INFLUENCE OF *LABLAB PURPUREUS* COVER CROP AND CROP RESIDUES ON WATER PRODUCTIVITY UNDER IRRIGATED MAIZE IN THE USANGU PLAINS, TANZANIA

BY

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN MANAGEMENT OF NATURAL RESOURCES FOR SUSTAINABLE AGRICULTURE OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

2008

ABSTRACT

This study was conducted in the Usangu plains to investigate the influence of maize crop residues and lablab cover crop live mulch on moisture conservation in irrigated maize. Irrigated maize under bare seed bed, maize crop residue mulch, lablab live mulch and mixture of maize crop residue and live lablab mulches were evaluated with respect to 7 and 14 days irrigation intervals. Split plot design was employed, irrigation intervals of 7 and 14 assigned to main plots while mulches treatments assigned to sub plots. The experiment had a total of 8 treatments replicated three times; four treatments being under 7-day irrigation interval and another four under 14 days irrigation interval. Irrigation depths of 30, 40 and 50 mm were applied at establishment, vegetative and tasselling to maturity stage of the maize crop respectively. The results show that treatments two (T2) and three (T3) which were under 7 days irrigation interval and mulched with maize crop residues and lablab live cover crop respectively had higher yield significant difference when compared to T7 treatment which was under 14 days irrigation interval and mulched with lablab live cover crop. All other treatments which were under 7 and 14 days irrigation intervals showed no maize yield statistical significant difference ($P < 0.05$). For treatments which were irrigated once in every two weeks T6, T7 and T8 indicated high soil volumetric moisture content (VMC) in their respective order from 0 to 45 cm soil depths compared to T5 treatment which had no mulch. Water productivity (WP) with respect to irrigation water was higher for treatments which had 14 days irrigation interval (0.8 – 0.94 kg/m^3) compared to those treatments which were under 7 days irrigation interval (0.61 – 0.63 kg/m^3) indicating a significant difference. Most of the treatments which were irrigated once in every two weeks also showed higher WP with respect to crop water use compared to those which were irrigated once in every 7 days. Irrigating once in every two weeks in this study has indicated to be an appropriate strategy for increased WP and water saving of about 30%, while causing insignificant maize grain yield loss.

DECLARATION

I, Ndabhemeye Mlengera, do hereby declare to the Senate of Sokoine University of Agriculture, Morogoro, Tanzania, that this dissertation is my own original work, and that it has never been submitted nor concurrently being submitted for a degree award in any other University.

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ACKNOWLEDGMENTS

This dissertation is a product of God's mercies and assistance. To Him alone belong all the praise and glory.

I would like to express my sincere thanks to my supervisors: Professor N.I. Kihupi and Dr. J.J. Kashaigili for their beyond measure assistance and encouragement in the course of my study. I also extend my sincere gratitude to the Ministry of Agriculture, Food and Cooperatives - my employer, for financing my MSc studies at SUA. My heartfelt thanks are also due to my wife Mrs Elizabeth N. Mulengera and my children: Don, Glory and Elishama, my parents Mr. M. Kabharu and Mrs Safi M.K., Dr M.K. Mulengera's family and all my family brothers and sisters who have been spiritually, materially and morally very supportive during the whole period of study at SUA. I acknowledge the cooperation I have received from my co-workers, Eng. S.S. Mkomwa, Eng. Z. J. Mkoga, Ms W. Tegambwage and Mr. A.Y. Mbogho for their moral, material and literature support. I would also like to extend my gratitude to Pastor Z. Ryoba, assistant pastors, church elders, all the brethren of the Church and my friends for their prayers.

I also wish to express my thanks to Mr. S. A. Kinyaga, the Principal of MATI Igurusi, who provided me with the experimental site. I would like to appreciate Mr. A. Kalinga's assistance with data collection and Mr. R.J. Kimati who provided me with cost effective indigenous knowledge of smearing mud on maize heads at milking stage in order to control birds attack. All literature/citations are acknowledged by listing them under the Reference section.

DEDICATION

I dedicate this dissertation to the Holy Spirit -The Spirit of the Living God, who single-handedly instructed, supervised, guided and provided me with strength to accomplish this work (Zachariah 4:6).

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LIST OF ABBREVIATIONS AND SYMBOLS

^0C	degree Fahrenheit
CRM	Crop residue mulching
FC	Field Capacity
MC	Moisture content
FAO	Food and Agricultural Organisation of the United Nations
ET_a	Actual crop evapotranspiration
ha	Hectare
IZTIS	Igurusi ya Zamani Traditional Irrigation Scheme
MATI	Ministry of Agriculture Training Institute
SMUWC	Sustainable Management of Usangu Wetlands and its Catchments
SWMRG	Soil Water Management Research Group
Tsh	Tanzania Shilling
VMC	Volumetric Moisture Content
WP	Water Productivity
WP_{ETa}	Water Productivity with respect to Evapotranspiration
WP_{irr}	Water Productivity with respect to Irrigation water

CHAPTER ONE

1.0 INTRODUCTION

1.1 Overview of Irrigated Agriculture

The chances of increasing crop production in Sub-Saharan Africa seems to depend much on irrigated agriculture, as the rainfall variability, both in terms of distribution and amount is a major limitation to agriculture in the region (Igbadun *et al.*, 2005). But this hope is strongly challenged by the rapidly declining water resources of the region and the growing increase in competition for water among agricultural, domestic and industrial uses (Ahmed *et al.*, 2004; Igbadun *et al.*, 2005). Of the three major sectors, agriculture remains the largest water user, accounting for more than 70% of water withdrawals worldwide and more than 90% of water withdrawals in the low-income developing countries (Brito *et al.*, 2003; Fereres and Soriano, 2006).

Irrigated agriculture is one of the major contributors to the supply of food and fibre in the world. Globally, food production from irrigation represents more than 40% of the total crop production and uses only about 17% of the land area devoted to food production (FAO, 2003; Fereres and Connor, 2004).

The Usangu plains in the Great Ruaha River catchment are one of the many places in Tanzania where irrigated agriculture is rapidly expanding. The effort of the Government of Tanzania in developing the irrigation facilities in the Usangu plains has enhanced all-year-round farming activities, with dry season irrigation on a continual increase (Igbadun, 2006). Intensive dry season irrigation in the upper courses of the rivers, mainly for high-value crops such as vegetables, onions, tomatoes, beans and green maize supports considerable livelihoods in the basin (Kashaigili *et al.*, 2005).

The Usangu plains have diverse multi-sectoral water use. Irrigation uses a large quantity of the water in the Rufiji basin as compared to other sectors (Sokile *et al.*, 2003). There are more than 100 intake structures for abstracting water from the rivers for irrigation (SMUWC, 2001; Rajabu *et al.*, 2005). Over 90% of the water flowing in the rivers in these catchments is abstracted during the peak of the dry season (SMUWC, 2001; Rajabu *et al.*, 2005). The high abstraction of water from the rivers has been claimed to be the cause of the drying up of the Great Ruaha River during the dry seasons (SMUWC, 2001; Kashaigili, 2006). The increase in irrigation activities in the catchments has led to communal conflicts as a result of the struggle for access to more water (van Koppen *et al.*, 2004).

The most challenging issue facing irrigated agriculture in Tanzania is that of making irrigated agriculture produce more crops per drop of water and sparing adequate water for use by other sectors within the river basins (Kadigi *et al.*, 2004). Irrigated agriculture is under pressure to cut down the amount of water use for crop production and at the same time to produce more crops with less water. As a step towards achieving the objective of more crops per drop of water, there is a need for irrigators to begin to adopt the use of techniques and practices that regulate water to crops and minimize needless waste (Igbadun *et al.*, 2005). Adoption of irrigation scheduling has been recognized as a viable practice that could lead to increased crop yield, and greater profit for farmers, significant water saving, reduced negative environmental impact of irrigation and improved sustainability of irrigated agriculture (Pereira, 1996; Degirmenci *et al.*, 2003). Well scheduled irrigation can lead to increase in water productivity when there is no reduction in water losses due to evaporation, deep percolation and runoff (Liu *et al.*, 1998).

The use of cover crops mulch and crop residues can reduce water loss through evaporation while increasing moisture availability to crops and hence improved yield (Li *et al.*, 2008; Thukkaiyannan *et al.*, 2005). Conventional tillage systems, which disrupt the soil surface and bury large amounts of crop residue, lose up to 30% of received rainfall in the form of runoff and also decrease irrigation efficiency due to increased evaporation (Arriaga and Balkcom, 2005). Retention of soil moisture under cover crop mulches can be a significant advantage (Blevins *et al.*, 1971).

1.2 Problem Statement and Justification

Water resource is scarce in the sense that it is not adlib enough to be concurrently accessed by all users all the time (Jury and Vaux Jr, 2005). The irrigation schedules are taken as the means of managing disputes of the equally demanding users. Farmers in many of the irrigation schemes in the Usangu plains practice rotational water delivery method as a measure to minimize water use conflicts in the schemes. This practice automatically constrains the farmers to a fixed-frequency of irrigation scheduling in those schemes. For example, at Igurusi ya Zamani Traditional Irrigation Scheme (IZTIS), water is rotated within and around the different sectors of the schemes such that farmers irrigate crops once in every seven days (Igbadun, 2006).

The bare seedbeds are prone to water losses from farm fields by evaporation and runoff leading to reduced moisture available for the crops. Evaporation and transpiration occur simultaneously and when the crop is small, water is predomintly lost by evaporation, but once the crop is well developed to its full canopy, transpiration becomes the main process (Zhang *et al.*, 2005). The use of agronomic practices such as the application of mulch in irrigated fields is believed to influence water availability, hence increased performance. However, not much is known on the use of cover crops and crop residues in moisture conservation. Much work on the use of cover crops and crop residues has been focused on fertility improvement and erosion control (Kalumuna, 2005; Sarrantonio and Gallandt, 2005). There is no work which has been done in the Usangu plains to examine the influence of mulch in moisture conservation for improved moisture availability to crops. The findings from this study contribute to bridging the existing knowledge gap on the influence of cover crops and crop residue mulch on moisture conservation and availability; leading to better crop yield under limited water supply and increase water use efficiency in catchments where water resource is becoming scarce.

1.3 Objectives of the Study

1.3.1 General objective

The main objective of the study was to investigate the efficacy of Lablab (*Lablab purpureus* L.) cover crop and maize crop residues in conservation of soil moisture in irrigated maize and their influence on water productivity.

1.3.2 Specific objectives

(i) To assess the effect of lablab cover crop on water use in irrigated maize

(ii) To evaluate the interactive effect of Lablab mulch and crop residues on moisture conservation.

(iii) To evaluate the interactive effect of Lablab mulch and crop residues on water productivity and maize yield.

1.3.2 Hypotheses

(i) Null hypothesis: Mulching in irrigated fields has no influence on soil moisture conservation and water productivity

(ii) Alternative hypothesis: Mulching in irrigated fields improves soil moisture conservation and water productivity

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Irrigation Scheduling Practices

Irrigation scheduling is defined as the technique of timely and accurately applying water to crop (Itier *et al.*, 1996). It is a primary tool for improving water use efficiency and increasing crop yields, ensuring greater availability of water resources, and result in a positive effect on the quality of soil and groundwater (FAO, 1996). The essential element of irrigation scheduling is 'how much, and when to apply that amount of water'. Irrigation scheduling therefore requires sound knowledge of the crop water requirements and soil water characteristics. Over the decades, advances in research have facilitated the development of quite a number of new techniques, methodologies and tools that are used in irrigation scheduling (Hill and Allen, 1996; Itier *et al.*, 1996). Notable among these new methodologies is regulated deficit irrigation scheduling. This technique has the potential to save water, energy and labour involved in irrigation (Itier *et al.*, 1996). For example in the Usangu plains, Irrigation Scheduling Impact Assessment Model (ISIAMod) was used to determine water application depth that is optimal in the conventional irrigation scheduling of the area (Igbadun, 2006). The results of the evaluation indicated that the optimal water application depth (WAD) per irrigation for the conventional seven days irrigation interval for the maize crop was between 40 and 50 mm. The percentage yield losses of maize with respect to 14 days irrigation interval throughout the growing cycle were found to be 46.9% (Igbadun *et al.*, 2005).

2.1.1 Deficit irrigation scheduling practice

Deficit irrigation scheduling practice is the technique of withholding or skipping irrigation, or reducing the amount of water applied per irrigation at some stages of the crop growth with the aim of saving water, labour, and in some cases energy (Igbadun *et al.*, 2007). This practice does lead to some degree of moisture stress on the crop (Smith *et al.*, 2002). However, when the moisture stress is not severe, the adverse effect on crop yield is minimal and there can be an appreciable increase in crop water use efficiency especially when there is reduction in water losses due to evaporation, deep percolation and runoff (Liu *et al.*, 1998; Panda *et al.*, 2004). Deficit irrigation is needed where essential resources such as water, capital, energy and labour are limited.

2.1.2 Economic aspects of deficit irrigation

Improvements in water use efficiency and water productivity are essential if the economic benefits from deficit irrigation are to be realised (Shideed *et al.*, 2003). The economic use of water depends largely on the management of water deployment and application, and on the technical, economic, and socio-cultural conditions. Deficit irrigation is one of the methods recommended as a means of improving the economic use of irrigation water (Wolff and Stein, 1999). Deficit irrigation scheduling reduces the amount of water used to irrigate crops and the maximum profit from a crop can be obtained using less water than is needed for maximum yield (Orloff *et al.*, 2003).

2.1.3 Water savings under deficit irrigation

Water savings from the deficit irrigation treatments can be established by comparing water applied under deficit irrigation to that applied in a well-watered control or reference treatment. The volume of water that can be saved using a deficit irrigation strategy over full irrigation depends on the climatic demand, stored available water and the irrigation strategy used (Prichard, 2004). Significant savings in irrigation under deficit irrigation were found in several studies without affecting yield and its components including quality and improved water use efficiency (FAO, 2002). Around 6 - 22 % of irrigation water was saved in citrus orchard (Gonzalez and Castel, 2004), 60% in apple trees (Mpelasoka *et al.*, 2001), and about 30% in mature almond trees (Romero *et al.*, 2004).

2.1.4 Water productivity

Productivity, in general, is a ratio referring to the unit of output per unit of input (Barker *et al.*, 2003; Kijne *et al.*, 2003). Until recently, water was not considered a scarce resource. Now with mounting water shortages and water quality concerns, there is growing interest in measures to increase water productivity (WP), commonly measured as crop output per unit volume of water (Kijne *et al.*, 2003). It is a useful indicator for quantifying the impact of irrigation scheduling decisions with regard to water management (Kijne *et al.*, 2003; Igbadun, *et al.*, 2006). Water productivity increases under deficit irrigation, relative to its value under full irrigation, as shown experimentally for many crops (Zwart and Bastiaansen, 2004; Fan *et al.*, 2005). WP values are affected by different definitions of the numerator and denominator, environmental circumstances, such as climate, year and sowing date, and crop characteristics. These parameters may result in 10-25% change in the water productivity values and sometimes even more (Bessembinder *et al.*, 2005). In deriving WP, the denominator remains the quantity of water diverted or depleted and the numerator can be expressed in general physical or economic terms (i.e. mass or monetary value of produce per unit volume of water) (Ahmad *et al.*, 2004).

2.2 Crop Residue Mulches in Crop Production

Arable farming with the retention of crop residues as mulch commonly known as conservation tillage has made a significant advent in the USA, comprising more than 35% of the cropped land since the mid 1990s (CTIC, 2000). The distinguishing and novel feature of these tillage systems is the retention of crop residue mulch just after crop establishment to ensure an adequate soil cover. These systems are revolutionary as over the centuries agriculture has traditionally emphasised the opposite, i.e. the need for a clean seedbed without crop residues. Numerous farmers in developing countries still rely on pre-plant burning of vegetative debris (Erenstein, 2002).

Crop residue mulching (CRM) can be defined as a technology whereby at the time of crop emergence, at least 30% of the soil surface is covered by organic residue of the previous crop (Erenstein, 2002). The objective of mulching is to conserve soil moisture; reduce runoff flows; evaporative losses, and wind erosion; prevent weed growth; enhance soil structure and control soil temperature (Ramesh and Devasenapathy, 2007). In East Africa mulching normally utilizes plant materials and involves covering the soil with cut grass, straw or other plant material (Mati, 2005).

However, the use of mulch is limited by inadequate supply of mulching material particularly in the dry seasons. There is, therefore, a need to identify cropping systems that will enable *in situ* generation of residue mulch. Studies have shown that when properly incorporated in the cropping systems cover crops can generate in situ biomass, which can serve as mulching material (Unger and Vigil, 1998). Other studies have shown that the performance of cover crops may vary with species and climate (Unger and Vigil, 1998; Gachene *et al.*, 2000).

2.2.1 Crop residues and moisture conservation

Addition of organic materials, mulching and use of cover crops are among the management practices that could be used to conserve soil moisture (Lal, 1990; Mahoo, *et al.*, 1996; Rasse *et al.*, 2000; Ghuman and Sur, 2001). Mulch densities range between 30 percent and 70 percent, based on availability of residues obtained from the previous season's crop (Kibwana, 2000). Zhang *et al.* (2005) reported that without mulching, soil evaporation accounted for 30% of the total evapotranspiration. With mulching, this value was reduced to approximately 15 to 20%. In areas where soil moisture is limiting for better crop performance, water conserving effect of CRM can induce a substantial yield increase. According to Mesfine, (2005) there was significant increase in yield of sorghum due to crop residue mulch application in semi-arid areas of Ethiopia as a result of soil moisture conservation effect. In Nigeria Ayotamuno *et al.* (2007) found that maize and cucumber yields were sensitive to different irrigation application depths and mulching levels. The study revealed that high yields were obtained in mulched plots compared to un-mulched plots. In Tanzania a participatory experiment with farmer innovators in marginal Mbozi District found that the use of crop residues to mulch coffee crop resulted in doubled coffee yield (Kibwana, 2000). In most instances, though, the water conserving effect may have little tangible effect on short-term yields in "normal" years. However, it will be particularly beneficial in dry years, with the important benefit of reducing productive risk and yield oscillations (Pierce and Lal, 1994).

2.2.2. Crop residue and agricultural externalities

CRM potentially redresses a number of the negative externalities traditionally associated with agriculture. Most obvious is CRM's ability to halt human-induced soil erosion in agriculture thereby retaining the productive capacity on-site and reducing the generally adverse off-site impacts of eroded sediment and soil erosion related pollutants (Erenstein, 2002). CRM also implies C-sequestration through the temporary immobilisation of CO_2, a green-house gas contributing to global warming by maintaining the crop residues on the soil surface. CRM thereby can convert annual cropping from a net source of CO_2 to a net sink (Kern and Johnson, 1993). CRM also implies more water infiltration and less runoff from agricultural land, thereby smoothing the downstream hydrological cycle and refilling acquifers and enhancing ground water recharge. CRM is typically water conserving and thereby tends to stabilise yields especially in drought-prone environments reducing national food production risks and enhancing food security (Erenstein, 2002). CRM can also aid in the sedentarisation of itinerant agriculture, thereby reducing existing pressures on fragile ecosystems (Erenstein, 2002).

2.2.3 Pest and disease management

Many of the weed management considerations also apply to pest and disease management (Erenstein, 2002). Incorporation and burning of crop residues frequently are used as phytosanitary measures, whereas CRM curtails their use (*ibid*). The effect of CRM on pests and diseases is varied (Unger, 1990). By retaining the crop residues, CRM may enhance the carry-over of both pest and disease organisms and their natural enemies (Rijn, 1982). CRM thus simultaneously affects the incidence and management of pests and diseases.

2.3 Cover Crops (black mulches) in Crop Production

A cover crop is any crop grown to provide soil cover. Regardless of whether, it is later incorporated or left to cover the soil surface (Sullivan, 2003). Green mulches are usually leguminous plants that cover the ground as runners, grown together with other crops. They are sometimes also termed as green manure because of the ability of the companion legume to fix nitrogen in the soil. The legume is used as a cover crop. Crops such as pumpkins and water melons have proved useful as green mulches (Mati, 2005).

2.3.1 Cover crops and moisture conservation

The mulches obtained from cover crops alter net radiation, vapour pressure deficit and surface temperature (Dabney, 1998). Consequently, cover crops reduce evaporation and conserve soil moisture. In his findings, Mati (2005) found that in a papaya plantation in Embu District of Kenya, the use of water melons as a companion crop improved soil moisture conservation. The effect of cover crops on soil moisture conservation is through the cover provided by the canopy and residues of cover crops (Kalumuna, 2005). By using cover crops to maximize ground cover, the ratio of soil water evaporation to crop transpiration decreases (Daniel, *et al.*, 1999). Such phenomenon will enable more water availability to the crop rather than being lost through evaporation.

2.3.2 Cover crops and runoff effects

Cover crops and their residues provide mulch to the soil surface that absorbs rain drop energy. The residues increase time of infiltration and reduce runoff velocity (Trojan and Linden, 1998). These effects increase the amount of rainwater that infiltrates the soil (Wall *et al.*, 1991; Zougmore *et al.*, 1998). Zougmore *et al.* (1998) found that sorghum – cowpea intercropping system in Burkina Faso reduced runoff by 20 – 30% compared to sole sorghum and 5 - 10% compared to sole cowpea. Runoff is appreciably reduced when the ground covered by vegetation exceeds 30% (Elwell and Stocking, 1976). Because most of the runoff losses are obtained early in the growing season, fast growing cover crops may be more efficient in reducing these losses hence increasing the amount of water infiltrating into the soil (Lal *et al.*, 1991).

2.3.3 Other benefits of cover crops

Cover crops suppress weeds (Semere and Williams, 1997; Carsky *et al.*, 1998; Fischler and Wortmann, 1999) and reduce crop pests (Skovgard and Pats, 1996; 1997). Skovgard and Pats (1996, 1997) reported that intercropping maize with cowpea in Kenya reduced stem borer (*Chilo spp* and *Sesamia calamistis*) incidences by 15 – 25% compared to sole maize. This resulted from increased parasitism of eggs of stem-borer by the *Hymenoptera* parasite whose population was increased by 80% after intercropping maize with cowpea. However, when cover crops are not properly incorporated in the farming system can act as weeds by competing with the primary crop for light, moisture, nutrients, and space. In a dry year, cover crop can rob primary crops of valuable soil moisture. In other years, they may also compete for other resources such as nitrogen if not managed properly (Peet, 1995; Curran *et al.*, 1996).

2.3.4 Timing of cover crop intercropping

Intercropping refers to a cropping system where more than one crop are grown together on the same piece of land in a specific pattern. It is an efficient use of limited land, is a way of spreading risks so that if one crop fails the other one will performe and therefore stabilizes crop production (Morris and Garrit, 1993; Virmani, 1993).

However, cover crops planted at the same time with the main crop may compete for moisture, particularly at early growth stages and reduce the yields of the main crop. For example Nordquist and Wicks (1974) observed maize yield reduction of 20 - 50% when maize was planted at the same time with alfalfa. In Ghana, maize grain yield was reduced by 1 Mg ha^{-1} when velvet bean was planted simultaneously with maize (Osei – Bonsu and Buckles, 1993).

Delaying planting of cover crop was suggested as a means to reduce competition for moisture between cover crops and the main crop and hence, maintain yields of the latter (Scott *et al.*, 1987; Abdin *et al.*, 1998). Scott *et al.* (1987) observed that when cover crop planting was delayed until when maize was 15 to 30 cm high, maize grain yield was not affected. This can be due to the reason that cover crops did not over shadow the main crop. Debele (1996) obtained highest maize grain yield by intercropping haricot bean (*Phaseolus vulgaris*) at 75% of the recommended plant density, 37 days after sowing maize. Abdin *et al.* (1998) evaluated the effect of cover crops planted 10 and 20 days after maize germination on maize yield and observed no significant difference between the tested planting dates. A study by Coultas *et al.* (1996) in northern Belize showed that mucuna intercropped two weeks after maize planting did not affect maize yield. Fischler and Wortmann (1999) reported contradicting results in Uganda, where velvet beans and lablab intercropped three weeks after sowing maize, reduced maize grain yield by 24 and 28% respectively.

These studies show that timing of cover crop planting under intercropping system influences yields of the intercropped cereal crop, possibly due to competition between cover crops and the cereals for soil moisture. Delaying planting of cover crop may reduce competition for moisture with the main crop.

2.4 Potentials of Lablab (*Lablab purpureus* L.)

Lablab also known as dolichos, is a herbaceous legume adapted to altitudes ranging from 0 to 1900 metres above sea level (ma.s.l.). It is thought to be indigenous to India, South East Asia, or Africa. Now it has been cultivated singly and in mixtures and distributed throughout the tropics and subtropics (Shivashankar and Kulkarni, 1989).

2.4.1 Characteristics and uses of lablab

Lablab is a climbing or erect perennial herbaceous crop often grown as an annual. It grows up to 1 m tall and has a strong taproot with many lateral and adventitious roots. It has fast growth rate, producing a lot of biomass and biomass ranging between 3.4 and 7.4 Mg DM ha^{-1} has been reported in Kitale, Kenya (Palm *et al.*, 1997; Gachene *et al.*, 2000). The leaves and beans of lablab are edible and may be used as animal feed, and have medicinal effects against blood pressure and diabetes (Palm *et al.*, 1997). In the Southern highlands of Tanzania it is incorporated in the cropping system for its green pods which are eaten as vegetable. The plant has medium to deep rooting system that enables it to survive dry spells. However, the potentials of lablab are limited by high susceptibility to pest and diseases (Kalumuna, 2005).

2.4.2 Environmental requirements of lablab

Lablab can grow in a wide range of soil textures, from well drained heavy clays to sandy soils. It tolerates acidic soils better than most legumes, growing well when soil pH is 4.5 – 6.5, and it does well in low fertility soils. Like most legumes, it is intolerant of waterlogged or flooded conditions. Lablab is adapted to annual rainfall ranging from fairly dry to very wet (750–2500 mm). Once established, it is fairly drought tolerant and can be grown in rainfed conditions or with minimal irrigation. Lablab is also shade tolerant (Shivashankar and Kulkarni, 1989).

2.4.3 Weed control effect of lablab

With its viny habit, fast early growth, and ability to grow with little applied water, lablab can be effective to smother weed growth and quickly provide an effective ground cover to protect the soil from erosion (Valenzuela and Smith, 2002; Kobayashi *et al.*, 2003).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study was carried out at the MATI Igurusi farm, in Igurusi village within the Usangu plains, south west of Tanzania. The village is located in the Mkoji sub-catchment (Fig. 1) that lies between latitudes $7^0 48'$ and $9^0 25'$ South, and longitudes $33^0 40'$ and $34^0 09'$ East, at an altitude of 1100 m to 1120 m above sea level (SWMRG, 2004). It is a sub-catchment of the Great Ruaha River catchment, which is one of the four sub-catchments of the Rufiji River Basin in Tanzania (Fig. 1).

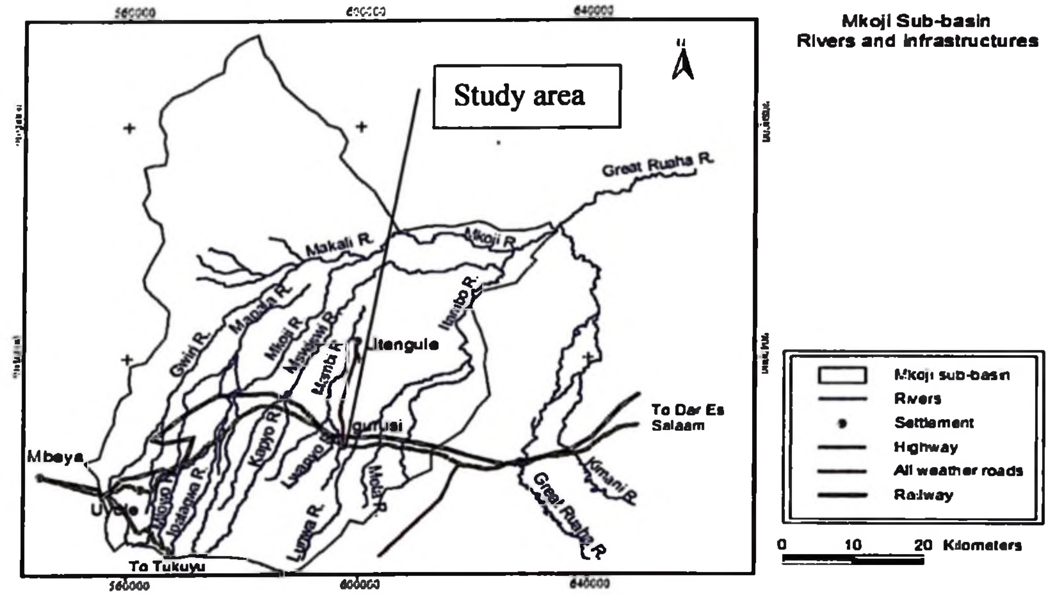

Figure :1: The map of Mkoji catchment showing the study area

Source: SWMRG (2004)

3.1.2 Climate of the area

The study area has a unimodal and erratic type of rainfall, concentrated within the period of December to May. The rain starts as early as mid-October but sometimes delays until early December and the mean annual rainfall is about 900 mm (Hazelwood and Livingstone, 1982). Mean daily maximum temperature range from 28°C to 32°C, while minimum temperature ranges from 9.5°C to 19.5°C. The average annual open pan evaporation is about 2430 mm, and the total open pan evaporation from June to October when dry season farming takes place is about 1080 mm (Igbadun, 2006). Table 1 presents the weather data for the 2007 irrigation season at the study site when the experiment was undertaken.

Table 1: Weather data for the 2007 cropping season

Month	Average maximum air temperature (°C)	Average minimum air temperature (°C)	Wind speed (km/h)	Open pan evaporation (mm/day)
June	28.9	11.7	12.25	
July	28.8	11.1	2.0	
August	32.7	9.3	3.8	
September	32.5	12.0	3.8	13.0
October	32.2	12.9	7.8	9.7
November	28.6	19.4	2.85	9.8
December	30.1	16.7	1.39	8.0

Source: MATI Igurusi and Study site (2007)

Data show that the lowest average minimum air temperature was recorded in August (Table 1). In the Igurusi ya Zamani Traditional Irrigation Scheme (IZTIS) where the experiment was carried out planting of maize crops starts in July rather than June to avoid tasselling to coincide with such period (August) which has shown to result into reduced yield of maize crops (Kimati, R.J. personal communication, 2007). Average maximum air temperature from August to December in the area was recorded to be high indicating high evapotranspiration and automatically demand for high irrigation frequency.

3.1.3 Soils at the experimental site

The soils at the experimental site vary from sandy clay to clay loam and are typical of the alluvial clay loam of the Usangu plains (SWMRG, 2004). The soils of the experimental site have water holding capacity of 118 mm m^{-1} and an average bulk density of 1.38 g cm^{-3} (Table 2).

Table 2: Soil properties of the experimental site

Soil profile depth (mm)	MC at FC (m^3/m^3)	MC at wilting point(m^3/m^3)	Soil bulk density (g/ cm^3) (dry)	Soil bulk density at FC (g/ cm^3)	Particle size distribution (%)			STC
					Clay	Silt	Sand	
0 - 150	0.262	0.127	1.44	1.86	19	18	64	SL
150-400	0.295	0.163	1.39	1.89	31	17	52	SCL
400-700	0.305	0.226	1.45	1.84	33	22	45	SCL
700-1000	0.278	0.212	1.38	1.76	36	19	45	SC

Note: STC = Soil Textural Class; SL = Sand loam; SCL = Sand clay loam; SC = Sandy clay,
FC = Field capacity; MC = Moisture content

Source: Igbadun (2006)

Such soils have high silt and sand, therefore poor water holding capacity. There will be more water infiltration below crop root zone. Agricultural productivity of this soil will be improved if less water will be less applied than when too much water is supplied. Such practice will enhance effective crop water use.

3.1.4 Irrigation water source

The source of water for the irrigation of experimental plots was the Lunwa River, which is one of the perennial rivers in the Mkoji sub-catchment of the Great Ruaha River catchment. Irrigation was by gravity, and an average discharge of 4.5 litres per second was diverted into the experimental field from a tertiary canal.

3.2 Experimental Design

Experimental design was a split-plot with two factors. The main plots factor was irrigation schedules of seven days which is conventional for IZTIS and 14 days intervals; the subplots factor was mulches treatments (Maize sole (control), Maize + crop residues, Maize + cover crop, and Maize + crop residue + cover crop). Table 3 presents details on the treatments.

Table 3: Description of the experimental treatments

Treatment	Description
T1	Maize sole and 7 days irrigation interval throughout the cropping season (Reference treatment)
T2	Maize crop residue mulch and 7 days irrigation interval throughout the cropping season
T3	Maize intercropped with Lablab live mulch and 7 days irrigation interval throughout the cropping season
T4	Maize intercropped with Lablab live mulch and maize crop residue mulch and 7 days irrigation interval throughout the cropping season
T5	Maize sole and 14 days irrigation interval throughout the cropping season except at establishment stage(1st 4 weeks after planting)
T6	Maize crop residue mulch and 14 days irrigation interval throughout the cropping season, except during establishment stage
T7	Maize intercropped with Lablab live mulch and 14 days irrigation interval throughout the cropping season except at establishment stage
T8	Maize intercropped with Lablab live mulch and maize crop residue mulch and 14 days irrigation interval throughout the cropping season, except at establishment stage

3.3 Field Layout

The experimental field was 26 m by 17 m. The plots sizes within the blocks were 3.5 m by 3.5 m and were separated by a buffer zone of about 1.0 m. Embankments of 0.3 m high were built around each plot to help retain and prevent runoff/spill over of the water applied. The treatments were randomly allocated in sub-plots as indicated in Fig. 2.

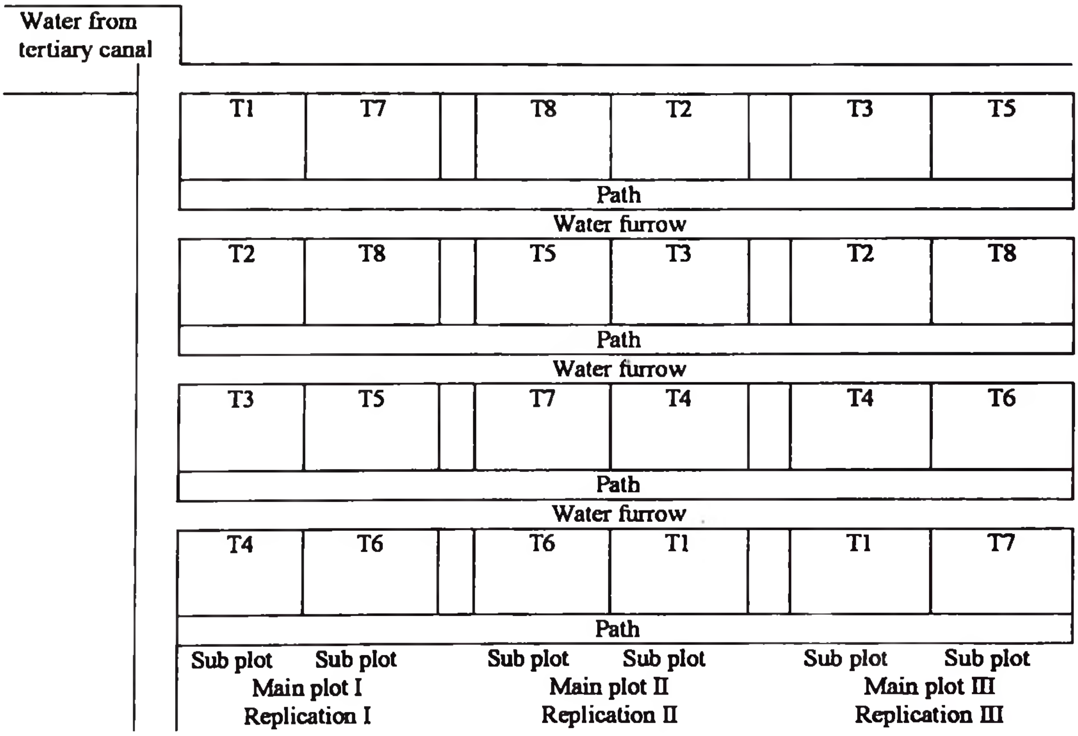

Figure 2: Field layout

3.4 Agronomic Operations

The experimental field was ploughed using a hand hoe. Planting was done on the well-levelled basins. TMV1–ST maize (*Zea mays* L.) composite variety was planted in all the experimental plots. TMV1-ST is one of the maize varieties commonly grown under irrigation in the study area. The characteristic of the maize variety which makes it preferred under irrigation is that it is stress tolerant, short growth duration (115-120 days) and tolerant to maize streak disease. The maize crop was planted in rows with spacing of 0.75 m between the rows and 0.30 m within the rows. A total of five rows were planted per plot (basin). Two seeds were placed in a hole, and three weeks after germination, the plants were thinned to one per stand as recommended by ARI - Uyole. Di-ammonium phosphate fertilizer (N: P: K 18:46:0) was applied at the rate of 60 kg P/ha at planting. Top-dressing was carried out five weeks after planting using Urea fertilizer at the rate of 98 kg N ha^{-1} to bring the total nitrogen applied from the two fertilizer applications to 120 kg N ha^{-1} (Igbadun *et al.*, 2005). The application of crop residues between the maize rows was done immediately after sowing the maize. Two cover crop rows were planted between the maize rows two weeks after planting maize in the respective plots. Weeding was carried out two times in treatments without cover crop or crop residues using hand hoe, while in those with cover, second weeding was only hand pulling of low intensity weeds. Pesticide application was done two times to control stem borers and elegant grasshoppers. The potential yield of the TMV1-ST is 4.0 tons ha^{-1} under low to medium altitude and the altitude for optimal yield is between 500-900 m above mean sea level (Lyimo and Temu, 2002). Planting was done on 1st September 2007 and harvesting was done on 31st December 2007.

3.5 Irrigation

Irrigation schedules of 7 and 14 days were employed except for the first four weeks of maize germination and establishment where all treatments were maintained at 7 days irrigation interval. This is because planting was done during the driest months of the dry season and so more regular watering was necessary to facilitate germination establishment. Surface irrigation was applied, and the calculated amount of water was discharged to the experimental field from the tertiary canal. The rectangular flume located about 0.5m from the entrance to each basin was used to determine the required amount of water to be applied to the basin. The discharge was regulated along the field canal, and high discharges (4.5 litres per second) were preferred than low discharge (<3.0 litres per second) to quickly distribute the water inside the plot especially when applying irrigation water depths. The depth of water applied at each irrigation included: 30 mm depth of water from the pre-planting irrigation to the end of vegetative growth stage (firth week after planting); 40 mm depth of water during the second vegetative growth stage (sixth-ninth) week after planting; and 50 mm depth of water during the flowering and fruiting growth stages (Appendix 1). These depths of water applied were based on weekly sums of the daily reference evapotranspiration for the study area. The following calibration equation was used for the flume as calibrated at the Department of Water Resources, University of Dar es salaam (Igbadun, H.E. personal communication, 2007):

$$Q = 1.4509bd^{1.3694} \quad \text{...} \quad (1)$$

Where: Q = discharge (l/s)

b = flume top width (mm)

d = flow depth (m)

In order to determine the depth of water applied to each plot, a pre-prepared chart for different Flume flow depths and time with respect to different water application depths of 30, 40 and 50 mm was used as presented in Appendix 2.

3.6 Instrumentation and Measurements for Data Collection

3.6.1 Measurement of soil moisture content

The soil moisture measurements were taken up to a depth of 600 mm. This was in accordance with findings by (Dardenelli *et al.*, 1997; Otegui *et al.*, 1995; Tijan *et al.*, 2008) that rooting activity for maize under irrigation is usually concentrated in the top 600 mm depth of the soil profile. Soil moisture trend in each plot was measured using a Neutron probe as shown in Plate 1. The Neutron probe (DIDCOT 2240 NK) which was used was calibrated for the experimental site (Mkoga, Z.J. personal communication, 2007). The Neutron probe was calibrated for the 0-150 mm depth and for the 150-1000 mm depths as to the manufacturer recommendations. The resulting calibration equations shown in Table 4 were used in converting probe readings into volumetric moisture content (Q).

Table 4: Neutron probe equations for the experimental site

Soil depth	Calibration equations	Criteria of fitness (R^2)
0-15 cm	$Q = 0.621X - 0.0103$	0.9717
15-100	$Q = 0.534X + 0.0537$	0.9249

……….. (2)

Source: Mkoga, Z.J. personal communication (2007).

Where Q = volumetric moisture content m^3/m^3,

X = count ratio = $(\varphi_{probe}/\varphi_{water})$ while φ_{water} ranges between 850 and 900 units,

The φ_{water} in this respect was practically estimated as a mean of 100 readings of the instrument in water which was 882.6 units.

Plate 1: Neutron probe for measuring soil moisture in treatments

Measurements were taken at 150, 300, 450 and 600 mm soil depths. A minimum of two readings were taken at each measuring depth as moisture counts which were then used to calculate an average counts.

3.6.2 Calculation of crop actual evapotranspiration

The crop actual evapotranspiration also referred to as crop water consumptive use was calculated from measured soil moisture content using the soil moisture depletion method as outlined by Michael (1999). The average daily crop water consumptive use (AWU) was expressed as:

$$AWU = \frac{\sum_{i=1}^{n}\left(VMC_{1i} - VMC_{2i}\right) * D_i}{t} \qquad \text{.............................. (3)}$$

Where: AWU = Crop water use (crop actual evapotranspiration) from the root zone for successive sampling periods or within one irrigation cycle (mm/day).

VMC_{1i} = Volumetric moisture content (m^3/m^3) at the time of the first sampling in the i^{th} layer;

VMC_{2i} = Volumetric moisture content (m^3/m^3) at the time of second sampling in the i^{th} layer;

D_i = depth of i^{th} layer (mm);

n = number of soil layers sampled in the root zone depth D

t = number of days between successive soil moisture content sampling periods.

The crop water consumptive use for a week was therefore the sum of the daily crop water consumptive use from successive soil moisture content sampling and the number of days in the week. The total crop water consumptive use for a growth stage and for the entire crop-growing season (seasonal evapotranspiration) was therefore the summation of the weekly crop water use for the growth stage and the entire crop growing season, respectively.

Therefore seasonal crop water use SWU (mm) was obtained as:

$$SWU = \sum_{i=1}^{n} WU \qquad \text{.......... (4)}$$

Where: SWU = Seasonal crop water use

n = number of days from establishment to crop maturity

i = from first day of crop water use

WU = Daily crop water use

3.6.3 Percentage cover of crop residues and cover crops

The maize crop residues were applied at the mulching rate of about 50% ground coverage after germination of maize. The total percent cover assessment for mulched treatments was done at tasselling stage of maize when lablab cover crop had already established. Quadrant-charting method (Chikoye, 1999) was used to quantify the extent of mulching offered by the cover crop and maize crop residues in the responsible basins after the cover crops had intensively covered the ground, four weeks after planting of cover crops. The 0.09 m^2 frame subdivided into 9 subdivisions measuring 10 cm * 10 cm was used. The frame was mounted over the soil cover in the basins to be assessed. Measurements were done between the maize rows and size of the frame was reduced from the 1m^2 frame in order to avoid interference of maize plants.

3.6.4 Maize grain and biomass yield determination

Three middle rows in each plot constituting an area of 2.25 m by 3.5 m was harvested by cutting the aboveground dry matter in each plot and weighed. The three middle rows were harvested in order to minimize border effect on the yield results (Igbadun *et al.*, 2005). Above ground maize biomass was determined in the laboratory where they were oven dried for 72 h at 65 °C (Adiku *et al.*, 2001) to constant weight and weighed. Threshing of maize and weighing was done to obtain the grain weight at 13% moisture content which is standard moisture for maize grain.

3.7 Derivation of Performance Indicators

3.7.1 Water productivity

The productivity of water with reference to evapotranspiration (PW_{ETa}) was computed using the following equation (Molden *et al.*, 2003; Igbadun *et al.*, 2005):

$$PW_{ETa} = \frac{crop\ yield}{SWU} \text{ (kg m}^{-3}\text{)} \quad \text{.......................................} \quad (5)$$

The productivity of water with reference to irrigation water applied (PW_{irr}) was computed using the following equation (Molden *et al.*, 2003; Igbadun *et al.*, 2005):

$$PW_{irr} = \frac{crop\ yield}{Volume\ of\ irrigation\ water\ applied} \text{ (kg m}^{-3}\text{)} \quad \text{.......................} \quad (6)$$

3.7.2 Irrigation water savings

The irrigation water savings with reference to the seven days irrigation interval was calculated using the following equation (Igbadun *et al.* 2005):

$$W_s = 100\left(\frac{W_m - W_d}{W_m}\right) \quad \text{...} \quad (10)$$

Where: W_s = irrigation water saved (%)

W_m = water applied in seven days irrigation interval treatment (mm)

W_d = water applied in 14 days irrigation interval treatments (mm)

3.7.3 Economic returns associated with scheduling protocols

Farmers in the study area have not started paying for water; they only pay a token of Tsh.1000-2000 to their association based on farm size once in a season either as membership due, or for coming to the scheme to farm. An attempt was made to put a price per cubic metre of water used in order to calculate the economic benefit of water saved. A price of Tsh. 50 per 10m^3 for small farm size (about 1 ha) and Tsh.100 per 10m^3 for large farm size (above 1 ha), while the value for domestic water in the area was estimated as 1000 Tsh/m^3 (SWMRG, 2004).

The cost of labour to irrigate one hectare was estimated at 6000 Tshs per irrigation based on a man-day labour cost of 1500 Tshs. Four people were projected to effectively irrigate one hectare within 6 hours of water supply. The economic return from the scheduling protocols was calculated as the difference between the sum of the cost of labour for irrigation and the cost of water that was saved for 14 days irrigation interval, and the revenue loss due to yield decrease resulting from the scheduling protocol. A farm gate price of 2000 Tanzanian Shilling (Tsh)/20kg of maize was used in the calculation of revenue lost due to yield decrease. This was expressed as:

$$ER = (g * LB + c * WS) - p * YL$$

Where:
ER = Economic returns
LB = Labour saved from skipped irrigation events
WS = Volume of water saved per ha
YL = Yield loss per ha
c = unit price per m^3 of water
p = unit price per kg of grain yield
g = unit cost of labour per irrigation ha^{-1} (Igbadun *et al.* 2005).

Economic return calculation did not consider input and other management costs like planting, weeding, pesticide, harvesting processing and packaging costs which were constant to all treatments

3.8 Data Analysis

Maize grain yield, biomass and percent cover data were subjected to analysis of variance (ANOVA) using MSTAT-C computer program. Analysis of variance was run in which treatment means separation was done by using New Duncans Multiple Range Test (NDMRT) (Snedecor and Cochran, 1980). The test of significance was based on a p-value of 0.05. Volumetric moisture content data and daily and weekly crop moisture use were computed and graphs plotted using Excel software.

The linear model for split-plot design (Douglass, 2004) was used.

$$Yijk = \mu + \rho_k + \alpha_i + \delta_{ik} + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

Where;

Y_{ijk} = is the observed value for the k^th replicate of the i^th level of factor A (irrigation interval) and the j^th level of factor B (mulches) (where i = 1 to a, j = 1 to b and k = 1 to r).

μ = is the general mean.

ρ_k = is the block effect for the k^th block.

α_i = is the effect of the i^th level of factor A.

δ_{ik} = is the whole plot random error effect, for the i^th, k^th combination of block and factor A.

β_j = is the effect for the j^th level of factor B.

$\alpha\beta_{ij}$ = is the interaction effect of the i^th of factor A with the j^th level of factor B.

ε_{ijk} = is the subplot random error effect associated with the Y_{ijk} subplot unit.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

Results on moisture regimes for different treatments resulting from mulching and irrigation interval, maize grain and biomass yields, water productivity due to irrigation water and crop water use are presented and discussed below. Economic benefits accrued due to irrigation protocol are also discussed.

4.1 Moisture Regime in Different Treatments

Figures 3, 4 and 5 presents soil volumetric moisture content (VMC) regimes for the different treatments in replication one, two and three respectively. Figure 6 presents average soil VMC variability for the three replications in different mulch treatments during tasselling of maize crop and when lablab cover crop was well established. The results (Figure 3-6) indicate that treatments which were irrigated once every week had high soil VMC compared to those treatments which were irrigated once in every two weeks from 0 - 45 cm of soil depth. This variation in soil VMC between these two categories of treatments seems to be influenced by irrigation intervals rather than mulch treatments. For treatments (T1 – T4) which were under 7 days irrigation interval, the influence of mulch on soil VMC did not show clear difference among treatments which had different types of mulches (Figure 3-5). These treatments did not show any consistence in soil VMC variability.

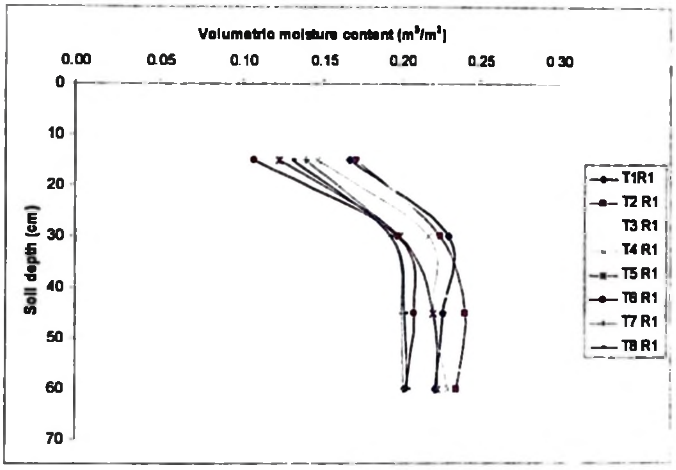

Figure 3: VMC for treatments in replication one

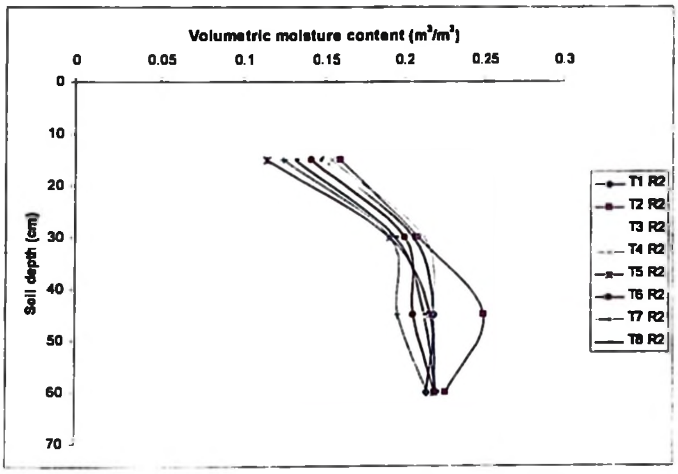

Figure 4: VMC for treatments in replication two

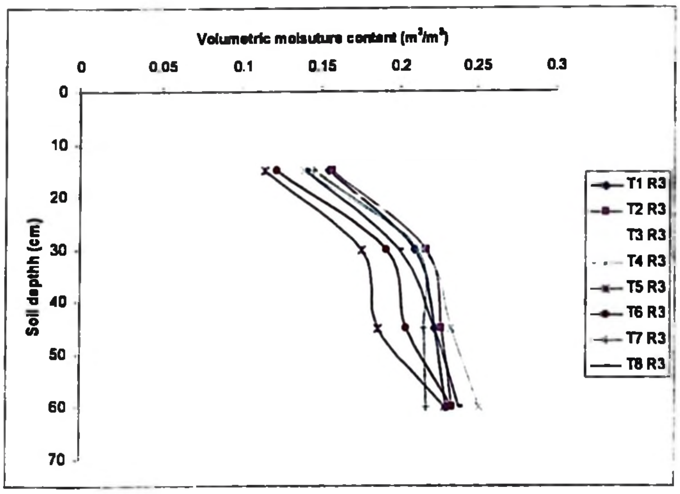

Figure 5: VMC for treatments in replication three

Figure 5 show clearly the difference in soil VMC for the respective treatments. Treatment T2 which was mulched with maize crop residue showed the highest soil VMC followed by T3 treatment (lablab live mulch). Treatment T1 ranked the third above treatment T4 (maize crop residue mixed with lablab live mulch) which performed the least. Considering Table 8, T4 treatment had high percent cover which was caused by well sprouted cover crop. This might have influenced high crop water use shown in Table 5. Among the treatments which were under 14 days irrigation interval (T5 – T8), treatments (T6 – T8) which had mulch showed high soil VMC (Figure 3-5) from 0-45 cm of soil depth compared to T5 treatment which had no mulch. This is an indication that mulching had influence on soil VMC of those treatments. Such high soil moisture was also observed by Ayotamuno *et al.* (2007) in experimental treatments which had mulch applied. Treatment T6 which was mulched with maize crop residue showed the highest soil VMC followed by treatment T8 (mixture of maize crop residue and lablab live mulch), then treatment T7 (lablab live mulch) and treatment T5 (un-mulched) being the least.

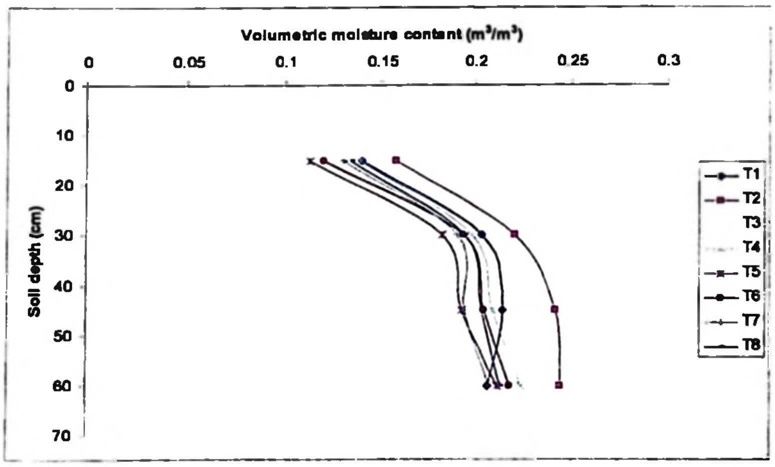

Figure 6: Average VMC for treatments during tasselling of maize

High soil VMC in upper soil layers (0-45 cm) in those treatments might have been caused by reduced soil evaporation caused by mulch application in the respective treatments. Zhang *et al.* (2005) in his experiments also reported that average soil evaporation during the season was 0.52 and 1.17 mm d^{-1} for the mulched and un-mulched treatments, respectively. The trend of soil VMC from 45 – 60 cm soil layer did not show consistence for all treatments which were under 7 and 14 days irrigation intervals (Figures 3, 4, 5 and 6). This is an indication that mulching does have more influence for the upper of 0 – 45 cm soil layer.

4.2 Interactive Effects of Irrigation and Mulch on CWU, WP and Grain yield

Table 5 present results on Interaction of irrigation and mulch for CWU, WP and grain yield for different treatments.

Table 5: Water productivity with respect to irrigation water and crop water use

Treatment	Irrigation water (mm)	CWU (mm)	Mean grain yield(kg/ha)	WP $^{(ETa)}$ kg/m^3	WP $^{(irr)}$ kg/m^3
T1	610	246.1 e	3 797 a	1.54 a	0.62 c
T2	610	253.8 d	3 872 a	1.53 a	0.63 c
T3	610	253.2 d	3 824 a	1.51 a	0.63 c
T4	610	290.5 a	3 733 a	1.29 cd	0.61 c
T5	390	263.8 c	3 612 a	1.37 b	0.93 a
T6	390	292.0 a	3 663 a	1.26 d	0.94 a
T7	390	199.0 f	3 113 a	1.56 a	0.80 b
T8	390	273.3 b	3 663 a	1.34 bc	0.94 a
EMS		5.815	248 745.0	0.001	0.001
CV		0.93%	13.63%	2.02%	1.28%

CWU = Crop water use; WP = Water productivity, EMS = Error mean square, CV= Coefficent of variation

The water productivity with respect to irrigation water applied (WP $_{(irr)}$) for maize varied from 0.61 – 0.63 kg/m^3 for T1 to T4 treatments which were irrigated once every week. All the four treatments (Table 5) had WP values below the range reported by Doorenbos and Kassam, (1986) and they indicated no significant difference among them ($P<0.05$). According to Doorenbos and Kassam (1986), water productivity for harvested maize can vary from 0.8 – 1.6 kg/m^3. Treatments T2 and T3 which were mulched with maize crop residue and lablab live mulch respectively, showed the highest WP for the respective treatments. Treatment T1 ranked third, T4 treatment ranking the fourth and lowest. The reason for this is high crop water use shown for T4 treatment (Table 5).

Treatments (T5 to T8) with an irrigation interval of 14 days had water productivity varying from 0.8 – 0.94 kg/m^3 (Table 5). The results indicate that water productivity was high for the respective treatments and they agree with the findings by Doorenbos and Kassam (1986). This increase in WP for treatments (T5 to T8) compared to (T1 to T4) treatments agree with the statement by Fan *et al.* (2005) that WP increases under deficit irrigation, relative to its value under full irrigation as shown experimentally for many crops. It is clear from Table 5 that there was significant difference in $WP_{(irr)}$ between treatments irrigated once every week and those irrigated once in every two week. There was no significant difference among treatments under 14 days irrigation interval, except for T7 treatment which showed significant difference. The reason for this is low grain yield which might be caused by caused by competition between main crop and cover crop due to low water supply. The water productivity with respect to crop water use ($WP_{(ETa)}$) in this study varied from 1.26 - 1.56 kg/m^3. This range is within the range by Zwart and Bastianssen (2004) who reported that water productivity for maize was between 1.1 – 2.7 kg/m^3. Most treatments which were irrigated every week showed high and significant difference in terms of WP $_{(ET_a)}$ compared to treatments which were irrigated once in every two weeks.

Interaction between irrigation and mulch on CWU indicated that there was significant difference between the treatments. Results (Table 5) indicate that treatments T4 (7-day irrigation interval) and T6 (14-day irrigation interval) which had crop residues mixed with lablab and crop residue respectively showed high CWU followed by T8 treatment which had a mixture of crop residues and lablab. Treatment T7 showed the lowest CWU among all the treatments.

4.3 The Influence of Mulch on Maize Grain and Biomass Yields

Table 6 shows the influence of mulch on grain and biomass yields.

Table 6: Effect of mulch on maize grain and biomass yields

Treatment	Biomass (kg/ha)	Grain yield (kg/ha)	Harvest index (Grain yield/Biomass)
T1	8 124 d	3 797 ab	0.46
T2	11 970 a	3 872 a	0.32
T3	11 760 ab	3 824 a	0.33
T4	12 480 a	3 733 ab	0.30
T5	9 290 bcd	3 612 ab	0.39
T6	9 938 abcd	3 663 ab	0.37
T7	8 806 cd	3 113 b	0.35
T8	10 770 abc	3 663 ab	0.34
EMS	30 321.5	248 745.0	
CV	18.05%	13.63%	

EMS = Error mean square, CV= Coefficent of variation

+ Figures in the same column with different alphabet indicate significant difference while those sharing same alphabet being not at ($P<0.05$).

The results indicate that only treatments two and three which were mulched with maize crop residue and lablab live mulches respectively and irrigated at 7 days interval showed significant difference in yield ($P < 0.05$) from T7 treatment which was irrigated every other week from vegetative to maturity stage and had lablab live mulch. Treatment T7 recorded the lowest yield as compared to other treatments. Such intercropping of maize and lablab required economic analysis to investigate if the maize yield loss due to intercropping and benefits accrued due to dry season green vegetable accessibility (lablab green pods) under such irrigation schedule was profitable. The results portray the fact that extended irrigation interval from vegetative to maturity stage of the crop do not result into significant yield loss as compared to 7 days irrigation interval.

4.4 Effects of Irrigation Scheduling on Biomass and Maize Grain Yields

The effects of irrigation scheduling on maize grain yields for different treatments are presented in Table 7.

Table 7: Biomass and grain yields of maize under irrigation scheduling

Treatment	Biomass (kg/ha)	Mean grain yield(kg/ha)	Yield gain or loss(kg/ha)	Percent yield gain or loss
T1(control)	8 124 e	3 797 a		
T2	11 970 ab	3 872 a	+75	2 gain
T3	11 760 ab	3 824 a	+27	0.7 gain
T4	12 480 a	3 733 a	-64	1.7 loss
T5	9 290 cde	3 612 a	-85	3.5 loss
T6	9 938 cd	3 663 a	-34	3.5 loss
T7	8 806 de	3 113 b	-684	4.9 loss
T8	10 770 bc	3 663 a	-134	18 loss

+ Figures in the same column with different alphabet are statistically different ($P<0.05$)

The results showed that under grain yield data, only T7 treatment showed significant difference ($P<0.05$) from the other treatments. Treatment T7 was mulched with live lablab, indicating that there might have been competition for moisture between main crop and lablab mulch. This implies that live mulch when there is moisture stress tends to compete for moisture with the main crop (Peet, 1995; Curran *et al.*, 1996) and had the greatest yield loss of 18%. Treatments (Tl to T4) which were irrigated once every week throughout the crop growing season yielded around 3.8 t/ha which was also reported by Igbadun (2006). Treatments (T5 to T8) which had skipping of irrigation every other week except at establishment stage had yields between 3.1 – 3.7 t/ha. The results portray the fact that extended irrigation interval from vegetative to maturity stage of the crop do not result into significant yield loss as compared to 7 days irrigation interval. The yields from all the treatments were higher than the average grain yield of irrigated maize from farmers' fields in the study area, which is 1.78 t/ha as reported in (SWMRG, 2004). This difference in yield could be due to the fact that many farmers are not able to afford fertilizer prices as a result they end up using low doses or not applying fertilizers at all (Kimati, R.J. personal communication, 2007).

The trend of the biomass and grain yield indicate that maize dry matter and grain yield increased with irrigation as reported by Yazar *et al.* (1999) and Pandey *et al.* (2000), although there was no significant difference in grain yield except for T7 treatment.

4.5 Cover Crop Establishment and Percent Cover for Different Treatments

Table 8 presents results on percent cover for different treatments.

Table 8: Maize crop residues and cover crop Lablab mulches percent cover

Treatment label	Percent cover	Ranked order
1	0.0 e	4 = 73.0 a
2	45.0 d	8 = 67.0 b
3	54.0 c	3 = 54.0 c
4	73.0 a	7 = 48.0 d
5	0.0 e	6 = 46.0 d
6	46 d	2 = 45.0 d
7	48.0 d	1 = 0.0 e
8	67.0 a	5 = 0.0 e
Ems	14.319	
CV	9.09%	

+ Figures in the same column with different alphabet are statistically different ($P < 0.05$)

Treatments four and eight which had a mixture of maize crop residues and lablab cover had the highest percent of cover (Plate 2), followed by treatments three and seven with sole cover crop as live mulch. Lablab covers which were irrigated once every week (T3 and T4) treatments appeared to establish faster than those which were under 14 days irrigation interval (T7 and T8) treatments. This slow rate of establishment of cover crops under extended irrigation interval (moisture stress environment) reveal the essence that cover crops grown for soil cover in order to conserve moisture during early stages of main crop development can not serve the purpose. The purpose of using cover crops is to maximize ground cover before main crop canopy closes the rows to decrease the ratio of soil water evaporation to crop transpiration (Daniel *et al.*, 1999).

Plate 2: Lablab under sown between maize rows

4.6 The Economic Returns with respect to Scheduled Protocol of Irrigation

Table 9 shows the economic returns from the irrigation scheduling protocol.

Table 9: Revenue gained from irrigation scheduling protocol

Irrigation	Cost of labour gained @ at 6000 Tsh/irrigation	Cost of water saved @ at the rate of 50 Tsh/10m^3	Total revenue saved (col. 2+3)	Cost of grain yield loss @ at the rate 2000 Tsh/20kg	Revenue loss or gained (col. 4-5)	Remark
1	-	-	-	-	-	-
2	30 000.00	11 000.00	41 000.00	29 400.00	11 600.00	Gain

Irrigation 1 = 7 days irrigation interval; Irrigation 2 = 14 days irrigation interval; @ = each; - = no cost or revenue

In this economic return analysis costs of inputs like fertilizer are not considered because they were constant for all treatments. The net revenue saved from 14 days interval for water and labour was 11 600.00 Tsh ha^{-1}. The saved labour can be used in other production activities while water saved can be allocated to other uses besides agricultural production. The amount of water saved from such irrigation schedule is 30.1%. Igbadun *et al.* (2006) found that water saving of 53% can be obtained under 14 days irrigation interval but with maize grain yield reduction of up to 48%. Such difference is due to the factor that he maintained the 14 days interval, while for my case, the 7 days interval was constant for all treatments during establishment stage.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions can be drawn from the study:

(i) Irrigation interval of 14 days in this study has indicated to save water (30%) while causing insignificant maize grain yield loss in the respective treatments as compared to other treatments which were under 7 days irrigation interval. Only T7 treatment which was mulched with lablab and under 14-day irrigation interval showed yield loss of 18%. This might be caused by competition for moisture between main crop and cover crop. Cover crops seem to be not good mulching materials in moisture stressed environments.

(ii) Water productivity in terms of irrigation water applied and crop water use was high in treatments which were irrigated once in every two weeks. For example WP in terms of irrigated water ranged between 0.61 to 0.63 for 7-day interval and 0.80 to 0.94 for 14-day interval. This might be caused by soils which had high silt and sand which cause high infiltration of water below the root zone. Such soils show high water productivity when water is applied in small amounts.

(iii) Mulched treatments also showed to conserve more moisture than un mulched treatments, especially at the upper soil layer.

5.2 Recommendations

The following recommendations can be drawn from the study:

(i) The influence of mulching in irrigated maize for this study based on the results obtained need more research. Different amounts of mulch application and material types that can be easily accessible need to be tested in irrigated maize in order to come up with more firm conclusions on maize irrigation schemes in Usangu plains.

(ii) The use of maize crop residues which are readily available at the field can be good cover during crop establishment leading to improved moisture conservation. The challenge is on the farmers' change of attitude from burning of crop residues to their use in moisture conservation.

(iii) More studies on the use of live mulch and proper choice of legume types which can increase household income at the same time maximizing available moisture need to be undertaken.

(iv) Research on different irrigation schedules which can be applied in irrigated maize fields with minimal effects on yields are suggested for the sake of minimizing water loss due to evaporation and deep percolation in agriculture. Research on the integration of different irrigation schedules and different mulching materials in irrigated maize can result in optimum maize yields at the same time saving water used in maize irrigation schemes.

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APPENDICES

Appendix 1: Depth of water applied during irrigation (mm)

Treatment	Growth stages															Total No of irrigation events	Total water applied
	Pre-palnting	Establishment				Vegetative				Flowering and grain filling							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
T1	30	30	30	30	30	40	40	40	40	50	50	50	50	50	50	15	610
T2	30	30	30	30	30	40	40	40	40	50	50	50	50	50	50	15	610
T3	30	30	30	30	30	40	40	40	40	50	50	50	50	50	50	15	610
T4	30	30	30	30	30	40	40	40	40	50	50	50	50	50	50	15	610
T5	30	30	30	30	30	40	X	40	X	50	X	50	X	50	X	10	390
T6	30	30	30	30	30	40	X	40	X	50	X	50	X	50	X	10	390
T7	30	30	30	30	30	40	X	40	X	50	X	50	X	50	X	10	390
T8	30	30	30	30	30	40	X	40	X	50	X	50	X	50	X	10	390

Appendix 2: Water irrigation depth determined by Flume flow depth and time

Basin legth(m)	Basin width(m)	Area(m^2)
3.5	3.5	12.25

		Application depth		
		30mm	40 mm	50 mm
Flume depth (cm)	Q(l/s)	Time in min	Time in min	Time in min
1	0.4	20.6	25.7	25.7
1.5	0.7	11.8	14.8	14.8
2	1.0	8.0	9.9	9.9
2.5	1.4	5.9	7.3	7.3
3	1.8	4.6	5.7	5.7
3.5	2.2	3.7	4.6	4.6
4	2.7	3.1	3.9	3.9
4.5	3.1	2.6	3.3	3.3
5	3.6	2.3	2.8	2.8
5.5	4.1	2.0	2.5	2.5
6	4.6	1.8	2.2	2.2
6.5	5.2	1.6	2.0	2.0
7	5.7	1.4	1.8	1.8
7.5	6.3	1.3	1.6	1.6
8	6.8	1.2	1.5	1.5
8.5	7.4	1.1	1.4	1.4
9	8.0	1.0	1.3	1.3
9.5	8.7	0.9	1.2	1.2
10	9.3	0.9	1.1	1.1
10.5	9.9	0.8	1.0	1.0
11	10.6	0.8	1.0	1.0
11.5	11.3	0.7	0.9	0.9
12	11.9	0.7	0.9	0.9
12.5	12.6	0.6	0.8	0.8
13	13.3	0.6	0.8	0.8
13.5	14.0	0.6	0.7	0.7
14	14.7	0.6	0.7	0.7
14.5	15.5	0.5	0.7	0.7
15	16.2	0.5	0.6	0.6