GROWTH AND YIELD OF SELECTED VEGETABLES UNDER ALTERNATE FURROW IRRIGATION IN THE "ASAL"AREAS OF EASTERN KENYA

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DEDICATION

To my beloved children – Victoria, Brenda and Thomas- who endured difficulties during my absence from the family while at studies and gave me moral support, I whole heartedly dedicate this work.

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DECLARATION

I hereby declare that this thesis is my original work and has not been presented to any other university or institution for the award of degree.

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List of Abbreviations

ASAL	Arid and Semi- Arid Lands
AFI	Alternate Furrow irrigation
CFI	Conventional Furrow Irrigation
CAN	Calcium Ammonium Nitrate
DAP	Diammonium Phosphate
DAS	Days After Sowing
DAT	Days After Transplanting
DAST	Days After Start of Treatment
FC	Field Capacity
KEFRI	Kenya Forestry Research Institute
LAR	Leaf Area Ratio
LDA	Leaf Dry Weight
MoA	Ministry of Agriculture
PRD	Partial Root Drying
PWC	Plant Water Content
PWP	Permanent Wilting Point
RAW	Readily Available Water
RWC	Relative Water Content
SAS	System Analysis Software (9.1)
SMC	Soil Moisture Content
SLA	Specific Leaf Area
WUE	Water Use Efficiency

Abstract

Water shortage is almost always the factor limiting agriculture production in Arid and Semi-Arid lands (ASALs) world over. Water scarcity in today’s world aggravated by climate change has resulted to increased competition for the resource. This has necessitated re-evaluation of irrigation water use management globally aimed at water conservation without overall reduced crop productivity. Kibwezi is a semi-arid area and successful farming there requires use of water saving irrigation technologies. To enhance the uptake of such technologies by the farmers, it is usually necessary to demonstrate and evaluate their effect on water use and crop performance.

The objective of this study in this regard was to determine the effect of alternate furrow irrigation (AFI) water saving technology on productivity of selected horticulture crops. The effect of alternate furrow irrigation and conventional furrow irrigation (CFI) on growth and yields of selected vegetables in the ASAL areas of Kenya was evaluated. Tomatoes, Collards and Cabbages were grown at a selected site in Kibwezi for two periods in year 2010 and 2011.Growth, biomass accumulation and yields were monitored and quantified. Applied irrigation water was also monitored during the two seasons. In AFI half of the root system was irrigated alternately resulting to Partial Root Drying (PRD). CFI was the conventional way of furrow irrigation and refers to the system where every furrow was irrigated during each watering. Each treatment was replicated three times in RCBD design. The use of AFI resulted to less use of irrigation water with savings of upto 45%. Most parameters of growth were not significantly affected by AFI except Leaf Area (LA) and Dry Matter (DM). Crops irrigated under AFI had 20% and 40% reduction of LA and DM respectively compared to crops irrigated under CFI. There was no significant reduction in overall yields. In conclusion, AFI is a reliable way to save and hence reduce irrigation water use and this study recommends its use in arid and semi-arid areas of Kenya.

CHAPTER ONE

1.0: INTRODUCTION

1.1: Background information

The ASAL areas of lower Eastern part of Kenya have low precipitation and are characterized by scarcity of water for crop production leading to frequent crop failure (Odame, Kibaara, Nderitu, Karin & Brook, 2010). The areas include Machakos, Makueni and Kitui counties. In some of these areas water is abstracted from existing rivers for irrigation e.g upper Yatta in Machakos, Kiboko and Kibwezi in lower Makueni. Other parts rely on water harvesting with farmers engaging in high value horticultural crop production at Athi River, Kathekani, Mitaboni (all in lower Machakos)and central areas of Kitui. The crops are mainly vegetables such as tomatoes, Cabbages and Collards. The experimental site for this research was Kibwezi sub-county which receives an average annual rainfall of 750mm per annum (MoA, 2010).

All these ASAL areas experience unreliable rains that are expected in two seasons. The rainfall usually received within spans of one or two months if they occur- April and December. Presently and in the future, the success of agriculture in these areas will depend on the extent of adoption, efficient and effective use of irrigation and specifically the water saving irrigation technologies to enable intensive production in these areas. These techniques are a tradeoff between minimum yield and maximum water savings (Odame *et al*, 2010).

Although these irrigation technologies can enable producers from arid regions to take the advantage of marketing their produce very early in the season thereby increasing their incomes, farmers in the ASAL areas of eastern Kenya have not fully exploited them. The main irrigation technologies include furrow, basin, sprinkler and drip irrigation. Their modified easily practicable forms have been developed. It is important today more than ever before that the modified and farm customerized forms be adopted especially at farm level to increase horticultural food production.

Water scarcity in dry regions is not the only factor limiting agriculture, but also the biological processes occurring inside the crops that determine the status and efficiency with which water is used. Knowledge of these biological processes is crucial for the successful vegetable farming in ASALs because they influence water status and use in plants (Davies, Kudoyarova & Harung, 2005) and hence plant development. The determination of the status and use of available water by plants relies on the knowledge of the input and output of the plant systems as a whole. Quantification of the different parameters of plant development to establish these inputs and outputs requires a multidisciplinary approach, involving plant physiology, soil physics, agrometeorology, and hydrology because the variations are influenced by both environmental and plant aspects. The environmental aspects at play include light, evaporation from the soil and runoff. The plant aspects include dry matter accumulation, evapotranspiration and others (Katerji, Mastrorilli & Rana, 2007). This study focused on soil moisture content, plant growth (dry matter accumulation) and yield as effected by partial root drying, the basis of Alternate Furrow Irrigation (AFI). Earlier experiments by Stikic, Katerji, Kang, Taisheng Du, and Webber established that the variability in water use by plant crops emanate from agro-techniques such as water and fertilizer applied to crops and analyzed in terms of quantity and quality, differences between species, variety effects, phenological stage sensitivity to water constraints and environmental factors (Stikic *et al*, 2003, Katerji *et al*, 2007; Kang *et al*, 2000; Taisheng *et al*, 2007: Webber *et al*, 2009). These environmental factors influence evaporative demand and are a function of atmospheric conditions and climatic changes. In reality, the different factors act together and independently (Katerji *et al*, 2007).

The ASAL areas of Kenya are characterized by low annual rainfall usually below 1000 mm (MoLD&F, 2012). They also have high day temperatures. These are among the many factors which lead to low productivity especially of horticultural produce in these areas and efficient irrigation is therefore needed (Kang, Shi, Pan & Liang, 2000). Kibwezi being in the southern part of the Eastern Kenya region is a lowland area at 750m above sea level (ASL) which receives an average annual rainfall of 800mm and with temperature ranging between 27 – 29°C. The average production of tomatoes, Collards and Cabbages at Kibwezi is 12.5, 25.0 and 14.5 t/ha respectively (MoA, 2010).

It is important to increase farmer adoption rates of water saving technologies in Kenya so as to improve the economics of ASAL agricultural production. This study on the growth and productivity of various vegetables under Alternate Furrow Irrigation (AFI) water saving technology was done at Kwa kyai area in Kibwezi sub-county. During this research, the effect of Partial Root Drying (PRD) technology applied as alternate furrow irrigation on water use and crop performance was studied.

1.2: Statement of the problem

ASAL areas have low and erratic rainfall. This results to unreliable soil moisture regimes in the soil. Crops require sustained minimum soil moisture for establishment, growth and production. Thus the low erratic rainfall in ASAL is a major hindrance to crop production. High temperature in ASAL areas is also a problem because it results to high evapotranspiration from soil and plants. Hence there is need to ensure maximum utilization of the available water for especially irrigation use over longer period using water saving methods to enable sustained soil moisture and reduction of evapotranspiration.

Despite the fact that several water saving technologies have been identified to assist farmers realize higher yields, many farmers have not adopted such practice. This research was to study the growth and productivity of various vegetables under AFI water saving technology in the ASAL areas of Eastern Kenya with reference to Kibwezi. This would lead to savings of enormous amounts of irrigation water hence the possibility of increasing acreage of irrigated area.

1.3: Objectives

General objectives

To evaluate the effect of Alternate Furrow Irrigation water saving technology on growth and yields of selected vegetables in the Arid and Semi-Arid Lands of Kenya.

Specific objective

1. To determine the effect of Alternate Furrow Irrigation (AFI) on growth, yields and water status of tomatoes, collards and cabbages in the Arid and Semi-Arid Lands of Kenya.
2. To determine the irrigation water use of tomatoes, collards and cabbages under Alternate Furrow Irrigation in the Arid and Semi-Arid Lands (ASALs) of Kenya.

1.4: Research questions

1. What are the effects of Alternate Furrow Irrigation (AFI) on the growth, yields and water status of tomatoes, collards and cabbages in the ASAL areas of Kenya?

2. What is the effect of AFI on soil moisture content and irrigation water use of tomatoes, collards and cabbages compared to CFI in the ASAL areas of Eastern Kenya?

1.5: Justification

Water saving technologies are key to increased production of crops in ASALs. Inadequate rainfall and inefficient farming techniques are some of the major problems that hinder sustainable vegetable production in ASAL areas. There is need for improving agricultural practices in dry lands through perfecting technologies to cultivate horticulture crops in these areas that would otherwise yield only meager and sporadic harvests. Because of low precipitation, special farming techniques like supplementary irrigation need be refined to enable intensive production systems. This includes improvement of the basic irrigation methods to modified forms eg Alternate Furrow Irrigation AFI. In this case producers from ASAL regions are able take the advantage of marketing their produce during times of scarcity (high demand) or very early in the season at better prices, thereby increasing their incomes. There is therefore need to demonstrate such technologies at the farmer’s fields in order to increase the adoption rates and hence increase crop production in dry areas especially in the ASAL areas of Kenya.

CHAPTER TWO

2.0: LITERATURE REVIEW

2.1: Horticultural Production in the ASAL

Arid and semi-arid lands (ASALs) are characterized by low erratic rainfall of up to 700mm per annum, periodic droughts and different associations of vegetative cover and soils. Inter annual rainfall varies from 50-100% in the arid zones of the world with averages of up to 350 mm. In the semi-arid zones, inter annual rainfall varies from 20-50% with averages of up to 700 mm (MoLD&F, 2012). The success of rainfed agriculture is usually not guaranteed. Agricultural harvests are likely to be irregular (Gooding & Northington, 1985). The ASALs exhibit ecological constraints which set limits to settled agriculture. These constraints include: rainfall patterns that are inherently erratic; rains which fall mostly as heavy showers and are lost to run-off; a high rate of potential evapotranspiration; weeds growing more vigorously than cultivated crops and competing for scarce reserves of moisture; low organic matter levels; and highly variable responses to fertilizer (Salih & Ahmed, 1993).

Generally, environmental deterioration due to water shortages is an urgent problem in ASAL areas. Agricultural production in these areas has necessitated utilization of the limited surface and underground water resources for irrigation to stabilize production (Fereres & Soriano, 2007). Excessive exploitation of these resources is leading to adverse consequences such as gradually falling water table, shrinking of vegetation areas, soil salinization, and desertification (Taisheng, Kang ,Zhang & Li, 2008). Water shortage (drought) is one of the most important factors constraining agricultural production in these regions because it has affected crop productivity nearly as much as all environmental factors combined (Boyer &West gate, 2004).These challenges of agricultural production in ASALs have necessitated researchers to focus on increasing water use efficiency through growing new drought tolerant varieties or through improved water management. New irrigation strategies must therefore be established to use the limited water resources efficiently (Topak, Suheri & Acar, 2010). For successful horticulture production these strategies will have to address the need to reduce the crop irrigation water requirements using water saving technologies.

Small scale agriculture is very important for food security in many countries (Montenegro *et al*,. 2010). In Kenya tomatoes (*Lycopersiconesculentum*), cabbages (*Brassica oleracea* var.*capitata*) and Collards(*Brassica oleracae* var. *acephala*) are horticultural crops mainly grown in Central, Rift valley and parts of Eastern, North Eastern, Western, Nyanza and Coast regions. In 2009, approximately 20,000 ha of tomato were planted and 600,000 MT were produced worth 15 billion shillings most of which was consumed locally. In the same year all vegetables exports were KSh 25 billion in total (Odame *et al*, 2010).

In Kibwezi sub-county irrigation horticulture production of vegetables is scantly documented. The sub county has a total area of 3985 km^2 (398,500 ha). It has three administrative divisions- Kibwezi, Machinery and Mutitu, which have 683 km^2, 261 km^2 and 941 km^2 under settled agriculture production respectively. The remaining area is under Tsavo National Game Reserve. Of the 1885 km^2 (188,500 ha) only about 20,000 hectares are currently under irrigation. Nearly 70% 0f the total area can easily be irrigated (MoA, 2010). Available water sources for this could be the nearby Athi River and the perennial underground river traversing the sub county and emerging at Kwa Kyai area.

2,2: Types of farm irrigation systems

Agricultural practice in the arid semi-arid regions is highly dependent on irrigation (Montenegro, Montenegro & Ragab, 2010). The conventional surface irrigation methods include basin, furrow, sprinkler and drip irrigation while sub surface irrigation methods include use of underground perforated tubes. In basin irrigation water is poured in sunken beds with raised sides to stand and percolate for some time. It is wasteful interms of water use and is best practiced on clay soils for crops which tolerate water logging (Merle, 2007).

Furrow irrigation is a type of flood irrigation in which the water supplied to the field is directed to flow through open narrow channels to deliver water to plants. Furrow irrigation is one of the easiest and cheapest methods of applying water to the crops. The water application efficiency in furrow irrigation ranges between 60 – 80 % (Merle, 2007). This technology has been applied on small scale in scattered areas of the ASAL of Eastern Kenya especially Yatta and Kibwezi.

Sprinkler irrigation involves conveyance and the spraying of piped water under pressure to fall on the ground in drop mimicking rain. It requires higher capital investment and skills. It also encourages some diseases to thrive because of uncontrolled wetting of the plants but has higher application efficiency than basin and furrow hence higher level of water saving (Merle, 2007)

Drip irrigation also involves conveyance of water through pipes and delivery to the plants precisely at the root zones. This is under some pressure from a pumping source or natural gravity head. It is more efficient than flood and furrow (Choudhari, Ghuman, Dhaliwal, Chawla, 2010) and has the highest application efficiency hence highest savings but costly and required high level of skill and experience (Merle, 2007).

2.3: Irrigation water distribution methods

Water in the farm is commonly distributed through open channels dug on the ground or by using plastic piping systems. Open channels rely mostly on gravity while piped water distribution requires external pressure. All these require a well-designed network for efficient distribution. Open channels are mostly used in gradually sloping areas with clay soils to prevent water loss through percolation. This method has low distribution efficiency. Piped water distribution method requires application of pressure. It has high distribution efficiency than open channels and can be used on varied situations (Merle, 2007).

2.4: Irrigation scheduling

Irrigation scheduling is the precise timing of irrigation and application of the water amount required for irrigation and is an accepted improved water management technique. Recommended timings of irrigation contributes to improve on farm management of water, improved soil water drainage and reduced N leaching (Xiaopeng, Jiabao, Jintao, Jianli, Anning , Feil & Congzhi , 2011).

ASALs suffer water resource deficiency of both surface and underground water. Because of increasing agricultural demand, uneven spatial and temporal distribution of water resources and especially poor water resource management in ASALs, optimization of irrigation scheduling has become an urgent task for local sustainable agricultural development. Accurate control and reasonable allocation of irrigation water at a reasonable area scale requires knowledge of the real time soil evaporation and crop evapotranspiration. Poor irrigation management leads to waste of water resources due to over irrigation or loss of crop yields due to under irrigation- water scarcity. Therefore monitoring soil water and plant water status is quite critical for reducing risk of crop failure or permanent damage to plants (Wang & Gartung, 2010)

Irrigation scheduling is planning when and how much water should be applied to achieve a desired crop yield. Effective irrigation is based on regular monitoring of soil water and crop development conditions in the field, and with the forecasting of future crop water needs. A proper irrigation schedule should (1) meet the crop water demands to prevent yield loss due to water stress; (2) maximize the irrigation water use efficiency to make beneficial use of and save local water resources; and (3) minimize the leaching potential of agricultural chemicals(NO_3-N and pesticides) that may impact on the local environment (Xiopeng *et al*, 2011).Considering the projected crop water requirement and the weather forecast to decide the irrigating plan an irrigation event is determined by establishing the acceptable maximum difference between RAW level in the soil and the real-time water deficit in the root zone by measurement or estimation by field observations. This can also be used to establish the amount of water needed for the irrigation event (Montoro, Lopez‘- Fuster & Fereres, 2011)

The irrigating decision is a daily judgment requiring consideration of soil water balance items, such as rainfall and crop water use (in terms of evapotranspiration). The readily available soil water in the root zone (RAW) is an important planning indicator that needs to be established for various crop growth stages and for each irrigated field. It is usually expressed in cm of soil water(Xiopeng *et al*, 2011).When an irrigation event is determined, the amount of the water required is the difference between RAW and the real-time water deficit in the root zone and is the fraction of TAW that a crop can extract from the root zone without suffering water stress. Using a soil water balance and comparing the latest soil water deficit data in the fields with RAW to check out whether irrigation is required, considering the projected crop water requirement and the weather forecast ,an irrigating plan can be decided (Xiopeng *et al*, 2011).

Effectiveness of irrigation scheduling depends heavily on the predicted results of soil water and crop development. Accurate calculation of the soil water deficit also requires daily weather data of an area, e.g. precipitation, solar radiation, daily maximum and minimum air temperature. Precipitation is the most important meteorological factor for soil water simulation and often has significant spatial variation (Montoro *et al*, 2010).

2.5: Water saving technologies

The growing pressure on fresh water resources has been widely acknowledged, and there is need for water resources to be managed better (Sander & Lucie, 2010). In most ASALs irrigated agriculture has been faced with increased limitations of water supply in the last few decades. To reduce the disproportion between water demand and supply, improved water management is required, particularly aimed at water saving and conservation in irrigated agriculture. One main way is demand management by reducing the irrigation water demand by improved crop irrigation management. In this perspective specially improved furrow irrigation alternatives such as AFI and CFI have been developed to enable intensive production in the ASALs (Montoro *et al*, 2010; Horst, Shamutalov, Pereira, Goncalves, 2005).Other methods include special adaptations to surface and sub-surface methods of irrigation. The extent of their innovative adaptation has depended and will continue to be determined by the desired internal rate of return and ease of use as per every specific situation demand.

The cheapest and easiest adaptations are those of furrow irrigation. An important adaptation of furrow irrigation is Alternate Furrow Irrigation (AFI) in which furrows are irrigated alternately rather than consecutively during irrigation water application. This is a form of partial root-zone drying (PRD) system which has been found to increase the production of various vegetables in the ASAL areas as well as saving irrigation water (Stikic, Popovic, Sardic, Savic, Jovanovic, Prokic & Zadravkovic, 2003)

The other extreme end adaptations are those of drip irrigation. Drip irrigation dramatically increases the water use efficiency over surface methods - sprinkler and furrow irrigation (Merle, 2007). Drip irrigation is the best means of water conservation along with control over increasing costs of water, fertilizer, labor and machinery. A major advantage is that up to 50% less water is used to grow a crop as compared to other methods of irrigation (Merle, 2007). This is especially true in soils having a high sand content. Drip irrigation will have an application efficiency of 90-95% compared with sprinkler at 70% and furrow at 60-80%, depending on soil type, level of field, and how the method of application to the furrows. In irrigation trials in North Africa, it was found that drip irrigation produced twice the tomato yield as the same amount of water used in sprinkler irrigation (Merle, 2007). In Southern California, a comparison between the effect of furrow irrigation and drip irrigation on tomato yields indicated that drip irrigation could provide a 26.8% increase in total yield and a 13.7% increase in fruit size. Using drip irrigation in combination with mulch will normally increase yields significantly through the application of water and fertilizer directly to the plant roots growing beneath the mulch. In the U.S., this technology was used as early as 1964 to produce tomato, cucumber and melon crops on different mulches under row covers (Merle, 2007).

Muskmelons, tomatoes, peppers, cucumbers, squash, eggplant, watermelons and okra are vegetable crops that have shown significant increases in earliness, yield, and fruit quality when grown on plastic paper mulch. In earlier experiments yields have been achieved of between 71 to 74 MT for tomato, cucumber, and melons. Some less valuable crops such as sweet corn, snap beans, southern peas and pumpkins have shown similar responses (Douglas sunders, 1996).

2.5.1: Partial Root Drying (PRD)

Partial root-zone drying (PRD), also called Controlled Alternate Partial Root-zone Irrigation (CAPRI), isa modified form of Regulated Deficit Irrigation technique which can improve the water use efficiency of crop production without significant yield reduction(Fereres & Soriano, 2007; Stikic *et al*, 2003; Jones, 2004). It is practiced in the field in one form as Alternate Furrow Irrigation (AFI). It involves part of the root system being exposed to drying soil while the remaining part is irrigated normally. The wetted and dried sides of the root system are alternated with a frequency according to soil drying rate and crop water requirement (Stikic *et al*, 2003).

The irrigation system is developed on the basis of two theoretical backgrounds.

(i) Fully irrigated plants usually have widely opened stomata. A small narrowing of the stomatal opening may reduce water loss substantially with little effect on photosynthesis.

(ii) Part of the root system in drying soil can respond to the drying by sending a root-sourced signal to the shoots where stomata may be inhibited so that water loss is reduced (Shaozhong & Zang, 2004).

Partial root drying has enabled significant water saving under field conditions to be achieved. It involves restriction of water application to parts of the soil surface around the plants. Because PRD involves exposing part of the root system to drying soil while maintaining others in well watered soil, it is most effective when the two sections are exposed alternately to wet and dry soil. Water savings resulting from PRD are attributed to reduction in stomata conductance which occurs as a result of plant roots encountering drying soil (Webber, Madramootoo, Bourgault, Horst, Stulina & Smith, 2009).Under controlled conditions in split root culture vessels with divided root system, PRD treatments to one half of the root system not only reduced water consumption but also induced flowering in young leech plants (Volker, Gweyi-Onyango, Spreer & Bangerth , 2005).

Plant growth in drying soil is commonly limited by a combination of chemical and hydraulic influences. These have been known to trigger series of physiological, cellular, and molecular plant processes and responses for survival under water deficit conditions culminating in stress tolerance (Shinozaki & Yamuguchi, 2007). Frequently, reductions in water availability result in reduced shoot turgor which can reduce shoot growth and development (Weele, Spollen, Sharp & Baskin, 2000). Even when turgor of growing shoot cells is sustained, growth can be limited by chemical 'signals' generated as a result of interactions between the root and the drying soil and transmitted to the shoot via the transpiration stream(Davies, Kudoyarova & Harung, 2005).

It has been demonstrated that production and expansion of leaves of apple trees could be restricted by watering only half the plant root and that this limitation occurred without any detectable influence of the shoot water status (Stoll, Loveys & Dry, 2000). This is thought to be mediated by Abscisic Acid (ABA) and alkalinization of the xylem flow(Webber *et al*, 2009: Sobeih, Dodd, Bacon, Grierson, Davies , 2004).The excision and other reactions of the roots in the drying soil has been attributed to presence of hormones (Poroyko, Spollen, Hejlek, Hernandez, LeNoble, Davis , Nguyen , Springer, Sharp, Bohnert , 2007; Kang *et al*, 2000) which also influenced shoot growth so that the growth limitation under PRD was attributable to delivery to the shoots of chemical inhibitors(ABA) in the transpiration stream, generated as a result of soil drying. The production of ABA from the roots is because of low vacuolization of root tip cells (Davies *et al*, 2005; Steudle, 2000). The ABA is then transported to the shoots and gets concentrated there resulting in restricted growth of leaves and shoot.

The PRD technique has been studied earlier by Webber and Davies and is developed on the knowledge basis of root-to-shoot signaling as one of the active applications of xerophytophysiology in plant production, where drought does not necessarily exist .The plant perceives the drought stimulus and transduces the signal to the internal gene systems, where related genes are activated and lead to biochemical and physiological regulations in response to the drought stimulus, no matter whether the drought stimulus causes real or false water deficit(Xu, Qin, Du, XuQ, Wang, Shah, Zhao & Li, 2009; Bray, 2004). The conventional view of drought is that drying soil induces restriction of water supply and this result in to consequent reduction of the tissue water content, growth and stomatal conductance. Therefore it appears that in some cases, changes in plant physiology (especially leaf) are more closely linked to the changes in soil water content. This kind of reaction requires that the plants have some mechanism for sensing the availability of water in the soil and regulating stomatal conductance and plant growth accordingly (Chaves & Oliveira, 2004).

It has been suggested that this may involve transfer of chemical information from roots to shoots via the xylem (Chavez *et al*, 2004). Such control has been termed as non-hydraulic or chemical signaling (positive or negative).This distinguishes it from hydraulic signaling, which represents transmission of reduced soil water availability via changes in xylem sap tension. Negative chemical signals include cytokinins and are supplied by turgid roots and promote stomatal opening and shoot growth. The production of these signals reduces as soil dries. Positive signals whose production increases as soil dries include inhibitors such as abscisic acid-ABA (Dodd, Theobald, Bacon, Davies, 2006).Changes in mineral composition and pH of xylem sap also provide additional signals. Investigations on the hormonal changes induced by PRD in plants show that xylem sap ABA concentration and pH increase, and as a result stomatal conductance reduces (Stoll *et al*, 2000). Concurrently also there is usually a reduction of cytokinin content in roots, shoot tips and buds and thus shoot growth is reduced. Alternating wet and dry zones of root system are essential to trigger continuous root-to-shoot signal (Dodd *et al,* 2006). This is necessary because the root system is not able to maintain root ABA production for long periods. In most published data PRD cycles range between 10 to 15 days (Xu *et al,* 2009, Davies *et al,* 2005).

In the past, there has been much interest in modifying the long-distance signaling through deficit irrigation and thereby modifying plant growth to the advantage of the producer and saving water (Davies *et al*, 2005). It has been suggested that reduced water application to grapevines restrict vegetative shoot development. It was proposed that irrigation could be regulated so as to control stomatal conductance, reduce plant water loss but sustain shoot water status to ensure 'normal' fruit development. The increased concentration of ABA in the xylem fluid from roots to leaves triggers closure of stomata (Taisheng *et al,* 2008: Dodd *et al,* 2006). While stomata control both transpiration and carbon dioxide entry into the cell, evidence suggests that initially, the reduction in stomatal conductance is greater than the concurrent reduction in carbon assimilation (Webber *et al,* 2009). In addition therefore, PRD regulates plant vegetative growth (Taisheng *et al*, 2008). Thus in theory, this dehydration control therefore usually limits the uptake of CO_2 and thus growth. However, practically carbon dioxide uptake may not necessarily be restricted by reductions in stomatal aperture (Davies *et al,* 2005; Kang *et al* 2000). Therefore this shows that turgor in crops e.g tomatoes fruits, can be sustained under a particular form of deficit irrigation. Results from experiments where grapevine vigour was significantly reduced and less water used without any yield penalty have been obtained. Fruit production per unit of water used was therefore greatly increased compared to the industry standard. In addition, the quality of fruit was improved significantly (Stoll, Loveys & Dry, 2007).

In PRD, the two halves of the plant's root system are watered alternately. Roots in wet soil supply most of the water, while roots in contact with drying soil generate signals that move to the shoot to restrict shoot growth and functioning. Irrigation must be switched regularly from one side of the root to the other to keep roots in dry soil alive and fully functional and sustain the supply of root signals (Davies *et al,* 2005). Maintenance of turgor and total water potential in the shoot can be important for maintenance of fruit growth and development although it is not entirely clear why fruit growth does not respond as sensitively as leaf growth to the increased flux of chemical signals. Increases in grape quality combined with reduced water use have now been reported as a result of the use of PRD on a commercial field scale (Stoll *et al,* 2000). The application of the technique is not restricted to grapevines or other tree crops. In an extended series of studies in Australia, the UK, China and in countries around the Mediterranean, application of PRD to a range of other crops with different irrigation methods has resulted in substantial saving of irrigation water coupled with the maintenance of an economic yield(Du Taisheng *et al,* 2008), In these experiments, Biomass Water Ratio(BWR)has often doubled and in some cases increased much more It has been hypothesized that PRD irrigation may reduce "luxury" transpiration loss without limiting photosynthesis rate by slightly limiting stomata opening (Du Taisheng *et al,* 2008).

Despite some difficulties in operating PRD irrigation techniques in certain soils and some climatic conditions, it is clear that substantial water savings and increases in crop quality can result. Water savings of between42% and46% have been realized (Menelik, Ayana & Rao, 2010; Xu *et al,* 2009) showed that the plant yield of chika and momontaro variety of tomatoes under AFI and CFI was not significantly different while most of the other parameters showed significant difference e.g plant height , number of leaves per plant, total sugars, organic acids, mineral nutrients, vitamin C. Stick *et al,* (2003) experimented and concluded that the lycopene content, mineral content and number of fruits per plant of the tomatoes varieties experimented was not significantly different under AFI and CFI while other traits were e.g plant height, number of leaves and flowers per truss, shoot dry weight.

In general PRD involves manipulating soil water to induce crop inherent responses to drought conditions, usually resulting to improved WUE and hence reduced period to maturity and overall irrigation water use. The mechanism is based on osmotic adjustment and symplastic water compartment which are not clear enough. PRD is thus an intentional stimulus used to induce a series of xerophytophysiological regulations, which make plant healthier than usual. It does not cause a real plant water stress but induces signals similar to those from real plant water stress. These false drought stimulus signals confer benefits similar to the gene expressions which activate metabolisms related with physiological and morphological regulations and adjustments which confer stress tolerance in drought resistant varieties (Xu *et al*, 2009). PRD as a technique in plant production has been practiced in many crops.

2.6: Water conservation technologies

As in most arid areas where irrigated agriculture has faced increased limitations of water supply in the last few decades (Montoro *et al*, 2010), the ASAL areas of eastern Kenya have inadequate water so conservation of the resource is mandatory. Many methods known to conserve water and increase its efficient use have been practiced for thousands of years in the arid regions of the world with great success. The best methods require little maintenance while yielding maximum success. The ability to add water during crucial crop growth periods can greatly increase yields.

The most common methods of water conservation include use of drip (micro) irrigation, bottle irrigation, mulching, growing crops in Zai pits and use of drought tolerant crops themselves.

CHAPTER THREE

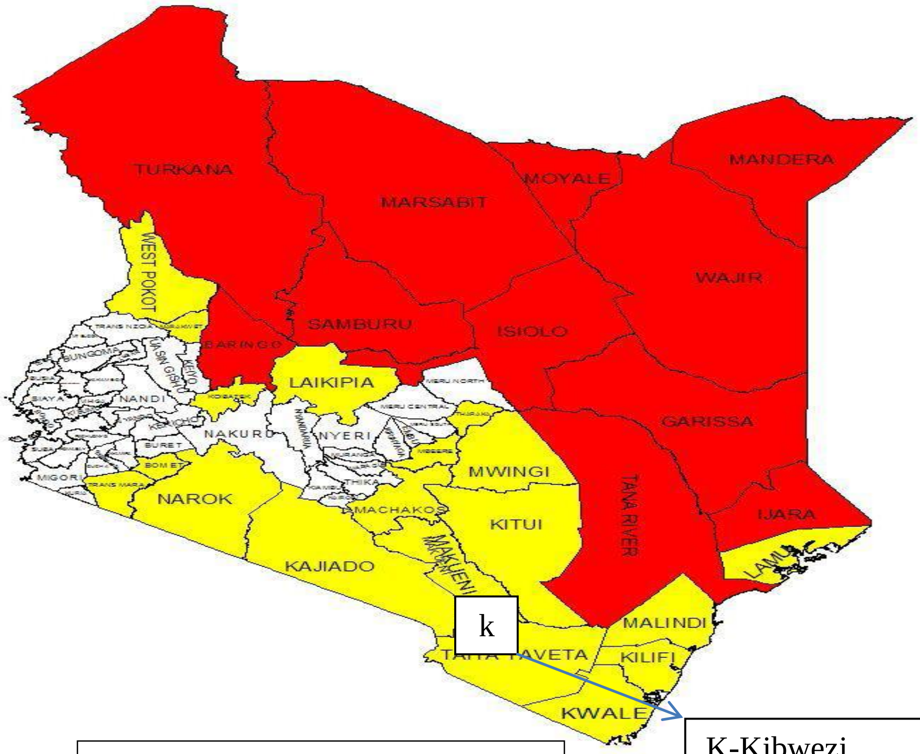
3.0: MATERIALS AND METHODS

Crops were grown both in green house and field.

3.1 The experimental site

This study on the growth and productivity of various vegetables under Alternate Furrow Irrigation (AFI) water saving technology was done at Kwa kyai area in Kibwezi sub-county (Figure 1).

Map of Kenya showing Arid and Semi-Arid areas



K-Kibwezi
(Makuenicounty)

Red are Arid areas
Yellow are Semi-Arid areas

Figure 1; Map of Kenya showing the location of Kibwezi (K)

Source; GoK sessional paper no 8 (2012)- Nat. ASAL devt policy.

The site at Kwa kyai irrigation scheme in Kibwezi (2.5^{o}S, 37^{o}E) is an area in the southern part of the Eastern region of Kenya (Figure 1). It has tropical ASAL climate (Sombroek *et al*, 1980) and is a lowland area at 800 m a.s.l which receives an average annual rainfall of 750 mm and has temperature range of 18-30^{o}C (MoA, 2010).

The soils are predominantly red haplicp haezems (FAO., 1988) with sandy-clay-loam texture and an average pH of 8.2. As in other ASAL areas the rains are unreliable. Irrigation water is available from nearby canal serving the irrigation scheme. The canal originates from the nearby perennial section of river Kibwezi near Kwa Kyai where the water intake for the canal is located.

Water to irrigate farms on the lower side of the canal is supplied using gravity flow through smaller channels. A one acre size of farm for the research was obtained from a willing farmer after recommendation from the Ministry of Agriculture office at Kibwezi. The field experiments were conducted in the periods June-August 2010 and January-March 2011.

Climatic data (rainfall and temperature) of the field experimental site for the period June 2010 to 2011 and the last 20 years (1990-2009) was obtained from the meteorological department and is presented in appendix 1.

A greenhouse experiment was conducted at Jomo Kenyatta University of Agriculture and Technology (JKUAT) in July to September 2011.The objective was to collect data on plant growth parameters in ideal laboratory setting for comparison purposes with those from the field.

The geographical location of JKUAT is at 1^{o}05’ S 31^{o}00’E. 30 Km North of Nairobi city centre. It is a coffee zone with cool wet modified tropical climate. The green house set up was for shielding away environmental interferences such as temperature and rainfall. The climatic data for JKUAT in year 2011 is presented in appendix 2.

3.2: Soil sampling and testing

Soil sampling was carried out only on the field experimental site at Kibwezi using the zigzag method. The samples were taken to JKUAT laboratory for testing to establish the status of some of the physical and chemical properties of the soil at the experimental site. Some of the physical properties tested included the soil texture, bulk density, field capacity (FC) and the permanent wilting point (PWP). Some of the chemical properties tested include the nutrient levels (N,P,K,Ca,Mg), soil pH and CEC as obtained from JKUAT horticulture laboratory.

3.3: Experimental design and treatment

For the field experiment the crops used - tomatoes (*Lycopersicon esculentum*), cabbages (*Brassica oleracea var. capitata*) and Collards (*Brassica oleracae var. acephala*) -were replicated three times in separate trials laid out in RCBD (Figure 2 a-f below).

a	AFI	CFI		CFI	AFI		CFI	AFI
b	CFI	AFI		AFI	CFI		AFI	CFI

RCBD layout for tomato plots at Kibwezi year 2010 (a) and year 2011 (b)

c	CFI	AFI		AFI	CFI		CFI	AFI
d	CFI	AFI		CFI	AFI		CFI	AFI

RCBD layout for kale plots at Kibwezi year 2010 (a) and year 2011 (b)

e	AFI	CFI		AFI	CFI		CFI	AFI
f	AFI	CFI		CFI	AFI		AFI	CFI

RCBD layout for cabbage plots at Kibwezi year 2010 (a) and year 2011 (b)

Figure 2: Schematic diagram of RCBD layout of Tomato, Collards and Cabbages in 2010(a,c, and e) and 2011(b,d and f) at Kibwezi

The treatments used were Alternate Furrow Irrigation (AFI) and a Conventional Furrow Irrigation (CFI). The conventional furrow irrigation was adopted from the farmer practice of irrigating all the furrows once every week. The alternate furrow irrigation consisted of skipping furrows alternately resulting in each furrow being irrigated once in two weeks. Each of the three crops were planted in 6m x 4m plots consisting of seven rows 60 cm apart and plant spacing of 30cm..

In the greenhouse only tomato crop was grown. The variety was Nuru F1. A seed bed was prepared and seedlings established in May 2011 for 21 days. Standard nursery practices were done. Transplanting was done in June 2011.The design used was similar to the field experiment – RCBD. The crop spacing used was similar to those used in the field experiment – 60cm x 30cm. The plots were 2.1m x3.2 m in size (Figure 3). Pre irrigation was done for two weeks to allow the crop to establish, and then AFI and CFI treatments were administered. Water used was measured based on flow rate of the piped water. This was established during each irrigation day by determining the time required to fill a 20L container. The discharge rate was then calculated. This enabled calculation of the total quantity of water applied in a single furrow or even the entire plot.

CFI		CFI		AFI
AFI		AFI		CFI

Figure 3: Schematic diagram of RCBD layout of Tomato plots in green house at JKUAT year 2011

3.4: Crop establishment and irrigation management

In the field all the crops were sown in nursery beds of 1 m wide and 4 m long on 5th April 2010 and 16thDecember 2010 for the first and second seasons, respectively. The tomato variety used was Nuru F1,a hardy high yielding determinate hybrid variety with good shelf life and high demand in the market. For Collards, Georgia Collard variety was planted. It is a high yielding variety known to bear wide leaves faster than most of the other varieties. The cabbage variety planted was Gloria F1, a hardy high yielding hybrid which enjoys high preference amongst consumers and less susceptible to some diseases such as head rot.

Standard nursery practices were done during the nursery period after which seedlings were transplanted to plots 4m x6m in size. Transplanting was done 30 DAS in period 2010 and 24DAS in period 2011, for the two seasons, respectively. Planting fertilizer DAP (18;46;0-N.P.K) was applied at 1.0 kg per plot (200kg/ha) and topdressing was done using NKP fertilizer (17;17;0) at 2.0 kg per plot (400kg/ha). All other standard field management activities were done as per the calendar of activities shown in the Appendix 4.

During both seasons, a pre-irrigation of approximately 20.1 mm of water was applied to every plot once a week for a period of 30 days after transplanting (DAT) to encourage full establishment of the transplanted plants. Thereafter the prescribed irrigation treatment–AFI and CFI- was administered until harvesting stage and the final day for tomato and cabbage, and reduced leaf yields for Collards. The amount of water supplied to each plot was measured using calibrated standard Parshal flume (Armfield – made by Armfield Technical Education Co. Ltd,

For the green house experiment nursery the crops were sown in beds of 1 m wide and 2 m long. Standard nursery practices were done during the nursery period after which seedlings were transplanted to plots 2.1m x 3.2 m in size. Transplanting was done 24 DAS. Planting fertilizer DAP was applied at 200kg/ha and CAN topdressing at 400kg/ha. All other standard field management activities were done. A pre-irrigation of approximately 22.68 mm of water was applied to every plot once a week for a period of 15DAST to encourage full establishment of the transplanted plants. Thereafter the prescribed irrigation treatment of AFI and CFI was administered until harvesting stage.

3.5: Data collection

3.5.1: Determination of Irrigation water use

Irrigation water was applied in the field by opening the inlet canals and letting water run into the furrows according to the treatment until the furrow was full of water the whole length. The volume of water supplied (Q) to each plot was estimated using the flume head on the basis of the flow rate (f) m^3/min and time (t) in minutes of watering. The computation was done using the following flume calibration equation as determined at JKUAT Engineering laboratory;

$$Q = f \times t \qquad . (1)$$

$$f = 4.9952\, h^{1.5919} \qquad . (2)$$

Where

h = flume head (m)

Irrigation water in the green house was applied by letting piped water run into the furrows to be watered until the furrow was full of water the whole length. The volume of water supplied (Q) to each plot was estimated using the pipe discharge rate per minute of time.

3.5.2: Determination of Soil Moisture Content

Soil moisture content(SMC) for each replicate was determined gravimetrically as follows ;-Before watering soil samples from a randomly selected furrow of the CFI plot taken at a depth of 10 cm and weighed immediately (FW).Also two soil samples from the AFI plot were taken before watering at the same depth. The AFI samples were taken one from a previously watered row 1 and another from alternate previously skipped dry row 2. The samples were immediately weighed. All samples were later dried at 105^{o}C for 24 hours and final weight obtained (DW). A day after watering the same procedure was repeated. The percentage gravimetric soil moisture content (SMC %) on dry weight basis was calculated using formula (FAO-IAEA 2008);

$$\%SMC = \frac{FW-DW}{DW}\ x\ 100 \qquad (3)$$

Where

FW – Fresh weight and DW= Dry weight

3.5.3: Determination of Plant Water Status

The Relative Water Content (RWC) was determined on young leaves in each replicate as follows -; Before watering a young leaf was cut from a randomly selected plant on CFI plot and weighed immediately to get fresh weight (FW). Also two leaves were cut from randomly selected plants in the AFI plot and weighed immediately to get fresh weight (FW). One leave was from a plant on previously watered row while the other was from a previously skipped dry row. The leaves were then floated on distilled water in a petri dish for 24 hours and then their turgid weights determined (TW). They were then dried at 72^{o}C for 48 hrs. Their dry weights were also obtained (DW).

The RWC% on weight basis was calculated using formula (Jones, 2007, Turner *et al*, 2007)

$$RWC = \frac{FW-DW}{TW-DW} \times 100\% \qquad (4)$$

Where

FW- Fresh weight DW- Dry weight and TW- Turgid weight

3.5.4: Determination of the rate of plant growth

Growth was quantified by measuring the plant height and the number of leaves at weekly intervals. For all crops, data on plant heights was collected weekly by measuring the randomly sampled plants from the base to the tallest tips of plant stem using a ruler.

The number of leaves were also counted and recorded weekly. For tomatoes and cabbages date of first flowering and head formation for the entire field were also recorded, respectively. The progression of flowering and number of flowers per branch in tomatoes was recorded weekly for the sampled plants. The progressive increase of head size for cabbages was also recorded on weekly basis as was determined by measuring the diameter of the heads.

3.5.5: Harvesting of produce and determination of yield

For tomatoes harvesting was done continuously by hand picking at different times as they ripened. Harvesting started after ripening was confirmed, for example in 2010 at 35 Days after start of treatment (DAST) for AFI and 42 DAST for CFI. All produce was harvested within one to two weeks after the 49 DAST because not much change in especially growth was noted towards this time. The total yield was summed at the end and converted to standard units (tonnes/ha). Kale harvesting started 14 DAST and was done by picking fully developed leaves twice per week until 54 DAST when yield diminished to very low levels. Similarly the total yield was summed at the end and converted to tonnes/ha. Cabbages were harvested wholesome at the end within a week after 49 DAST when most of the heads had attained maximum size. The yields were also converted to tonnes/ha.

3.6: Data analysis

For SMC and RWC of leaves Analysis of Variance (ANOVA) was done using General Linear Models(GLM) in SAS(9.1) mode of statistical analysis at 5% level of significance and means separation was done using LSD. For data on other parameters - plant height, number of leaves, branches, trusses fruits per plant and yield, water used per plot- analysis was done using non-paired t-Test procedure in SAS and means separation done using Confidence Intervals (CI) at 95% Confidence level.

CHAPTER FOUR

4.0: RESULTS

4.1: Soil sampling and testing (field experimental site)

Some of the physical and chemical properties of the soil at the field experimental site as obtained from JKUAT horticulture laboratory are also tabulated in the Table 1 and 2.

Table 1: Some Physical properties of soil at the experimental site.

Season	Plot(s)	Clay%	Loam%	Sand%	Texture	Bulk density	FC %W/W	PWP %W/W
May-July2010	All	45	30	26	C	1.35	32	5
Jan – Mar2011	All	45	30	26	C	1.35	32	5

Table 2: Some Chemical Properties of soil at the experimental site.

Season	Plot(s)	N%	P%	K%	Ca(ppm)	Mg(ppm)	pH	EC
May-July2010	All	0.19	0.16	3.5	8.3	2.74	8.5	0.2
Jan – Mar2011	All	0.19	0.16	3.5	8.3	2.74	8.5	0.2

4.2: The tomato experiment

4.2.1: Irrigation water use.

The average water quantity (mm) applied in the field experiment in year 2010 and 2011 for the three replications of each treatment every watering time is as presented in Table 3.

Table 3: Irrigation water quantities (mm) applied on AFI and CFI treated tomato plots at Kibwezi inJune-August 2010 and January – March 2011.

Period	Treatment	Days after start of treatment									
		1	7	14	21	28	35	42	49	TT	Saving
2010	Alternate	39a	37a	37a	40a	38a	44a	43a	40a	318	
	Conventional	60b	55b	66b	64b	64b	68b	68b	69b	514	196
2011	Alternate	24a	16a	19a	31a	27a	29a	34a	31a	211	
	Conventional	38b	32b	43b	49a	44b	43b	54b	48b	351	140

Different Letters represent LSD ($P \leq 0.05$).

The amounts of water applied per plot on various irrigation events in 2010 were significantly different ($P<0.05$) for AFI and CFI. The cumulative totals used for AFI and CFI plots in 2010 and 2011were 318.7mm and 514mm respectively as noted after 49 DAST. A total savings of 196mm was achieved when AFI was used.

During the period January-March 2011 the AFI plots 6mx4m received an average amount of water between 16.6 to 31.25 mm water per irrigation day while those of CFI received 37.5mm to 56.25 mm water per irrigation day. Thus the amounts were significantly different in most of the days also for AFI and CFI. The cumulative water amounts for AFI and CFI plots were 211mm and 351mm respectively as noted after 49 DAT. A total savings of 140mm was achieved during this period.

In the green house experiment during the period July-August 2011 the AFI plots 2.1mx3m received average amounts of water ranging between 13mm to 18.mm water per irrigation day while those of CFI with similar size received 32mm to 34 mm water per irrigation day (Table 4).

Table 4: Irrigation water quantities applied on greenhouse AFI and CFI treated tomato plots inJune – September 2011

Period	Treatment	Days after start of treatment									
		1	7	14	21	28	35	42	49	TT	Saving
2011	Alternate	13a	15a	17.6a	18.2a	17.6a	18a	18.6a	17.8a	136	
	Conventional	34b	33.2b	34b	34b	33.2b	34a	34b	34b	270	146

Different Letters represent LSD ($P \leq 0.05$)

Thus the amounts used per plot on any irrigation event were significantly different ($P < 0.05$). In most of the days for AFI and CFI except on the 14, 35 and 49 DAST. The cumulative totals for AFI and CFI plots were 136mm and 270mm respectively as noted after 49 DAST. A total savings of 134mm was achieved when AFI was used.

4.2.2: Soil Moisture Content

The soil moisture content (SMC) under AFI followed an alternate pattern with high levels in the watered furrow and low levels in the non-watered furrow (Figure 4).

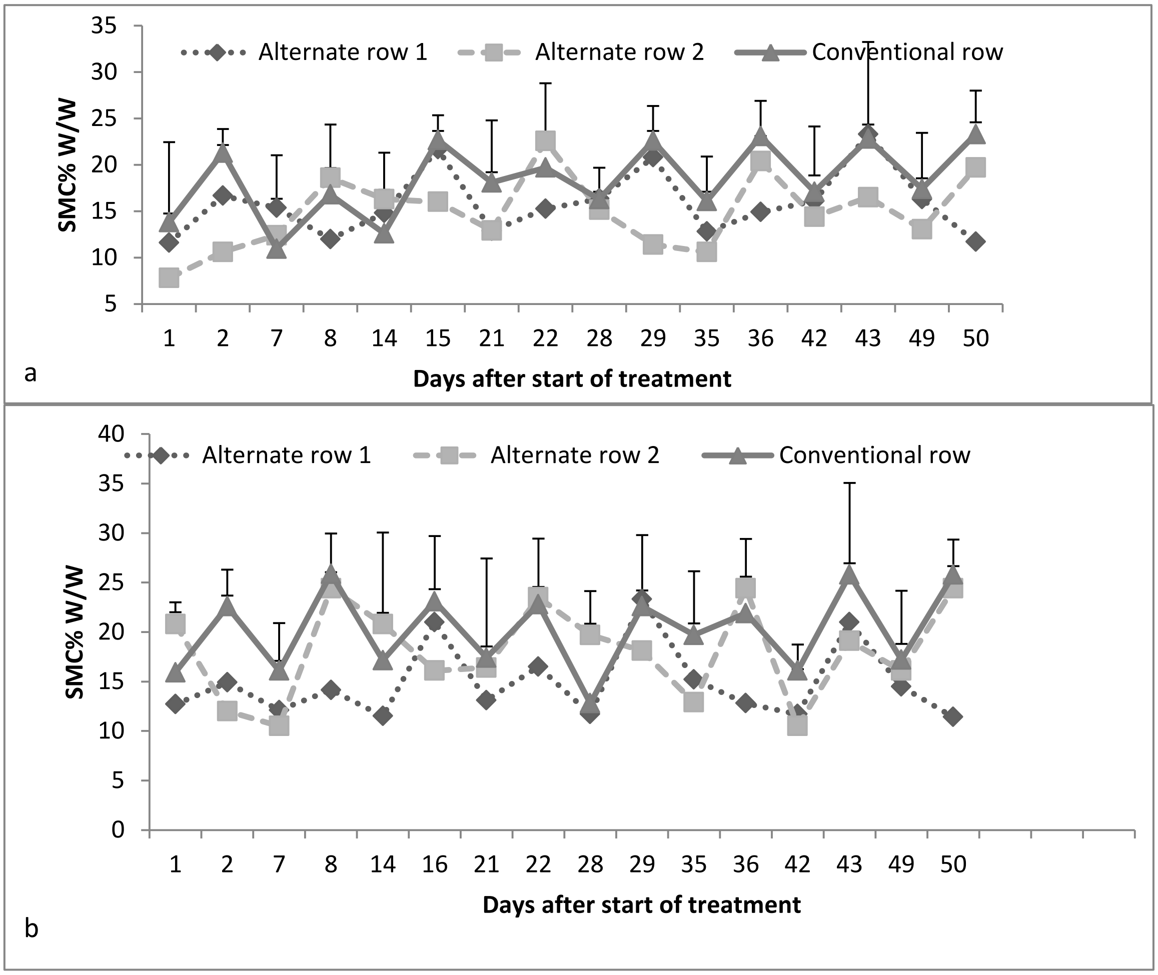


Figure 4:Soil moisturevariations during the periods June-August 2010 (a) and January-March 2011 (b) in AFI and CFI treated tomato plots in Kibwezi. (LSD at P≤0.05).

In the 2010 experiment the SMC ranged 6-12%during the non-watered time and 15-20% in the watered furrows in the two periods. The soil moisture pattern in this treatment followed a two week cycle. CFI furrows on the other hand exhibited an increase and decrease soil moisture pattern in a one week cycle in line with the weekly irrigation for both periods. During most of the time, the CFI plots had high soil moisture in the rows than the AFI in both periods. This was significant on 2, 15, 29 and 50 Days After Start of Treatment (DAST) in 2010 and 2, 8, 22, 36 and 50 DAT in 2011.

The soil moisture dynamics for the greenhouse experiment are presented in Figure 5.

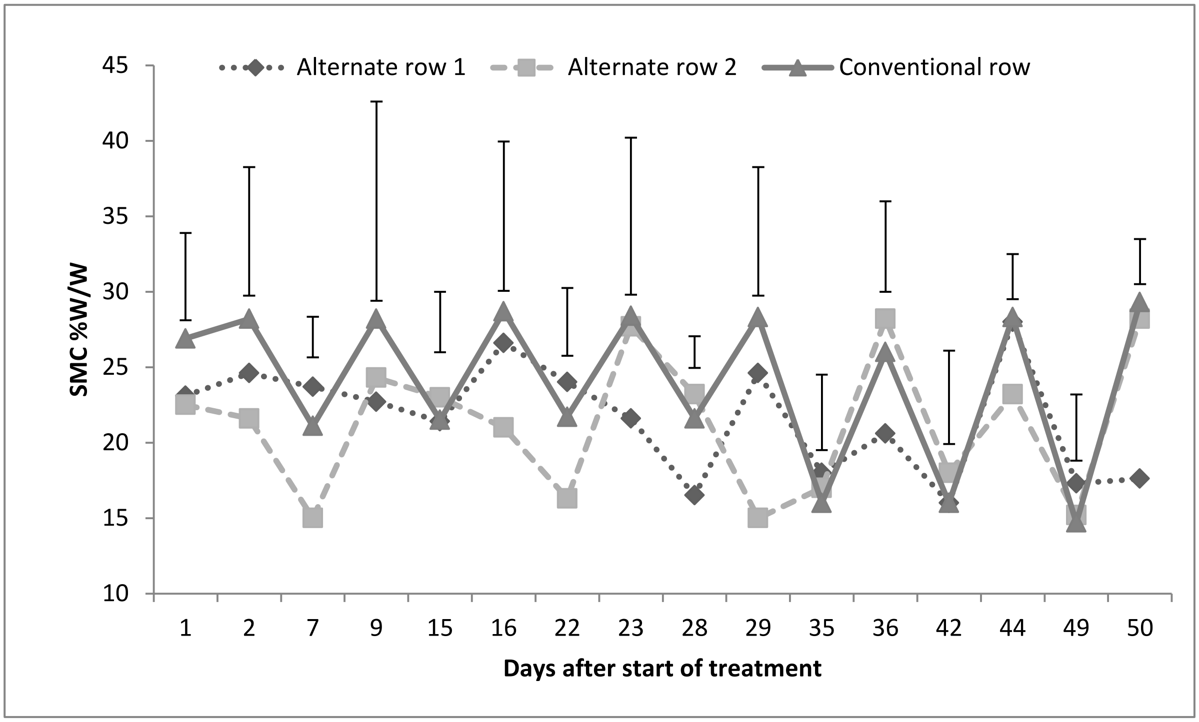


Figure 5: SMC variations during the periods July-August 2011 in AFI and CFI treated tomato plots in greenhouse at JKUAT. (LSD at P≤0.05)

For the July-August 2011 AFI furrows the SMC ranged 12-24% during the non-watered time and 22-28% in the watered furrows. The soil moisture pattern in this treatment also followed a two week cycle. CFI plots also exhibited an increase and decrease soil moisture pattern in a one week cycle in line with the weekly irrigation for the seasons as well. During most of the time, the CFI plots had high soil moisture in the rows than the unwatered AFI rows. This was significant on 2, 23, 29, 36, 44 and 50 DAST.

4.2.3: Relative Water Content

The relative water content (RWC) of the leaves was increasing and decreasing in a weekly pattern in cycles in both AFI and CFI treated plants in both 2010 and 2011 (Figure 6).

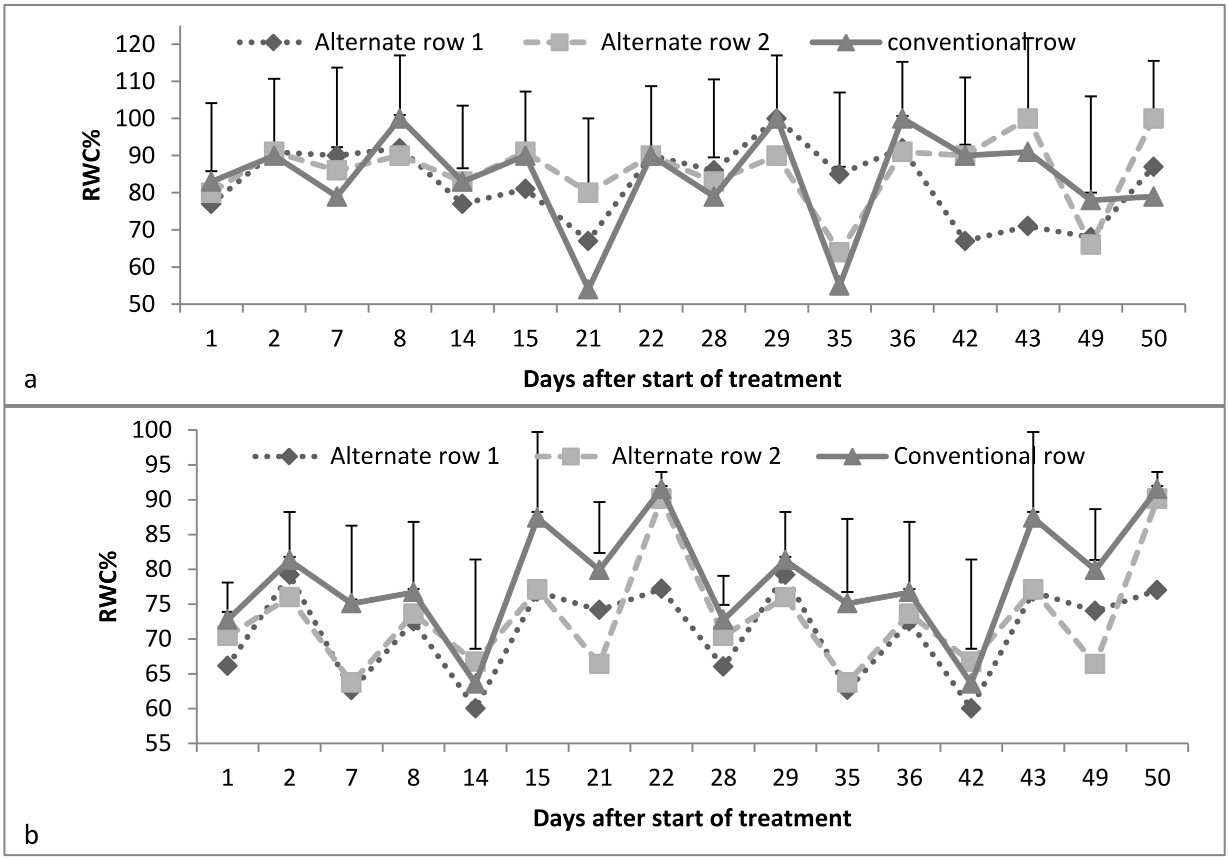


Figure 6:RWC of leaves during the periods June-August 2010 (a) and January-March 2011(b) in AFI and CFI treated tomato plots in Kibwezi. (LSD at P≤0.05)

The RWC variations generally revolved around 95% and 60% in the 2010 and 2011 seasons, respectively. The RWC of plants under CFI was generally higher than plants under AFI for most of the period in both seasons. The lowest levels reached were 50% on the 21 DAST in 2010 and 60% on 14 and 42 DAST in 2011 for both treatments.

It was noted that the average RWC of plants under AFI and CFI prior to watering ranged between 75-88%. The range after watering was between85–95%. Thus at any particular time there were no significant differences (P> 0.05) between the RWC of the AFI and CFI plants except for some instances as noted in 2010 on the 21, 35 and 43 DAST and 2011 on the 21 and 50 DAST.

In the greenhouse experiment also the relative water content of the leaves was increasing and decreasing in a weekly pattern in cycles in both AFI and CFI treated plants (Figure 7).

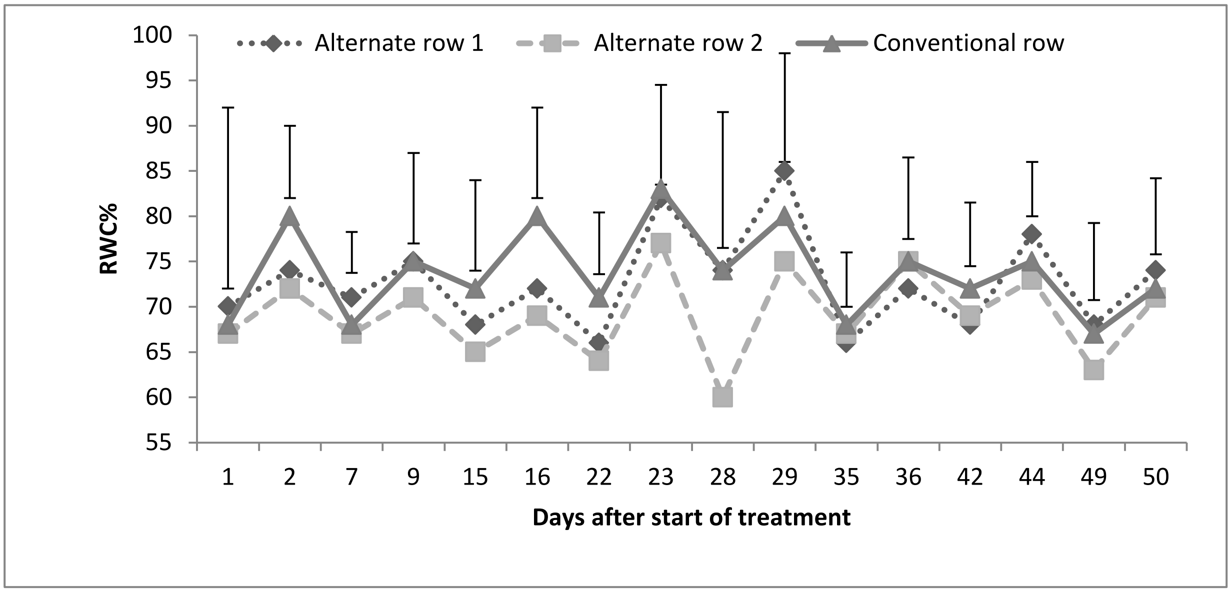


Figure 7: RWC of leaves during the periods July-August 2011 in AFI and CFI treated tomato plots in greenhouse at JKUAT. (LSD at P≤0.05).

The RWC oscillations generally revolved around 60% and 85% in the period July-August 2011. The RWC of plants under CFI was generally higher than plants in the unwatered AFI rows. The lowest levels reached were 60% on the 28 DAST in the green house plants.

It was noted that the average RWC of plants under AFI and CFI prior to watering ranged between 65-75%. The range after watering was between70–85%.

4.2.4: Plant growth trends

In the field experiment the sampled tomato plants under AFI were initially of similar height to those under CFI in both seasons as shown in Figure 8.

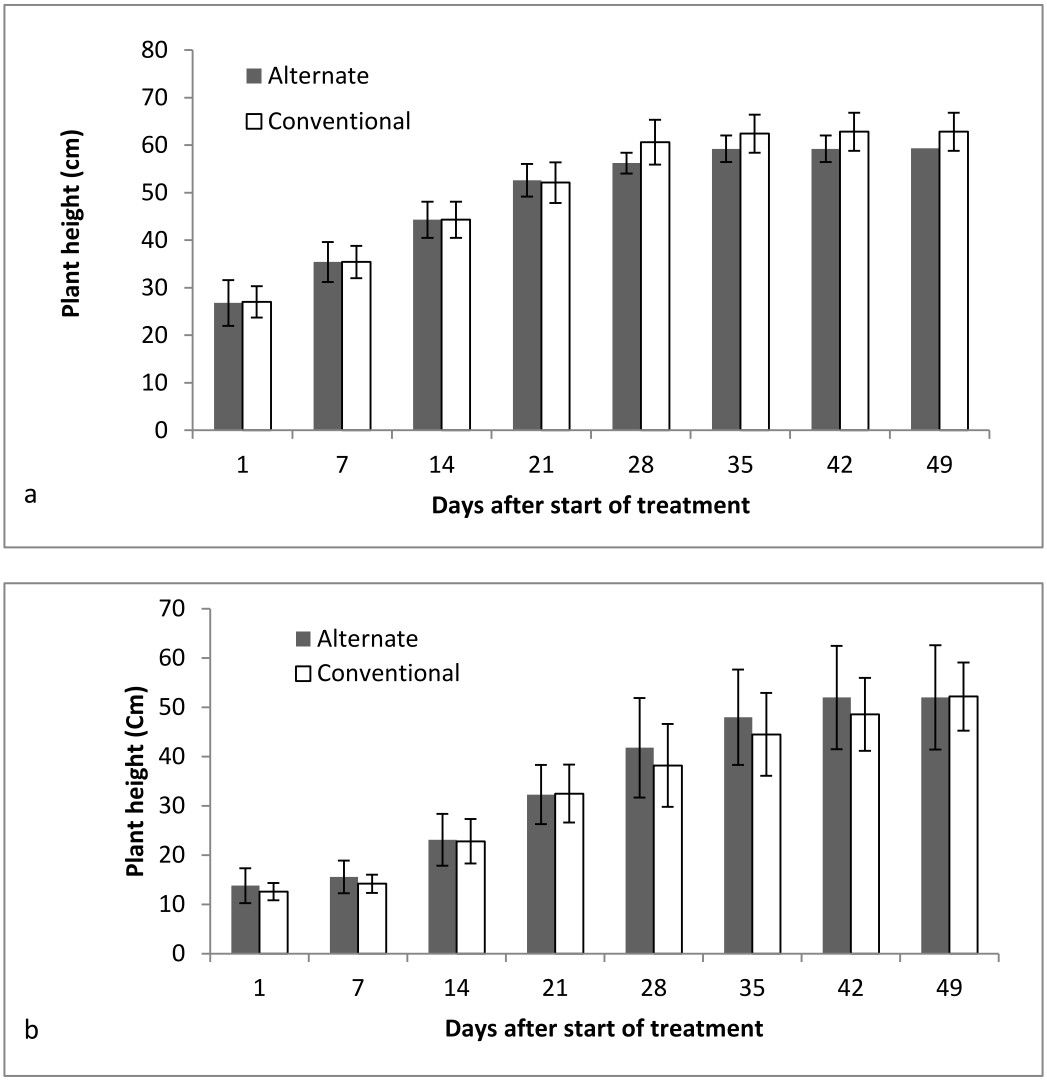


Figure 8: Plantheight during the periods June-August 2010 and January-March 2011 in AFI and CFI treated tomato plots in Kibwezi. Vertical bars represent Confidence Intervals.

At the end of the season, plants from CFI plots had an average height of 60cm hence taller than plants in AFI which were 55cm high in 2010. In 2011 the AFI and CFI plants were 49cm and 50cm tall respectively. However, the differences in plant height between the two treatments were not significantly different ($P > 0.05$) in both 2010 and 2011 though CFI plants were usually slightly taller at the end of the season.

In the greenhouse experiment the sampled tomato plants under AFI were initially of same or higher height than those under CFI as shown in Figure 9.

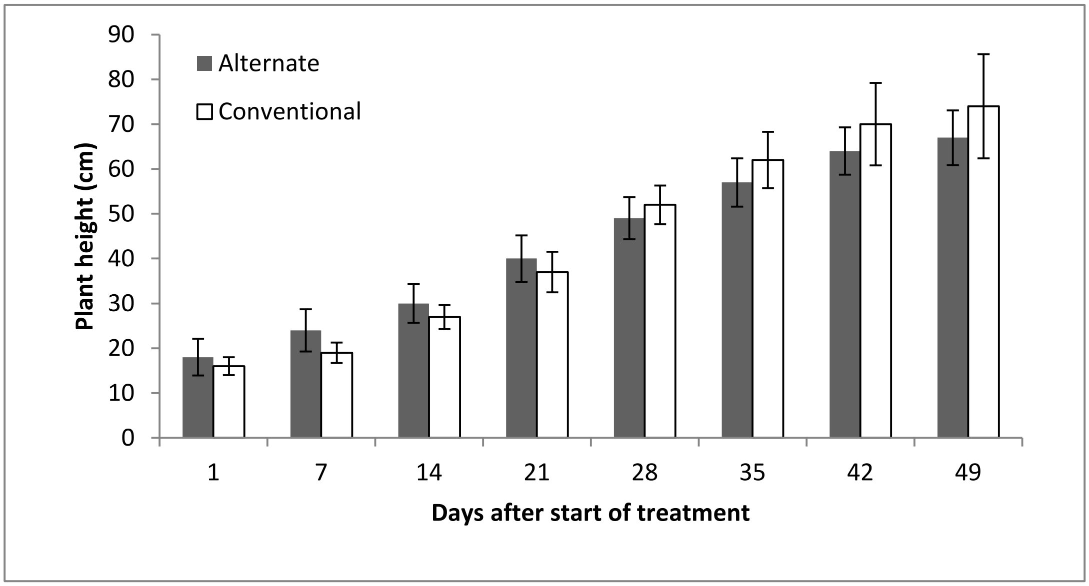


Figure 9: Plant height during the periods July-August 2011 in AFI and CFI treated tomato plots in greenhouse at JKUAT. vertical bars represent Confidence Intervals.

There was no significant difference (P > 0.05) in the number of leaves per plant between the CFI and AFI plants in both seasons (Figure10).

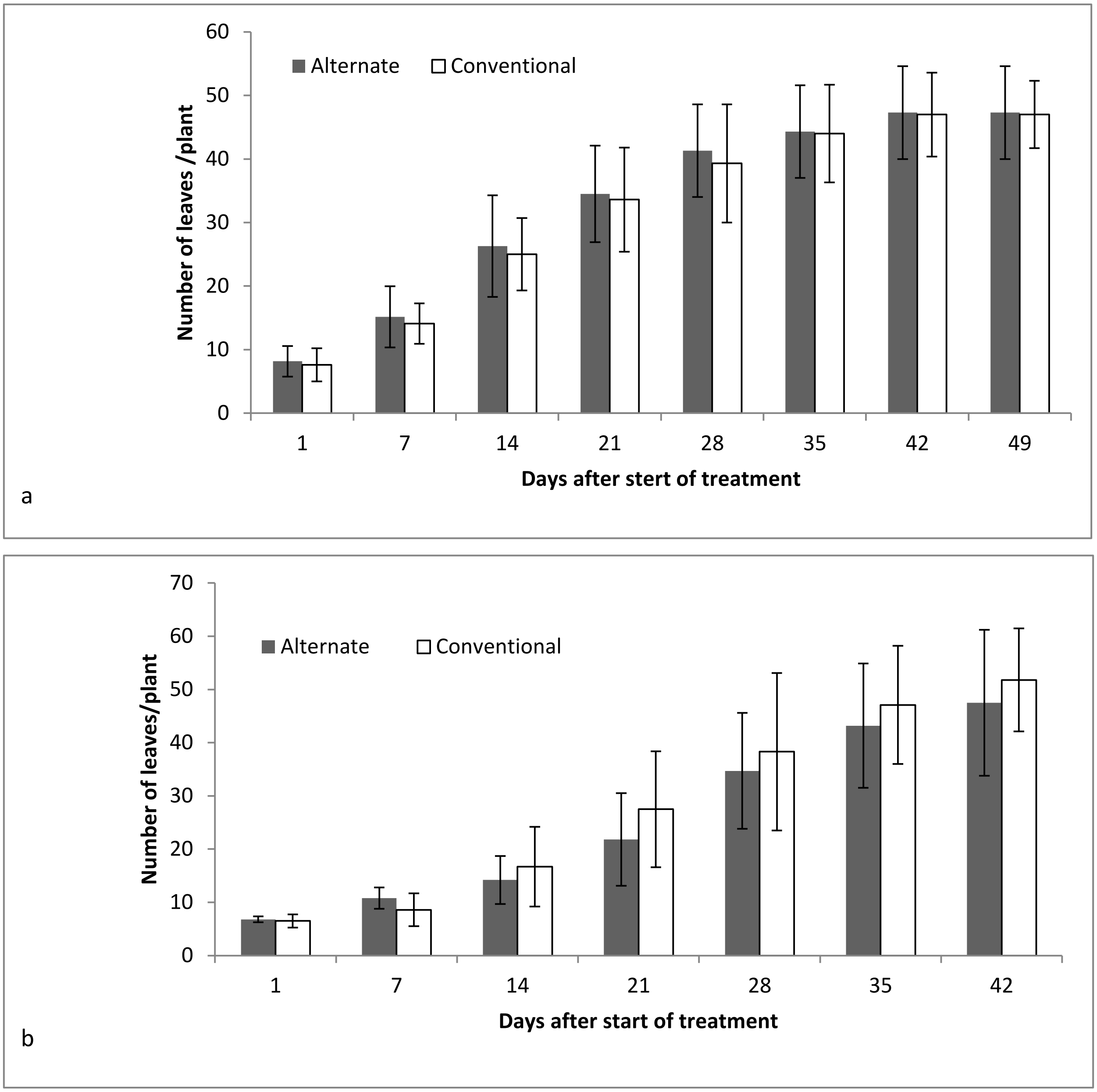


Figure 10: Number of leaves during the periods June-August 2010 and January-March 2011 in AFI and CFI treated tomato plots in Kibwezi. Vertical bars represent Confidence Intervals.

In 2010 AFI and CFI plants had 48 and 47 leaves per plant respectively while in 2011 the leaves were 49 and 51.

In the greenhouse the AFI plants had faster leaf initiation at the start of the experiment during every season but the CFI plants later surpassed them (Figure 11). This was despite that the crop had a mild attack by Powderly mildew and the CFI crops were more affected.

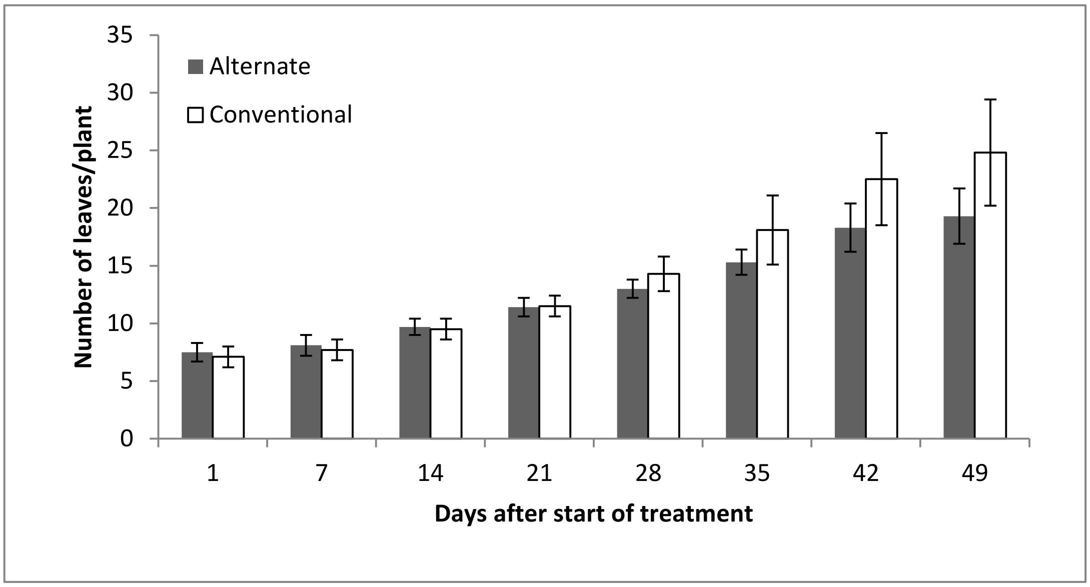


Figure 11:Number of leaves per plant during the periods July-August 2011 in AFI and CFI treated tomato plots in greenhouse at JKUAT.Vertical bars represent Confidence Intervals.

Similarly, the number of branches per plant showed no significant differences (P> 0.05) between CFI and AFI plants in both seasons (Figure 12). The AFI had 4.5 and 5.5 in 2010 and 2011 respectively. The CFI plants had 5 and 6 branches respectively in 2010 and 2011.

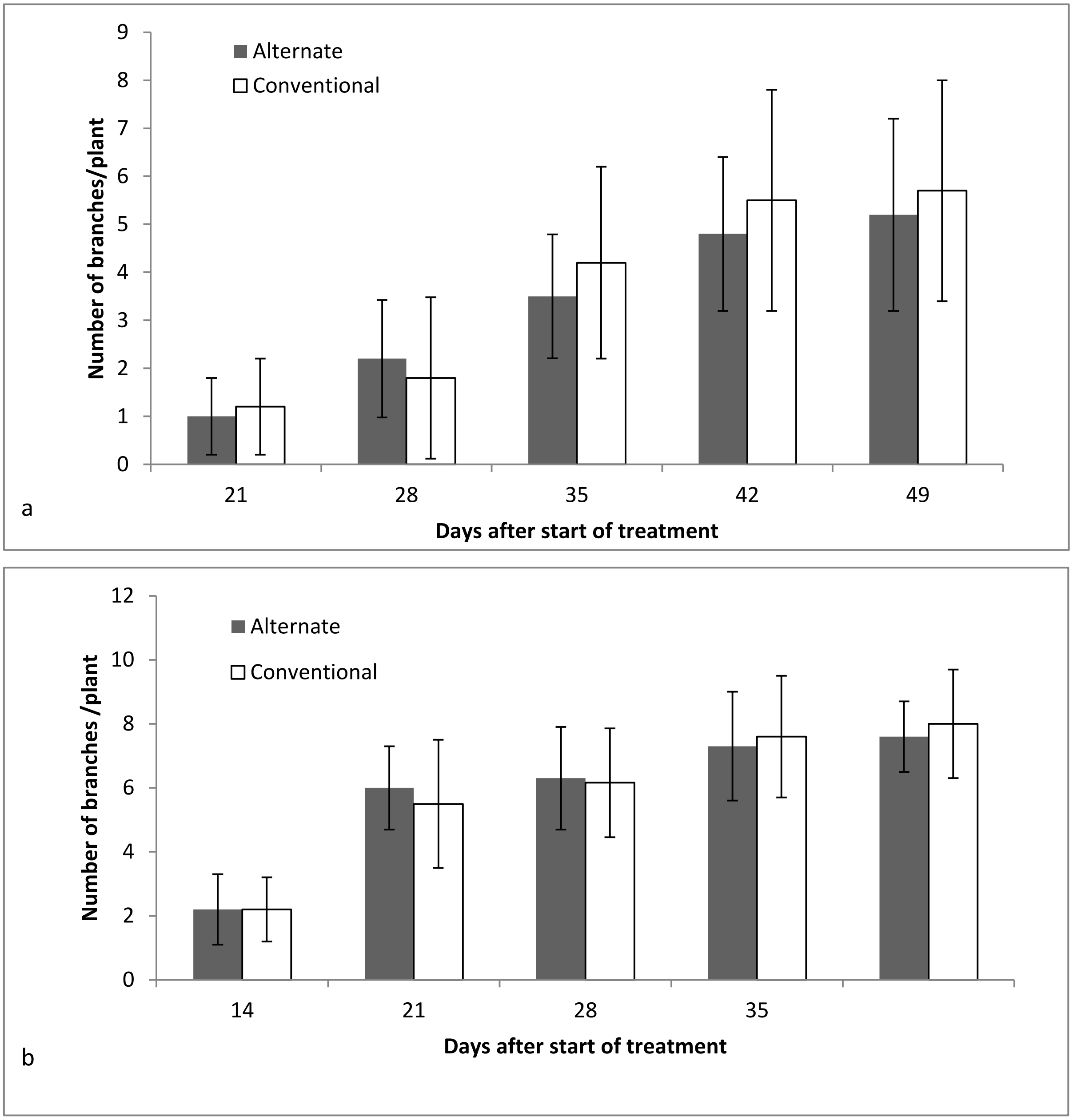


Figure 12:Number of branches/ plant during the periods June-August 2010 and January-March 2011 in AFI and CFI treated tomato plots in Kibwezi.Vertical bars are Confidence Intervals.

In the greenhouse branching among the AFI plants had similar trends as the leaves. They had higher number of branches but CFI later had similar numbers and later had more branches as shown in Figure 13.

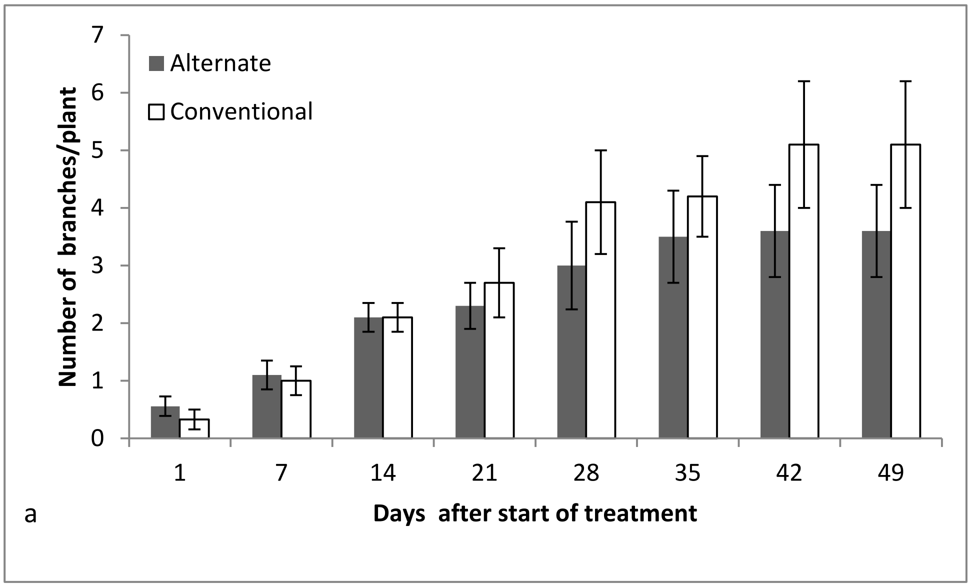


Figure 13: Number of branchesper plant during the periods July-August 2011 in AFI and CFI treated tomato plots in greenhouse at JKUAT.Vertical bars represent Confidence Intervals.

The AFI plants had higher number of trusses and fruits in 2010. However, there were no significant differences ($P > 0.05$) in number of trusses and fruits between CFI and AFI plants in both 2010 and 2011 (Figure 14). It was also noted that AFI shorted time to flowering and ripening.

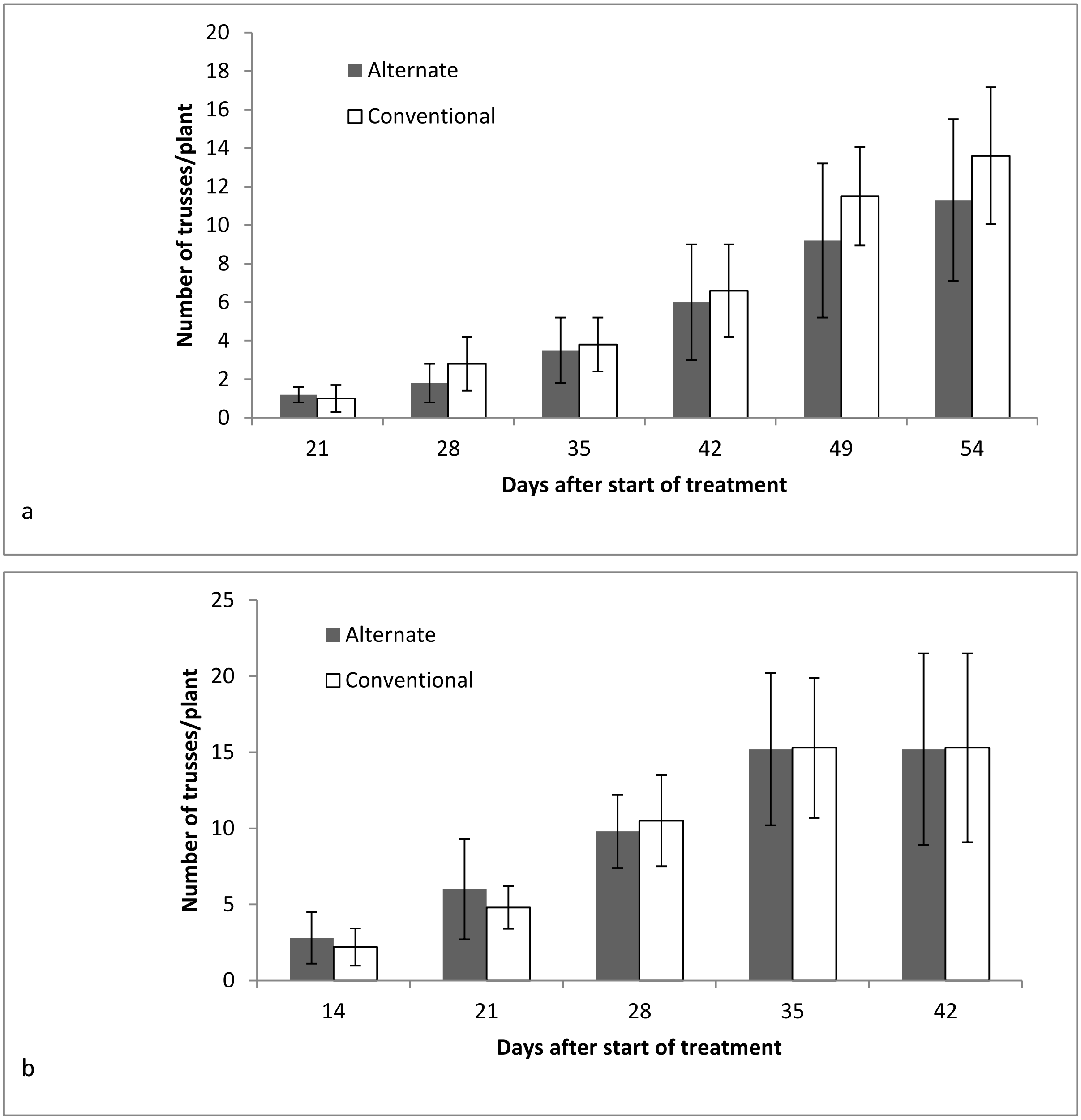


Figure14: Number of trusses/plant during the periods June-August 2010 and January-March 2011 in AFI and CFI treated tomato plots in Kibwezi.Vertical bars are Confidence Intervals.

In Figure 15, greenhouse AFI plants had higher number of trusses at start but CFI plant had a higher number at the end. It was also noted that AFI shorted time to flowering and ripening. (Table 5)

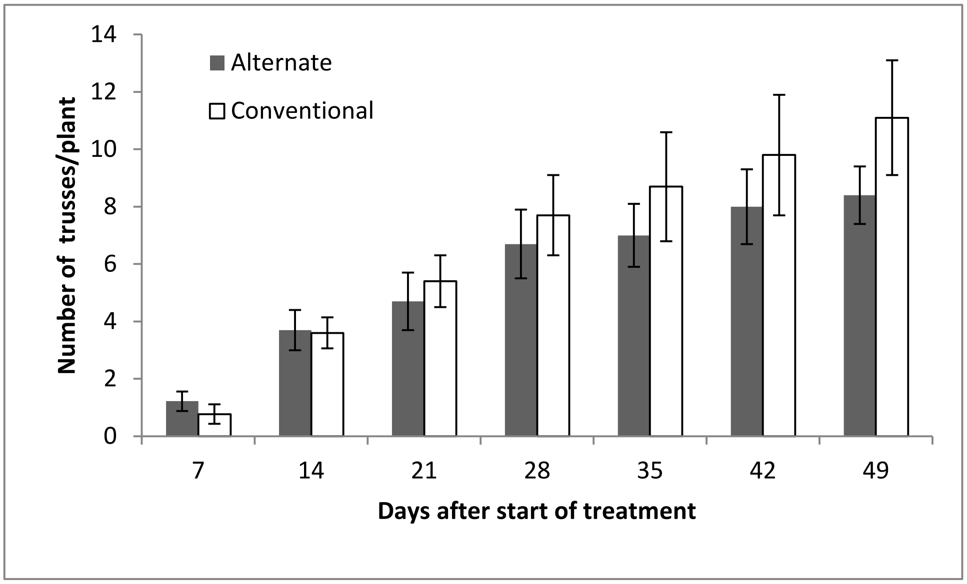


Figure 15: Number of trussesper plant during the periods July-August 2011 in AFI and CFI treated tomato plots in greenhouse at JKUAT.Vertical bars represent Confidence Intervals.

Table 5: Growth stages and cumulative irrigation water used on AFI and CFI treated tomato plots in kibwezi during the period June-August 2010 and period January – March 2011.

Period	Growth stage	Alternate		Conventional		TT Saving
		DAST	TT-irrigation(mm)	DAST	TT-irrigation(mm)	
June-August 2010	Flowering	7	44	14	119	75
	Fruiting	14	77	18	164	87
	Ripening	35	171	42	366	189
January-March 2011	Flowering	5	20	11	75	55
	Fruiting	13	51	18	128	77
	Ripening	31	125	38	325	200

DAST= days after start of treatment TT-irrigation = Total irrigation water applied (mm)

In the field and green house mostly AFI plants were noted to have similar number of fruits (Figure 16 and 17) with CFI plants at start but at the end CFI plants had more fruits though these were noted to be of small sizes. It was also noted that AFI shorted time to flowering and ripening (Table 6).

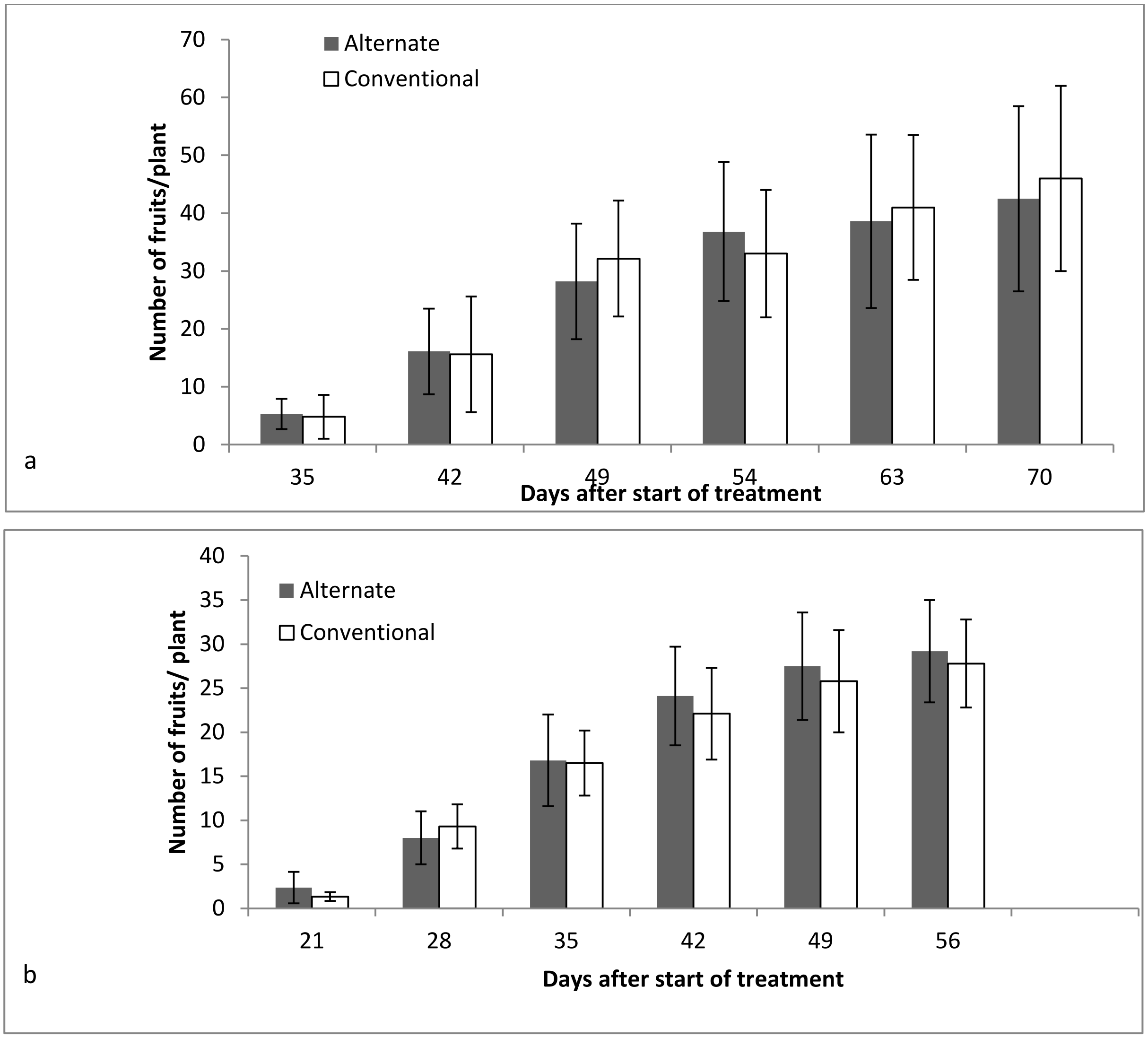


Figure 16: Number of fruits/plant during the periods June-August 2010 (a) and January-March 2011(b) in AFI and CFI treated tomato plots in Kibwezi. Vertical bars are Confidence Intervals.

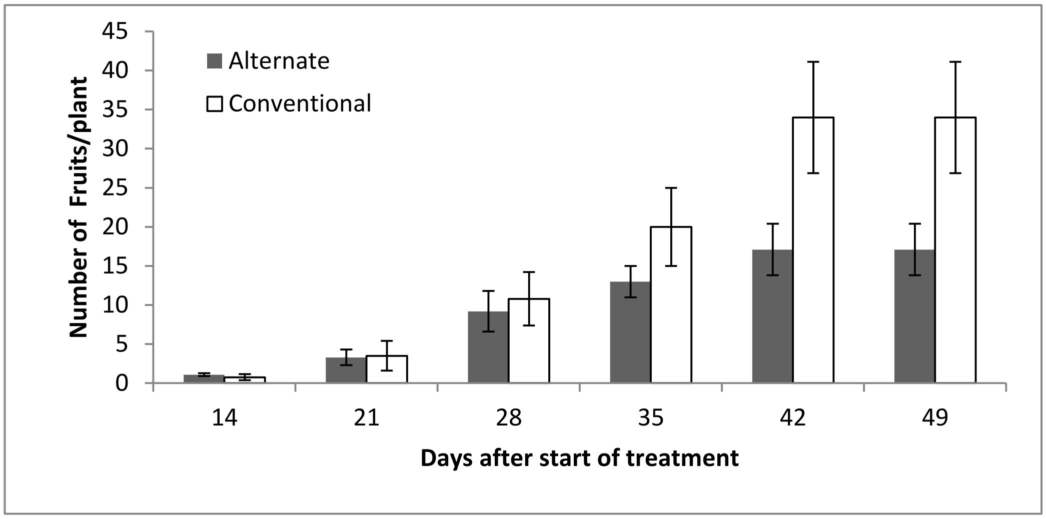


Figure 17; Number of fruits/plant during the periods July-August 2011 in AFI and CFI treated tomato plots in greenhouse at JKUAT.Vertical bars represent Confidence Intervals.

Table 6: Growth stages and cumulative irrigation water applied on greenhouse AFI and CFI treated tomato plots during the period July-August 2011.

Period	Growth stage	Alternate		CFI		TT Saving
		DAST	TT-irrigation(mm)	DAST	TT-irrigation(mm)	
July-August 2011	Flowering	10	64	20	178	114
	Fruiting	19	96	26	236	140
	Ripening	38	202	45	420	210

DST= days after start of treatment TT-irrigation = Total irrigation water applied (Liters)

The temporal variation in leaf area per plant in green house was determined (Figure18). The AFI and CFI plants had similar leaf areas at the very start but immediately afterwards the latter had higher leaf area always.

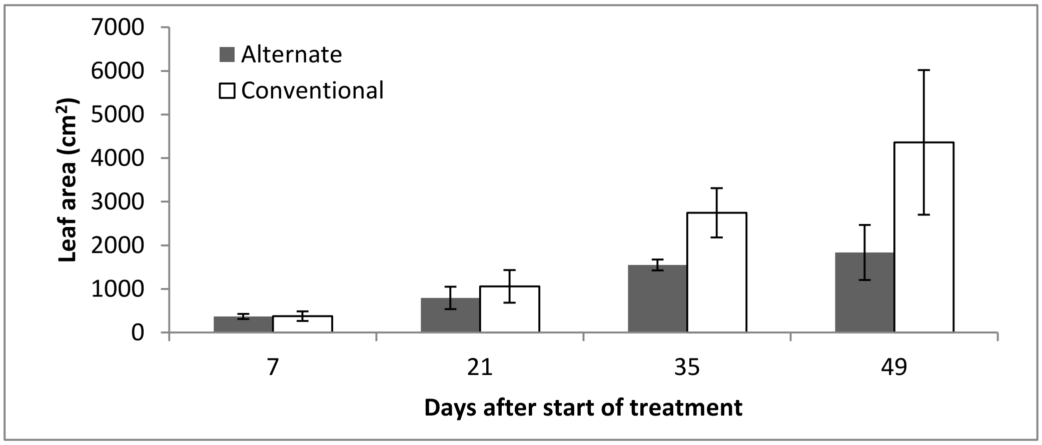


Figure 18: Leaf area per plant during the periods July-August 2011 in AFI and CFI treated tomato plots in greenhouse at JKUAT.Vertical bars represent Confidence Intervals.

Shoot dry matter (DM) biomass variations per plant in both 2010 and 2011 are shown in Table 7.The plants under CFI out performed those under PRD in shoot biomass (DM) accumulation. The average shoot DM for the AFI was60g while that of the CFI was115g.

Table 7: Shoot DM (g)accumulation after 50 days for the periods June-August 2010 and January-March 2011 in AFI and CFI treated tomato plots in Kibwezi.

		Period	
		June-August 2010	Jan- Mar 2011
Treatment	AFI	68a	75a
	CFI	108b	123b

Different Letters represent LSD (P≤0.05).

Table 8: Shoot DM/Biomass (g) accumulation during the period July-August 2011 in AFI and CFI treated tomato plots in greenhouse at JKUAT.

		Days after start of treatment				
		1	14	28	42	49
Treatment	AFI	1.6a	4.2a	13a	30a	46a
	CFI	1.9a	5.3a	20b	42b	59b

Different Letters represent LSD (P≤0.05).

4.2.5: Tomato Yields

Harvesting of tomatoes started after ripening was noted i.e at 35 and 42 DAST for AFI and CFI respectively. All of the produce had been harvested within one to two weeks after the 49 DAST. In the year 2010 and 2011 experiments the average yields of tomatoes for the AFI were 42 and 40 t/ha respectively as shown in Table 9. Those of the CFI plots were 52 and 49 t/ha. In both cases there were no significant differences (P>0.05) in yield. In year 2011, the fruit yields were low because of the disease attack. The CFI crops were more affected hence the yield for some plots were even lower than those under AFI. Average yield components of AFI and CFI are presented in Table 9. There were no significant differences (P> 0.05) noted in the two periods.

Table 9: Yield(t/ha) in AFI and CFI treated tomato in Kibwezi during the periods June-August 2010 and January-March 2011

		Period	
		June-August 2010	Jan- Mar 2011
Treatment	AFI	42a	40a
	CFI	52a	49a

Different Letters represent LSD (P≤0.05).

In greenhouse tomato fruit were weighed after hand harvesting as produce of the crop became ready and the total summed at the end. Harvesting started seven days after ripening was confirmed i.e at 35 DAST for AFI and 42 DAST for CFI. The harvesting durations were nearly the same for the field and greenhouse experiments probably because the greenhouse conditions mimicked the hot climate of Kibwezi. Hence the harvest durations were similar. Most of the produce had been harvested fourteen days after the 49 DAST. The average yields for the AFI were 54t/ha while that of the CFI plots was59t/ha. The differences between the two were not significant. Lower than expected yield may have resulted because of the disease attack. The CFI crops were more affected hence the yield was even lower than those under AFI. Yield components of AFI and CFI are presented in Table 10. It was noted that there was no significant difference (P> 0.05).

Table 10: Yield of AFI and CFI treated tomato (t/ha) during the periods July-August 2011in greenhouse at JKUAT.

		Period
		July-August 2011
Treatment	CFI	59a
	AFI	54a

Different Letters represent LSD ($P \leq 0.05$).

4.3: The collard experiment

4.3.1: Irrigation water use.

The period between June-August 2010 was dry. The AFI plots 6mx4m received an average amount of water between 32.5mm to 52.1 mm water per plot during an irrigation day while those of CFI with similar size received 54.2mm to 70.8 mm water per irrigation day (Table 11).

Table 11: Irrigation water quantities (mm)applied on AFI and CFI treated Kale plots inJune-August 2010 and January – March 2011.

Period	Treatment	Days after start of treatment									
		1	7	14	21	28	35	42	49	TT	Saving
2010	Alternate	21a	34a	30a	37a	40a	44a	42a	38a	286	
	Conventional	55b	54b	59b	58b	55a	65b	69b	71b	487	199
2011	Alternate	17a	20a	22a	20a	27a	29a	31a	31a	187	
	Conventional	36b	39b	35b	33b	43b	46b	53b	48b	333	146

Different Letters represent LSD (P≤0.05).

Thus the amounts were significantly different (P≤0.05) in most of the irrigation days for AFI and CFI except on day 28. The cumulative totals for AFI and CFI plots in year 2010 were 286mm and 487mm as noted after 49 DAST A total savings of 199mm was achieved when AFI was used.

Fairly dry weather prevailed during the period January-March 2011. The AFI plots (6mx4m) received average amounts of water between 18.75mm to29.2 mm of water per irrigation day while those of CFI with similar size received between 33.3mm to 58.3mm of water per irrigation day (Table 11). Thus the amounts per plot were significantly different (P≤0.05) in most of the days for AFI and CFI except on day 35. The cumulative totals for AFI and CFI plots were 187mm and 333mm as noted after 49 DAST. A total savings of 146mm was achieved when AFI was used.

4.3.2: Soil Moisture Content

The temporal and spatial variations of SMC for the periods June-August 2010 and January-March 2011 are presented in Figure 19.

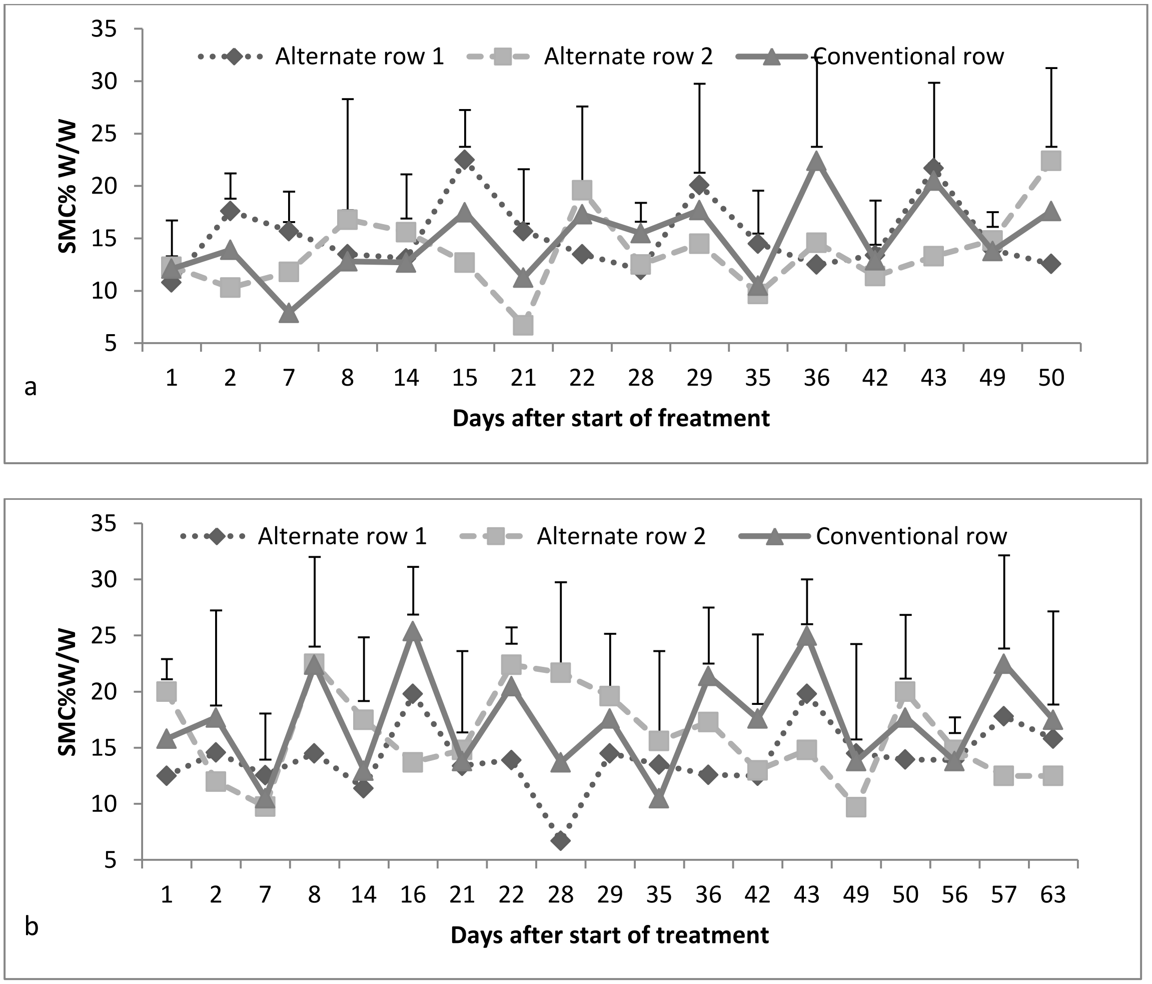


Figure 19: SMC variations during the periods June-August 2010 (a) and January-March 2011 in AFI and CFI treated Kale plots in Kibwezi. (LSD at P≤0.05).

The soil moisture under AFI followed an alternate pattern with high levels in the watered furrow and low levels in the non-watered furrow. In the 2010 and 2011 experiments the SMC ranged 15-20% in the watered furrows immediately after irrigation and progressively decreased to lows of 6-12% during the non-watered time in the two seasons. The soil moisture pattern in this treatment followed a two week cycle. CFI plots on the other hand exhibited an increase and decrease soil moisture pattern in a one week cycle in line with the weekly irrigation for both seasons. During most of the time, the CFI plots had high soil moisture in the rows than the unwatered AFI rows in both seasons. This was significant on 2,15, 36,43 and 50 DAST in 2010 and 8, 16, 22, 36,43 and 50 DAST in 2011.

4.3.3: Relative Water Content (RWC).

The relative water content of the leaves was increasing and decreasing in a weekly pattern in cycles for both AFI and CFI treated plants in both 2010 and 2011. The RWC oscillations generally revolved around 95% and 75% in the 2010 and 90% and 70% in 2011respectively (Figure 20).

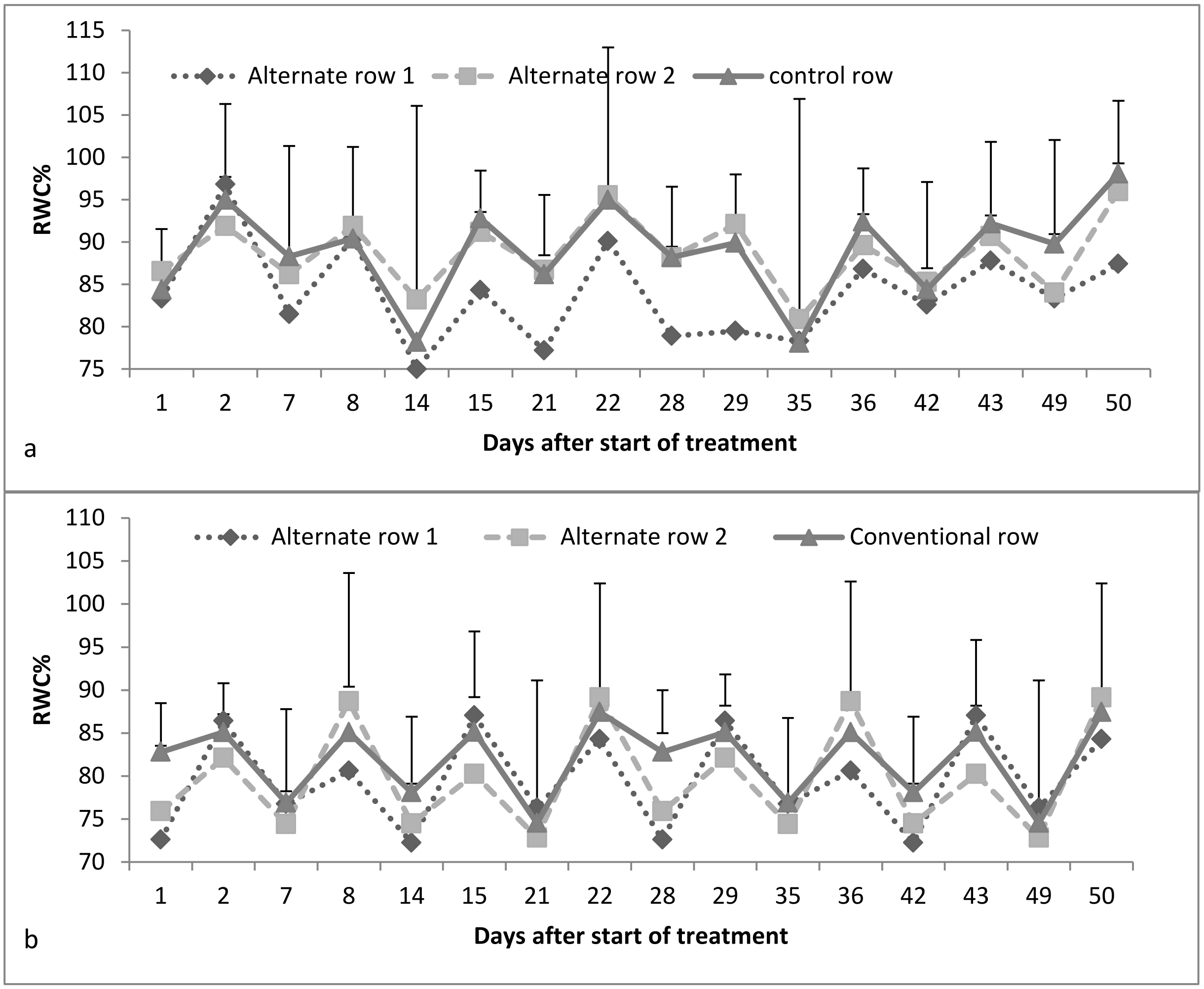


Figure 20: RWC of leaves during the periods June-August 2010 and January-March 2011 in AFI and CFI treated Kale plots in Kibwezi. (LSD at P≤0.05).

The RWC of plants under CFI was generally higher than plants under unwatered AFI rows for most of the period in both seasons. The lowest levels reached were 75% on the 14th DAST in 2010 and 72% on 7, 21, 28 and 42 DAST in 2011.

It was noted that the average RWC of plants under AFI prior to watering in 2010 ranged between 75-82% and 72-75% in 2011. The CFI plants prior to watering ranged between 78-88% in 2010 and 75-78% in 2011. The range for both AFI and CFI after watering in 2010 was 90-97% and 85-90% in 2011.

4.3.4: Plant growth trends.

In this study the plant heights and leaf numbers of sampled collard plants under both AFI and CFI were not significantly different (P>0.05) for most of the time in both seasons as shown in Figures 21 and 22. The final height for AFI and CFI plants was 22cm and 24cm respectively in 2010. In 2011 the heights were 26cm and 29cm.

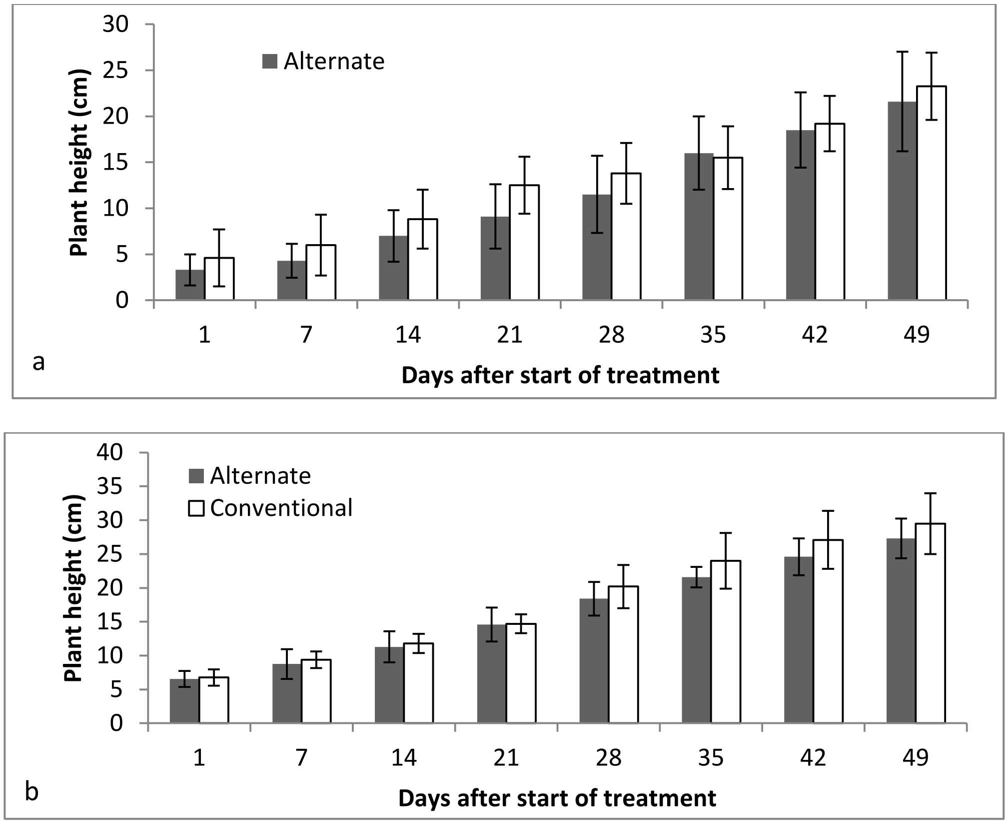


Figure21: Plant heightduring the periods June-August 2010 and January-March 2011 in AFI and CFI treated Kale plots in Kibwezi.Vertical bars represent Confidence Intervals.

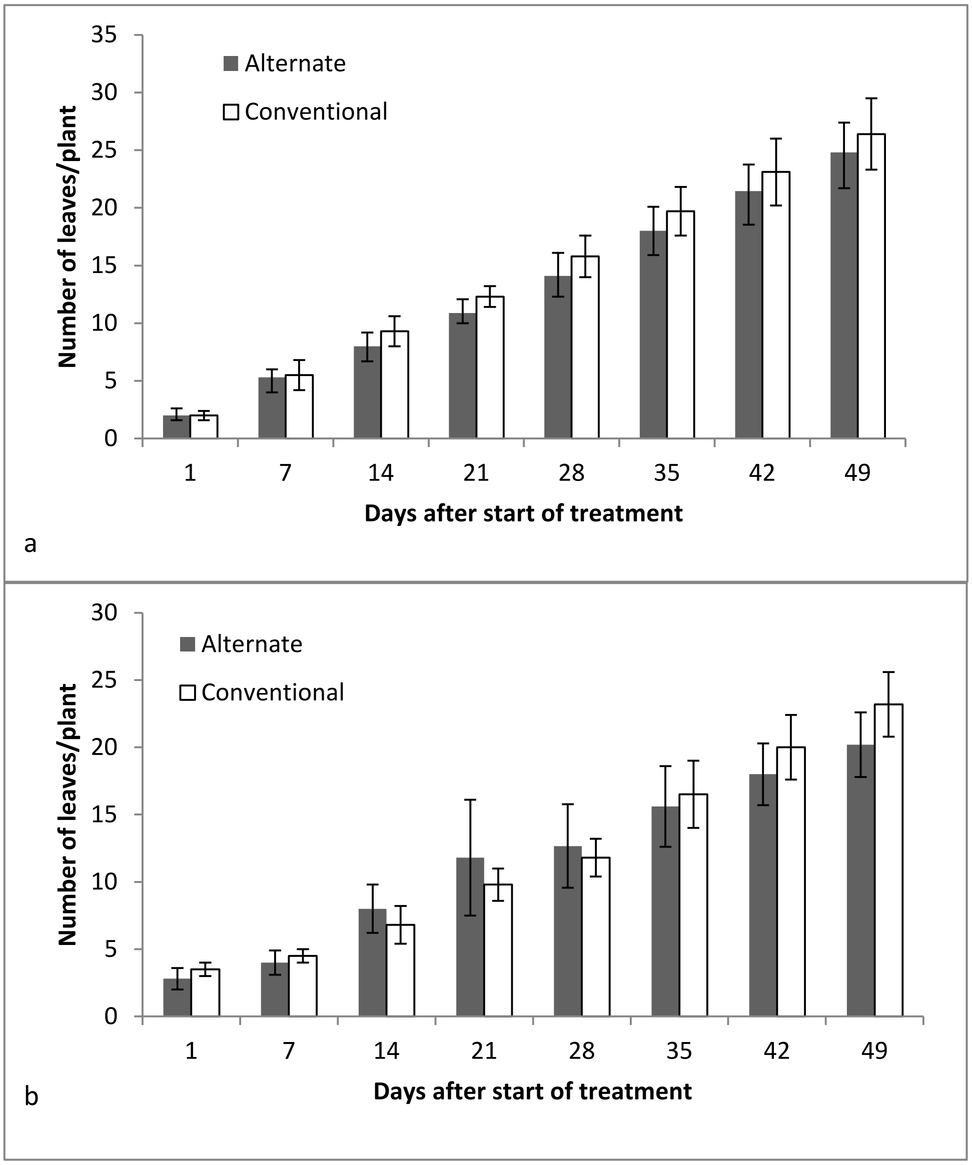


Figure 22: Plant leaves during the periods June-August 2010 and January-March 2011 in AFI and CFI treated Kale plots in Kibwezi. Vertical bars represent Confidence Intervals.

The average shoot DM per plant at the end for the AFI in year 2010 and year 2011 were 204g and 210g respectively, while that of the CFI were 305g and 228g respectively (Table 12). Temporal variations in DM accumulation for AFI and CFI are shown in following Table 12.

Table 12: Shoot DM/Biomass (g) accumulation during the periods June-August 2010 and January-March 2011 in AFI and CFI treated Kale plots in Kibwezi.

		Period(50 days)	
		June-August 2010	Jan- Mar 2011
Treatment	AFI	204a	210a
	CFI	305b	228b

Different Letters represent LSD (P≤0.05).

4.3.5: Harvesting and Yields.

In year 2010 and year 2011experiments the average yields were as in Table 13. For AFI the yields were 60 and 37 t/ha respectively. Those of the CFI plots were 65 and 40 t/ha. In both cases there were no significant differences in yield (P> 0.05).

Table 13:Yield of AFI and CFI treated Kale (t/ha) during the periods June-August 2010 (a) and January-March 2011 in Kibwezi.

		Period	
		June-August 2010	Jan- Mar 2011
Treatment	CFI	65a	40a
	AFI	60a	37a

Different Letters represent LSD (P≤0.05).

4.4: **The cabbage experiment**

4.4.1: Irrigation water use.

The AFI plots (6 m x4 m) of cabbage during the period June-August 2010 received an average amount of water between 31mm to 50mm water per irrigation day while those of CFI received amounts of water between 66 mm to 73mm water per irrigation day (Table 14).

Table 14: Irrigation water quantities(mm) applied on AFI and CFI treated cabbage plots inJune-August 2010 and January – March 2011.

Period	Treatment	Days after start of treatment									
		1	7	14	21	28	35	42	49	TT	Saving
2010	Alternate	31a	35a	32a	37a	43a	50a	46a	50a	324	
	Conventional	66b	66b	68b	68b	61b	76b	73b	76b	554	230
2011	Alternate	24a	19a	23a	20a	27a	25a	39a	43a	220	
	Conventional	36b	36b	39b	33b	46b	58b	60b	66b	374	150

Different Letters represent LSD ($P \leq 0.05$) TT- cumulative total (49 DAST)

The variances represented significant differences ($P \leq 0.05$) of water use between AFI and CFI. The cumulative totals for AFI and CFI plots in year 2010 were 324mm and 554mm as noted on day 49. A total saving of 230mm was achieved.

During the period January-March 2011the AFI plots (6mx4m) received an average amount of water between 19mm to 43 mm water per irrigation day while those of CFI with similar size received 33mm to 66mm of water per irrigation day. The cumulative total amounts for AFI and CFI plots were 220mm and 374mm as noted after 49DAST.A total savings of 150mm was achieved when AFI was used.

4.4.2: Soil Moisture Content.

The temporal and spatial variations of SMC for the periods June-August 2010 and January-March 2011 are presented in Figure 23.

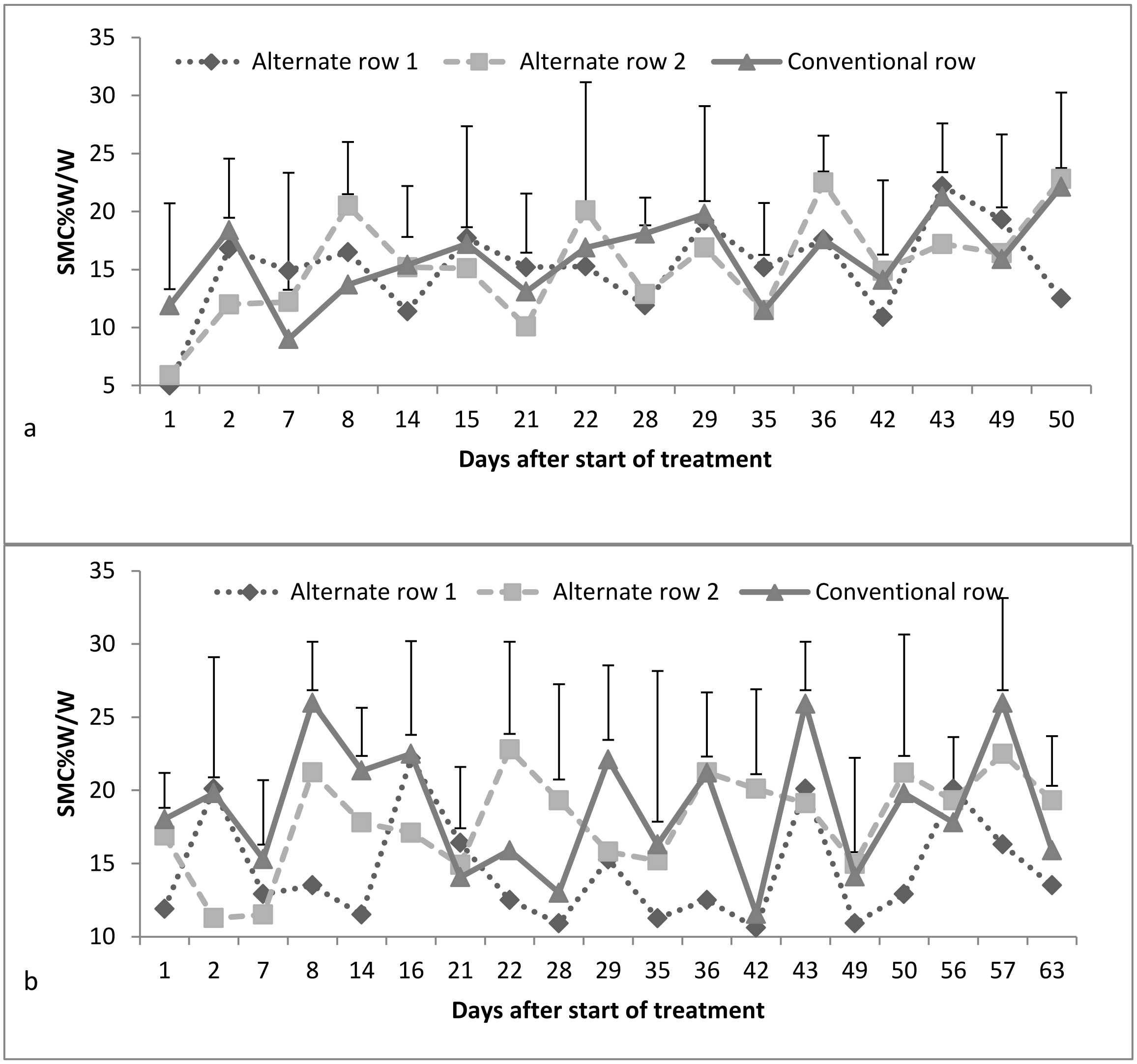


Figure 23: SMC variations during the periods June-August 2010 (a) and January-March 2011 in AFI and CFI treated cabbage plots in Kibwezi. (LSD at P≤0.05).

The soil moisture under AFI followed an alternate pattern with high levels in the watered furrow and low levels in the non-watered furrow. In the 2010 and 2011 experiments the SMC ranged 20-25% in the watered furrows immediately after irrigation and progressively decreased to lows of 8-13%during the non-watered time in the two seasons. The soil moisture pattern in this treatment followed a two week cycle. CFI plots on the other hand exhibited an increase and decrease soil moisture pattern in a one week cycle in line with the weekly irrigation for both seasons. During most of the time, the CFI plots had high soil moisture in the rows than the unwatered AFI rows in both seasons. This was significance on 2, 8, 36, and 50 DAST in 2010 and 2,8,22,36,43 and 50 DAST in 2011.

4.4.3: Relative Water Content.

During the two experiments June-August 2010 and January-March 2011 the relative water content of the leaves was increasing and decreasing in a weekly pattern in cycles for both AFI and CFI treated plants (Figure 24).

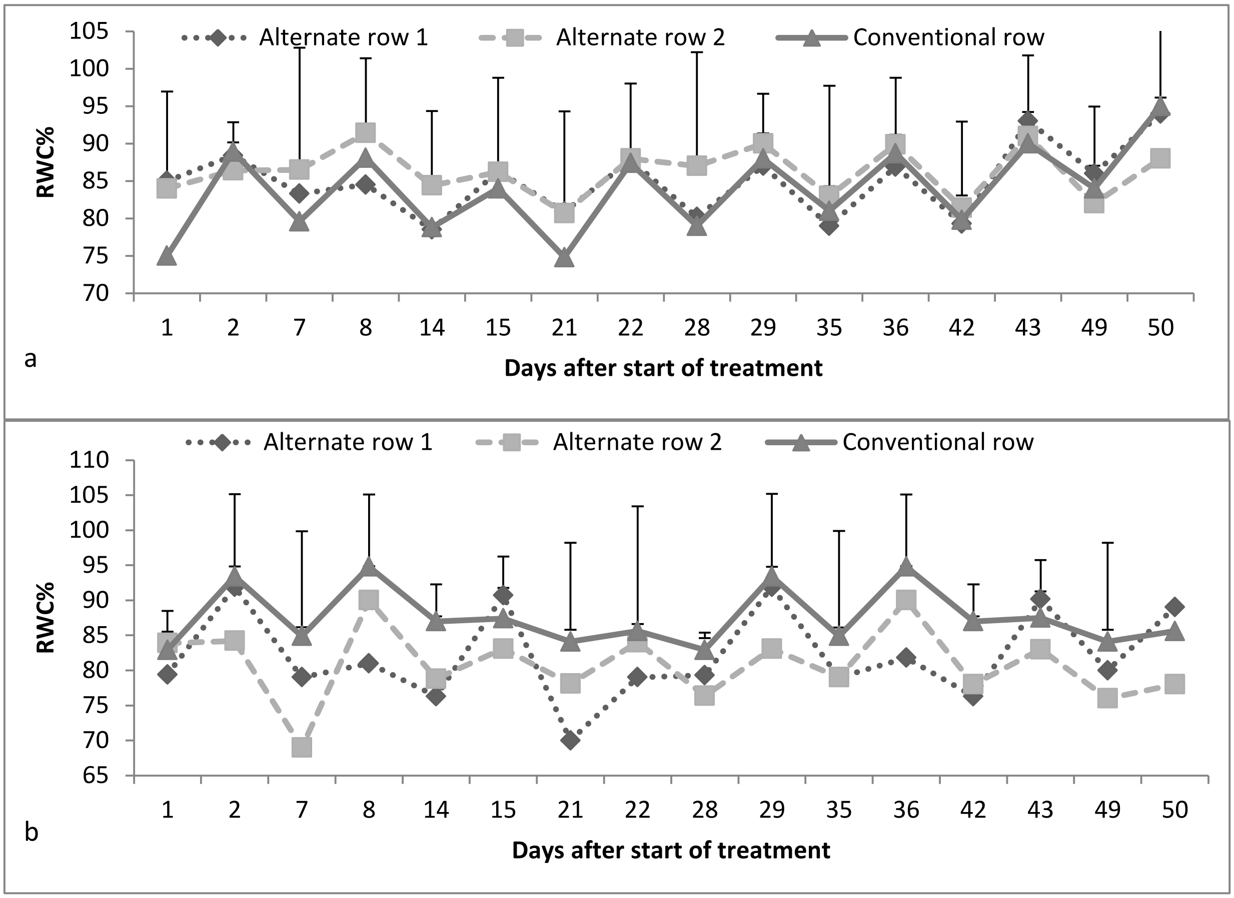


Figure 24: RWC of leaves during the periods June-August 2010 (a) and January-March 2011(b) in AFI and CFI treated cabbage plots in Kibwezi. (LSD at P≤0.05).

The RWC varied between 95% and 75% in the 2010 and 95% and 70% 2011 seasons. The RWC of plants under CFI was generally higher than plants under unwatered AFI rows especially in 2011. The lowest levels reached were 75% on day 21 in 2010 and 70% on day 7 and 21 in 2011.

It was noted that the average RWC of plants under AFI and CFI prior to watering ranged between 72-86%. The range after watering was between 80–95%.

4.4.4: Plant growth trends.

In this study the sampled cabbage plants under both AFI and CFI had near constant rate of increase in leaf numbers and head diameter for most of the time in both seasons (Figure 25 and 26).

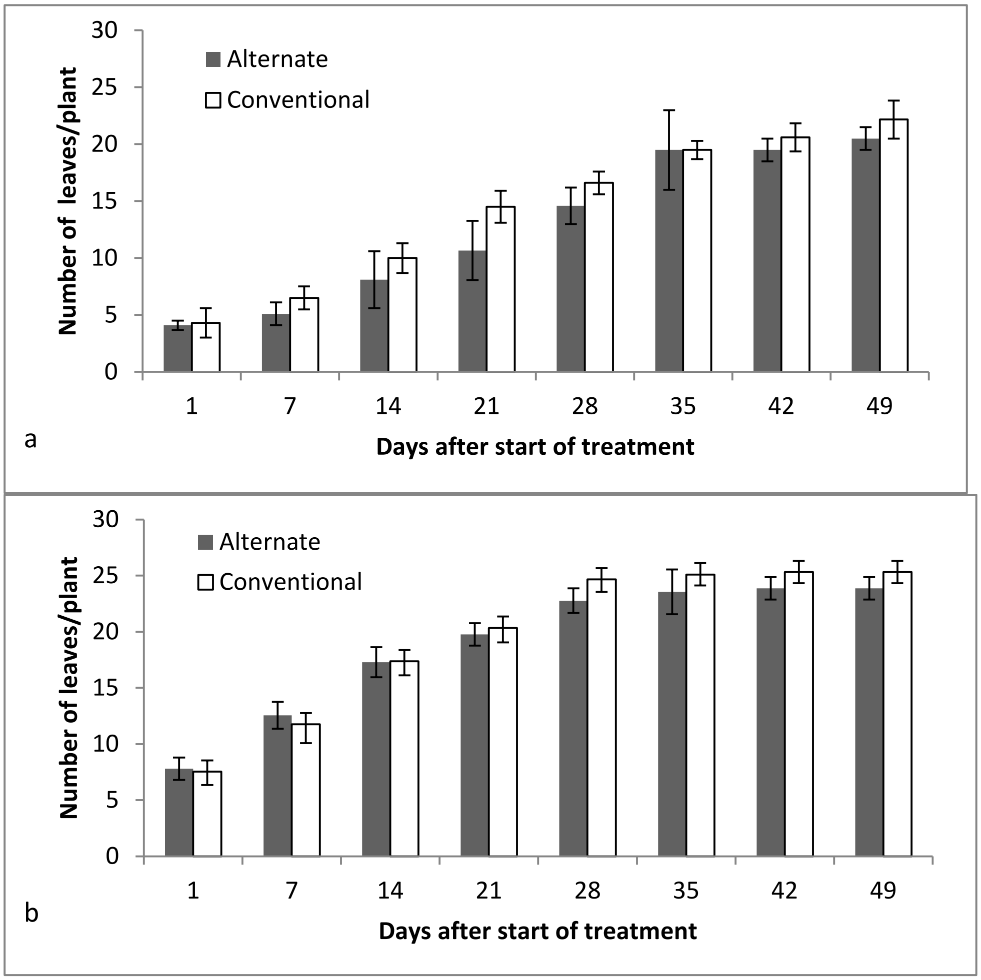


Figure 25: Number of leaves (a-b)during the periods June-August 2010 and January-March 2011 in AFI and CFI treated cabbage plots in Kibwezi.Vertical bars represent Confidence Intervals.

The AFI plants had 21 and 24leaves in 2010 and 2011 respectively while CFI plants had 23 and 25 leaves in 2010 and 2011. The final average head diameter for AFI and CFI plants was 18cm and 20cm respectively in 2010, 17cm and 19 cm in 2011.

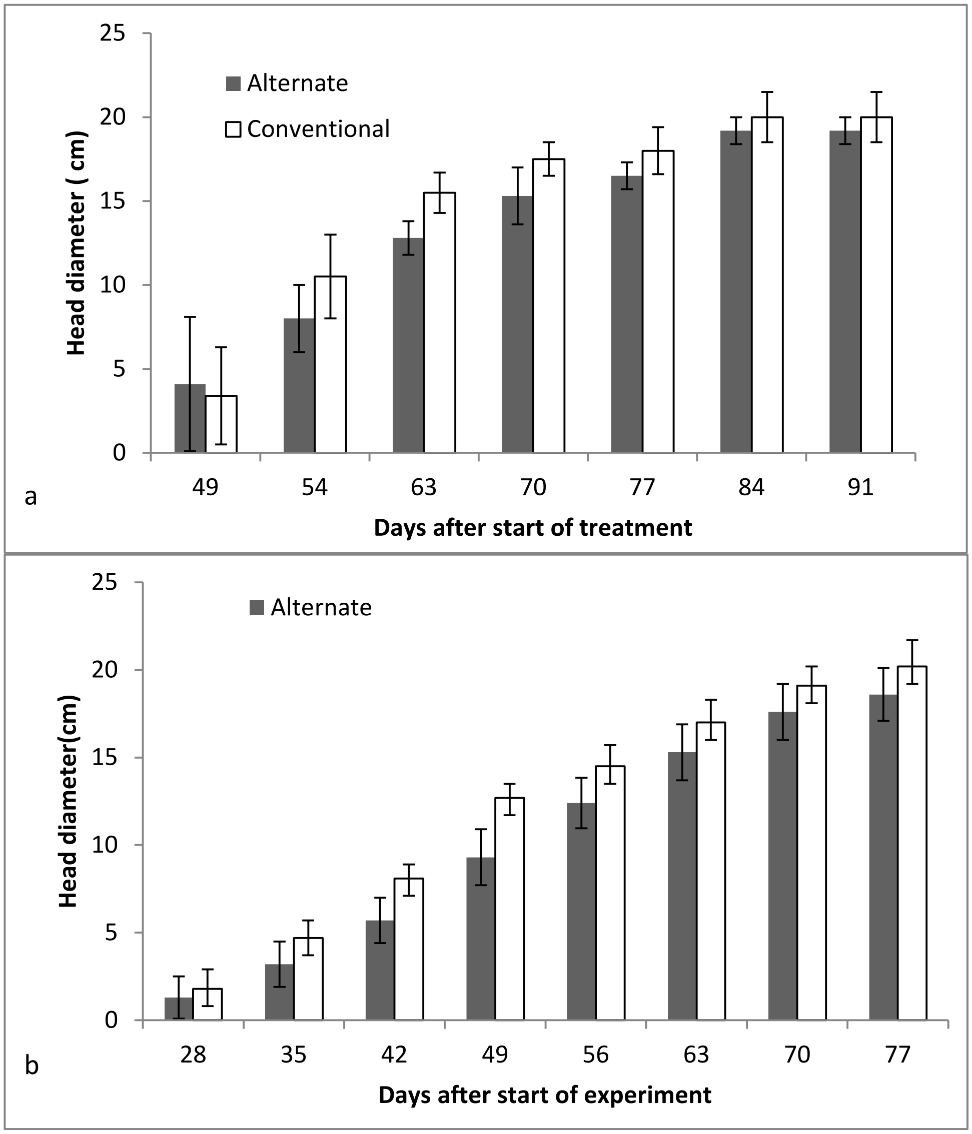


Figure 26: Head diameter during the periods June-August 2010 and January-March 2011 in AFI and CFI treated cabbage plots in Kibwezi.Vertical bars represent Confidence Intervals.

The average shoots DM per plant at the end for the AFI in year 2010 and year 2011 were 157g and 151g respectively, while that of the CFI were 243g and 202g respectively (Table 15).

Table 15: Shoot DM/Biomass accumulation(g) during the periods June-August 2010 and January-March 2011 in AFI and CFI treated cabbage plots in Kibwezi.

Treatment	Period	
	June-August 2010	Jan- Mar 2011
AFI	157a	151a
CFI	223b	202b

Different Letters represent LSD (P≤0.05).

4.4.5: Harvesting and yields

The cabbage heads were weighed after hand harvesting when they matured at the end of the period. For year 2010 and year 2011the average yields for the AFI were 102 and 56 t/ha respectively. Those of the CFI plots were 115and 59 t/ha. The yield in 2011was lower than that of year 2010after rotating plots possibly because this affected water infiltration in the soil.

Yield components of AFI and CFI are presented in Table 16. It was noted that AFI had noticeable but not significant effect on cabbage yields. This may have resulted because of the noted trend that cabbages under AFI had slightly smaller heads (diameter) than those in CFI. Otherwise there was no significant difference (P> 0.05) in yield.

Table 16: Yield in AFI and CFI treated Cabbage (t/ha) during the periods June-August 2010 and January-March 2011 in Kibwezi

Treatment	Period	
	June-August 2010	Jan- Mar 2011
AFI	102a	56a
CFI	115a	59a

Different Letters represent LSD (P≤0.05).

CHAPTER FIVE

5.0: DISCUSSION

5.1: The Tomato experiment.

In both field and greenhouse experiments, less water was used under AFI than the CFI. The amounts applied and used were significantly different ($P \leq 0.05$) and hence there was considerable savings under AFI though this was not 50% as can be expected. This may have been partly because of dry soil hysteresis behavior (Dodd *et al*, 2006) and again because in AFI only a section of soil in the plots was wetted and surface tension assisting to keep much of the water only to these sections (Boyer & Westgate, 2004). Thus in year 2010 there was 196 mm savings and in year 2011 savings of up to 140mm were realized in the field experiments. Water savings of 45% and 41% for 2010 and 2011 respectively were realized. In earlier studies by Menelik, water savings of between 42% and 46% have been realized (Menelik *et al*, 2010). For the greenhouse experiment 49% water savings were achieved under AFI. This is explained by the fact that for the same soil water potential, dry soil is known to take more water than previously wet soils (Dodd *et al*, 2006, Kang *et al*, 2000). In earlier studies by Kang, up to 50% savings were realized by growing maize crop by AFI method in the laboratory (Kang *et al.* 2000).

SMC in the alternate furrows of the AFI treatment were different during the alternate wetting and drying cycle i.e they alternately increased and decreased. SMC of the wetted/irrigated furrows was higher than that of drying furrows. But soil water content was found to be relatively constant or increased slightly one day after irrigation in the skipped furrows in all the days except on day 16 and 50. This may have been caused by lateral infiltration or redistribution of water through the soil (Kang *et al*, 2000). The SMC in the CFI treatment furrows and that of the previously watered furrows tended to be higher than that of previously dry currently watered rows and remained significantly different ($P \leq 0.05$) from the drying unwatered furrow until a succeeding watering. However the SMC trends in all furrows of the CFI treatment were similar. Unlike field situation where SMC in watered furrows was noted to decline fast, in the greenhouse experiment this SMC decrease occurred over a longer time.

During the first two weeks the RWC changes ranged from 75% to 85% and hence were not very marked for both experiments probably because of the remnant pretreatment moisture. In general the variations of leaf water status measured during the vegetative growth and reproductive stage ranged from 65%to 95% and showed that crops under AFI and CFI had similar changes in the field and green house. The differences between them were not significant if irrigation was done at same time. So AFI did not lead to a leaf water deficit that might have contributed to growth regulation. It is evident that the roots in the watered side supply adequate water to the plant and this maintains more or less similar RWC in both AFI and CFI plants. Earlier studies have showed that RWC has a direct relation with growth and yields of leafy vegetables- height, number of leaves and leave area, branching and others (Gaveh, Timpo, Agodzo, Dong, 2011; Masinde, ,Stützel, Agong & Fricke, 2006).

In both field and greenhouse experiments the heights, number of leaves and biomass (shoot DM) of the plants under AFI were evaluated to determine response of the crop to PRD and were found to be sensitive to the stress resulting from the treatment (suggesting high production of ABA).At the end the field experiment AFI plants were on average 45-50 cm tall, had about 45 leaves and upto 12 trusses with about 40-45 fruits on 5-6 branches per plant. Hence were noted to be shorter, had less leaves and biomass at the end than CFI plants which noted to be on average 50-60 cm tall, with 50-60 leaves, 15 trusses and upto 45-50 fruits on 6-8 branches. This represented a reduction of upto 25% reduction in height, 17.5% in number of leaves, 20% in number of trusses and 25% number of branches and 20% number of fruits in the AFI plants. But this did not result to significant differences (P>0.05). This is in line with many other studies which have reported ABA inhibition of shoot growth under PRD (Stoll *et al*, 2000) and hence reduction in various growth parameters. Stickic showed that tomato plants grown under PRD had 26% reduction in height, 10% reduction in number of leaves and 30% reduction in the number of fruits (Stickic *et al*, 2003). In the greenhouse the was

10%,15%,30%,25%, and 40 % reduction in height, leaves, branches, trusses and fruits per plant respectively. Also in the green house leaf area per plant reduced by 60% in AFI compared to CFI. This was a significant difference ($P \leq 0.05$).

The decline in height, leaves and other growth parameters among AFI crops is attributed to production of drought adjustment substance Abscisic Acid (ABA) which causes reduction of growth (Chaves *et al,* 2004). ABA is produced in PRD treated crops because of false drought signals elicited in the plants from the roots in the side of drying soil though the plant has adequate water in its systems supplied by the roots in the watered side of the soil. Under water stress plants are known to modify their growth characteristics to reduce water loss by closing stomata, reduction of leaf area and even leaf abscission (Gaveh *et al,* 2011). In a world where rainfall is unpredictable as in the ASALs these regulation mechanisms mean that the plant must be able to detect the soil drying and then respond by regulating water consumption- feed forward mechanism (Kang *et al,* 2004). They also confer some advantage of reducing plant shoot intensity making easier light penetration, spraying all of which assist maintain the plant health (Stoll *et al*, 2000). It has been showed in the past studies that PRD treated plants produce and sent more and hence strong drought signals (ABA) to the shoots than conventionally watered plants leading to less growth and leaf initiation hence less biomass accumulation (Fulai *et al,* 2006; Davies *et al,* 2000). The cumulative less significant differences in height, leaves and branches may have led to the significant difference in shoot DM**.** Conventionally watered plants send weaker signals to shoots resulting to late flowering.

In both these experiments the AFI plots yields were slightly less than the CFI plots. This was despite the observation that the CFI plants had more trusses and fruits than the AFI plants may be ostensibly because of lower average fruit weight amongst the CFI fruits. But there were no significant differences ($P > 0.05$) in yield although in year 2011, there were lower than expected yield because of early blight disease attack. The CFI crops were more affected hence the yields were even lower than those under AFI, suggesting that AFI may also be a suitable technology to mitigate some of the diseases because it does not encourage excessive soil.

5.2: The Collard experiment.

In both seasons, less water was used under AFI than the CFI. There was considerable savings under AFI though this was not 50% as expected. This may explained by the fact that for the same soil water potential, dry soil is known to take more water than previously wet soils (Dodd *et al*, 2006; Kang *et al*, 2000). Thus in 2010 there was 41% savings and in2011 savings of upto 45% were realized. This is in agreement with earlier studies that have showed that upto 46% saving can be achieved.

In the plots planted with Collards (*Brassica oleraceae var acephala*), SMC in the AFI treatment were different during the alternate wetting and drying cycles ie they alternately increased and decreased. SMC of the irrigated furrows was higher than that of drying furrows. But soil moisture content was found to be relatively constant or increased slightly one day after irrigation in the skipped furrows as noted for all irrigation days except on day 21 in 2010 and day 29 in 2011 and hence no significant difference ($P>0.05$). This may have been caused by lateral infiltration, redistribution and equilibration of water in the soil (Kang *et al*, 2000). The SMC in the CFI treatment was mostly higher than that of the previously watered furrow and tended to even be much higher than and significantly different ($P\leq0.05$) from the drying furrow. This may be because repeated wetting and drying have been shown to prevent dry soil from rehydrating to the same capacity as previously wet soil(Dodd *et al*, 2006; Kang *et al*, 2000). However the SMC trends in all furrows of the CFI treatment were similar. Water savings of 33% and 41% of the water used in CFI for year 2010 and year 2011 respectively were realized when AFI was used.

The variations of RWC of plants measured during the vegetative growth and reproductive stage showed that crops under AFI and CFI had similar changes and that the differences between them were not significant if irrigation was done at same time. So AFI did not lead to a leaf water deficit that might have contributed to growth regulation. It is evident that the roots in the watered side supply adequate water to the plant and this maintains more or less similar relative RWC in both AFI and CFI plants.

AFI thus did not affect growth parameter trends noticeably. The CFI plants were taller than the AFI plants most of the time. There was 8% reduction in height amongst AFI plants. The CFI treated plants had a similar leaf initiation at start of the seasons but the CFI had more leaves until the end of the season in both cases. At the end AFI plants had 12% less leaves than the CFI plant. Consequently therefore, the plants under CFI finally out performed those under AFI slightly in biomass (DM) accumulation in both seasons. In earlier studies reduction in plant height, number of leaves has been reported in spinach (Afetsi *et al,* 2011) and leafy vegetables e.g black nightshade (Masinde *et al,* 2006).

In this experiment the heights, number of leaves and shoot biomass (DM) of the plants under AFI were evaluated to determine response of the crop to water stress and were found to be sensitive to the stress resulting from the treatment (suggesting high production of Abscisic acid - ABA) and hence were noted to be shorter, had less leaves and biomass at the end than CFI plants, but this did not result to significant differences. This is in line with many other studies which have reported reduction in shoot growth under AFI. The decline in height, and leaves among AFI crops is attributed to production of drought adaptive substance ABA which causes reduction of growth (Chaves *et al,* 2004). ABA is produced in AFI treated crops because of false water stress/drought signals elicited in the plants from the roots in the side of drying soil though the plant has adequate water in its systems supplied by the roots in the watered side of the soil. Under water stress plants are known to modify their growth characteristics to reduce water loss e.g closing stomata, reduction of leaf area and even leaf abscission (Afetsi *et al,* 2011). It has been showed in the past studies that PRD treated plants produce and sent more and hence strong drought signals (ABA) to the shoots than conventionally watered plants leading to less growth and leaf initiation hence less biomass accumulation (Fulai, Shahnazari, Mathias, Sven-Erik, Christian, 2006; Davies *et al,* 2000; Dodd *et al,* 2006) and consequently yield, because the harvestable part in this case are the plant leaves. Although the AFI yields were less than those of CFI in agreement with this, but the difference was not significant.

On harvest, an important note was made in that the leaves of the AFI crop were found to have developed slight bitterness taste. This may be associated with increased levels of stress associated phytochemical compounds eg gluccosinolates which assist in drought tolerance in collards and other brassicas.

5.3: The Cabbage experiment.

In this experiments too, there was considerable savings under AFI. In the period 2010 there was 230mm representing 41% savings and in year 2011 savings of upto150mm representing 40% were realized. In earlier studies by Menelik and Kang, water savings of between 42% and 50% have been realized (Menelik *et al*, 2010; Kang *et al*, 2000).

SMC in the AFI treatment were different during the alternate wetting and drying cycles i.e they alternately increased and decreased. SMC of the wetted furrows was higher than that of drying furrows. But soil water content was found to be relatively constant or increased slightly one day after irrigation in the skipped furrows as noted on 29 DAST in 2010 and 22 DAST in 2011, hence no significant difference (at $P > 0.05$). This may have been caused by lateral infiltration or redistribution of water through the soil (Kang *et al,* 2000). The SMC in the CFI treatment and that of the watered AFI furrow tended to be higher than and significantly different ($P \leq 0.05$) from the drying furrow. However the spatial and temporal variations in SMC trends of all furrows of the CFI treatment were similar. Water savings of 37% and 45% for year 2010 and year 2011 respectively were realized. It was noted that moisture took quite some time after watering to start fluctuating. This may be because soil cover formed by the dense cabbage leaves making AFI water saving in cabbage very successful.

The variations of RWC measured during the vegetative growth and reproductive stage showed that crops under AFI and CFI had similar changes and that the differences between them were not significant if irrigation was done at same time. Hence AFI did not lead to leaf water deficit that might have contributed to significant growth regulation. The possibility of stimulating water deficit responses is based in that root derived chemical signals affect stomatal conductance i.e transpiration (Stoll *et al,* 2000). The roots in the watered side supply adequate water to the plant and this maintains more or less similar relative RWC in both AFI and CFI plants.

AFI did not affect growth parameter trends noticeably. Many studies have reported reduction in shoot growth under PRD. As noted before this is because ABA is known to be produced in PRD treated crops because of false water stress/drought signals elicited in the plants from the roots in the side of drying soil though the plant has adequate water in its systems supplied by the roots in the watered side of the soil.

In cabbage (*Brassicaceae oleraceae var capitata*) plants studied, AFI lead a slight delay of head formation. One explanation might be that AFI treated plants produce and sent more and hence strong drought signals (ABA) to the shoots than conventionally watered plants leading to less growth and leaf initiation. Also the heads formed under AFI were noticeably smaller than those of CFI though the sizes (diameter) were not significantly different ($P>0.05$). The DM accumulation was not significantly different ($P> 0.05$). The total yields were also not significantly different ($P> 0.05$).

CHAPTER SIX

6.0: CONCLUSIONS AND RECOMMENDATIONS

5.1: Conclusions.

The use of AFI enabled significant savings of irrigation water use compared to CFI during the periods of study in 2010 and 2011. The results of this study show that AFI/PRD is a practical water saving technique that can enable at least 42% to 46% water savings. In agreement with other studies in the past, this study supports the conclusion that AFI is a practical water saving method that if adopted can enable increase to horticulture production in arid areas because most of these ASAL areas face diminishing water resources.

Again the temporal and spatial variations in soil water content, also assumed to be the readily available water (RAW) in AFI and CFI furrows in year 2010 and year 2011 were different as also noted in earlier study by Li. During the alternate wetting and drying cycles they alternately increased and decreased. SMC of the wetted furrows was higher than that of drying furrows most of the time in the AFI. After watering the SMC of the alternate furrows after one day of equilibrating was found to be lower than that of CFI furrows a factor that may be associated with soil hysteresis as also noted in earlier study by Dodd. But SMC of skipped furrows was found to be relatively constant or increased slightly one day after irrigation in the skipped (drying) furrows. This may have been caused by lateral infiltration or redistribution of water through the soil. However the cycle of SMC variations before and after irrigation days in the CFI treatment was similar.

The ANOVA on RWC values did not show any significant differences in leaf water potentials. The mechanism is based on osmotic adjustment and symplastic water compartment, but these are not clear enough. Actually PRD is an intentional stimulus used to induce a series of xerophytophysiological regulations, which make plant healthier than usual. It does not cause a real plant water stress but induces signals similar to those from real plant water stress as also noted by Xu in a past experiment. These false drought stimulus signals confer benefits similar to the gene expressions which activate metabolisms related with physiological and morphological regulations and adjustments which confer stress tolerance in drought resistant varieties.

The AFI technology can assist stabilize farmers' incomes because it promotes early ripening of tomato crop by approximately one week, it has no consequential effects on head formation of cabbage does not affect leaf formation in collards and hence is of significant value to increasing horticulture production and yields in arid areas where meager or no crop harvests are usually realized. In all the crops, there was a no significant PRD effect on overall yield related growth parameters and yield itself though there were varied yield amounts on various seasons. Yield components of conventionally watered plants only slightly out performed PRD plants in biomass production in most cases. Therefore the results showed that applied PRD was sufficient to trigger shoot response.

5.2: Recommendations

This research indicates that significant water savings are possible with the adoption of on-farm water saving technologies in the ASAL areas of Eastern Kenya. From this study, it is suggested and recommended that AFI can be used to enable water savings of about40% if at least the farmer's goals are to obtain appreciable yields of crops like tomatoes to market timely and put more area under production especially in areas with water scarcity. It is also a recommendation that promotion of its adoption should be done extensively amongst farmer in the ASAL areas of Kenya. Further studies here are necessary to establish the economics of large scale use AFI in the region.

This study tested the hypothesis that AFI does not lead to decreased yields of the crops grown. Because there were no significant difference ($P > 0.05$) in yield between AFI and CFI and hence the study succeeded to show that PRD is a good technique to bring about intentional stimulus to induce a series of xerphytophysiological regulations and responses in crops which bring about improved crop yield and quality especially in crops like tomato. It is an additional recommendation that more studies in PRD be continuously done to help understand the effects of PRD in horticulture crops and may provide useful approaches to apply the theory of root-to-shoot long distance signaling processes in field horticulture production. This knowledge will also be valuable in making modifications to irrigation strategies and this could be used as a good basis for irrigation strategy development in ASAL areas. Further studies to establish the improvement of vegetable produce quality by using AFI are recommended.

REFERENCES

Birhanu K, T. K. (2010). Fruit yield and quality of drip irrigated tomato under deficit irrigation. *African Journal of Food Agriculture, Nutrition and Development* , 10,2139-2159.

Boyer J S, W. M. (2004). Grain yields with limited water. *Journal of Experimental Botany* , 55,2385-2394.

Bray, E. (2004). Genes commonly regulated by deficit water stress in Arabidopsis thaliana. *Journal of Experimental Botany* , 55,2331-2341.

Chaudhari O P, G. B. (2010). Yield and quality of tomato cultivars as influenced by drip and furrow irrigation using waters with high RSC. *Irrigation science* , 58,513-523.

Cheves M M, O. M. (2004). Mecahanisms underlying plant resilience to water deficits; prospects for water saving agriculture. *Journal of Experimental Botany* , 55,2331-2341.

Davies W, K. G. (2005). Long disatnce ABA signaling in the detection of soil drying and the mediation of plants response to drought. *Journal of Plant Growth Regulation* , 24,285-295.

Dodd I C, T. J. (2006). Alteration of wet and dry sides during PRD alters root-to-shoot signaling of ABA. *Functional Plant Biology* , 33,1081-1089.

FAO-. (2008). *Field estimation of soil water content; Apractical guide methods, instrumentation and sensor technology*. Vienna: Austria.

FAO. (1988). Soil Map of the world. In UNESCO, *World soils report* (p. 24). Rome;Italy: IAEA.

Fereres E, S. M. (2007). Deficit irrigationfor reducing agric water use. *Journal of Experimental Botany* , 58,147-159.

Fulai L, S. A. (2006). Physiological responses of potato (solanum tuberosum) to PRD. *Journal of Exprimental Botany* , 57,3727-3735.

Gaveh E A, T. G. (2011). Effect of irrigation , transplat age and season on growth, yield and WUE of african eggplant. *Horticulture, Enviroment and Biotecnology* , 52,13-28.

Gooding, N. (1985, December 7th). *irrigation methods*. Retrieved July 12th, 2010, from fao: http;//www.fao.org

Horst M G, S. S. (2005). Field water assesment of water saving potential with furrow irrigation in fergana, Aral sea basin. *Agriculture and Water Management* , 77,210-231.

Jones, H. G. (2004). Irrigation scheduling;advantages and pitfalls of plant based methods. *Journal of Experimental Botany* , 55,2427-2436.

Jones, H. G. (2007). Monitoring plant and soil water status. *Journal of Experimental Botany* , 58,119-130.

Kang S Z, S. P. (2000). Soil Water distribution, uniformity and WUE under AFI in the arid areas. *Irrigation science* , 19,181-190.

Katereji n, M. M. (2007). WUE of crops cultivated in the meditreanesn region; Review and analysis. *Journal of Agronomy* , 28,493-507.

Li X, J. Z. (2011). A modified checkbook irrigation method based on GIS- coupled model for irrigation schedulling. *Irrigation science* , 29,115-126.

Masinde P W, S. H. (2006). Plant growth, water relations and transpiration of two species of African nightshade (solanum villosum mill.ssp. miniatum and S. sarrachoides.0 under water limited conditions. *Scientia Horticulturae* , 110,7-15.

Menelik G, A. G. (2010). Evaluation of the effects of alternate Furrow Irrigation AFI on yield and WUE of potato. *Proceedings of the 3rd Annual conference on soil and water management, forestry and agric mechanization (2008)* (pp. 310-320**). ARARI: Birhai Dar.

MoA. (2009). *Annual Report.* Nairobi: AIC.

MoA. (2010). *Annual report.* Nairobi: AIC.

MoLD&F. (2012). *National policy for the sustainable development of Northern Kenya and other arid Lands.* Nairobi: GP.

Montenegro S G, M. A. (2010). Improving water management in the semi-arid region of Brazil; experimental and modeling study. *Irrigation Science* , 28,3010316.

Montoro A, L.-F. P. (2011). Improving on-farm water management through an irrigation scheduling service. *Irrigation Science* , 29,311-319.

Odame H, K. B. (2010, December 12). *irrigation methods*. Retrieved Feb 8, 2012, from Fao: http;//www.fao.org

Poroyko V, S. W. (2007). Comparing regional transcript profiles from maize primary roots underwell watered and low water potential conditions. *Journal of Experimental Botany* , 58,279-289.

Saleh A, S. M. (1993, 7 15). *Arid and semi-arid lands; Characteristics and importance-community adaptations and sustainable livelihoods*. Retrieved July friday, 2010, from iids: http;//www.iisd.org

Sander J Z, L. M. (2010). A remote sensing-based irrigation performance assessment - A case study of office DU Niger in Mali. *Irrigation Science* , 28,371-385.

Shaozong K, Z. J. (2004). Controled Alternate Partial Root Drying - Its physiological consequences and impact on WUE. *Journal of Experimental Botany* , 55,407-409.

Shinozaki K, Y. S. (2007). Gene networks involved in drought stress response and tolerance. *Journal of Experimental Botany* , 58,221-227.

Sobeih W Y, D. I. (2004). Long Distance signals regulating stomatal conductance and leaf growth in tomato(Lycopersicon esculentum) plants subjected to PRD. *Journal of Experimental Botany* , 55,2353-2363.

Stickic R, P. S. (2003). Partial Root Drying-A new Technique for growing plants that saves water and improves quality of fruit. *Bulgarian Journal Of Plant Physiology* , special issue;164-171.

Stoll M, L. B. (2000). Hormonal Changes induced by PRD of irrrigated gravevines. *Journal of Experimental Botany* , 51,1621-1634.

Studle, E. (2000). Water uptake by roots ; Effects of water deficit. *Journal of Experimental Botany* , 51,1531-1542.

Taisheng D S, K. J. (2008). WUE and yield responses of cotton to Alternate PRD Drip Irrigation in the arid area of North West China. *Journal of Irrigation Science* , 26,147-159.

Topak R, S. S. (2010). Effect of drip irrigation regimes on sugar beet (Beta vulgaris L.) yield,quality and WUE in middle Anatolian, Turkey. *Irrigation Science* , 10,107.

Turner N C, A. S. (2006). Osmotic adjustments in chick pea under water stress conditions. *Journal of Experimental Botany* , 58;187-194.

Volker R, G.-O. J. (2005). Non-Nutritional fertigation effects as a challange for improved production and quality in horticulture. *Proceedings for fertigation Symposium* (pp. 103-115). Beijing: China Agric Press (CAP).

Wang J, G. J. (2010). Infra Red Cannopy temperature of ripening peach trees under post harvest deficit irrigation. *Agriculture and Water Management* , 97,1787-1794.

Wang L, K. H. (2005). PRD effects on Biomass production in Brassica napus and the significance of root responses. *Plant and soil* , 276,313-326.

Weeber C M, M. C. (2009). Plant soil water dynamics of AFI and RDI for two legume crops in Fergana valley,Uzebekistan. *Agriculture Water Management* , 86,213-221.

Weele C M, S. G. (2000). Growth of Arabidopsis thaliana seedlings under water deficit studied by control of water potential in nutrient agar media. *Journal of Experimental Botany* , 51,1555-1662.

Xiaopeng Li, J. Z. (2011). A modified checkbook irrigation method based on GIS-coupled model for regional irrigation scheduling. *Irrigation Science* , 29,111-126.

Xu H L, Q. F. (2009). Application of xerophytophysiology in plant production; PRD improves tomato crops. *Journal of Food, Agriculture and Enviroment* , 7,981-988.

APPENDICES

Appendix1: Climatic data of the Kibwezi experimental site.

Climatic data of Kibwezi sub-county for the year 2010, year 2011 and the last 10 yrs1999-2009

Period	Climatic data	Months												Annual
		J	F	M	A	M	J	J	A	S	O	N	D	
Year 2010	Temp	21	15	19	25	35	34	32	35	34	32	27	24	
	Rainfall	36	47	330	73	0	0	0	0	0	0	154	73	714
Year 2011	Temp	*23*	*18*	*20*	*26*	*32*	*33*	*28*	*26*	*35*	*30*	*28*	*22*	
	Rainfall	*14*	*24*	*86*	*19*	*7*	*0*	*0*	*0*	*0*	*8*	*53*	*172*	428
Long term	Temp	*22*	*16*	*19*	*25*	*33*	*34*	*30*	*29*	*34*	*31*	*27*	*23*	
1990-2009	Rainfall	*46*	*11*	*68*	*41*	*5*	*1.3*	*0*	*0*	*5*	*15*	*84*	*9*	

Rainfall days; 2010; May,June,July = 0,0,0 Nov & Dec= 9,7 2011; Feb-Mar =3,5

(Source; KEFRI Kibwezi)

Appendix 2:Climatic data of the JKUAT experimental site.

Climatic data of JUJA for the year 2011.

Period	Climatic data	Months												Annual
		J	F	M	A	M	J	J	A	S	O	N	D	
Year 2011	Rainfall (mm)	*11*	*48*	*155*	*109*	*71*	*50*	*00*	*10.7*	*394*	*130*	*177*	*559*	
	Temp (^{o}C)	*20*	*20.6*	*21.6*	*21.9*	*21*	*19.8*	*18.8*	*18.6*	*20.4*	*21.4*	*21.6*	*21.3*	

Min Temp= 14.6 ^{o}C (Aug) Max Temp= 26^{o}C (Source; KARI-THIKA)

Appendix3: Schedule of activities

Season 1	Season 2	Green house	Activity
April2010	Jan 2011	May 2011	Land preparation
May2010	Jan 2011	May 2011	Nursery Establishment
June2010	Feb2011	June 2011	T/Planting
July-August 2010	Feb-Mar2011	July- August 2011	Weeding
June-August 2010	Feb – Apr2011	July- August 2011	Pest and disease control
August- Sept 2010	Mar- Apr 2011	August- Sept 2011	Harvesting

Appendix 4: Layout photographs of selected experiment plots

Plate 1: The tomato crop in Kibwezi in year 2010

Plate 2: The Cabbage crop in Kibwezi during year 2011

Plate 3:The Collard crop in Kibwezi during year 2011

Plate 4: Tomato plots in greenhouse at JKUAT

Appendix 5: Irrigation water savings (L).

Irrigation water quantities applied on AFI and CFI treated tomato plots at Kibwezi in June-August 2010 and January – March 2011.

Period	Treatment	Days after start of treatment								Total	Saving (L)	Saving %
		1	7	14	21	28	35	42	49			
2010	Alternate	937a	892a	897a	959a	923a	1048a	1026a	969a	7651		
	Conventional	1430b	1308b	1583b	1541b	1531b	1631b	1640b	1628b	12292	5641	45%
2011	Alternate	568a	380a	450a	740a	654a	690a	812a	739a	5033		
	Conventional	923b	765b	1025b	1178a	1056b	1039b	1300b	1151b	8437	3404	41%

Different Letters represent LSD (P≤0.05)

Irrigation water quantities applied on greenhouse AFI and CFI treated tomato plots at JKUAT in June – September 2011

Period	Treatment	Days after start of treatment								Total	Saving (L)	Saving %
		1	7	14	21	28	35	42	49			
2011	Alternate	110a	124a	148a	152a	148a	152a	154a	150a	1138		
	Conventional	284b	280b	282a	284b	282b	284a	286b	292b	2274	1136	49%

Different Letters represent LSD (P≤0.05)

NB- Seasonal water requirement for tomato crop is 600mm to 800mm (90-150 days)

Irrigation water quantities applied on AFI and CFI treated cabbage plots at Kibwezi in June-August 2010 and January – March 2011.

Period	Treatment	Days after start of treatment								Total	Saving (L)	Saving %
		1	7	14	21	28	35	42	49			
2010	Alternate	744a	840a	768a	892a	1032a	1205a	1104a	1199a	7776		
	Conventional	1583b	1583b	1630b	1631b	1462b	1823b	1752b	1824b	13288	5512	41%
2011	Alternate	569a	463a	545a	487a	647a	609a	937a	1022a	5280		
	Conventional	855b	854b	934b	799b	1099b	1381b	1448b	1583b	8953	3673	40%

Different Letters represent LSD (P≤0.05)

Irrigation water quantities applied on AFI and CFI treated Kale plots in June-August 2010 and January – March 2011.

Period	Treatment	Days after start of treatment								Total	Saving (L)	Saving %
		1	7	14	21	28	35	42	49			
2010	Alternate	504a	816a	720a	892a	960a	1051a	1014a	920a	6877		
	Conventional	1320b	1296b	1416b	1392b	1320a	1568b	1659b	1727b	11698	4821	41%
2011	Alternate	414a	487a	535a	484a	650a	694a	744a	739a	4693		
	Conventional	853b	934b	828b	797b	1041b	1095b	1281b	1151b	7628	2935	46%

Different Letters represent LSD (P≤0.05)

NB- Seasonal water requirement for brasicae crop e.g cabbage is 400mm to 600mm (90-120 days)

Appendix 6: Anova and *t*-Test output tables

t-Test values for Irrigation water use on Tomato plots at Kibwezi in year 2010

Treatment	Days after Start of Treatment							
	1	7	14	21	28	35	42	49
Alternate	937	892	897	959	923	1048	1026	969
Conventional	1430	1308	1583	1541	1531	1631	1640	1628
CI- Alternate	105	92	335	100	300	227	298	185
CI- Conventional	135	100	92	122	576	133	244	400

t-Test values for Irrigation water use on Kale plots at Kibwezi in year 2010

Treatment	Days after Start of Treatment							
	1	7	14	21	28	35	42	49
Alternate	737	1048	950	892	1193	1051	1014	920
Conventional	1570	1541	1626	1631	1308	1568	1659	1727
CI- Alternate	105	92	252	100	361	331	273	121
CI- Conventional	91	100	23	22	488	125	308	455

t-Test values for Irrigation water use on cabbage plots at Kibwezi in year 2010

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	937	1091	1009	892	1501	1205	1104	1199
Conventional	1583	1583	1630	1631	1462	1823	1989	1957
CI- Alternate	105	160	259	100	615	325	131	41
CI- Conventional	135	184	272	22	476	249	321	440

t-Test values for Irrigation water use on tomato plots at Kibwezi in year 2011

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	568	380	450	740	654	690	812	739
Conventional	923	765	1025	1178	1056	1039	1300	1151
CI- A	84	43	200	392	32	50	200	70
CI- C	83	44	200	50	347	200	313	291

t-Test values for Irrigation water use on Cabbage plots at Kibwezi in year 2011

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	569	463	545	487	647	609	937	1022
Conventional	855	854	934	799	1099	1381	1448	1583
CI- A	182	122	105	100	269	303	228	279
CI- C	234	193	250	542	166	175	250	120

t-Test values for Irrigation water use on collards plots at Kibwezi in year 2011

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	414	487	535	484	650	694	744	739
Conventional	853	934	828	797	1041	1095	1281	1151
CI- A	205	50	50	73	200	191	287	79
CI- C	203	100	202	155	145	326	169	241

t-Test values for irrigation water use on greenhouse Tomato plots year 2011

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	50	44	50	52	49	52	54	50
Conventional	85	81	83	85	82	84	86	82
CI- A	2	19	15	15	12	18	5	13
CI- C	18	10	23	16	15	19	17	25

Anova values for RWC% of Kale plants at Kibwezi in year 2010

Treatment	Days after start of treatment															
	1	2	7	8	14	15	21	22	28	29	35	36	42	43	49	50
Alternate row 1	83.3	96.8	81.5	90.4	75	84.3	77.2	90.1	78.9	79.5	78.3	86.8	82.6	87.8	83.3	87.4
Alternate row 2	86.57	91.9	86.2	91.9	83.2	91.2	86.7	95.5	88.2	92.1	80.9	89.6	85.3	90.7	84	96
Conventional row	84.4	95	88.3	90.4	78.2	92.8	86.2	95	88.2	89.9	78.1	92.4	84.4	92.2	89.8	98.1
LSD	4.1	8.6	12.7	8.5	22.2	4.9	7.1	18	7.1	5	25.8	5.4	10.2	8.7	11.1	7.4

Anova values for RWC% of Cabbage plants at Kibwezi in year 2010

Treatment	Days after start of treatment															
	1	2	7	8	14	15	21	22	28	29	35	36	42	43	49	50
Alternate row 1	85	88.4	83.3	84.5	78.5	86.3	80.9	87.8	80.2	87	79	86.9	79.3	93	86	94
Alternate row 2	84	86.4	86.5	91.4	84.4	86.2	80.7	88	87	90	83	89.9	81.4	91	82	88
Conventional row	75	88.9	79.6	88.1	78.8	84	74.8	87.4	79	88	81	88.7	79.8	90	84	95
LSD	11.9	2.7	15.6	8.77	8.7	11.55	12.6	9	14.4	5.3	13.4	7.6	9.9	7.6	7.9	9.7

Anova values for RWC% of Tomato plants at Kibwezi in year 2010

Treatment	Days after start of treatment															
	1	2	7	8	14	15	21	22	28	29	35	36	42	43	49	50
Alternate row 1	77	91	90	92	77	81	67	90	86	100	85	92	67	71	68	87
Alternate row 2	80	91	86	90	83	91	80	90	83	90	64	91	90	100	66	100
conventional row	83	90	79	100	83	90	54	90	79	100	55	100	90	91	78	79
LSD	36.6	35	42.8	32	33.8	29	36	35	42	32	40	29	36.1	40.7	52	30

Anova values for RWC% of Collard plants at Kibwezi in year 2011

Treatment	Days after start of treatment															
	1	2	7	8	14	15	21	22	28	29	35	36	42	43	49	50
Alternate row 1	72.6	86.4	76.75	80.6	72.25	87.05	76.32	84.28	72.6	86.4	76.75	80.6	72.25	87.05	76.32	84.28
Alternate row 2	75.9	82.1	74.39	88.7	74.48	80.24	72.83	89.14	75.9	82.1	74.39	88.7	74.48	80.24	72.83	89.14
Conventional row	82.8	85.1	76.9	85.1	78.1	85.14	74.55	87.42	82.8	85.1	76.9	85.1	78.1	85.14	74.55	87.42
LSD	4.98	3.63	9.55	13.23	7.78	7.62	14.27	12.79	4.98	3.63	9.55	13.23	7.78	7.62	14.27	12.79
P≤0.05	0.02	0.11	0.88	0.598	0.043	0.304	0.79	0.57	0.018	0.106	0.879	0.598	0.0431	0.3043	0.79	0.5696

Anova values for RWC% of Tomato plants at Kibwezi in year 2011

Treatment	Days after start of treatment															
	1	2	7	8	14	15	21	22	28	29	35	36	42	43	49	50
Alternate row 1	66.1	79.2	62.6	72.5	60	76.76	74.12	77.18	66	79.2	62.65	72.5	60	76.76	74	77
Alternate row 2	70.4	76	63.7	73.6	66.7	77.1	66.4	90.1	70.4	76	63.7	73.6	66.7	77.1	66.4	90.1
Conventional row	72.76	81.3	75.1	76.7	63.6	87.4	79.9	91.5	72.76	81.3	75.1	76.7	63.6	87.4	79.9	91.5
LSD	4.2	6.4	10.6	9.7	12.8	11.5	7.3	2	4.2	6.4	10.5	9.7	12.8	11.5	7.3	2
s.e	1.08	1.63	2.69	2.47	3.27	5.47	1.86	0.434	1.08	1.63	2.69	2.47	3.27	5.47	1.86	0.434

Anova values for RWC% of Tomato plants at Cabbage in year 2011

Treatment	Days after start of treatment															
	1	2	7	8	14	15	21	22	28	29	35	36	42	43	49	50
Alternate row 1	79.39	91.9	79	81	76.3	90.7	70	79	79.3	91.9	79	81.8	76.3	90.14	80	89
Alternate row 2	83.9	84.2	69	90	78.8	83.1	78.1	84	76.36	83.1	79	90	78	83	76	78
Conventional row	82.9	93.4	84.9	94.8	87	87.4	84.1	85.6	82.9	93.4	84.9	94.8	87	87.5	84.1	85.6
LSD	2.98	10.3	13.7	10.2	4.55	4.47	12.4	16.8	0.75	10.4	13.77	10.2	4.55	4.47	12.4	16.8

Anova values for RWC% of greenhouse Tomato plants at JKUAT in year 2011

Treatment	Days after start of treatment															
	1	2	7	9	15	16	22	23	28	29	35	36	42	44	49	50
Alternate row 1	70	74	71	75	68	72	66	82	74	85	66	72	68	78	68	74
Alternate row 2	67	72	67	71	65	69	64	77	60	75	67	75	69	73	63	71
Conventional row	68	80	68	75	72	80	71	83	74	80	68	75	72	75	67	72
LSD	20	8	4.5	10	10	10	6.8	11	15	12	6	9	7	6	8.5	8.4

Anova values for SMC%W/W of Tomato plots at Kibwezi in year 2010

Treatment	Days after start of treatment															
	1	2	7	8	14	15	21	22	28	29	35	36	42	43	49	50
Alternate row 1	11.59	16.67	15.36	11.98	14.8	21.68	12.89	15.24	16.35	20.8	12.8	14.9	16.1	23.3	16.3	11.7
Alternate row 2	7.8	10.6	12.4	18.6	16.3	16	12.92	22.56	15.15	11.4	10.58	20.41	14.4	16.5	13.06	19.7
Conventional row	13.8	21.3	10.945	16.8	12.6	22.68	18.1	19.7	16.3	22.6	16.1	23.1	17.1	22.8	17.4	23.3
LSD	7.7	1.7	4.7	4.7	4	1.7	5.6	5.2	2.57	2.67	3.8	3.8	5.3	8.9	4.9	3.4

Anova values for SMC%W/W of Kale plots at Kibwezi in year 2010

Treatment	Days after start of treatment															
	1	2	7	8	14	15	21	22	28	29	35	36	42	43	49	50
Alternate row 1	10.8	17.6	15.7	13.5	13.1	22.5	15.69	13.5	12	20.1	14.5	12.5	13.4	21.7	13.9	12.56
Alternate row 2	12.3	10.3	11.8	16.8	15.6	12.7	6.7	19.6	12.5	14.5	9.7	14.6	11.4	13.3	14.8	22.4
Conventional row	12.1	13.9	7.9	12.8	12.7	17.5	11.24	17.3	15.5	17.7	10.5	22.4	12.9	20.5	13.8	17.6
LSD	3.4	2.4	2.9	10.6	4.2	3.5	5.2	7.2	1.8	8.5	4.11	8.5	4.2	7.7	1.4	7.5

Anova values for SMC%W/W of Cabbage plots at Kibwezi in year 2010

Treatment	Days after start of treatment															
	1	2	7	8	14	15	21	22	28	29	35	36	42	43	49	50
Alternate row 1	5	16.8	14.9	16.5	11.4	17.7	15.2	15.27	11.9	19.2	15.2	17.6	10.9	22.2	19.3	12.5
Alternate row 2	5.9	12	12.2	20.5	15.2	15.1	10.1	20.1	12.9	16.9	11.5	22.5	14.9	17.2	16.4	22.8
Conventional row	11.9	18.4	9	13.7	15.4	17.2	13.1	16.9	18.1	19.8	11.5	17.6	14.1	21.3	15.9	22.14
LSD	7.4	5.1	10.1	4.5	4.4	8.7	5.1	10.3	2.4	8.2	4.5	3.1	6.4	4.2	6.3	6.5

Anova values for SMC%W/W of Tomato plots at Kibwezi in year 2011

Treatment	Days after start of treatment															
	1	2	7	8	14	16	21	22	28	29	35	36	42	43	49	50
Alternate row 1	12.7	14.9	12.1	14.14	11.5	21	13.1	16.5	11.7	23.3	15.2	12.8	11.7	21	14.5	11.4
Alternate row 2	20.8	12	10.5	24.4	20.8	16.1	16.4	23.5	19.7	18.1	12.9	24.4	10.5	19.1	16.1	24.4
Conventional row	15.92	22.6	16.1	25.88	17.14	23.1	17.4	22.8	12.8	22.6	19.7	21.9	16.1	25.8	17.2	25.8
LSD	1	2.6	3.8	3.9	8.1	5.37	8.9	4.9	3.3	5.6	5.28	3.8	2.5	8.1	5.37	2.67

Anova values for SMC%W/W of greenhouse Tomato plots at JKUAT in year 2011

Treatment	Days after start of treatment															
	1	2	7	9	15	16	22	23	28	29	35	36	42	44	49	50
Alternate row 1	23.1	24.6	23.7	22.7	21.4	26.6	24	21.6	16.5	24.6	18	20.6	16	28	17.3	17.6
Alternate row 2	22.5	21.6	15	24.3	23	21	16.3	27.7	23.2	15	17	28.2	18	23.2	15.2	28.2
Conventional row	26.9	28.2	21.1	28.2	21.5	28.7	21.7	28.4	21.6	28.3	16	26	16	28.3	14.7	29.3
LSD	5.8	8.5	2.7	13.2	4	9.9	4.5	10.4	2.1	8.5	5	6	6.2	3	4.4	3

Anova values for SMC%W/W of Collards plots at Kibwezi in year 2011

Treatment	Days after start of treatment															
	1	2	7	8	14	16	21	22	28	29	35	36	42	43	49	50
Alternate row 1	12.5	14.6	12.56	14.5	11.4	19.8	13.4	13.9	6.7	14.5	13.5	12.6	12.5	19.8	14.5	13.95
Alternate row 2	20	12	9.75	22.5	17.5	13.7	14.8	22.4	21.7	19.6	15.6	17.3	13	14.8	9.7	20
Conventional row	15.8	17.7	10.5	22.4	12.96	25.4	13.8	20.5	13.7	17.6	10.5	21.4	17.6	25	13.8	17.7
LSD	1.8	8.5	4.1	8	5.7	4.25	7.25	1.45	7.5	6.3	7.24	5	6.19	4	8.5	5.7

Anova values for SMC%W/W of Cabbage plots at Kibwezi in year 2011

Treatment	Days after start of treatment															
	1	2	7	8	14	16	21	22	28	29	35	36	42	43	49	50
Alternate row 1	11.9	20.1	12.9	13.5	11.5	22.2	16.4	12.5	10.9	15.27	11.25	12.5	10.6	20.1	10.9	12.9
Alternate row 2	16.9	11.26	11.5	21.23	17.8	17.1	14.9	22.8	19.32	15.8	15.2	21.23	20.1	19.12	14.97	21.2
Conventional row	18.03	19.8	15.3	25.98	21.35	22.5	14.06	15.9	13	22.1	16.3	21.2	11.56	25.9	14.1	19.8
LSD	2.4	8.2	4.4	3.3	3.3	6.4	4.2	6.3	6.5	5.1	10.3	4.4	5.8	3.3	6.45	8.3

t-Test values for Plant height of tomato at Kibwezi year 2010

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	13.8	15.6	23.1	32.3	41.8	48	52	52
Conventional	12.6	14.2	22.8	32.5	38.2	44.5	48.6	52.2
CI- A	3.56	3.3	5.26	6	10.1	9.7	10.5	10.6
CI- C	1.74	1.84	4.52	5.9	8.4	8.4	7.4	6.92

t-Test values for Plant height of tomato at Kibwezi year 2011

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	26.8	35.4	44.3	52.6	56.22	59.22	59.22	59.33
Conventional	27	35.4	44.3	52.1	60.6	62.4	62.8	62.8
CI- A	4.8	4.2	3.8	3.4	2.2	2.8	2.8	2.8
CI- C	3.3	3.4	3.8	4.3	4.7	4	4	4

t-Test values for Plant height of greenhouse tomato at JKUAT year 2011

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	18	24	30	40	49	57	64	67
Conventional	16	19	27	37	52	62	70	74
CI- A	4.1	4.7	4.3	5.2	4.7	5.4	5.3	6.1
CI- C	2	2.3	2.7	4.5	4.3	6.3	9.2	11.6

t-Test values for number of leaves per tomato plant at Kibwezi year 2010

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	6.8	10.8	14.2	21.8	34.7	43.2	47.5	47.5
Conventional	6.5	8.6	16.7	27.5	38.3	47.1	51.8	51.8
CI- A	0.55	2	4.5	8.7	10.9	11.69	13.7	13.7
CI- C	1.22	3.1	7.5	10.9	14.8	11.11	9.67	9.67

t-Test values for number of leaves per tomato plant at Kibwezi year 2011

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	8.16	15.16	26.3	34.5	41.3	44.3	47.3	47.3
Conventional	7.6	14.1	25	33.6	39.3	44	47	47
CI- A	2.4	4.8	8	7.6	7.3	7.3	7.3	7.3
CI- C	2.6	3.2	5.7	8.2	9.3	7.7	6.6	5.3

t-Test values for number of leaves per tomato plant in green house at JKUAT year 2011

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	7.5	8.1	9.7	11.4	13	15.3	18.3	19.3
Conventional	7.1	7.7	9.5	11.5	14.3	18.1	22.5	24.8
CI- A	0.8	0.9	0.7	0.8	0.8	1.1	2.1	2.4
CI- C	0.9	0.9	0.9	0.9	1.5	3	4	4.6

t-Test values for number of branches per tomato plant at Kibwezi year 2010

Treatment	Days after start of treatment						
	7	14	21	28	35	42	49
Alternate	0	1	1	2.2	3.5	4.8	5.2
Conventional	0	1.2	1.2	1.8	4.2	5.5	5.7
CI- A	0	0.8	0.8	1.22	1.29	1.6	2
CI- C		1	1	1.68	2	2.3	2.3

t-Test values for number of branches per tomato plant at Kibwezi year 2011

Treatment	Days after start of treatment					
	14	21	28	35	42	49
Alternate	2.2	6	6.3	7.3	7.6	7.6
Conventional	2.2	5.5	6.16	7.6	8	8
CI- A	1.1	1.3	1.6	1.7	1.1	1.1
CI- C	1	2	1.7	1.9	1.7	1.7

t-Test values for number of branches per green-house tomato plant at JKUAT year 2011

Treatment	Days after start of treatment						
	7	14	21	28	35	42	49
Alternate	1.1	2.1	2.3	3	3.5	3.6	3.6
Conventional	1	2.1	2.7	4.1	4.2	5.1	5.1
CI- A	0.25	0.25	0.4	0.76	0.8	0.8	0.8
CI- C	0.25	0.25	0.6	0.9	0.7	1.1	1.1

t-Test values for number of trusses per tomato plant at Kibwezi year 2010

Treatment	Days after start of treatment					
	21	28	35	42	49	54
Alternate	1.2	1.8	3.5	6	9.2	11.3
Conventional	1	2.8	3.8	6.6	11.5	13.6
CI- A	0.4	1	1.7	3	4	4.2
CI- C	0.7	1.4	1.4	2.4	2.55	3.55

t-Test values for number of trusses per tomato plant at Kibwezi year 2011

Treatment	Days after start of treatment					
	14	21	28	35	42	49
Alternate	2.8	6	9.8	15.2	15.2	15.2
Conventional	2.2	4.8	10.5	15.3	15.3	15.3
CI- A	1.7	3.3	2.4	5	6.3	6.3
CI- C	1.23	1.4	3	4.6	6.2	6.2

t-Test values for number of trusses per greenhouse tomato plant at JKUAT year 2011

Treatment	Days after start of treatment						
	7	14	21	28	35	42	49
Alternate	1.22	3.7	4.7	6.7	7	8	8.4
Conventional	0.77	3.6	5.4	7.7	8.7	9.8	11.1
CI- A	0.34	0.7	1	1.2	1.1	1.3	1
CI- C	0.34	0.54	0.9	1.4	1.9	2.1	2

t-Test values for number of fruits per tomato plant at Kibwezi year 2010

Treatment	Days after start of treatment					
	35	42	49	54	63	70
Alternate	5.3	16.1	28.2	36.8	38.6	42.5
Conventional	4.8	15.6	32.16	33	41	46
CI- A	2.6	7.4	10	12	15	16
CI- C	3.8	10	10	11	12.55	16

t-Test values for number of fruits per tomato plant at Kibwezi year 2011

Treatment	Days after start of treatment					
	21	28	35	42	49	56
Alternate	2.36	8	16.8	24.1	27.5	29.2
Conventional	1.33	9.3	16.5	22.1	25.8	27.8
CI- A	1.8	3	5.2	5.6	6.1	5.8
CI- C	0.5	2.5	3.7	5.2	5.8	5

t-Test values for number of fruits per greenhouse tomato plant at JKUAT year 2011

Treatment	Days after start of treatment					
	14	21	28	35	42	49
Alternate	1.1	3.3	9.2	13	17.1	21
Conventional	0.77	3.5	10.8	20	24	34
CI- A	0.2	1	2.6	2	3.3	3.3
CI- C	0.4	1.9	3.4	5	7.12	7.12

t-Test values for the Leaf Area (cm2) per tomato plant in green house at JKUAT year 2011

Treatment	Days after start of treatment			
	7	21	35	49
Alternate	372	794	1549	1838
Conventional	373	1061	2745	4364
CI- A	58	255	125	630
CI- C	110	375	466	658

t-Test values for shoot DM per tomato plant at Kibwezi and JKUAT

Treatment	Kibwezi		Treatment	JKUAT G/house
	yr 2010	Yr 2011		Yr 2011
Alternate	68	75	Alternate	46
Conventional	108	123	Conventional	59
Cl- A	58	49	CL- A	6
Cl- C	35	40	CL- C	3

t-Test values for Yield of tomato at Kibwezi year 2010,2011 and in green houseat JKUAT

	Kibwezi			JKUAT G/house
	yr 2010	yr 2011		Aug-11
Alternate	**83**	**62**	Alternate	60
Conventional	**88**	**55**	Conventional	55
Cl- A	**2.5**	**2.5**	CL-A	4.2
Cl- C	**7**	**3**	CL-C	6

t-Test values for the Plant height of Collards at Kibwezi yr2010

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	3.3	4.3	7	9.1	11.5	16	18.5	21.6
Conventional	4.6	6	8.8	12.5	13.8	15.5	19.2	23.26
Cl- A	1.7	1.84	2.8	3.5	4.2	4	4.1	5.4
Cl- C	3.1	3.3	3.2	3.1	3.3	3.4	3	3.66

t-Test values for the Plant height of Collards at Kibwezi yr2011

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	6.55	8.77	11.3	14.6	18.4	21.6	24.6	27.3
Conventional	6.77	9.4	11.8	14.7	20.2	24	27.1	29.5
Cl- A	1.2	2.2	2.3	2.5	2.5	1.5	2.72	2.93
Cl- C	1.2	1.22	1.4	1.4	3.2	4.1	4.3	4.5

t-Test values for the number of leaves per Collards plant at Kibweziyr2010

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	2.8	4	8	11.8	12.66	15.6	18	20.2
Conventional	3.5	4.5	6.8	9.8	11.8	16.5	20	23.2
CI- A	0.8	0.9	1.8	4.3	3.1	3	2.3	2.4
CI- C	0.5	0.5	1.4	1.2	1.4	2.5	2.4	2.4

t-Test values for the number of leaves per Collards plant at Kibweziyr2011

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	2	5.3	8	10.88	14.1	18	21.44	24.8
Conventional	2	5.5	9.3	12.3	15.8	19.7	23.11	26.4
CI- A	0.6	0.7	1.2	1.2	2	2.1	2.3	2.6
CI- C	0.4	1.3	1.3	0.9	1.8	2.1	2.9	3.1

t-Test values for the number of leaves per Cabbage plant at Kibweziyr2010

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	4.1	5.1	8.1	10.66	14.6	19.5	19.5	20.5
Conventional	4.3	6.5	10	14.5	16.6	19.5	20.6	22.16
CI- A	0.4	1	2.5	2.6	1.6	3.5	1	1
CI- C	1.3	1	1.3	1.4	1	0.8	1.23	1.68

t-Test values for the number of leaves per Cabbage plant at Kibweziyr2011

Treatment	Days after start of treatment							
	1	7	14	21	28	35	42	49
Alternate	7.8	12.55	17.3	19.77	22.77	23.55	23.88	23.88
Conventional	7.55	11.77	17.38	20.35	24.66	25.11	25.33	25.33
CI- A	1	1.2	1.34	1	1.1	2	1	1
CI- C	1.2	1.7	1.27	1.3	1.1	0.98	1	1

t-Test values for the head diameter of Cabbage plants at Kibweziyr2010

Treatment	Days after start of treatment						
	49	54	63	70	77	84	91
Alternate	4.1	8	12.8	15.3	16.5	19.2	19.2
Conventional	3.4	10.5	15.5	17.5	18	20	20
CI- A	4	2	1	1.7	0.8	0.8	0.8
CI- C	2.9	2.5	1.2	1	1.4	1.5	1.5

t-Test values for the head diameter of Cabbage plants at Kibweziyr2011

Treatment	Days after start of treatment							
	28	35	42	49	56	63	70	77
Alternate	1.3	3.2	5.7	9.3	12.4	15.3	17.6	18.6
Conventional	1.8	4.7	8.1	12.7	14.5	17	19.1	20.2
CI- A	1.2	1.3	1.3	1.6	1.44	1.6	1.6	1.5
CI- C	1.1	1	0.8	0.8	1.2	1.3	1.1	1.5

t-Test values for shoot DM per Kale and Cabbage plant at Kibwezi year 2010 and 2011

	Kale			Cabbage	
	yr2010	yr2011		yr2010	yr2011
Alternate	204	210	Alternate	151	151
Conventional	304	228	Conventional	206	257
CI- A	52	11	CL- A	44	44
CI- C	92	61	CL- C	81	42

t-Test values for Yield of Kale and Cabbage at Kibwezi year 2010 and 2011

	Kale			cabbage	
	yr 2010	yr 2011		yr 2011	yr 2010
Alternate	**98**	**53**	Alternate	**135**	**78**
Conventional	**95**	**55**	Conventional	**148**	**70**
CI- A	**5.4**	**4.6**	CL- A	**9**	**6.4**
CI- C	**5.3**	**1.6**	CL- C	**12**	**5.1**