NITROGEN AND SALT LEACHING MANAGEMENT ON IRRIGATED SALT-AFFECTED SOILS IN CHÓKWÈ IRRIGATION SCHEME, MOZAMBIQUE

by

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DECLARATION

I hereby certify that this proposal is my own work, except where duly acknowledged. I also certify that no plagiarism was committed in writing this proposal.

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ABBREVIATIONS AND ACRONYMS

CEC - Cation Exchange Capacity

CGIAR - Consultative Group on International Agricultural Research

CIS - Chókwè Irrigation Scheme

DNA – Direcção Nacional de Águas (National Directorate of Water Affairs)

EC - Electrical Conductivity

EC_e - Electrical Conductivity of the Saturated Paste Extract

ESP - Exchangeable Sodium Percentage

FAEF - Faculdade de Agronomia e Engenharia Florestal (Faculty of Agronomy and Foresty Engineering)

FAO - The United Nations Food and Agriculture Organization

FEWS NET - Famine Early Warning Systems Network

GDP - Gross Domestic Product

HICEP - Hidráulica de Chókwè Empresa Pública

ILRI - International Institute for Land Reclamation and Improvement

INE - Instituto Nacional de Estatística (National Statistic Institute)

INGC - Instituto Nacional de Gestão de Calamidades (National Intitue for Disaster Management)

IWRM -Integrated Water Resources Management

LAI - Leaf Area Index

MGD - Millennium Development Goal

NARES - National Agriculture Research Institutions

OM - Organic Matter

PAW - Plant Available Water

RBD - Randomised Block Design

SADC - Southern African Development Community

SAR - Sodium Adsorption Ratio

SAS - Statistical Analysis System

SWB - Soil Water Balance

TDR - Time Domain Reflectometry

UEM - Universidade Eduardo Mondlane (University Eduardo Mondlane)

USA - United States of America

WFD - Wetting Front Detector

ABSTRACT

Worldwide, food production to feed the increasing population growth is still a big challenge, especially in arid and semi-arid areas of Africa where about 70% of the rural population depend on agriculture for their livelihood. Chemical and physical land degradation processes aggravate the declining crop production in these areas. Therefore, efficient use of water and nutrients is a priority to guarantee sustainable crop production and improve the rural livelihoods of poor rural farmers.

This research proposal focuses on understanding and assessing the impact of the interaction between water (leaching fractions) and nutrient management practices in the Chókwè Irrigation Scheme (CIS) located in the Limpopo River Basin, Mozambique. In the CIS, crop yields are variable and declining mainly due to soil salinization and other agronomic practices that include water and nutrient management. This is aggravated by the semi-arid climatic conditions and climate changes phenomena which affect availability of water and increases the occurrence of flood and drought events in the region. The present study is intended to contribute to improving the livelihoods of poor rural farmers in this region through the provision of additional knowledge/strategies that will enable an improvement in the long-term agricultural water productivity and nutrient management.

CHAPTER 1

1 INTRODUCTION

1.1 Background and problem statement

Water for food to feed the population growth worldwide is one of the Millennium Development Goals (MGD) to be achieved by 2015. In this regard, food security and poverty alleviation have been among the most important issues playing a role in the global political arena (Falkenmark & Rockström, 2005a; Falkenmark & Rockström, 2005b; Eickhout, Bouwman & van Zeijts, 2006). Nevertheless, in many water scarce regions, poor rural communities are still facing problems of food insecurity and, therefore, their vulnerability to absolute poverty is higher (Rosegrant, Cai, Cline & Nakagawa, 2002; Akasaka, 2006). Efficient use of water and nutrients by crops is crucial to sustain agricultural production, particularly in arid and semi-arid areas of Africa, where more than 70% of the rural population depend on agriculture for their livelihood (FAO, 1995).

In arid and semi-arid areas, besides the concern over water and nutrient management, the growing land degradation process due to chemical soil degradation (salinization and/or sodification) also contributes to aggravate the unsustainable and variable declining crop yields (FAO, 1995; Rao, Giller, Yeo & Flowers, 2002; Zhang, 2003). The land degradation process increases the dependence on agricultural inputs for crop production. Nutrients leaching will occur under saturated soil conditions with water percolating downward through the soil profile (Silvertooth, Galadima & Norton, 2002). Therefore, the challenge under arid and semi-arid conditions is to manage properly crop fertilization and soil-water relations to enhance maximum and sustainable crop production.

In Mozambique, the population is estimated at 18 million inhabitants, of which about 80% are rural and account for roughly 93% of the national agricultural crop production (INE, 1999). Smallholder farmers produce essentially for their subsistence, contributing about 27% of the Gross Domestic Product (GDP) (INE, 2000). These figures show the important role of crop production for food security and poverty alleviation in the country.

Funded by the CGIAR Challenge Program on Water & Food, WaterNet PN 17, a four year research project is being implemented in the Limpopo River Basin that includes Mozambique, Zimbabwe and South Africa, having commenced in 2005. The main goal of the CP 17 project is to improve rural livelihoods through integrated water resources management (IWRM). Smallholder irrigation activities are prevalent in riparian areas of most of the rivers making the Limpopo Basin. In Mozambique, the Chókwè Irrigation Scheme (CIS) was selected as the focus due to its high potential for agriculture production, as well as the existence of irrigation infrastructure. The CIS occupies an area of about 32 000 ha and farmed by 12 500 families and the current water consumption is approximately 21 500 m^3 ha^{-1} $year^{-1}$ (WAPCOS & CEE-UP, 1989; FAEF, 2001 & HICEP, 2001). Another relevant factor is that, despite its high agricultural potential, crop yields are variable and declining, mainly due to soil salinization, deficient natural drainage and aggravated by the current poor irrigation water management practices (Brito, 1999). The CIS is located almost at the end of the Limpopo River system, in a floodplain area about 100 km from the sea. The area is also subject to extreme events like floods and droughts. Because of its proximity to the sea and the soil parental material the groundwater is of a bed quality (EC > 2 10^3 mS m^{-1}) and therefore, problematic for crop production.

The soils are mainly, heavy clays to loamy clays (Konstapel, 1981 & INIA, 1993) and the deficient existing drainage system (designed in the 1950s) also contributes to aggravate the soil salinization. Although it is believed that other agronomic practices like pest and disease control, cropping system, appropriated cultivars and nutrient management play an important role in crop production, these aspects were not yet well studied and understood within the CIS. Soil salinity contributes largely to the lowering of crop yields, affecting more than 50% of the top soil (0-30 cm) within CIS, and currently about 1000 ha of land have already been abandoned due to salinization (FAEF, 2001; Brito, Munguambe, Magaia, Machele, Sithoe, Tomo & Chilundo, 2002). For example, FAEF (2001) & Menete (2005) report the declining rice yield in the CIS from 4-5 t ha^{-1} in the 1980s, to about 1-2 t ha^{-1} in 2004. Besides the factors listed previously, the long-lasting droughts (1983 to 1992) and the civil war that affected the country during this period were pointed out as the main reasons for the observed declining crop yield. The rainfall in the region is inadequate, being short in duration and poorly distributed and variable between and within seasons and the evapotranspiration rate is high (1580 mm $year^{-1}$) (Reddy, 1984 & FAEF, 2001). Therefore, the need of full and/or supplementary irrigation due to prevalence of dry spells during the crop growing period is a priority to ensure crop production and guarantee food security in the region.

Although some studies have been carried out in the past regarding soil salinization (Savenije, 1980; Engelen, 1981; Konstapel, 1981; Brito, 1985; Touber e Noort, 1985; Brito *et al,* 2002; Munguambe, 2004), the need for an integrated approach to manage soil salinization, nutrient and water management for crop production is still a major challenge in the CIS. Therefore, in this context, the present research will be conducted in the CIS, in order to comprehensively understand and assess the impact of selected water (leaching fractions and strategies) and nutrient (different application rates) management practices on soil water and salt balances and crop production, through an interactive and adaptive approaches involving all the stakeholders.

1.2 Research objectives

1.2.1 Goal

The goal of the present research is to study the interaction between water management practices and nitrogen use efficiency and how this interaction affects crop production in salt-affected soils of the CIS. Under the main objective of the Challenge Program, Project PN 17-Water & Food, which is to contribute to the improvement of the livelihoods of poor rural farmers, the study is expected to provide additional knowledge that will enable an improvement in the long-term agricultural water productivity, as well as better nitrogen management strategies. This will be achieved by (i) improving nutrient balance, through monitoring nitrogen leaching in the root zone during irrigation and/or significant rainfall events; and (ii) testing irrigation water management strategies (leaching efficiency strategies) that will result in balanced salt and nitrogen leaching, and therefore, increased water productivity in the CIS.

1.2.2 Research questions, hypothesis and specific objectives

Three major questions will constitute the focus of the present study. By answering these questions appropriate strategies and recommendations will then be identified and formulated.

(1) *How is irrigation water managed at scheme and field level in the CIS?*

Hypothesis 1: Under the current soil and water management practices at scheme and field levels, the availability of irrigation water to farmers in salt-affected soils of the CIS does not contribute significantly to both lower water and crop productivity.

Objective 1: To assess the existing irrigation water administration system within the CIS at scheme and field levels including the current soil and water management practices and the current water productivity.

This will provide information which will assist in understanding the process of water demand from farmers and the respective supply from the irrigation scheme management authority (HICEP-Hidráulica de Chókwè Empresa Pública). It is intended to identify a reasonable strategy among users and other stakeholders, to minimize water losses and increase the efficiency of water use at both scheme and field levels.

(2) *What are the other agronomic factors affecting crop yields under current water management practices in the CIS?*

Hypothesis 2: Other agronomic practices like improved cultivars, pest control and sowing dates also play an important role on determining crop yield.

Objective 2: To describe the current agronomic practices including cultivars, sowing dates, pest and disease control and their impact on crop yield.

(3) How do we leach salts but conserve nutrients on salt-affected soil of the CIS?

Hypothesis 3: Improved nutrient and salt management strategies will increase water productivity in salt-affected soils of the CIS.

Objective 3: To evaluate the interaction between nitrogen leaching and water management practices under different soil salinity conditions with the aim of:

i. Reducing nitrogen leaching and improving crop yields;

ii. Identifying appropriate water management (leaching fraction) strategies under different soil salinity conditions, and developing suitable recommendations;

iii. Identifying suitable nitrogen application rates under different soil salinity conditions; and

iv. Contributing to increased irrigated water use efficiency and productivity in the CIS.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Soil degradation and salt-affected-soils concepts

Land degradation has been defined as the reduction of current or potential land capacity to produce goods or services through one or more types of soil degradation: soil erosion, salinization, sodification, waterlogging, chemical degradation, physical degradation and biological degradation (FAO, 1979; Nabhan, Mashali & Mermut, 1999). The process is not necessarily continuous and may take place between periods of ecological stability or equilibrium.

Salinity refers to the presence of various electrolytic mineral solutes in concentrations in soils which are harmful to many agricultural crops and other natural vegetation (Amacher, Koenig & Kitchen, 1997; Nabhan *et al.*, 1999; FAO, 2000; Franzen, 2003; Rengasamy, 2006). The problem of soil salinity occurs under different climatic conditions. Salt-affected soil is simply defined as a soil that has been adversely modified for the growth of most crops by the presence of soluble salts, exchangeable sodium or both (Amacher *et al.*, 1997; ILRI, 1998; Nabhan *et al.*, 1999; Rengasamy, 2006).

In semi-arid areas of the world, the scarcity, variability and unreliability of rainfall and a high potential evaporation affect the water and salt balance of the soil. Low atmospheric humidity, high temperatures and wind velocities promote the upward movement of the soil solution and the precipitation and concentration of salts in surface horizons (Nabhan *et al.*, 1999). Soil salinization is caused by a number of factors. The most significant is the accumulation of saline water in the root zone by capillary rise and subsequent evaporation and accumulation of saline minerals near the soil surface. The rate of capillary rise from a water table depends on the hydraulic properties of the soil. Local topography, rainfall pattern, seasonal weather, drainage, farming practices, soil composition and vegetation cover greatly influence the extent to which the effects of salinization are observed (Dehaan & Taylor, 2002).

In semi-arid regions, the most common salts are Na, Mg and Ca, mainly in chloride and sulphate compounds (Nabhan *et al.*, 1999; FAO 2000; Rengasamy, 2006). Soil salinity is determined by measuring the electrical conductivity of solution extracted from a water-saturated soil paste. Salinity is abbreviated as EC_e (electrical conductivity of the saturated paste extract) and the unit is mS m^{-1} (Amacher *et al.*, 1997). According to the classification of salt-affected soils as presented by the USA Salinity Laboratory, a soil is considered saline if the EC_e is above 400 mS m^{-1} at 25ºC with an Exchangeable Sodium Percentage (ESP) < 15 (van Hoorn & van Alphen, 1994). The threshold value above which damaging effects occur can vary depending on several factors including plant type, soil water regime and climatic condition (van Hoorn & van Alphen, 1994; Rengasamy, 2006). The classification of salt-affected soils includes the saline-sodic soils (EC_e > 400 mS m^{-1} and ESP > 15) and sodic soils (EC_e < 400 mS m^{-1} and ESP > 15).

Additional literature review will be carried out on this study. The following specific areas will be investigated:

- Salinity and tomato growth
- Strategies to improve tomato yield on salt-affected soils
- Tomato yield as affected by nitrogen management under irrigation
- Strategies to improve nitrogen use efficiency on salt-affected soils
- Efficient salt leaching strategies
- Irrigation water administration system

CHAPTER 3

3 DESCRIPTION OF STUDY AREA AND METHODOLOGY

3.1 General description of study area

This study will be carried out in the Limpopo River basin, specifically in the Chókwè Irrigation Scheme (CIS) (Figure 3.1). The Limpopo River basin is shared by four SADC countries namely South Africa (193 500 km^2), Botswana (73 000 km^2), Zimbabwe (68 000 km^2) and Mozambique (79,600 km^2) (Ashton *et al.*, 2001). In Mozambique the basin is the second largest river system after the Zambezi. Within Mozambique, the river has two main tributaries namely the Elephant and the Changane Rivers. The river flow in the Mozambique is mostly dependent on the flow from the upstream countries, however, the Changane River system is responsible for the observed permanent flow downstream of the Limpopo River (Xai-Xai) throughout the year (Vaz, 2000). The CIS (Figure 3.1) is located in Chókwè district, Gaza Province in southern Mozambique at 24^o22'S, 33^o00'E, altitude 33 meters above sea level. Established in the 1950s, CIS is the largest irrigation scheme in the country with about 32 000 ha (HICEP, 2001). Small-scale farmers occupy roughly about 10 000 ha of the total area (FAEF, 2001). The Chókwè district has about 173 000 inhabitants, 43% of which are male and 57% female (INE, 1999). Irrigated agriculture within the basin is the main economic activity as well as the major water user with 33 500 $m^3\,ha^{-1}\,year^{-1}$ (WAPCOS & CEE-UP, 1989).

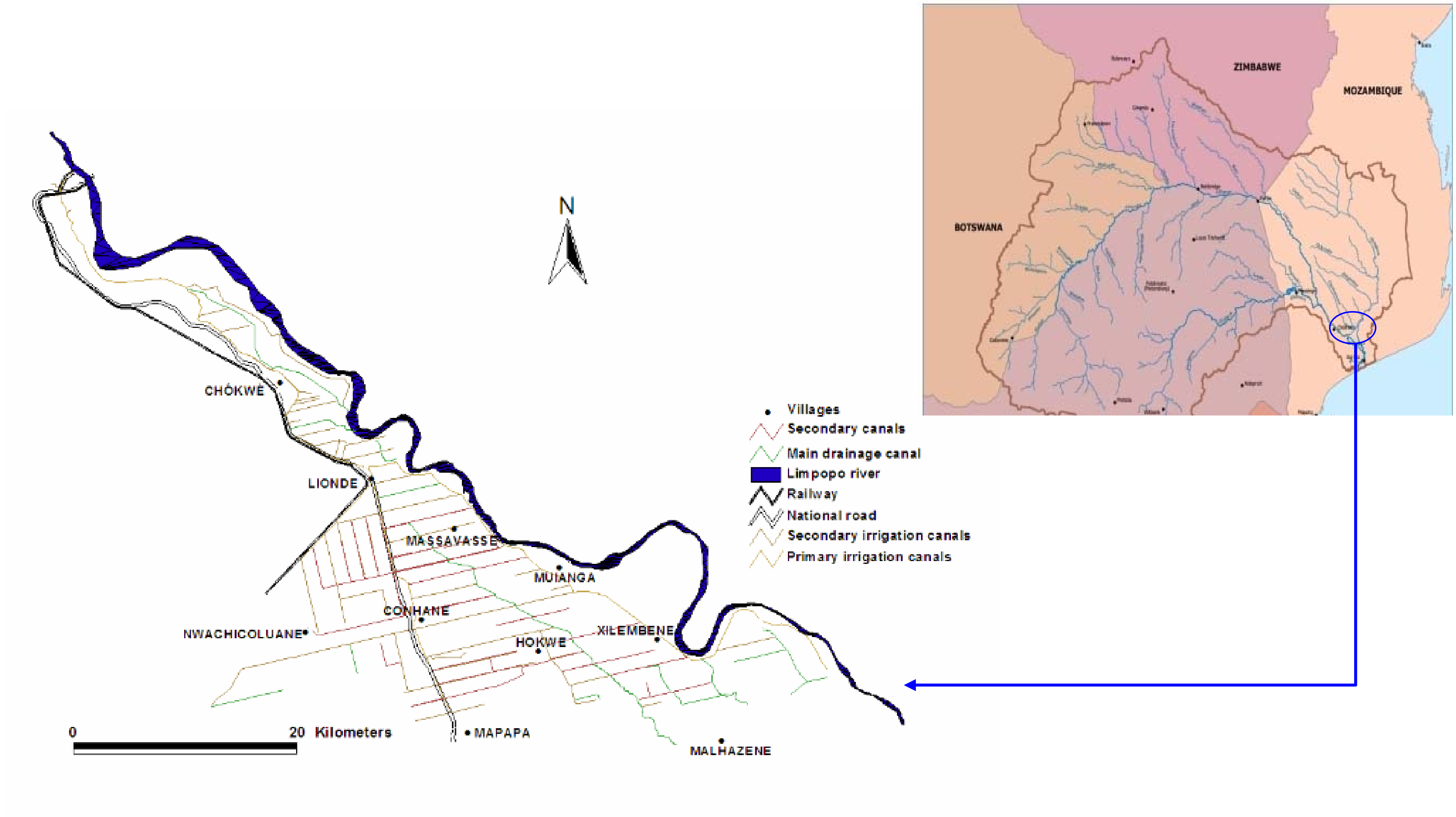

FIGURE 3.1: Map of the study area, the Chókwè Irrigation Scheme (adapted from HICEP, 2001; INGC, UEM & FEWS NET, 2003)

3.1.1 Climate

The climate is dry savannah (Bs) according to the Köppen classification (Reddy, 1984; Gomes & Famba, 1999). The mean annual rainfall is around 630 mm and the mean annual reference evapotranspiration according to the Penmam-Monteith method (FAO 56) of 1580 mm year^{-1} (FAEF, 2001). The rainfall variability from year to year is high and the values range from 25 to 50%. Chókwè has two distinct seasons, a hot, rainy season (summer) from October to April (88% of the total rainfall), and a cool, dry season (winter) from May to September (12% of the total rainfall). The mean annual temperature is 23.6ºC, being observed a maximum of 33.7ºC during January and a minimum temperature of 11.5ºC is observed in June (FAO, 1984 & FAO, 1993). Droughts and floods are also common events in the basin and the mitigation of the impacts has to be part of an integrated national and regional management plan. The most severe floods in the Limpopo River Basin were observed during the years 1975, 1977, 1981, 1988, 1996 and 2000 (Vaz, 2000); severe droughts were observed during the years 1917 to 1918, 1961 to 1965, 1980 to 1984 and from 1991 to 1995 (Maule, 1999).

3.1.2 Soil types

The main soil types (Brito, 1985 & INIA, 1993) in the CIS are:

Group I: includes the soil unities MP1. Mp2, Mp3 and Ppf which are homogenous soils with upper soil layer permeability of 0.07 m day^{-1}. These are clayey marine Pleistocene sediments occurring in a flat depression, with slopes less than 0.5%. Imperfectly drained and may be flooded for some time during heavy rain events. They are mostly recommended for rice production;

Group II: includes the soil unities MI2, Mm1 which are fluvial marine deposits, loamy sand to sand-clay-loam. Non-saline but may be containing sodium after 1 m with soil hydraulic conductivity of about 0.07 m day^{-1}. These soils are also recommended for rice production;

Group III: recent fluvial sediments, very deep and stratified with variation in texture (*Fs*), but of high natural fertility such as the alluvial and organic (*Ft*) very heavy, clayey such as *Fa*. The soil hydraulic conductivity varies from 0.07 to 0.65 m $day^{-1}$and they are suitable for rice production;

Group IV: include the soil unities Fp1, Fp2, Fp3, Mm2 and Mmc. They are 1 meter deep and the hydraulic conductivity is about 0.4 m day^{-1} standing over a more permeable layer (0.65 m day^{-1}).

Group V: include the soil unities FI and Fm which are sandy, deep and well drained. Non-saline and non-sodic, low soil fertility with water table at more than 10 m.

3.1.3 Cropping system

Three major categories of farmers are distinguished in the CIS namely, (i) small-scale farmers with a physical area varying from 1 to 4 ha; (ii) medium farmers with 4 to 20 ha; and (iii) large farmers with more than 20 ha. The small-scale farmers occupy usually the marginal lands in terms of soil fertility and water availability and accessibility. Small-scale farmers produce maize and vegetables basically for there subsistence. The use of agricultural inputs (pesticides, fertilizers and/or improved seeds) by this group of farmers is low to medium due to apparent lack of accessible agricultural credit systems. Cash crops like tomatoes and rice are mainly produced by the medium and large farmers. Rice is the main cultivated crop during the rainy season, followed by maize or vegetables (tomatoes, cabbage, green beans, potatoes and onions) during winter season (FAEF, 2001) as indicated in Figure 3.2.

Soil permeability of different soil layers

	I	II	III	IV	V
	$K_1 = 0.07$ m day^{-1}			$K_1 = 0.40$ m day^{-1}	$K_1 = 1.55$ m day^{-1}
	$K_2 < 0.10$ m day^{-1}	$K_2 = 0.20$ m day^{-1}	$K_2 = 0.65$ m day^{-1}	$K_2 = 0.65$ m day^{-1}	$K_2 = 1.80$ m day^{-1}
Soil unity	Mp1, Mp2, Mp3 & Mpf	MI2 & Mm1	MI1	Fp1, Fp2, Fp3, Mm2 & Mmc	FI & Fm
Soil group	I	II	III	IV	V

Chokwe Irrigation Scheme Cropping Pattern

SOIL GROUP	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
I, II & III							land preparation					
	rice		rice harvesting							direct sowing		rice
			fallow period and/or vegetables									
IV & V		vegetables										
	maize	maize harvesting				land praparation				maize		

FIGURE 3.2: Soil permeability and cropping pattern in Chókwè Irrigation Scheme (Adapted: FAEF, 2001)

The common cropping system during summer is rice under monoculture due to its specific soil, water and labour requirements. Rice is firstly produced in nursery by the small-scale farmers and weed control is done basically by hands, while the medium and large farmers sow the seeds directly and weed control is done chemically. Other crops (vegetables and maize) can be found in a mixed system especially on small-scale farms. Land occupation of maize (75%) and cowpeas (25%) are the common system during summer. Maize (75%) and beans (25%) and Tomato (90%) and maize (10%) are the most dominant during winter (FAEF, 2001). Crop rotation techniques are not common in the CIS.

Grazing is observed in both salinized and fallow areas throughout the year on a community basis. Cattle is used during land preparation and also as a mean of transport during harvesting periods.

Due to its economic value and dietary importance, tomato (*Lycopersicon esculentum*) is the selected crop for the current research in the CIS. The other reason for selecting this crop is that, although tomato is a winter crop in Chókwè, it can also be grown during the summer as long as the diseases and pest control calendars are properly followed.

3.1.4 Irrigation and drainage system of main crops

The irrigation water is of good quality with an electrical conductivity (EC) ranging from 25 mS m^{-1} (at the end of the rainy season) to 70 mS m^{-1} (at the end of the dry season) (FAEF, 2001). The high salt content of the groundwater (EC > 200 mS m^{-1}) associated with semi-arid climatic conditions makes the salinity a relevant issue during the irrigation process.

The estimated current water consumption in the CIS is about 21 500 m^3 ha^{-1} $year^{-1}$ (WAPCOS & CEE-UP, 1989). Flooding is the most predominant irrigation type occupying about 23 000 ha (72%) followed by a mixed system from which water is pumped from the main canal using small to medium motorised pumps and then irrigated by gravity with 7000 ha (22%) and finally sprinkler and drip irrigation with 2 000 ha (6%). Although 72% of the area is flood irrigated, the irrigation infrastructure is somehow broken down, and the initial irrigation capacity of 49 m^3 s^{-1} has dropped down for currently 12 m^3 s^{-1} (FAEF, 2001). The drainage system consists basically of open collectors with 0.7 to 1 meter depth spaced at a distance of about 360 meters (Konstapel, 1981). The functioning of the drainage system for both flooded (rice) and non-flooded crops (vegetables and maize) is illustrated in Figure 3.3.

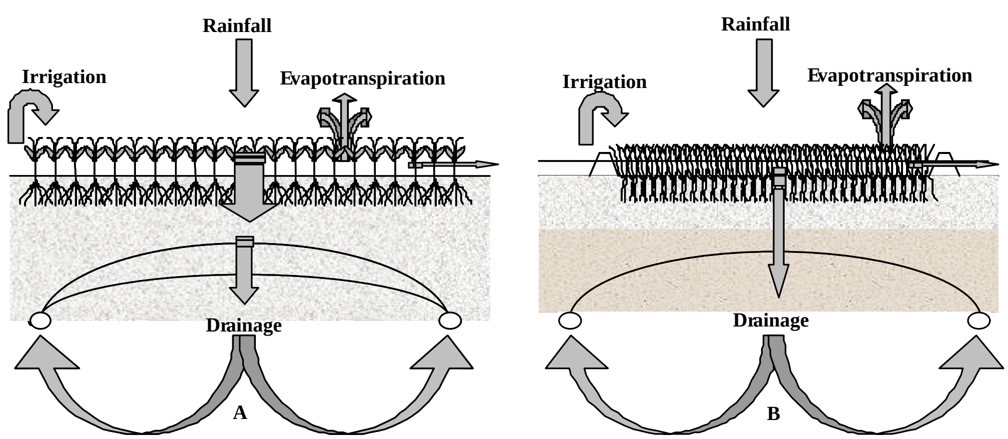

FIGURE 3.3: Drainage system for flood (A) and non-flooded (B) crops in the CIS (Source: Adapted from Brito, 1999)

The water table (or depth of water in case of flooded crop) fluctuation is the result of rainfall intensity and the irrigation water inflow. The evapotranspiration intensity is generally negligible due to its relative small magnitude. The water table height as well as the drain spacing and soil permeability also contributes to the fluctuation of the water table.

The drainage system under non-flooded conditions (maize and vegetables) is intended to control the height of the water table (drainage of surface runoff and/or deep percolation resulting from rainfall or irrigation water). The water table height depends on crop as well as soil physical characteristics. Soil salinity is also another relevant factor being controlled by the drainage system.

Under flooded conditions (rice) the drainage system is mainly intended to control the level of water inside the basin through rainfall runoff control. Soil salinization as well as machinery movement (workability) during harvesting also justify the presence of the drainage system.

3.2 Methodology

3.2.1 Fieldwork preparation

The selection of the farmers and fields within CIS where the research will be conducted will constitute the first task of fieldwork preparation. This will be done through the review of available reports and consultation with farmers and other stakeholders working within the CIS. The pre-identified salt-affected areas for trial installation are presented in Figure 3.4. These locations will be confirmed during the exploratory survey and field visits.

Informal interviews with key informants like extension workers, researchers at the local national agriculture research institutions (NARES), staff responsible for operation and maintenance (HICEP) of the CIS, will be held to discuss the objectives of the research and adjustment to the real situation will be done if applicable. This is an essential step because farmers are expected to actively participate and directly benefit from this research. Therefore, during this process it is also expected of farmers to make a certain commitment, particularly for the implementation of on-farm trials. During the process of getting to know the area, information about farmers willing to run on-farm trials during the research stage of the present study, will also be collected. Besides farmers' willingness, other aspects like the know-how regarding tomato production, field location (accessibility) and water availability will also be taken into account.

3.2.2 Experimental set-up

On-farm trials will be installed in three locations of the CIS as indicated in Figure 3.4, during winter and summer of 2007. The site-specific information regarding the biophysical environment of each selected farm (soils, topography, cropping systems, etc.) will represent the first step in the process of gathering specific information.

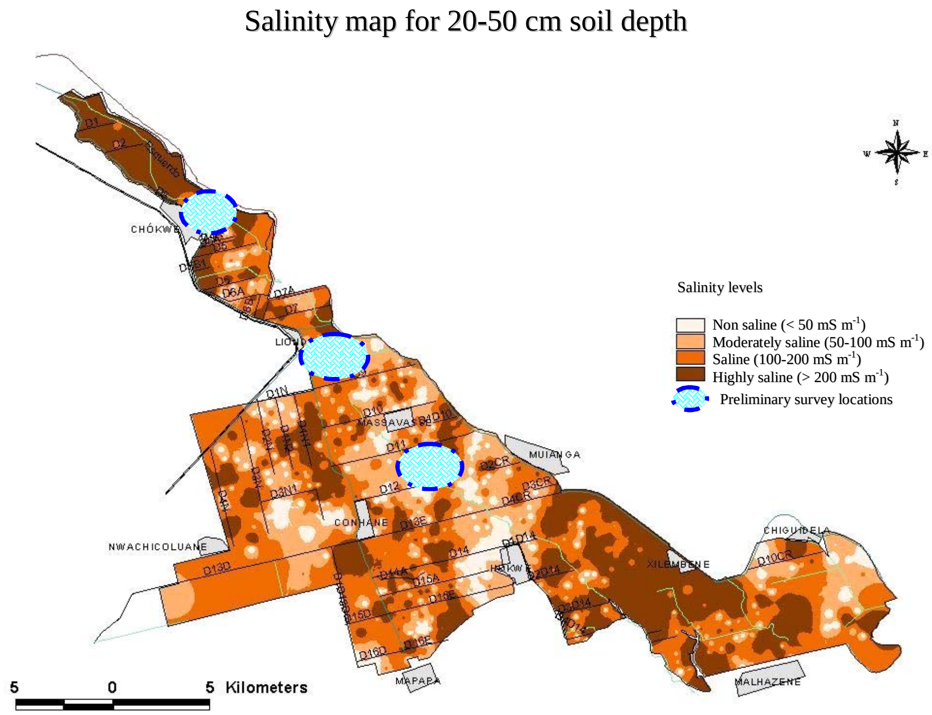

FIGURE 3.4: Proposed locations for preliminary survey in the CIS

The experiments will be conducted in a randomised block design (RBD). Three categories of salt-affected soils will represent the block effects:

i. the non-saline soil or control ($EC_e < 200$ mS m^{-1});

ii. moderately saline soil (EC_e: 200-400 mS m^{-1}); and

iii. saline soil ($EC_e > 4000$ mS m^{-1}).

As the dynamics and distribution of salinity within a single field vary largely, the variation within the furrows will also be considered if applicable.

It is intended to have a plot size of 5m x 15m each (≈ 6 furrows) which would be reasonable, four middle (harvest) and two border rows. A spacing of 1.2m between rows and 0.7m between plants will be used, resulting in a planting density of about 11 900 plants ha^{-1}. To obtain uniform seedling and to check early diseases and pests a nursery will be previously installed. Crop management, pest and disease control practices will be carried out to ensure optimal growing conditions. An example of the proposed layout is presented in Figure 3.5.

		N_1W_2	N_1W_1	N_1W_3	N_1W_C
SITE-I	Non-saline	N_CW_2	N_CW_1	N_CW_3	N_CW_C
		N_2W_2	N_2W_1	N_2W_3	N_2W_C
		N_1W_1	N_1W_3	N_1W_2	N_1W_C
SITE-II	Moderately saline	N_2W_1	N_2W_3	N_2W_2	N_2W_C
		N_CW_1	N_CW_3	N_CW_2	N_CW_C
		N_CW_3	N_CW_2	N_CW_1	N_CW_C
SITE-III	Saline	N_1W_3	N_1W_2	N_1W_1	N_1W_C
		N_2W_3	N_2W_2	N_2W_1	N_2W_C

FIGURE 3.5: Sketch of the experimental design

N stands for nitrogen and W for water. The two letters N and W indicate respectively the nitrogen application rate and the irrigation water treatment. The following four water regimes and three nitrogen application rates will be imposed:

Water treatments:

i. W_C: is the current farmer practice in terms of irrigation management (amount and timing);

ii. W_1: this water treatment will represent crop evapotranspiration (ETc) according to the FAO (CropWat) or SWB models. Irrigation water will be applied according to a fixed amount of water and timing throughout the growing season;

iii. W_2: this irrigation treatment will represent 80% of the ETc. The frequency and amount of irrigation water will be applied depending on the soil water content measurements throughout the growing season; and

iv. W_3: this will represent 120% of the ETc, i.e., 20% will represent the leaching fraction. Irrigation water will be applied according to a certain irrigation schedule based on CropWat and/or SWB.

As mentioned earlier, flood is the common irrigation system in the CIS and tomato is mainly irrigated using furrows. The quantification of the applied irrigation water under flood conditions can be tricky. Therefore, in the present experiment it is intended to use a hose/pipe as siphon to uptake water from the secondary irrigation canal and then quantify the volume of water applied and/or to be applied. The assumption to use this procedure is that the water level in the secondary canal is high than the field/furrow level. This procedure will also minimize eventual errors resulting from land levelling.

Soil water content measurements on each plot will be monitored weekly using the Time Domain Reflectometry (TDR). Therefore, a total of 36 access tubes (4 water treatments x 3 Nitrogen application rates x 3 replications = 36 access tubes) will be installed to assess the soil water content between 0 and 0.6m soil depth (20 cm intervals). Plots being irrigated depending on soil water content, irrigation water will be applied when 30% of the plant available water (PAW) has depleted.

Wetting front detectors (WFDs) will be installed to allow collecting the irrigation water samples to analyse the nitrogen leaching. Therefore, a total of 72 unities of WFDs are required, two will be installed in each plot, one shallow at 30 or 45cm and the second at 60 or 90cm deeper. Soil samples will also be collected to perform additional soil analysis (pH, CEC, organic matter and others). The analysis will be performed according to standard recommended methods for each specific parameter. Other key parameters required by the APSIM model will also be measured and/or determined.

Nitrogen treatments (application rates):

i. N_C: is the current farmer practice of nitrogen application rate (250 kg ha^{-1} of $NPK_{12:24:12}$ & 100 kg ha^{-1} of urea);

ii. N_1: N application rate of 200 kg ha^{-1}; and

iii. N_2: N application rate of 300 kg ha^{-1}.

Nitrogen (200 kg ha^{-1} & 400 kg ha^{-1}) will be applied in three equally split doses. The first dose will be given before transplanting as basal dressing, the second one three weeks after transplanting, and the last one two weeks later. The second and the third applications will be top dressing. Phosphorus (P) and Potassium (K) fertilizers will also be applied to the experiment in a dosage of 200 kg ha^{-1} each right at the beginning of the experiment in a top dressing manner.

3.2.3 Data collection

Within the plots, at least one rain gauge will be installed per field to record the amount of rainfall. Crop water requirement will be determined according to the FAO guidelines developed by Allen, Pereira, Raes & Smith (1998).

Observations of crop performance corresponding to different development stages will be done. Therefore, tomato plants will be sampled from each treatment on a weekly basis to perform the growth analysis. Parameters like leaf area index (LAI), fresh and dry mass of different plant components (leaves, stems and fruits) will be measured and at harvest, fruit yield will also be determined.

Nitrogen and salt measurements will always be taken after any irrigation or considerable rainfall event. Samples will be collected from the WFDs cups. Water depletion from different soil layers throughout the development stages of the crop will be determined based on TDR readings. Besides the weekly basis readings, readings after each irrigation and/or considerable rainfall event will also be taken at 20, 40, 60, 80 and 100cm soil depth. Seasonal water use, water use per growth stage, water use efficiency (kg ha^{-1} mm^{-1}), and nitrogen uptake and efficiency will then be calculated according to standard procedures. Piezometers will be installed to monitor the groundwater table in strategic locations of the CIS including the experimental sites. Other modelling required data will also be collected as specified in section 3.2.5.

3.2.4 Data analysis

Statistical analysis will be performed to assess the variation between different treatments. The effect of nitrogen application rate and irrigation treatment on final tomato yield for different soil salinity conditions will be determined. The SAS package will be used for all the statistical analysis.

3.2.5 Modelling

Agricultural Production System Simulator (APSIM) model will be used to simulate different long term scenarios regarding soil and water management at CIS. APSIM is a modelling framework that uses various component modules to simulate cropping systems in the semi-arid tropics (McGown, Hammer, Hargreaves, Holzworth & Freebairn, 1996). This model can be applied to a big range of agricultural situations, but the main advantage to use the APSIM model in this study is because it contains modules that permit the simulation of crop-interactions, nutrient leaching and the effect of soil salinization under different soil, crop and water management practices. The key inputs comprise site (latitude, slope); soil properties (soil texture and depth, soil water content per layer at field capacity and permanent wilting point, total soil nitrogen of the top layer, soil bulk density per layer, NO_3-N); daily climate data (maximum and minimum temperatures, solar radiation and rainfall); crop phenology (crop type and cultivar, days to flowering, days to maturity) and agronomic management (dates of all the operations, sowing depth, plant density, type and amount of fertilizer, tillage- type and depth) (McGown *et al*, 1996). APSIM outputs will then be used for spatial representation by linking with geographic information systems (GIS) as schematically illustrated in Figure 3.6. The lack of a well equipped weather station will probably constitute a limitation due to availability of some parameters regarding daily climate data.

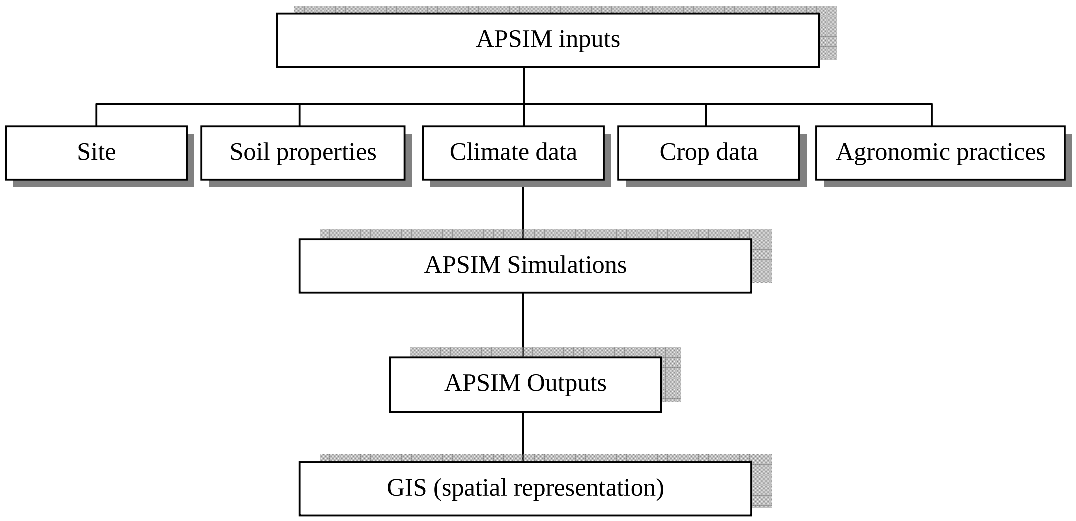

FIGURE 3.6: Flow diagram of the required information and input data by the APSIM model

3.3 Potential sources of error

Although the consideration of standard procedures for the sampling and determination of field parameters will be followed, other limitations may become likely sources of errors. Such limitations include:

- The limited number of field observations in two seasons. Possible seasonal changes and/or trends on soil salinity and nitrogen dynamic may be lost. This will be minimized by looking to the nature of data required by the APSIM model to run the simulations and then use the available data from other studies.

- Soil salinity and nitrogen dynamics vary from farm to farm and with soil water content and agronomic practices. The sampling in farmers' fields may yield different apparent salt and nitrogen concentrations and, therefore, the blocking effect might not be effective.

4 EXPECTED RESULTS

The following results are expected:

- Better understanding of the factors and processes causing yield decline under salt-affected soil conditions in the CIS;

- Identify and recommend appropriate water management practices to minimize soil degradation due to the salinization process and improve crop yield;

- Better understanding of the long term impact of different soil and water management practices on tomato yield and soil salinity in the CIS;

- Site specific nitrogen recommendations for tomato production at different salinity levels and water management practices; and

- Farmers' awareness of different water management practices to control the salinity levels in their fields.

Generally, it is expected from this study to contribute improving the long-term agricultural water and nutrient use efficiency and crop productivity in the CIS. With high production levels, farmers' income and profitability will increase and therefore contribute towards the reduction of poverty and enhance sustainable socio-economic development of the region.

5 RESEARCH BUDGET AND RESEARCH SCHEDULE

5.1 Research budget

TABLE 5.1: Estimated budget

ITEM	COST(U$D)	TOTAL(U$D)
Transport & trials installations	Petrol	2 400
Soil analysis (EC; pH; OM; CEC; Nitrates, SAR; ESP; etc)	-	2 000
Supervisors visit	2x2 round-trip to Mozambique	1 000
Stationery	Paper, CDs, copies	400
WFDs	-	1000
Consumables: paper bags, fertilizer, crop protection, seeds, etc.)	-	1 200
Rain gauges	-	200
Hose (500 m; ø ¾)	-	400
Rental of facilities (land, lab space, ovens, scales, other instruments)	-	2 000
APSIM training		**3 000**
Sub-Total		**13 600**
Overhead costs (10%)		**1 360**
Total		**14 960**

5.2 Research schedule

TABLE 5.2: Time frame

ACTIVITIES	YEAR I Jan-Dec 06				YEAR II Jan-Dec 07				YEAR III Jan-Dec 08			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Course work												
Literature Review												
Proposal development												
Field work preparation												
Field work research												
Data collection & pre-analysis												
Data analysis												
Thesis writing-up												

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