequate.

7	Fertilization	The nutrient levels found in the soil at planting time should be supplemented with application of fertilizer. Fertile soil may not require any fertilizer but may be required if the soil has been depleted. If essential, apply N.P.K. 15:15:15 at 5 to 6 Coke bottle capfuls in a loop approximately 10 cm around the plant. The applications are done at 2, 5 and 7 months after planting. The initial fertilizer application should include 1.5% Mg, 1% Mn, and 0.1% Zn.
8	Irrigation	Irrigation can be applied at a minimum of 15 mm of water three times a week with an overhead sprinkler or drip irrigation.
9	Weed and pest control	Weeding should be done at least three times per season monitored for the first three months after planting. Weed rivalry during this period may negatively affect yields. Pests (white ants, rodents) are accountable for suboptimal yields as well as decline of the quality of the tuber in storage and should be controlled. Planting should be done with disease-free propagating material by closely inspecting each cutting, wash with potable water, immerse hulls in a 10% bleach solution for 30 seconds.
10	Harvesting	Most species mature in about eight to ten months from planting. The growth cycle continues from nine to eleven months. However, corms and leaves would have developed during the first six months. The foliage remains stable in the last four months, when it starts to dry, the plants are prepared for the corms to be harvested. Harvesting is by uprooting when the leaves have turned yellow and are beginning to dry.

4.3 Previous Studies on Madumbe

The study on the effect of planting density on growth and yield of *Taro* was carried out by Sibiya (2015). The study determined the effect of water stress and density of plant on growth and yield of *Taro* landraces. The outcome of the field trial disclosed that emergence was affected by plant density, with plants developing slower at high planting density. Growth and yield responded positively to increasing plant density with yield being highest at high plant density. The research also disclosed that emergence was slow and yield reduced at 30% crop actual evapotranspiration (ETa) compared to 100% ETa. It was concluded that growth was affected negatively by water stress. The study on evaluation of growth, yield and water use of three South African landraces under changing water regimes was carried out by Mabhaudhi *et al.* (2013). The yield at 60% ETa and 30% ETa was 15% and 46% higher at optimal irrigation respectively. Water use efficiency across varying water regimes was comparatively unaffected. The effect of irrigation regime on yield and quality of three varieties of *Taro* was evaluated by Uyeda *et al.* (2011). Their results indicated no meaningful effect of irrigation on objective measures of quality. Yet, high yield responses were discovered for all species but the extent of response of corm fresh weight to irrigation rates differ. The study conducted by Mabhaudhi and Modi (2016) revealed that growth of taro landraces as well as stomatal conductance remained lower under rain-fed when compared with irrigated situations. Some landraces showed reasonable sensitivity to restricted availability of water under rain-fed conditions.

The study to evaluate the effect of planting date and intra-row spacing on growth, yield and quality of *Taro* concluded that early planting dates (mid-November and mid-December) coupled with closer distances between plants gives highest yields (Abd-Ellatif *et al.*, 2010). Miyasaka *et al.* (2003), investigated the effect of site and planting date on *Taro* growth. They established that increased corm fresh weight was considerably higher for spring plus summer plantings as against fall plus winter plantings which is in agreement with the findings of Abd-Ellatif *et al.* (2010). Tumuhimbise (2015) investigated plant spacing and planting depth effects on corm yield of *Taro*. It was concluded that plant spacing and planting depth played a substantial role in defining the overall performance of *Taro*. The wider the spacing, the higher the corm yield of an individual *Taro* plants and vice-versa. However, Abd-Ellatif *et al.* (2010) discovered that closer spacing gives overall high yields as against wider spacing for high individual *Taro* plants. Mare (2009) carried out a study on yield and quality of *Taro* (Madumbe) in response to planting date and organic fertilisation. He suggested that *Dumbe-dumbe* is the best *Taro* species for crisping and it is best planted in October with 160 kg.ha^{-1} of organic fertiliser and November with 320 kg.ha^{-1} at Ukulinga while it is best planted with 320 kg.ha^{-1} of the fertiliser at Umbumbulu. The findings by Mare (2009) also agreed with the planting date closer to November.

Anikwe *et al.* (2015), observed that various fertilizer administration strategies have influence on development and growth of cocoyam, it responds rapidly to changes in the availability of nutrients. The highest yield of corm (19 – 21 mg.ha^{-1}) were obtained at plots treated split dose

NPK with banding. According to Ibudialo and Anikwe (2015), NPK fertilizer rates and tillage methods could be used to manipulate the environment of soil (such as bulk density of soil, TN, SOC C: N ratio etc.) of cocoyam for production profitability of this significant crop in the tropic. In a study done by Ogbonna and Nweze (2012), to investigate the response of cocoyam to growth and yield with regards to application of NPK 15:15:15 fertilizer, it was discovered that use of NPK 15:15:15 fertilizer has the highest yield of 37.85 and 20.85 tons.ha^{-1} with the application of 200 and 250 kg.ha^{-1} respectively in the south-eastern part of Nigeria. A study carried out by Hota *et al.* (2014) revealed that the reaction of cocoyam to numerous treatments of organic and inorganic amendments encourages yield. It was also discovered that only inorganic application tended to decrease pH while integrated application of organic and inorganic sources significantly improved the soil pH. Generally, application of potassium fertilizer did not wield much effect on development and yield of cocoyam (Iwuagwu *et al.*, 2016) but the outcome of the study has shown the efficiency of cow dung enhanced the production of cocoyam, thus guaranteeing food security in Nigeria. The higher growth due to application of cow dung could be ascribed to the likely impacts of the manure in refining soil chemical, physical and biological parameters that are significant for crop performance.

According to Ndaeyo *et al.* (2003), research was carried out to determine the effect of four tillage practices (mounding, surface hoeing, zero and ridging) on performance of cocoyam. It was discovered at the end of the field trail that the tillage practices had substantial impact on sprouting, nonetheless height and number of leaves were not affected but girth of the stem varied significantly at 60 days with surface hoeing after planting. The effect of tillage and plastic mulch on properties of soil and yield of cocoyam was investigated by Anikwe *et al.* (2007), it was discovered that the highest yield of corm was obtained in tilled-black plastic mulched plots (29.1 mg.ha^{-1}). This yield was also higher by 29, 47 and 59% if compared with tilled-clear plastic, no-till black plastic and no-till transparent plastic mulched plots, respectively. The outcome showed lower bulk density (1.1 – 1.3 mg.m^{-3}) for tilled transparent and black plastic when compared with no-till transparent or black plastic mulched field (1.4 – 1.45 mg.m^{-3}). Their results suggested that plastic mulched field and particularly tilled-black plastic mulch offer cocoyam a healthier soil environment.

McEwan (2008) evaluated three *Amadumbe* phenotypes for their nutritional potentials. The locally grown madumbe consist of high starch levels, acceptable protein and low sterol content.

The results suggest that even though it is an ignored crop in South Africa, it is highly nutritious. Its consumption could be useful to diabetic and hypertensive patients.

Onwueme and Johnston (2000), carried out field experiments to observe the shading effect on stomatal density, leaf dry matter, leaf size and thickness of leaf lamina in the main tropical root and tuber crops (tannia, sweet potato, yam, cassava and taro). It was reported that shading reduced stomatal density of all except for taro. Taro posed an increased density stomatal under shade and it was confirmed by pot experiments. Cocoyam grown under shade had leaf lamina growth, more petiole, increased corm and cormel than those cultivated in 100% daylight (Valenzuela *et al.*, 1991).

According to Oladokun (1990), food crops such as plantain (*Musa paradisiaca*), maize (*Zea mays*), melon (*Cucumis melo*), cowpea (*Vigna unguiculata*) and pineapple (*Ananas comosus*) can be intercropped with cocoyam. Tree crops like oil palm (*Elaeis guineensis*), kola (*Cola acuminate*), coffee (*Coffea spp.*), coconut (*Cocos nucifera*) and citrus (*Citrus medica*) can also be some intercrops. Experiments conducted by Osundare and Agboola (2003), showed a significant reduction in cassava (*Manihot esculenta*) leave area and stem girth when intercropped with cocoyam and sweet potato (*Lopmoea batatas*). Stem height, weight of fresh cassava and number were meaningfully low by intercropping at harvest. An experiment conducted by Unamma *et al.* (1985) showed that intercropping of cocoyam, maize and sweet potato significantly out-yielded either of the singular crop components as per experimental unit. Plantain populations had an irrelevant impact on the yields of *Colocasia esculenta.* When intercropped, perhaps the profuse suckers formed by *Colocasia* suppressed growth of plantain (Igbokwe *et al.*, 1984). Intercropping cocoyam with maize and yam (*Dioscorea spp.*) is a very common practice (Knipscheer and Wilson, 1980). Amusa *et al.* (2011) reported that virtually all farmers intercropped cocoyam with crops like maize, cassava and vegetables. Intercropping and mulching of cocoyam and plantain can be strategic in decreasing weed interfering with the crops, conservation of labour, and minimising production costs and fertilizer efficiency and ensuring optimal productivity of the intercrops (Shiyam *et al.*, 2011). Intercropping cocoyam with maize increased the marketable cocoyam tuber yields as compared to cocoyam sole cropping (Olasantan, 1990). Inter-cropping of taro with pepper (*Capsicum spp.*) could decrease the viral diseases occurrence rate on pepper (Fa-wan *et al.*, 2009)**.** Cocoyam-sweet potato-maize intercrop depressed yield of the component crops by 50 to 90% in the absence of weed control measures. It indicates the status of choosing a spatially and temporally well-matched intercrop grouping for control of weed and advanced yields of constituent crops in an intercrop (Weerarathne *et al.*, 2017). Mabhaudhi and Modi (2014) reported that for two seasons of intercropping madumbe with bambara nuts (*Vigna subterranean L. Verdc.*), plant height and leaf number of madumbe was negatively affected as compared with sole crop. Nevertheless, in spite of this decrease, plant height in the sole crop was similar statistically to the 1:1 intercrop. The intercrop had no substantial effect on yield of madumbe per hectare.

4.4 Rice

Rice, as a crop, requires sixteen (16) vital elements which must be available in optimum quantities and in forms readily available for suitable growth. Nitrogen, phosphorus, and potassium are the most usually applied elements by rice farmers as fertilizers and a significant percentage of the nutrients is used up by rice crops as they germinate to harvest magnitude (Yoon *et al.*, 2003). Rice cultivation needs enormous quantities of water and nutrients, and significant amounts of water and nutrients can be lost via surface run-off and drainage, unless there is a means for balancing between inputs and what is really consumed by the rice (Yoon *et al.*, 2003).

Currently, rice is cultivated on every continent except for Antarctica (Muthayya *et al.*, 2014). According to Balasubramanian *et al.* (2007), Sub-Saharan Africa (SSA) faces numerous problems. The key one is to improve the lives of 30% of its populace that is affected by poverty and food insecurity. Above 70% of the people that live in farming areas will need to play a main part in improving the situation. Rice production in the world has increased from 200 million tons of paddy in 1960 to above 678 million tons in 2009 with China, India and Indonesia being the three largest producers (Carriger and Vallee, 2007).

According to Khush (1997), there exist two cultivated varieties of rice; *O. sativa* (Asian) that is grown worldwide and *O. glaberrima* (African) which is cultivated in West Africa on a limited scale. It belongs to the family of Gramineae or grass family. It is of superior importance for the nourishment of large spreads of the population in Asia, parts of Latin America and Caribbean and, progressively so, in Africa. It is similarly the principal source of income generation and employment for above 200 million homes in developing countries (Muthayya *et al.*, 2014). Production of rice under irrigation requires high quantities of water at about 2 500 litres for 1 kg of rice (Price *et al.*, 2013). Quantity of water application during the growing season can vary from 500 to 800 mm up to more than 3 000 mm. The root zone is between 0–20 cm for lowland rice (anaerobic) while that of upland (aerobic) rice is 0–40 cm (Bouman *et al.*, 2007).

According to IRRI, rice is typically grown in bunded fields that are continuously flooded up to 7–10 days before harvest. Continuous floodin to ensure sufficient water and to control weeds. Lowland rice requires a lot more water than upland rice. Before rice can be planted, the soil should be in the best physical condition for crop growth and the surface is level. Land preparation involves ploughing, harrowing-up, mixing and level the soil. The two main practices of establishing rice plants are transplanting and direct seeding. Rice completes two distinct growth phases: vegetative and reproductive. The vegetative phase is subdivided into germination, early seedling growth and tillering; the reproductive phase is subdivided into the time before and after heading, that is, panicle exertion. Harvesting can be manual or mechanical. Depending on the varieties, rice crop usually reaches maturity at around 105–150 days after crop establishment (IRRI).

The research gaps identified during the literature review sections are discussed in the next chapter.

5. DISCUSSION AND CONCLUSION

None of the above research has taken in to consideration the use or effect of treated wastewater, particularly the abundant ABR effluents, of urban and peri-urban locations. It has also not been reported of the need to evaluate the impact of wastewater management approaches using flood-basin irrigation on madumbe. During the literature review, madumbe was not reported to have been intercropped with a water hungry crop such as rice. The wastewater irrigation management for madumbe has also not been monitored as a way of addressing the imbalance between the input and output using water balance analysis. Most of the water application approaches under review discussed AWD and CFI, but did not investigate what happens between the two, termed WWF. There is need to understand what happens if the land is made to have continuous wetting (well-watered conditions) without ponding. In addition, the crop will also be grown during winter with treated wastewater for irrigation as against the traditional way of growing madumbe in South Africa. It may also be of interest that none of the literature consulted and referenced have considered flooded madumbe planted in the field and in pots under tunnel. Madumbe and rice have been carefully chosen because both of them are water and nutrient loving crops that will address the existing problems of disposing treated wastewater. All these constitute knowledge gaps that must be filled. The two crops are also considered to be irrigated with effluent because they are cooked before consumption, which reduces health risks on consumers. There is no need to investigate the effect of ABR wastewater on soil properties in the proposed work because it was reported that use of treated effluents for three consecutive seasons has no effects on the soil.

The abundancy of municipal treated wastewater at the experimental site is a problem that must be addressed. Hence, if successful, the proposed study might develop a useful way of disposing the wastewater because both madumbe and rice are water loving wetland crops. It is believed that this will enhance the production and utilization of madumbe in urban and peri-urban areas where wastewater is abundant and also because madumbe can contribute substantially to household food and income security.

Having identified the knowledge or research gaps above, the next chapter is the main research focus of this work that tends to address the research gaps and is therefore presented as the research proposal which involves the problem statement, research objectives, methodology, data collection, analysis, originality statement, work plan and budget.

6. RESEARCH PROPOSAL

The section presents the proposed works to be done.

6.1 Problem Statement

The volume of wastewater generated by domestic-municipal sources has increased with population, urbanization, improved living conditions, and economic development. Hence, there is need to utilize the continuous and abundant volume of municipal treated wastewater productively (e.g. irrigation) before safely discharging into water bodies. The productive use of wastewater has increased with millions of small-scale farmers in urban and peri-urban areas of developing countries depending on wastewater sources to irrigate high-valued edible crops for consumption and ornamental crops such as flowers and tree plants because they often have no alternative sources of irrigation water.

It is of great importance to take proper monitoring measures for treated wastewater and nutrients balances in order to identify imbalances that exist and to take corrective measures. The challenges of water ponding (standing water) on the surface of the field especially during summer season also call for the need to investigate the water balance. Nutrients in treated municipal wastewater (effluents) are an advantage over conventional irrigation water sources.

Hence, management and re-use of treated wastewater for irrigation has the possibility of reducing the hazards of environmental contamination, reducing the amount of fresh water resources that need to be extracted and increasing production of crops per household.

6.2 Main Research Objective

To investigate the effects of using municipal treated anaerobic baffled reactor (ABR) wastewater irrigation management on growth and yield parameters of madumbe and rice using anaerobic baffled reactor (ABR).

6.3 Null Hypothesis

Treated wastewater irrigation management and intercropping do have an effect on the agronomic performance of madumbe and rice.

6.3.1 Specific objectives

1. To evaluate the impact of CFI, AWD and WWF irrigation regimes on the growth and yield parameters of Madumbe.
2. To appraise the effect of CFI, AWD and WWF irrigation regimes on the growth and yield components of rice.
3. To quantify the effect of intercropping madumbe with rice in terms of land productivity and yield complement.
4. To compare the growth and yield component of irrigated Madumbe and rice grown in field and tunnel.
5. To carry out monthly water balance analyses for good irrigation management.

6.4 Methodology

The section describes the study area and the methods of achieving the main and specific objectives.

6.4.1 Study site

The experimental site and ABR effluents treatment plant are located at the Permaculture site, Newlands-Mashu, near Durban. The site is on longitude 30.95 ^{0}E and latitude 29.97 ^{0}S. It is characterized by an average annual precipitation of 1 000 mm and mean daily temperature of 20.5 ^{0}C. The field experiments and pot experiments will be conducted at open agricultural field and inside a tunnel for zero effective rainfall respectively. The trials will be carried out for two seasons (2017 winter – 2018 summer and 2017 summer – 2018 winter). The dumbe landrace of amadumbe will be considered from Umbubulu village because of its wide spread availability.

6.4.2 Field trial design

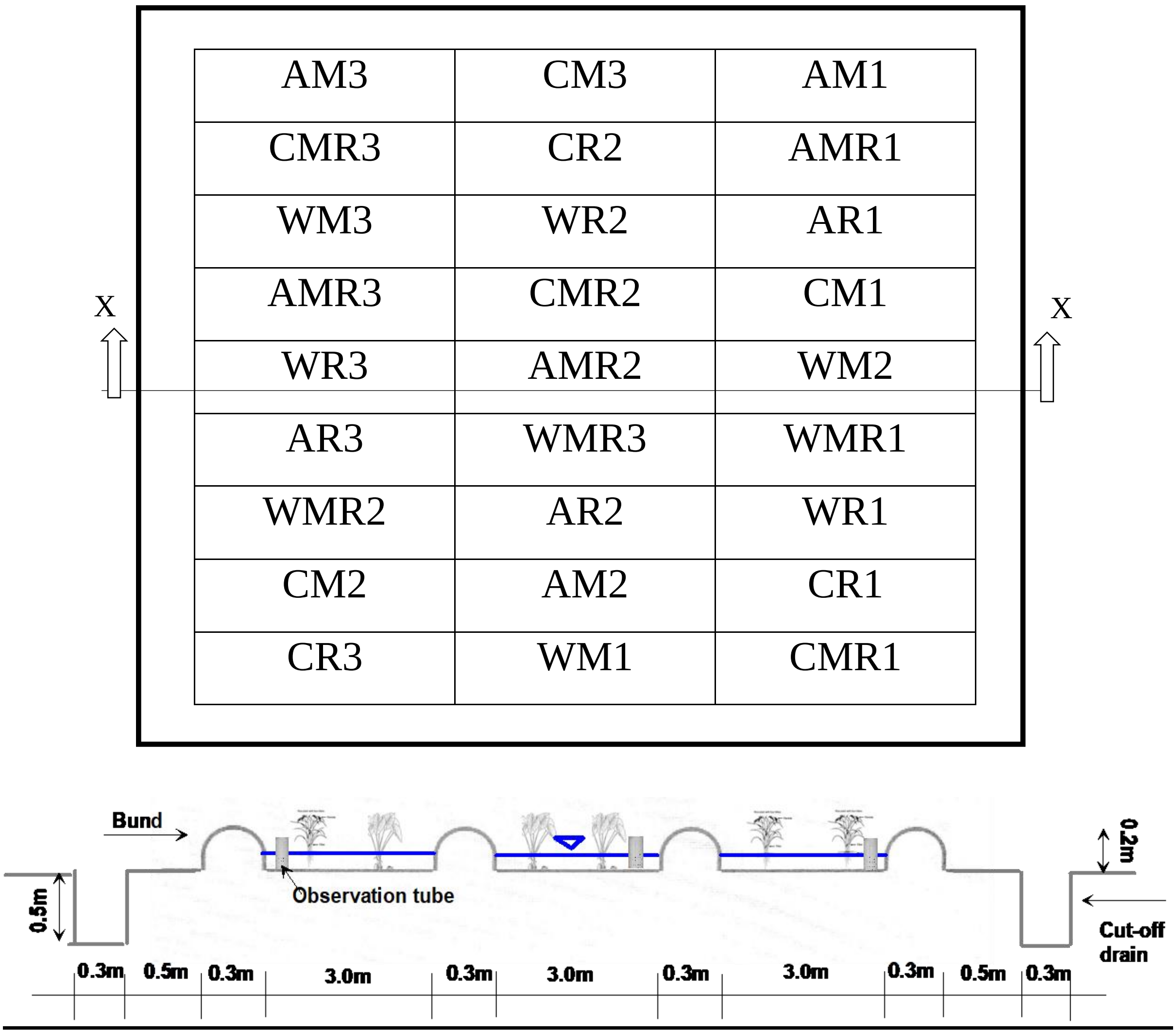
The experiments will be laid out in a randomized complete block design (RCBD). Randomization for both field and pot experiments was done using *Kutools for Excel* software to avoid bias (Kutools, 2017). The experiments consist of three irrigation treatments (main plot), alternate wetting and drying (AWD), conventional flooding irrigation (CFI) and continuous wetting without flooding (WWF), and three cropping treatments combination (sub-plot) for each irrigation treatment, madumbe (M), madumbe and rice (MR) and rice (R). Treatments with WWF and CFI for madumbe and rice respectively, are the control for both field and pot trials. Table 6.1 below shows various treatments combination.

Table 6.1: Treatments combination

S/N	**Code**	**Treatments Detail**
1	AM	Alternate wetting and drying with Madumbe
2	AR	Alternate wetting and drying with Rice
3	AMR	Alternate wetting and drying with Madumbe and Rice
4	CM	Continuous flooding with Madumbe
5	CR	Continuous flooding with Rice
6	CMR	Continuous flooding with Madumbe and Rice
7	WM	Wetting without ponding with Madumbe
8	WR	Wetting without ponding with Rice
9	WMR	Wetting without ponding with Madumbe and Rice

The whole field layout gives rise to 27 plots of equal size (Figure 6.1). All plot dimensions would be 3 by 1.5 m each. Bunds would be established between plots to isolate them from adjacent plots. Bunds (30 cm wide at the base and 20 cm high) would be covered with plastic sheeting (250 microns) which will be buried into the soil with the aid of metal sheeting to a depth of 0.6 m to prevent run-on, run-off, lateral-in and lateral off in each plot for a proper water balance analysis. Tan *et al.* (2013), Zhang *et al.* (2010), Pascual and Wang (2016) suggested 0.5 m, Ye *et al.* (2013) used 0.3 m, while Yao *et al.* (2012) suggested 0.2 m. Inserted in each plot will be a 400 mm long and 110 mm diameter PVC observation tube perforated with 5 mm diameter holes at 40 mm intervals (Figure 6.2). About the half side of the tube would be inserted into the field (at least 500 mm away from the bond, 200 mm above and 200 mm below the topsoil) for the monitoring of water table and to instruct when to irrigate (Oliver *et al.*, 2008;

Cabangon *et al.*, 2011; Price *et al.*, 2013; Ye *et al.*, 2013; Lampayan *et al.*, 2015). Apart from water management application regimes, all other cultural practices would be the same. Cut-off drains will be trenched around the perimeter of the field to prevent surface run-off entering the whole field. The drain collects the whole runoff coming to the field, empty in to a still basin that will be dug at the outlet of the cut-off drain. The still basin prevents the damaging or scouring effect that could cause damage to the adjacent land. The spacing for madumbe shall be 0.5 m by 0.5 m, while rice will be 0.25 m by 0.25 m. Madumbe and rice will be established for two months and two weeks respectively before transplanting. Prior to sowing, rice seeds would be washed and soaked for 24 hr in fresh water, following which they would be incubated at 30^{O}C for another 24 hr to stimulate strong germination (Mulbah, 2010).



AM3	CM3	AM1
CMR3	CR2	AMR1
WM3	WR2	AR1
AMR3	CMR2	CM1
WR3	AMR2	WM2
AR3	WMR3	WMR1
WMR2	AR2	WR1
CM2	AM2	CR1
CR3	WM1	CMR1

Cross-section X - X

Figure 6.1 Layout of experimental field with different wastewater irrigation management approaches and intercropping treatments.

Legend

CM:	Continuous flooding with madumbe
CMR:	Continuous flooding with madumbe & rice
CR:	Continuous flooding with rice
AM:	Alternate wetting and drying cycle with madumbe
AMR:	Alternate wetting and drying cycle with madumbe & rice
AR:	Alternate wetting and drying cycle with rice
WM:	Wetting without flooding with madumbe
WMR:	Wetting without flooding with madumbe & rice
WR:	Wetting without flooding with rice

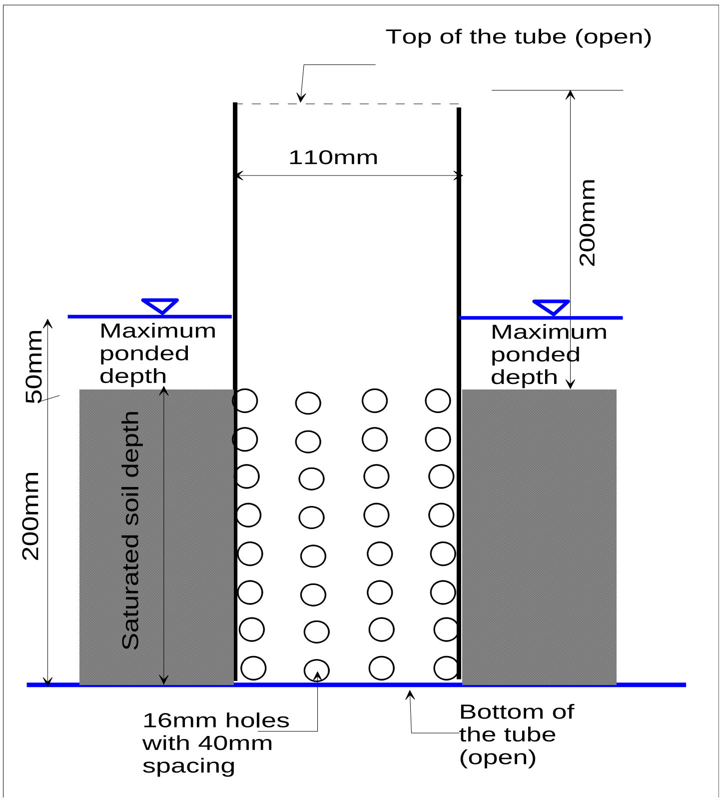


Figure 6.2 Field water tube/observation well (Adopted from Lampayan *et al.* (2015))

6.4.3 Pot trial design

The experimental design for the pot trial will also be RCBD with six treatments and three replications (Figure 6.3). The factors to be considered are wastewater irrigation management (CF, AWD and WWF) and cropping types (madumbe and rice). An observation water tube described above but with different in diameter (50 mm) will be used to monitor the water level. A measuring tape (metal) will be used to measure the water level in the tube for both field and pot experiments. The treatments are the same as the field trial except for intercropping treatment.

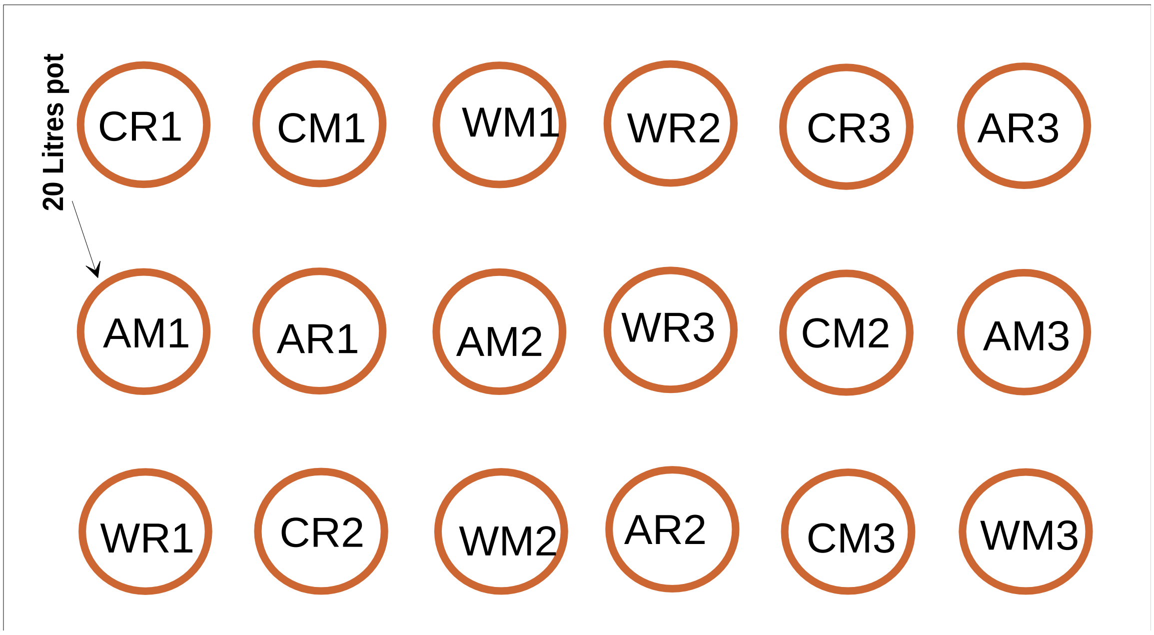


Figure 6.3 Layout of experimental pot with different treatments of wastewater management and crops

6.4.4 Irrigation

The field will be irrigated by basin/flood method with bunds to control run-off. There will be a network of PVC pipes (main, lateral and field) with a ball gate control valve at each plot (point of discharge). A scouring protection (boulders or granites) will be placed at the point of discharge to plots. The depth of irrigation water (pond) will continuously be maintained at a depth of 50 mm (Oliver *et al.*, 2008) and stopped at 2 weeks before harvesting for all treatments of CFI. AWD treatments will also maintain an irrigation water pond of 50 mm whenever the ponded water level in the tube has dropped to 150 mm below the surface (Cabangon *et al.*, 2011; Lampayan *et al.*, 2015). The level of water in the tube of WWF plots would be the same level with the field (well-watered i.e. 100% field capacity). Measurement of depth and when to irrigate are dictated by manual observation of water table level in the water observation tube.

The pots will also have a network of pipes for irrigation and there will be a plastic cup positioned at the point of discharge to prevent splash erosion in the pot. The pots to be used for the tunnel trial are 20 liters capacity plastic materials. The methods of irrigation are the same as in the field. The irrigation will be done inside pots lined with double-plastic bags of 25 microns thick to keep water from seeping out of the drainage holes.

6.4.5 Water balance

The water balance in the root zone of an irrigated soil in a given time interval is given in Equation 6.1 as:

$$\Delta Wt = (I + P + RON + LATON + CR)t - (ET + ROFF + LATOFF + DP)t \qquad 6.1$$

where ΔWt = changes in soil water storage over in a month (mm),
I = applied irrigation water (mm),
P = precipitation (mm),
RON = run-on to field (mm),
$LATON$ = lateral or seepage flow into the field (mm),
CR = capillary rise from the water table (mm),
ET =evapotranspiration (mm),
$ROFF$ = run-off leaving field (mm),
$LATOFF$ = lateral or seepage leaving field (mm), and
DP = deep percolation below the root zone (mm).

The effect of plastic sheeting between plots changes Equation 6.1 to 6.2

$$\Delta Wt = (I + P + CR)t - (ET + DP)t \qquad 6.2$$

According to Fereres and Connor (2004), deep percolation is negative if capillary rise occurs and Mermoud *et al.* (2005) said rising capillary movement into the root zone results in negative value of deep percolation. Hence, water balance equation becomes that in Equation 6.3:

$$\Delta Wt = (I + P)t - (ET)t \qquad 6.3$$

The water balance would be measured on monthly basis. Amount of irrigation applied per treatment over a period of one month will be added. Rainfall within the month (if it rains) will be measured using a rain gauge. The ET will be obtained from the product of reference evapotranspiration (ET_0) and the crop coefficient (K_c) of the crop at different stages of growth. ET_0 will be calculated from data that will be obtained from the meteorological data of the location by means of the FAO Penman-Monteith equation.

6.4.6 Nutrient balance analysis

Nutrients input to crop farm can be categorized into natural source such as atmospheric deposition and irrigation water while fertilization involves mineral and organic sources. The output comprises of surface run-off, deep percolation, and plant uptake (Yoon *et al.*, 2003). Therefore, the nutrient mass balance equation is given by Equation 6.4:

$$I_{IR1} + I_{IR2} + I_{PR} + I_{FER} = O_{DR} + O_{INF} + O_{HRV} \qquad 6.4$$

where I_{IR1} = input from wastewater irrigation,

I_{IR2} = input from surface run-on (zero due to effect of plastic sheeting),

I_{PR} = input from rainfall,

I_{FER} = input from fertilization (zero because, no additional fertilizer is required),

O_{DR} = output through surface run-off (zero due to effect of plastic sheeting),

O_{INF}= output through deep percolation (deep percolation assumed to be negative) and

O_{HRV} = output through plant harvest.

Therefore, nutrient balance equation becomes that in Equation 6.5:

$$I_{IR1} + I_{PR} = O_{HRV} \qquad 6.5$$

6.5 Data Collection

Data on the growth and yield parameters will be taken on the sample size (3 plants per plot for madumbe and 4 for rice at 3 replications each) after planting for both madumbe and rice.

Madumbe will be measured every fortnight while rice will be measured weekly. The height of individual plants will be measured as the distance (m) from the ground level to the shoot apex. Number of leaves for each plant will be determined by direct counting of functional leaves on a plant. Leaf area index (LAI) will be measured using LAI-2200C Plant Canopy Analyzer (LI-COR Environmental) throughout the growing season while land equivalent ratio (LER) and harvest index (HI) will be calculated. Plants will be uprooted individually and data collected on corm yield of each plant when the leaves have turned yellow and senescing. Corm yield of each plant will be recorded as the weight of a corm of an individual plant (kg.plant^{-1}) using a digital weighing scale. Corm yield (t.ha^{-1}) will be estimated from the total corm weight of the total number of plants harvested. Number of leaves, tillers and panicles per plant as well as the leaf area index are the growth parameters of rice to be quantified. The yield component is calculated as the product of number of panicles per area, number of grains in the panicle and weight of grains in the panicle. Amount of irrigation water will be measured, while rainfall, temperature, relative humidity, wind speed, solar radiation will be obtained from meteorological data for water balance.

6.6 Data Analysis

Data sets for the two seasons will be subjected to an ANOVA analysis to statistically quantify the effect of the various treatments on madumbe and rice performance. The expected results from the analysis will increase and make available information which will enhance the production of madumbe and rice throughout the year and thereby enhance food security. Water balance will be calculated and if is positive, then Inflow > Outflow, if WB is negative, then Inflow < Outflow and if WB is zero, then Inflow = Outflow per treatments.

6.7 Originality Statement

To fill the research gap, there is need to use treated municipal wastewater with flood irrigation because of its availability in abundant and none of the literatures consulted and referenced have reported the use of treated wastewater for madumbe and rice. Hence, the need to consider water and nutrient loving crops which is entirely a new research in South Africa and other parts of the World since there is abundant treated municipal wastewater.

6.8 Work Plan

		2017												**2018**												**2019**											
S/ No	**Activities**	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
1	Development of Research Proposal		■	■	■	■	■	■	■	■	■	■																									
2	Literature Review		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
3	Laboratory Tests								■	■	■	■	■	■	■																						
4	Field Experiments A and Data Collection										■	■	■	■	■	■	■	■	■	■																	
5	Field Experiments B and Data Collection												■	■	■	■	■	■	■	■	■	■	■														
6	Analysis of Data Collected																				■	■	■	■	■												
7	Completion of Draft and final Reports																									■	■	■	■	■	■						
8	Submission of Thesis for Examination and Corrections																													■	■						

6.9 Tentative Budget

S/NO	Item	QUANTITY	UNIT	COST (R)
1	Excavation of cut-off drain to a depth of 1.0 m and width of 0.3 m other than in rock foundation trench including haulage of all excavated materials.	66	40.00	2 640.00
2	Scrapping and filling of 20 litres capacity pots	2	600.00	1 200.00
3	Forming or moulding of field bunds	58	37.00	2 146.00
4	Polythene sheeting material (100 micron)	8	300.00	2 400.00
5	110mm diameter underground PVC pipe (6 m per length)	8	149.00	1 192.00
6	Electrical hand drill	1	799.00	799.00
7	16mm drilling bits	1	80.00	80.00
8	Nylon elbow 25 mm	20	9.00	180.00
9	Nylon elbow 20 mm	20	7.00	140.00
10	Pipe LDPE 25 mm	96	8.00	768.00
11	Pipe LDPE 20 mm	288	6.00	1 728.00
12	Pipe LDPE 15 mm	120	5.00	600.00
13	Nylon reducer Tee 25x20 mm	30	9.00	270.00
14	Nylon reducer Tee 20x15 mm	70	7.00	490.00
15	Nylon coupler 25 mm	32	6.00	192.00
16	Nylon coupler 20 mm	96	5.5	528.00
17	Nylon coupler 15 mm	40	5.00	200.00
18	Ball valve 25 mm PVC	8	25.00	200.00
19	Ball valve 20 mm PVC	24	20.00	480.00
20	Ball valve 15 mm PVC	60	15.00	900.00
21	Nylon end plug 25 mm	20	4.00	80.00
22	Full flow coupler Snap on 20 mm	28	40.00	1 120.00
23	Tape thread plumbing	8	4.00	32.00
24	Tangit PVC cement 250 ml	6	110.00	660.00
25	Lighter refillable zenith	2	10.00	20.00
26	Sacking needle	2	9.00	18.00
27	Full flow adaptor 25mmx1"	16	20.00	320.00
28	Full flow adaptor 20mmx3 4"	48	16.00	768.00
	Total			**21 030.00**

7. REFERENCES

Abd-Ellatif, A, Shehata, A and Youssef, S. 2010. Effect of planting date and intra-row spacing on growth, yield and quality of taro. *Research Journal of Agriculture and Biological Sciences* 6 (6): 806-814.

Al-Rashed, MF and Sherif, MM. 2000. Water resources in the GCC countries: an overview. *Water resources management* 14 (1): 59-75.

Al Salem, SS. 1996. Environmental considerations for wastewater reuse in agriculture. *Water science and technology* 33 (10-11): 345-353.

Alghobar, MA and Suresha, S. 2016. Effect of Wastewater Irrigation on Growth and Yield of Rice Crop and Uptake and Accumulation of Nutrient and Heavy Metals in Soil. *Applied Ecology and Environmental Sciences* 4 (3): 53-60.

Amossé, C, Jeuffroy, M-H and David, C. 2013. Relay intercropping of legume cover crops in organic winter wheat: Effects on performance and resource availability. *Field Crops Research* 145: 78-87.

Amusa, T, Enete, A and Okon, U. 2011. Socioeconomic determinants of cocoyam production among small holder farmers in Ekiti state, Nigeria. *International Journal of Agricultural Economics & Rural Development* 4 (2): 97-109.

Anikwe, M, Emmanuel, O, Eze, J, Ibudialo, A and Edeh, V. 2015. Identifying Fertilizer Management Strategies to Maximize Soil Nutrient Acquisition by Cocoyam (Colocasia esculenta) in a Degraded Ultisol in Agbani, Enugu Area, Southeastern Nigeria. *American Journal of Plant Nutrition and Fertilization Technology* 5 (2): 61-70.

Anikwe, M, Mbah, C, Ezeaku, P and Onyia, V. 2007. Tillage and plastic mulch effects on soil properties and growth and yield of cocoyam (Colocasia esculenta) on an ultisol in southeastern Nigeria. *Soil and Tillage Research* 93 (2): 264-272.

Anil, L, Park, J, Phipps, R and Miller, F. 1998. Temperate intercropping of cereals for forage: a review of the potential for growth and utilization with particular reference to the UK. *Grass and Forage Science* 53 (4): 301-317.

Balasubramanian, V, Sie, M, Hijmans, R and Otsuka, K. 2007. Increasing rice production in sub-Saharan Africa: challenges and opportunities. *Advances in agronomy* 94: 55-133.

Baldé, AB, Scopel, E, Affholder, F, Corbeels, M, Da Silva, FAM, Xavier, JHV and Wery, J. 2011. Agronomic performance of no-tillage relay intercropping with maize under smallholder conditions in Central Brazil. *Field Crops Research* 124 (2): 240-251.

Bame, I, Hughes, J, Titshall, L and Buckley, C. 2014. The effect of irrigation with anaerobic baffled reactor effluent on nutrient availability, soil properties and maize growth. *Agricultural water management* 134: 50-59.

Bedbabis, S, Rouina, BB, Boukhris, M and Ferrara, G. 2014. Effect of irrigation with treated wastewater on soil chemical properties and infiltration rate. *Journal of environmental management* 133: 45-50.

Bhardwaj, A, Mandal, U, Bar-Tal, A, Gilboa, A and Levy, G. 2008. Replacing saline–sodic irrigation water with treated wastewater: effects on saturated hydraulic conductivity, slaking, and swelling. *Irrigation Science* 26 (2): 139-146.

Bouman, B, Feng, L, Tuong, T, Lu, G, Wang, H and Feng, Y. 2007. Exploring options to grow rice using less water in northern China using a modelling approach: II. Quantifying yield, water balance components, and water productivity. *Agricultural Water Management* 88 (1): 23-33.

Cabangon, R, Castillo, E and Tuong, T. 2011. Chlorophyll meter-based nitrogen management of rice grown under alternate wetting and drying irrigation. *Field Crops Research* 121 (1): 136-146.

Carr, RM, Blumenthal, UJ and Mara, DD. 2008. *Health Guidelines for the Use of Wastewater in Agriculture: Developing Realistic Guidelines*. CAB International, Nosworthy Way, Wallingford, Oxfordshire, OX10 8DE, United Kingdom.

Carriger, S and Vallee, D. 2007. More crop per drop. *Rice Today* 6 (2): 10-13.

DAFF. 2011. Production guidelines for amadumbe, Directorate of Plant Production. Department of Agriculture, Forestry and Fisheries, Directorate Communication Services Private Bag X144, Pretoria 0001, RSA.

de Zeeuw, H and Drechsel, P. 2015. *Cities and agriculture: developing resilient urban food systems*. Routledge.

Erhabor, JO and Filson, GC. 1999. Soil fertility changes under an oil palm-based intercropping system. *Journal of Sustainable Agriculture* 14 (2-3): 45-61.

Fa-wan, L, Ze-zhou, S, ZHONG, L, Rong, Q, ZHANG, L-q, Yan, Z, Wen-zhen, Y and Wei-fen, L. 2009. Effect of Inter Cropping on Hot Pepper Main Disease Management and Output Value of Chilli Pepper, Maize and Taro [J]. *Southwest China Journal of Agricultural Sciences* 3: 029.

Farooq, M, Basra, S, Wahid, A, Cheema, Z, Cheema, M and Khaliq, A. 2008. Physiological role of exogenously applied glycinebetaine to improve drought tolerance in fine grain aromatic rice (Oryza sativa L.). *Journal of Agronomy and Crop Science* 194 (5): 325-333.

Fereres, E and Connor, D. 2004. Sustainable water management in agriculture. *Challenges of the New Water Policies for the XXI Century: Proceedings of the Seminar on Challenges of the New Water Policies for the 21st Century, Valencia, 29-31 October 2002*, 164. CRC Press.

Foxon, K, Pillay, S, Lalbahadur, T, Rodda, N, Holder, F and Buckley, C. 2004. The anaerobic baffled reactor (ABR): an appropriate technology for on-site sanitation. *Water SA* 30 (5): 44-50.

Hari, R, Guriqbal, S and Navneet, A. 2016. Effect of irrigation, straw mulching and weed control on growth, water use efficiency and productivity of summer mungbean. *Agricultural Research Communication Centre, Legume Research* 39 (2): 284-289.

Hartley, TW. 2003. *Water reuse: Understanding public perception and participation*. Water Environment Research Foundation Virginia.

Hauggaard-Nielsen, H, Ambus, P and Jensen, ES. 2001. Interspecific competition, N use and interference with weeds in pea–barley intercropping. *Field Crops Research* 70 (2): 101-109.

Heidarpour, M, Mostafazadeh-Fard, B, Abedi Koupai, J and Malekian, R. 2007. The effects of treated wastewater on soil chemical properties using subsurface and surface irrigation methods. *Agricultural Water Management* 90 (1): 87-94.

Homma, K, Mochizuki, A, Watatsu, E, Horie, T, Shiraiwa, T, Supapoj, N and Thongthai, C. 2008. Relay-intercropping of Stylosanthes guianensis in rainfed lowland rice ecosystem in Northeast Thailand. *Plant production science* 11 (3): 385-392.

Hota, R, Jena, AK and Narayana, KL. 2014. Effect of inorganic and organic amendments on yield of cocoyam (Colocasia esculenta), and on soil properties. *World Journal of Agricultural Research* 2 (2): 70-81.

Ibeawuchi, I. 2007. Intercropping-A Food Production Strategy for the Resource Poor farmers. *Nature and Science* 5 (1): 46-59.

Ibudialo, A and Anikwe, M. 2015. Stratification of soil physicochemical properties as affected by tillage and NPK fertilization rates under cocoyam (Colocasia esculenta) in two agro-environment of southeastern Nigeria. *Elix. Agric.* 88: 36230-36241.

Igbokwe, M, Arene, O, Ndubuizu, T and Umana, E. 1984. Intercropping cocoyams with plantain: effects on the yield and disease of cocoyams. *Tropical root crops: production and uses in Africa: proceedings of the Second Triennial Symposium of the International*

Society for Tropical Root Crops-Africa Branch held in Douala, Cameroon, 14-19 Aug. 1983. IDRC, Ottawa, ON, CA.

Iwuagwu, MO, Okpara, DA, Muoneke, CO and Ukaoma, AA. 2016. Organic and mineral fertilizer effects on growth and yield of cocoyam in a tropical Ultisol in South Eastern Nigeria. *Journal of Plant Breeding and Crop Science* 8 (10): 175-181.

Jasrotia, A, Majhi, A and Singh, S. 2009. Water balance approach for rainwater harvesting using remote sensing and GIS techniques, Jammu Himalaya, India. *Water resources management* 23 (14): 3035-3055.

Jeranyama, P, Hesterman, OB, Waddington, SR and Harwood, RR. 2000. Relay-intercropping of sunnhemp and cowpea into a smallholder maize system in Zimbabwe. *Agronomy Journal* 92 (2): 239-244.

Kamwendo, G and Kamwendo, J. 2014. Indigenous Knowledge-Systems and Food Security: Some Examples from Malawi. *J Hum Ecol* 48 (1): 97-101.

Kanawade, SM. 2015. Reuse of grey water for Agricultural irrigation. *IJAR* 1 (10): 169-175.

Kang, S, Liang, Z, Hu, W and Zhang, J. 1998. Water use efficiency of controlled alternate irrigation on root-divided maize plants. *Agricultural Water Management* 38 (1): 69-76.

Kang, S and Zhang, J. 2004. Controlled alternate partial root-zone irrigation: its physiological consequences and impact on water use efficiency. *Journal of experimental botany* 55 (407): 2437-2446.

Khush, GS. 1997. Origin, dispersal, cultivation and variation of rice. *Plant molecular biology* 35 (1): 25-34.

Kiziloglu, F, Turan, M, Sahin, U, Kuslu, Y and Dursun, A. 2008. Effects of untreated and treated wastewater irrigation on some chemical properties of cauliflower (Brassica olerecea L. var. botrytis) and red cabbage (Brassica olerecea L. var. rubra) grown on calcareous soil in Turkey. *Agricultural water management* 95 (6): 716-724.

Knipscheer, H and Wilson, J. 1980. Cocoyam cultivation in SE Nigeria. IITA Ibadan. Discussion paper.

Kutools. 2017. Kutools for Excel Software. 16.50.

Lampayan, RM, Palis, FG, Flor, RB, Bouman, BA, Quicho, E, De Dios, J, Espiritu, A, Sibayan, E, Vicmudo, V and Lactaoen, A. 2009. Adoption and dissemi wetting and drying” in pump irrigated ric *60th International Executive Council Meeting of the International Commission on Irrigation and Drainage (ICID), 5th Regional Conference.*

Lampayan, RM, Rejesus, RM, Singleton, GR and Bouman, BA. 2015. Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. *Field Crops Research* 170: 95-108.

Lebot, V and Aradhya, K. 1991. Isozyme variation in taro (Colocasia esculenta (L.) Schott) from Asia and Oceania. *Euphytica* 56 (1): 55-66.

Liang, X, Chen, Y, Nie, Z, Ye, Y, Liu, J, Tian, G, Wang, G and Tuong, T. 2013. Mitigation of nutrient losses via surface runoff from rice cropping systems with alternate wetting and drying irrigation and site-specific nutrient management practices. *Environmental Science and Pollution Research* 20 (10): 6980-6991.

Mabhaudhi, T and Modi, A. 2014. Intercropping Taro and Bambara Groundnut. in: *Sustainable Agriculture Reviews*, Springer, pp. 275-290.

Mabhaudhi, T and Modi, A. 2016. Yield response of selected taro (Colocasia esculenta) landraces from South Africa to irrigated and rain-fed field conditions. *3rd International conference on neglected*, 8.

Mabhaudhi, T, Modi, A and Beletse, Y. 2013. Response of taro (Colocasia esculenta L. Schott) landraces to varying water regimes under a rainshelter. *Agricultural water management* 121: 102-112.

Mandal, UK, Bhardwaj, A, Warrington, D, Goldstein, D, Tal, AB and Levy, G. 2008a. Changes in soil hydraulic conductivity, runoff, and soil loss due to irrigation with different types of saline–sodic water. *Geoderma* 144 (3): 509-516.

Mandal, UK, Warrington, D, Bhardwaj, A, Bar-Tal, A, Kautsky, L, Minz, D and Levy, G. 2008b. Evaluating impact of irrigation water quality on a calcareous clay soil using principal component analysis. *Geoderma* 144 (1): 189-197.

Mare, R. 2009. Taro (Colocasia esculenta L. Schott) yield and quality in response to planting date and organic fertilisation. in: *Crop Science*, Vol. PhD, School of Agricultural Sciences and Agribusiness, Crop Science, University of KwaZulu-Natal, Pietermaritzburg, RSA. Unpublished.

McEwan, R. 2008. Anti-nutritional Constituent of Colocasia Esculenta (Amadumbe): A Traditional Crop Food in Kwazulu-Natal. Unpublished PhD Thesis, Faculty of Science, Biochemistry and Microbiology, University of KwaZulu-Natal, Pietermaritzburg, RSA. .

Mermoud, A, Tamini, T and Yacouba, H. 2005. Impacts of different irrigation schedules on the water balance components of an onion crop in a semi-arid zone. *Agricultural water management* 77 (1): 282-295.

Miyasaka, SC, Ogoshi, RM, Tsuji, GY and Kodani, LS. 2003. Site and planting date effects on taro growth. *Agronomy journal* 95 (3): 545-557.

Mohammad, MJ and Ayadi, M. 2004. Forage yield and nutrient uptake as influenced by secondary treated wastewater. *Journal of Plant Nutrition* 27 (2): 351-365.

Mohammad, MJ and Mazahreh, N. 2003. Changes in soil fertility parameters in response to irrigation of forage crops with secondary treated wastewater. *Communications in soil science and plant analysis* 34 (9-10): 1281-1294.

Mulbah, QS. 2010. Effect of simulating flooding pattern on nitrogen management in rice (oryza sativa l.) production. in: *Crop Science*, Vol. M Sc, University of KwaZulu-Natal Pietermaritzburg, South Africa. Unpublished.

Musazura, W, Odindo, A, Bame, I and Tesfamariam, E. 2015. Effect of irrigation with anaerobic baffled reactor effluent on Swiss chard (Beta vulgaris cicla.) yield, nutrient uptake and leaching. *Journal of Water Reuse and Desalination* 5 (4): 592-609.

Muthayya, S, Sugimoto, JD, Montgomery, S and Maberly, GF. 2014. An overview of global rice production, supply, trade, and consumption. *Annals of the New York Academy of Sciences* 1324 (1): 7-14.

Myburgh, P and Howell, C. 2014. The impact of wastewater irrigation by wineries on soils, crop growth and product quality. WRC Report.

Nafchi, RA. 2016. Comparison of Water Use Efficiency in Alfalfa Using Water and Waste Water. *Journal of Agricultural Chemistry and Environment* 5 (04): 191.

Najafi, P and Tabatabaei, SH. 2008. Effects of SDI filtration on wastewater quality for irrigation. *12th International water technology conference (IWTC12), Alexandria Egypt*, 837-884.

Ndaeyo, N, Ekpe, E, Edem, S and UMOH, UG. 2003. Growth and yield responses of Colocasia esculenta and Xanthosoma saggitifolium to tillage practices in Uyo, south-eastern Nigeria. *Indian journal of agricultural science* 73 (4): 194-198.

Njoku, D and Muoneke, C. 2008. Effect of cowpea planting density on growth, yield and productivity of component crops in cowpea/cassava intercropping system. *Agrosci. J* 7 (2): 106-113.

Ofori, F and Stern, W. 1987. Cereal–legume intercropping systems. *Advances in agronomy* 41: 41-90.

Ogbonna, P and Nweze, N. 2012. Evaluation of growth and yield responses of cocoyam (Colocasia esculenta) cultivars to rates of NPK 15: 15: 15 fertilizer. *African Journal of Agricultural Research* 7 (49): 6553-6561.

Oladokun, MA. 1990. Tree crop based agroforestry in Nigeria: a checklist of crops intercropped with cocoa. *Agroforestry systems* 11 (3): 227-241.

Olasantan, F. 1990. The response of cocoyam, Xanthosoma sagittifolium (L.) Schott, to row arrangement, maize intercrop, and frequency of young leaf harvest. *Beiträge zur Tropischen Landwirtschaft und Veterinärmedizin* 28 (1): 49-58.

Oliver, M, Talukder, M and Ahmed, M. 2008. Alternate wetting and drying irrigation for rice cultivation. *Journal of the Bangladesh Agricultural University* 6 (2): 409-414.

Onwueme, I and Johnston, M. 2000. Influence of shade on stomatal density, leaf size and other leaf characteristics in the major tropical root crops, tannia, sweet potato, yam, cassava and taro. *Experimental Agriculture* 36 (4): 509-516.

Osundare, B and Agboola, A. 2003. Effects of different companion crops on the performance of cassava. *Moor Journal of Agricultural Research* 4 (1): 50-53.

Ouma, G and Jeruto, P. 2010. Sustainable horticultural crop production through intercropping: The case of fruits and vegetable crops: A review. *Agriculture and Biology Journal of North America* 1 (5): 1098-1105.

Owusu-Darko, PG, Paterson, A and Omenyo, EL. 2014. Cocoyam (corms and cormels)—An underexploited food and feed resource. *Journal of Agricultural Chemistry and Environment* 3 (01): 22.

Parajulee, M, Montandon, R and Slosser, J. 1997. Relay intercropping to enhance abundance of insect predators of cotton aphid (Aphis gossypii Glover) in Texas cotton. *International Journal of Pest Management* 43 (3): 227-232.

Pascual, VJ and Wang, Y-M. 2016. Impact of Water Management on Rice Varieties, Yield, and Water Productivity under the System of Rice Intensification in Southern Taiwan. *Water* 9 (1): 3.

Peasey, A, Blumenthal, U, Mara, D and Ruiz-Palacios, G. 2000. A review of policy and standards for wastewater reuse in agriculture: a Latin American perspective. *WELL study, Task* 68.

Pedrero, F, Kalavrouziotis, I, Alarcón, JJ, Koukoulakis, P and Asano, T. 2010. Use of treated municipal wastewater in irrigated agriculture—Review of some practices in Spain and Greece. *Agricultural Water Management* 97 (9): 1233-1241.

Price, AH, Norton, GJ, Salt, DE, Ebenhoeh, O, Meharg, AA, Meharg, C, Islam, MR, Sarma, RN, Dasgupta, T and Ismail, AM. 2013. Alternate wetting and drying irrigation for rice in Bangladesh: Is it sustainable and has plant breeding something to offer? *Food and Energy Security* 2 (2): 120-129.

Renner, J. 2012. Global Irrigated Area at Record Levels, But Expansion Slowing. *Worldwatch Institute. Np* 27.

Ruíz-Sánchez, M, Armada, E, Muñoz, Y, de Salamone, IEG, Aroca, R, Ruíz-Lozano, JM and Azcón, R. 2011. Azospirillum and arbuscular mycorrhizal colonization enhance rice growth and physiological traits under well-watered and drought conditions. *Journal of plant physiology* 168 (10): 1031-1037.

Rusan, MJM, Hinnawi, S and Rousan, L. 2007. Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. *Desalination* 215 (1): 143-152.

Rutkowski, T, Raschid-Sally, L and Buechler, S. 2007. Wastewater irrigation in the developing world—two case studies from the Kathmandu Valley in Nepal. *Agricultural Water Management* 88 (1): 83-91.

Scott, CA, Faruqui, NI and Raschid-Sally, L. 2008. *Wastewater Use in Irrigated Agriculture: Management Challenges in Developing Countries*. CAB International, Nosworthy Way, Wallingford, Oxfordshire, OX10 8DE, United Kingdom.

Seck, PA, Tollens, E, Wopereis, MCS, Diagne, A and Bamba, I. 2010. Rising trends and variability of rice prices: Threats and opportunities for sub-Saharan Africa. *Food Policy* 35 (5): 403-411.

Shao, D, Tan, X, Liu, H, Yang, H, Xiao, C and Yang, F. 2013. Performance analysis of on-farm irrigation tanks on agricultural drainage water reuse and treatment. *Resources, Conservation and Recycling* 75: 1-13.

Shiyam, J, Oko, B, Obiefuna, J and Ofoh, M. 2011. Optimizing the productivity of Plantain/Cocoyam mixture by mulching and fertilizer application. *World Journal of Agricultural Sciences* 7 (5): 633-637.

Sibiya, SG. 2015. Planting Density Effect on Growth and Yield of Taro (Colocasia Esculenta) Landraces, University of KwaZulu-Natal, Pietermaritzburg.

Singh, D, Mace, E, Godwin, I, Mathur, P, Okpul, T, Taylor, M, Hunter, D, Kambuou, R, Rao, VR and Jackson, G. 2008. Assessment and rationalization of genetic diversity of Papua New Guinea taro (Colocasia esculenta) using SSR DNA fingerprinting. *Genetic resources and crop evolution* 55 (6): 811-822.

Singh, S, Ladha, J, Gupta, R, Bhushan, L, Rao, A, Sivaprasad, B and Singh, P. 2007. Evaluation of mulching, intercropping with Sesbania and herbicide use for weed management in dry-seeded rice (Oryza sativa L.). *Crop Protection* 26 (4): 518-524.

Sonou, M. 2001. Peri-urban irrigated agriculture and health risks in Ghana. *Urban Agriculture Magazine* 3 (3): 33-34.

Tabatabaei, S-H, Nafchi, RF, Najafi, P, Karizan, MM and Nazem, Z. 2017. Comparison of traditional and modern deficit irrigation techniques in corn cultivation using treated municipal wastewater. *International Journal of Recycling of Organic Waste in Agriculture* 6 (1): 47-55.

Tamoutsidis, E, Lazaridou, M, Papadopoulos, I, Spanos, T, Papathanasiou, F, Tamoutsidou, M, Mitlianga, P and Vasiliou, G. 2009. The effect of treated urban wastewater on soil properties, plant tissue composition and biomass productivity in berseem clover and corn. *J Food Agric Environ* 7 (3&4): 782-786.

Tan, X, Shao, D, Liu, H, Yang, F, Xiao, C and Yang, H. 2013. Effects of alternate wetting and drying irrigation on percolation and nitrogen leaching in paddy fields. *Paddy and Water Environment* 11 (1-4): 381-395.

Tilley, E, Ulrich, L, Luethi, C, Reymond, P and Zurbruegg, C. 2014. Waste Stabilisation Ponds. in: *Compedium of sanitation systems and technologies*, (Ed.) S Swiss Federal Institute of Aquatic Science and Technology.

Toze, S. 2006. Reuse of effluent water—benefits and risks. *Agricultural water management* 80 (1): 147-159.

Tumuhimbise, R. 2015. Plant Spacing and Planting Depth Effects on Corm Yield of Taro (Colocasia esculenta (L.) Schott). *Journal of Crop Improvement* 29 (6): 747-757.

Unamma, R, Enyinnia, T and Emezie, J. 1985. Critical period of weed interference in cocoyam/maize/sweet potato intercrop. *International Journal of Pest Management* 31 (1): 21-23.

Uyeda, J, Radovich, T, Sugano, J, Fares, A and Paul, R. 2011. Effect of irrigation regime on yield and quality of three varieties of
Provider, May-April, 2011.

Valenzuela, HR, Stephen, K and Schaffer, B. 1991. Shading, growth, and dry-matter partitioning of cocoyam [Xanthosoma sagittifolium (L.) Schott]. *Journal of the American Society for Horticultural Science* 116 (6): 1117-1121.

Vazquez-Montiel, O, Horan, NJ and Mara, DD. 1996. Management of domestic wastewater for reuse in irrigation. *Water Science and Technology* 33 (10-11): 355-362.

Wang, J, Huang, Y and Zhao, X. 2004. Performance and characteristics of an anaerobic baffled reactor. *Bioresource Technology* 93 (2): 205-208.

Weber, B, Avnimelech, Y and Juanico, M. 1996. Salt enrichment of municipal sewage: new prevention approaches in Israel. *Environmental management* 20 (4): 487-495.

Weerarathne, L, Marambe, B and Chauhan, BS. 2017. Intercropping as an effective component of integrated weed management in tropical root and tuber crops: A review. *Crop Protection* 95: 89-100.

Yang, J, Huang, D, Duan, H, Tan, G and Zhang, J. 2009. Alternate wetting and moderate soil drying increases grain yield and reduces cadmium accumulation in rice grains. *Journal of the Science of Food and Agriculture* 89 (10): 1728-1736.

Yao, F, Huang, J, Cui, K, Nie, L, Xiang, J, Liu, X, Wu, W, Chen, M and Peng, S. 2012. Agronomic performance of high-yielding rice variety grown under alternate wetting and drying irrigation. *Field crops research* 126: 16-22.

Ye, Y, Liang, X, Chen, Y, Liu, J, Gu, J, Guo, R and Li, L. 2013. Alternate wetting and drying irrigation and controlled-release nitrogen fertilizer in late-season rice. Effects on dry matter accumulation, yield, water and nitrogen use. *Field Crops Research* 144: 212-224.

Yoon, CG, Ham, J-H and Jeon, J-H. 2003. Mass balance analysis in Korean paddy rice culture. *Paddy and Water Environment* 1 (2): 99-106.

Zhang, H, Chen, T, Wang, Z, Yang, J and Zhang, J. 2010. Involvement of cytokinins in the grain filling of rice under alternate wetting and drying irrigation. *Journal of Experimental Botany* 61 (13): 3719-3733.