TJ Lebea

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TOMATO YIELD AND EARLY BLIGHT INCIDENCE IN RESPONSE TO CULTIVAR AND IRRIGATION MANAGEMENT PRACTICES IN THE GIYANI MUNICIPALITY

MASTER OF AGRICULTURAL MANAGEMENT

(PLANT PRODUCTION)

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TOMATO YIELD AND EARLY BLIGHT INCIDENCE IN RESPONSE TO CULTIVAR AND IRRIGATION MANAGEMENT PRACTICES IN THE GIYANI MUNICIPALITY

by

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DECLARATION

I declare that the dissertation hereby submitted to the University of Limpopo, for the degree of Masters in Agricultural Management (Plant production) (degree & field of research) has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

Student's signature: T.J. Lebea (Mr)   Date

DEDICATION

I dedicate this project to all mighty God who assisted me to reach thus far irrespective of the challenges encountered. He has been the source of my strength, wisdom and understanding throughout the project proceedings. In fact, obstacles and struggles are the stepping stones to success.

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LIST OF ABBREVIATIONS AND SYMBOLS

A. alternata	*Alternaria alternata*
Anon	Anonymous
APAP	Agricultural Policy Action Plan
A. solani	*Alternaria solani*
A. tomatophila	*Alternaria tomatophila*
°C	Degrees Celsius
Ca	Calcium
Cl	Closing
CIP	International Potato Center
CCM	Chlorophyll Content Meter
Cm	Centimetre
cm-3	Cubic centimetre
D	Deep percolation
DAFF	Department of Agriculture, Fishery And Forestry
DAP	Days After Planting
DI	Deficit Irrigation
EB	Early Blight
EC	Electrical Conductivity
ET	Evapo Transpiration
FI	Full Irrigation
g/m3	grams per cubic meter
I	Irrigation
K	Potassium

kg	Kilogram
LAI	Leaf Area Index
LAN	Limestone Ammonium Nitrate
LSD	Least Significance Difference
Mg	Magnesium
mgm2	Kilogram per square meter
Mid	Middle
Mill	Miller
ml	Millilitre
mm	Millimetre
N	Nitrogen
Na	Sodium
NDA	National Department of Agriculture
No	Number
NDP	National Development Plan
NGP	New Growth Path
NO3	Nitrate
Op	Opening
Opti	Optimum
P	Phosphorus
P	Precipitation
R	Runoff
RCBD	randomized complete block design
S/C	Service Center
ΔS	Soil water storage

t/ha	Tons per hectare
USA	United States of America
VWC	Volumetric water Content
WP	Water Productivity
Y	Yield
Zn	Zinc

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ABSTRACT

Tomato is a major vegetable crop produced in Limpopo province by subsistence and commercial farmers. Biotic and abiotic factors such as diseases and drought affect its productivity and yield negatively. The most economically important tomato disease in Limpopo is early blight, caused by *Alternaria solani.* Early blight affects tomato growing under stressful conditions such as drought. The main aim of this study was to evaluate water management in tomato production and its effect on tomato yield, early blight occurrence and severity under smallholder farming systems in Giyani. A survey study and field experiments on early blight occurrence and severity were conducted in the Greater Giyani municipality in Limpopo province. Firstly, a survey of early blight was conducted in tomato fields selected from three service centres namely Guwela, Hlaneki and Mhlava Willem. Twenty five potential tomato grower's farms were randomly selected for survey based on the location and production management strategies. A second study was carried out by establishing field experiments at two farms in the same area, namely: A hi tirheni Mqekwa and Duvadzi farms. The experiments were laid out in a randomized complete block design (RCBD) in a split plot arrangement, with irrigation as the main plot treatment and tomato variety as the subplot treatment. Each treatment was replicated four times. The irrigation treatments consisted of full irrigation up to field capacity and deficit irrigation. The tomato varieties planted were HTX14, Rodade, STAR9006 and Commander, and were irrigated with a drip irrigation system. The overall survey results showed that Guwela s/c had high disease incidence and the lowest disease severity as compared to the other two service centers. The lowest disease incidence was observed at Hlaneki s/c whilst Mhlava willem s/c had the highest disease severity. The two water treatments (full and deficit irrigation) in both farms have shown no significant pairwise differences among the volumetric water content means. There was no significant difference (P≥0.05) in early blight disease severity in both farms. Results shows that, all tomato varieties did not differ significantly (P≥0.05) in yield observed between treatments at Duvadzi and A hi tirheni Mqekwa Farm. Deficit irrigation can be used effectively to produce high yields in tomato production provided the cropping season window does not coincide with the hottest time of the year. Full and deficit irrigation did not have influence on the early blight disease incidence on tomato plants.

Key words: *Alternaria solani;* disease incidence; disease severity and drip irrigation.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background of the study

Tomato (*Lycopersicon esculentum* Mill) is one of the most produced and extensively consumed vegetable crop in the world (Grandillo *et al*., 1999). Its origin is believed to be South American Andes which is present day Peru (Naika *et al*., 2005). Recent estimates put global tomato production at around 130 million tons, of which 88 million are destined for the fresh market and 42 million are processed (FAO, 2014). Tomato is one of the main contributors to economic development of the South African agricultural sector (Department of Agriculture Fishery and Forestry, (DAFF, 2012) and the second most important and popular vegetable after potatoes in South Africa (DAFF, 2006). Despite ranking 35th in the world based on total tonnage in 2011, South Africa remains a major regional tomato producer (Stephanus, 2015). The commercial sector in South Africa contributes 95% of the total produce while the emerging sector contributes 5% (DAFF, 2016).

Despite its contribution to the economic growth in South Africa and worldwide, various constraints, including abiotic and biotic stresses are responsible for yield reduction in tomato production (Abdel- Sayed, 2006). Among biotic factors, early blight caused by *Alternaria solani* is one of the major diseases of tomato causing major yield losses where this crop is produced (Chaerani *et al*., 2006; Olanya *et al*., 2009). The primary damage caused by early blight is defoliation of the plant resulting in reduced photosynthetic ability of the plant and consequently, poor health (Simmons, 2000). Fruit infection results in reduced quantity and quality of marketable produce and increase in the number of secondary pathogens (Van der Waals, 2002). The disease is favoured by warm to hot temperatures and leaf wetness from dew, rainfall, irrigation and crowded plantation. Warm to hot conditions exposes plants to extreme stress resulting in reduced tolerance to pathogen attack and reduction in tomato yields, especially during drought periods (DAFF, 2006).

Management of tomato early blight has been almost exclusively based on the intensive application of protectant fungicides (Batista *et al*., 2006). However, their prolonged application and indiscriminate use has let to pathogen resistance resulting in loss of effectiveness (Batista *et al*., 2006). Manipulation of the agro-ecological conditions such as soil moisture, canopy humidity and rotation has been reported to suppress plant diseases of various crops (Pal, 2006). The proposed study therefore seeks to find out the effect of water management practices on tomato yield and occurrence of early blight. Therefore the main aim of this study was to evaluate water management in tomato production as a major factor in reducing early blight occurrence and severity and increasing yield, especially under smallholder farming systems in Giyani.

1.2 Problem statement

Demand on tomatoes and its end products continues to rise as a result of its high nutritional value (Adhikari, 2017). Higher production of tomato is therefore required to satisfy the ever increasing demand. However, production is highly impacted by various factors, including pathogenic and non-pathogenic. Environmental stresses such as drought, high temperatures and salinity have been shown to negatively affect growth and productivity of various crops including tomato (Afroz *et al*., 2010). All over the world, tomato production is reliant on irrigation; however, application mainly depends on soil type, plant and quality of irrigation water (Abd-El-Mageen *et al*., 2015). Water availability is therefore very important in the production of tomato, especially in South Africa. Water shortage therefore can negatively affect plant growth and development as water stress induces a decrease in leaf water potential and in stomatal opening, resulting in reduced crop yield (Osakabe *et al*., 2014).

Disease infestations are also well known factors that decreases crop yields and expand production costs (Ishag *et al*., 2009). Early blight is a major cause of yield loss in tomato production especially when plants are stressed due to reduced water availability. The disease is more prevalent under small holder farming system where farmers lack water management skills and knowledge on the proper application of fungicides. Hence there is a need to develop an alternative, safe and cheap method for the management of pathogenic microorganisms. Managing plant stress conditions is therefore expected to improve plant tolerance to this disease, thus reducing disease incidences and increasing crop yield.

1.3 Motivation for the study

Tomato productivity requires availability of water throughout the cycle, as the tomato plant is very sensitive to water stress (Lopes *et al*., 2005). Water shortage is the most important factor restricting plant growth and production in the world where improved water productivity of the farm is essential for optimised water management (Abd- EL-Mageed and Semida, 2015).

Early blight caused by *A. solani* is the most devastating disease of tomatoes worldwide under varying farming systems (Gomaa, 2001; Abdel-Sayed, 2006; Abada *et al.,* 2008). The disease causes severe reduction in the quantity and quality of fruit yield. Environmental factors such as temperature, wetness, duration and relative humidity (moisture) affect the development of early blight on tomatoes (Vloutoglou and Kalogerakis, 2000).

Tomato yield loss may be minimised with the application of fungicides. However, their high costs and negative impact on the environment has resulted in a search for alternatives including modification of farming practices. Also, most of the fungicides used in the management of early blight by Limpopo farmers have lost sensitivity towards *A. solani* populations in this area (Mphahlele *et al*., 2018) and they may not be effective under weather conditions favourable for epidemics (Schultz and French, 2009). Investigation on the effect of water management practices on tomato yield and occurrence of early blight will provide an alternative disease management strategy.

1.4 Aim and objectives

1.4.1 Aim

The main aim of this study was evaluate water management in tomato production as a major factor in reducing early blight occurrence and severity; and improving tomato yield, especially under smallholder farming systems in Giyani, Limpopo.

1.4.2 Objectives

The objectives of this study were to:

- Determine the prevalence and distribution of early blight in Greater Giyani Municipality, Limpopo Province.
- Determine the effect of irrigation management practices on the occurrence and severity of tomato early Blight.
- Determine the response of tomato cultivars yield to varying water management practices.

1.5 Hypotheses

i. There is high prevalence of early blight in Greater Giyani Municipality.

ii. Water management has effect on occurrence and severity of tomato early blight.

iii. Water management has effect on tomato cultivar yield.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Early blight, one of the most destructive tomato (*Solanum lycopersicum*) diseases is appearing as a major threat to tomato production worldwide (Foolad *et al*. (2002).

Alternaria solani is a soil inhabiting air-borne cosmopolitan fungal pathogen responsible for leaf blight, collar and fruit rot of tomato and related plants such as potatoes. The mode of infection is mainly through asexual spores and mycelium which can be disseminated by wind or water (Tsedaley, 2014).

It is estimated that fungal diseases of tomato are responsible for 30% increase in production costs on fungicides used to combat these diseases (Grigolli *et al*., 2011). Tomato early blight has been reported as the most destructive disease in tomato production globally with yield losses of up to 80% (Chandravanshi *et al*., 1994). In recent years in South Africa, reports indicate that early blight has become a key limiting factor in tomato production, especially in Limpopo Province (DAFF, 2001).

The disease is more prevalent under warm to hot temperatures especially in the presence of morning dew (Keinath, 1996). The disease can cause severe defoliation, resulting in fewer, smaller fruit. Loss of yield reaching 100% has been reported, especially in areas with heavy rainfall, high humidity and fairly high temperatures (24-29°C) (Prasad, 2003). Many control measures, including prophylactic methods, fungicides applications and the use of partially resistant tomato cultivars are currently used to control EB. Under high pressure, none of these measures is completely able to manage EB (Rao *et al*., 2008). Managing plant stress conditions is therefore expected to improve plant tolerance to this disease, thus reducing disease incidences and increasing crop yield.

2.2 The causal organism

Early blight is a fungal disease caused by several species of *Alternaria* including *Alternaria linariae* (which includes *A. solani* and *A. tomatophila*), as well as *A. alternata* (Adhikari *et al.*, 2017). Besides causing early blight on tomatoes, other species of Alternaria are significant causes of necrotrophic diseases in various crops (Adhikari, 2017). *A. solani* belongs to the fungi imperfecti (Deuteromycotina) in the class Hyphomycetes and order Hypheles (Agrios, 2005). It survives on infested debris from the previous tomato crop and may also survive on contaminated seeds from infected fruit or on other solanaceous hosts (Chaerani *et al*., 2007). *Alternaria solani* overwinters primarily on infected crop debris. The dark pigmentation of the Mycelium increases resistance to lysis which extends the survival time in the soil to several years. The mycelium consists of light brown, slender, septate sparsely branched hyphae which become dark-coloured with age. The hyphae ramify in the intercellular spaces but later penetrate the cells of the invaded tissues (Chaerani *et al*., 2007).

Alternaria produces unique club-shaped Conidia, often beaked with horizontal and often with vertical septa that may be produced either individually or in a chain, depending on the species. Hyphal cells are darkly pigmented with melanin, which guard hyphae and spores against environmental stress and allows spores to survive in soil for long periods of time (Rotem *et al*., 1994). The mature Conidia are detached readily and dispersed chiefly by air currents, water and insects. On a suitable host they germinate readily in moist weather each by putting out 5-10 germ tubes.

2.3 The disease cycle

Alternaria solani overwinters in the soil, plant debris, seeds and alternate hosts in the form of conidia or mycelia, which may serve as primary sources of inoculum. The cell wall of conidia enables fungus to adapt to adverse climatic condition (Dang, 2015). Infections occur during warm and humid conditions. Conidia germinate at temperature of 18-32°C in cool and humid conditions in the presence of moisture to form germ tubes (Kemmitt, 2002). Germ tubes penetrate host tissue directly or enter through stomata or wounds, thereby causing infection. Lesions appear after two to three days of infections depending on the environmental conditions, leaf age, cultivar susceptibility and spores are produced 3 to 5 days after the appearance of lesions (Jones, 1991). Generally, a long period of wetness is needed for spore production but spores are also produced during alternate wet and dry conditions. Conidiophores are developed first during wet night which then produces spores or conidia in another wet night after the period of day light and dryness. In the next step, conidia are rapidly dispersed through wind and rain splash and continue the disease cycle in other healthy parts of the same plant or different plants. Early Blight has the potential of causing polycyclic infection because of its short disease cycle (Kemmitt, 2002).

2.4 Tomato early blight symptoms

The primary damage of early blight is defoliation of the plant resulting in reduced photosynthetic ability of the plant and poor health (Van der Waals, 2002). The most susceptible plants are those that are physiologically old, weak, and malnourished and wounded by wind, sand, hail, or insects (Van der Waals, 2002). Typical disease symptoms are characteristic dark necrotic lesions with concentric rings on leaves, collar rust on the stems and fruits that crack at the stem (Kemmitt, 2002). Disease symptoms appears on all above ground parts particularly on leaves, stems, petiole, twig and fruits, under favourable condition results in defoliation, drying off of twigs and premature fruit drop and thus causing 35–78% loss in fruit yield (Grigolli *et al*., 2011). When tomato fruits become infected, the quantity and quality of marketable produce is decreased and the number of secondary pathogens increases (Tsedaley, 2014).

Under severe epidemics complete defoliation can occur resulting in major crops losses in short period of time (Chaerani and Voorrips, 2006). The fungal spores can be spread by wind, rain, irrigation, insects, workers, tools and equipment. Once the primary infections have occurred, they become the most important source of new spore production and are responsible for the rapid disease spread (Baysal-Gurel, 2010). Early blight can develop quickly at mid-to-late season and is more severe when plants are stressed by poor nutrition, drought, other diseases or pests. *Alternaria solani* survives on infested debris from the previous tomato crop and may also survive on contaminated seeds from infected fruit or on other solanaceous hosts (Chaerani *et al*., 2007). Early blight can severely damage the crop during all its developmental stages if not properly controlled and can cause and yield reduction up to 80 % (Derbalah *et al*., 2011).

2.5 Disease distribution and economic importance

Air currents, windblown soil, splashing rain, running water and moving machinery can spread the fungus to the new crop in the field (Chaerani *et al*., 2007). Early blight is widespread in most areas where tomatoes and potatoes are grown, but especially prevalent in the tropics and temperate zones. Since older leaves and senescing leaves are more susceptible, severe epidemics of the disease occur at physiological plant maturity (Grigolly *et al*., 2010). Early tomato varieties tend to be more susceptible. The primary damage of early blight is due to premature defoliation of the plant. Photosynthesis rates increase and respiration rates decrease in apparently healthy tissues (Tsedaley, 2014). When tomato fruits become infected, the quantity and quality of marketable produce is decreased and the number of secondary pathogens increases (Van der Waals, 2002). Among the major diseases of tomato, early blight caused by *Alternaria solani* is the most damaging and causes reduction in quantity and quality of the crop (Abdel-Sayed, 2006). The disease is becoming more severe in all regions partly due to warmer temperatures experienced worldwide (Keinath, 1996).

2.6 Factors affecting disease development

2.6.1 Environment factors

Environment has traditionally been considered to have a major impact on disease development. Changes in environmental conditions are strongly associated with differences in the crop losses caused by a disease because the environment directly or indirectly influences growth, survival and dissemination, and hence the disease incidence and severity (Hudec *et al*., 2008; Paterson *et al*., 2013). Even if a susceptible host and the virulent pathogen are present in a certain locality, serious disease will not occur even if the particular host plant is planted, unless the environment favours its development (Keane, 1997). Moisture (water availability) is the most important environmental factor influencing disease outbreaks caused by fungi and bacteria (Van der Waals, 2001).

2.6.1.1 Temperature

The disease develops over a wide range of temperatures under wet and humid condition and the spores can germinate within one to two hours, and symptoms develop two to three days later under favourable conditions (Ganie *et al*., 2013). Spore germination and leaf infection requires warm temperature and high humidity or longer periods of wetness (Yonghao, 2012). As well as influencing the time necessary for infection, temperature affects the incubation of latent period (time between infection and the first appearance of disease symptoms), the generation time (the time between infection and sporulation), and the infectious period (the time during which the pathogen continues producing propagules).

At higher temperatures, the disease cycle is speeded such that the epidemics develop faster. Temperature increases *A. solani* infection and sporulation (Vloutoglou and Kalogerakis, 2000). Under cooler conditions, epidemics progress is usually slower in such a way that the disease incidence and severity may not reach the threshold levels necessary to cause significant crop loss.

2.6.1.2 Moisture

As with many other plant diseases, soil moisture plays a major role in the development of tomato early blight. In previous studies, it has been shown that supplementary irrigation system can lead to increase in some foliar and soil borne diseases (Olanya *et al*., 2009). Drip irrigation systems, unlike sprinklers, minimize the incidence of disease in the tomato shoots by not wetting the plants but favour those diseases caused by pathogens in the soil, especially under conditions of poor drainage (Marouelli *et al.*, 2005). Avoiding irrigation in cool cloudy weather; increasing the spacing between plants to improve airflow; and promoting drying of the plants aid to minimize the disease damage (Holm *et al.,* 2003). Furthermore, correlation between water stress and production of leaf photosynthetic pigments such as chlorophylls and carotenoids have been reported (Ren *et al*., 2016). These pigments are normally used as biochemical markers that indicates the intensity of stress conditions under reduced water availability (Ren *et al*., 2016). Reduction in chlorophyll contents has been reported in various planted under water stressed conditions. For example, correlation between water stress, high disease severity and reduced chlorophyll content were reported in rice, wheat, pigeon peas and peanuts (Bansal & Srivastava, 2015; Das *et al*., 2017; Wu *et al*., 2015). Despite availability of information disease development in relation to chlorophyll content and water stress, few studies have applied this information in studying the development of early blight disease in tomatoes.

Alternaria sporulates best at about 28˚C when abundant moisture (as provided by rain, mist, fog, dew, irrigation) is present on plant surface or foliage (Gomaa, 2001). Development and spread of fungi i.e. *A. solani* is determined by free moisture, rainfall, relative humidity, and temperature (Nitzsche, 2005).

2.6.1.3 Host susceptibility

Climate is a primary determinant of agricultural productivity and as such it influences disease development to the type of crops that grows in a specific location. Early blight is favoured by warm temperatures and extended periods of leaf wetness from frequent rain, overhead irrigation, or dew (Baysal-Gurel, 2009). Susceptibility to early blight increases with the age of the plant tissue and of the plant, particularly after flowering and fruit initiation (Schultz *et al.*, 2009). Crop susceptibility is thus strongly correlated with plant maturity and early blight resistance decreases as plant maturity levels increase (Van der Waals, 2002). This type of resistance is known as temporary resistance and should be distinguished from permanent resistance which is unaffected by plant age, rate of cultivar maturity and yield (Van der Waals, 2002).

On young tomato seedlings lesions may completely girdle the stem, a phase of the disease known as "collar rot," which may lead to reduced plant vigour or death (Kemmitt, 2002). The disease appears on leaves, stems, petioles, twigs, and fruits, under favourable conditions results in defoliation, drying off of twigs and premature fruits drop and thus causing 35-78% loss in fruit yield (Grigolli *et al*., 2011). Stems and petioles affected by early blight have elliptical concentric lesions, which severely weaken the plant (Shankar *et al.*, 2014).

2.7 Work done on the problem

2.7.1 Early blight management

Implementation of varying plant disease management strategies is crucial in the quest to reduce the economic and aesthetic damage caused by plant diseases (Ponsidha, 2015). Early blight is one of the most significant plant disease affecting tomatoes requiring a combined application of control measures, including fungicides applications. The disease occurs wherever tomato is grown and can cause severe defoliation, resulting in smaller, fewer fruits (Jackson, 2010). Currently sanitation, long-term crop rotation to reduce the spore concentration on decaying plant material and routine application of fungicides are the most common early blight management options in tomato production (Mate *et al*., 2005).

2.7.2 Chemical control

The most common control measure used in the management of early blight is through application of foliar fungicides. Several types of fungicides have been developed for the control of early blight, but fungicides treatment is not economically feasible, nor environmentally friendly. Fungicides application can be before or after appearance of symptoms and this can continue for as long as conditions are suitable for disease development (Grigolli *et al*., 2010). The fungicides protect only the plant tissues that have been sprayed, however, and must be reapplied on a regular basis at least every 7-10 days to provide sufficient protection (Chaerani *et al*., 2007). According to Yazici *et al*. (2011), numerous effective fungicides have been recommended for use against the early blight pathogen, but are not considered to be long-term solutions, due to concerns of expense, fungicide residues and other health and environmental hazards. The frequent use of fungicides have however been shown to result in the emergence of new fungicide resistance isolates due to high selection pressure (Foolad, 2008; Adhikari *et al*., 2017). In fact recently there has been an increase in the number of reports on A. solani population variability due to fungicides application frequencies (Dita Rodríguez *et al*., 2006). Chemical control is conducted mainly with protected fungicides such as Mancozeb and Chlorothalonil (Shtienberg *et al*., 2006). Since these fungicides have only preventive, not curative properties, fruit infestation, cannot be prevented and crucial loss still occurs (Abdel-Samen *et al.*, 2015).

2.7.3 Cultural practices

Most cultural control methods aim at helping plants to avoid contact with pathogens by creating environmental conditions unfavourable to the pathogen or reducing the amount of pathogen in a plant, a field, or an area (Agrios, 2005). Cultural practices such as crop rotation, removing and burning infected pant debris, and eradicating weed hosts help reduce the inoculum level for subsequent plantings (Wharton, 2017). Cultural management of early blight also involves the use of certified disease free seeds; planting of disease free transplants; crop rotation of tomatoes with non-host plants for at least 2 to 3 years; and removal of dead plant materials, volunteer plants and weed in order to reduce pathogen inoculum. Organic soil amendment in the form of good quality compost also improves soil structure and its ability to hold water and nutrients; it also supports microorganisms that contribute to biological control (Baysal-Gurel *et al*., 2009). It also involves avoiding irrigation in cool, cloudy weather, and time irrigation to allow plants time to dry before night-fall.

2.7.4 Crop rotation

Crop rotation is also regarded as a good management tool for early blight control as a soil borne disease. Cropping system significantly impacted early blight disease based on disease incidence, severity and lesion numbers (Olanya *et al.,* 2009). The focus in designing a rotation for disease management is to alternate the different crop family that are susceptible to different pathogens. It mitigates the build-up of pathogens and pests that often occurs when one species is continuously cropped. Using a three or four year crop rotation with non-solanaceous crops will allow infested plant debris to decompose in the soil (Baysal-Gurel, 2010). Rotations with grains, corn, legumes and maize are preferable.

A high frequency of tomato cropping in one field or place, as well as consecutive plantings of tomatoes, are associated with an earlier appearance of initial early lesions (Shtienberg, 1990). Some plants suppress pathogens in addition to being unsuitable hosts. These include some cover and green manure crops, as well as cash crops. Disease-suppressive species in a rotation sometimes reduces the time needed before a particular cash crop can again be produced successfully.

The specific mechanisms involved appear to vary with the crop and the pathogen. Depending on the mechanism, the beneficial effect can disappear shortly after incorporation or last for years. Suppression can vary with how well the pathogen is established in a field. Also, to achieve success, beneficial crops may need to be grown more than once before a susceptible cash crop is replanted.

2.7.5 Organic amendments

Other studies have also reported on the positive effect of organic amendments in the management of early blight disease in tomatoes and potatoes (Larney *et al.,* 2003; Ghorbani *et al.,* 2008). Organic soil amendments in the form of compost improves biological, chemical and physical properties of amended soils and can provide effective biological control of diseases caused by plant pathogens (Ghorbani *et al.*, 2008; Kena & Swart, 2008). Because early blight pathogen has saprophytic capabilities that facilitate survival and dispersal, on site survival techniques are avoided in favour of diverting material to the land fill (Van der Waals, 2002). However, composting these material on local farm has the potential to destroy these pathogens and weeds. This will further enable farmers to reduce import of nutrients and organic matter for their operations and generate local source of disease and weed-free planting medium (Liebman *et al.*, 2000; Larney *et al.*, 2003).

Good quality compost improves soil structure and its ability to hold water and nutrients. It also supports microorganisms that contribute to biological control (Kena & Swart, 2009). Early blight severity was less in tomato plants grown in compost-amended soil in the high tunnel than in non-amended soil; furthermore, incorporating the amendments into soil increased the total and marketable yield (Baysal-Gurel *et al*., 2009).

2.7.6 Integrated Disease Management

Early blight management is done excellently with the use of different fungicides (Verma, 2010; Zhang *et al*., 2013). However, the worldwide trend towards environmentally safe methods of plant disease control in sustainable agriculture calls for reducing the use of these synthetic chemical fungicides (Nashwa, 2011). Minimizing leaf wetness by managing irrigation water to the plants assists in suppressing Inoculum germination on plant debris. Effective management of this disease requires implementation of an integrated disease management approach (Stevenson *et al*., 2007). This integration of control measures includes the use of cultural practices such as sanitation, planting of resistant cultivars and application of foliar fungicides. Sanitation can be achieved through removal and destruction of crop debris from the infected field after harvest in order to reduce the primary source of inoculum for the next crop (Shankar *et al*., 2014). Since the causal pathogen can also be carried on tomato seed, the planting of pathogen-free organically produced tomato transplants is essential in managing early blight disease (Baysal-Gurel, 2010).

2.7.7 Resistant variety

Resistant cultivars are potentially the most economical control measure because they can extend the intervals between fungicide sprays while maintaining control of the disease (Keinath *et al*., 1996). Tomato plant varieties express varying degrees of resistance to many diseases. Source of early blight resistance have been identified in wild relatives of tomato. Some of these have been utilised through traditional breeding approaches, but an increased level of resistance is negatively correlated with earliness and yield (Foolad *et al.*, 2002).

The most resistant breeding lines and hybrid cultivars with acceptable horticultural characteristics that are currently available have moderate resistance to early blight and slightly later in maturity (Gardner, 2000). Younger leaves are more resistant to early blight than older leaves because of high sugar content and glycoalkaloids (Solanine, Chaconine and Solanidine) (Rotem, 1994). Therefore, a late maturity crop may appear early blight resistant without having resistant genes due to high sugar content and glycoalkaloids (Chaerani *et al*., 2007)

Although genetic resistance is the most efficient control method, there is still no tomato variety available with the acceptance level of resistance to early blight. As a result, the main control method involves the application of protective and systemic fungicides, raising production costs, besides being little effective in wetter periods (Holm *et al.*, 2003).

2.8 Work not done on the problem

2.8.1 Irrigation water management and its effect on crop yield and disease incidences

Irrigation water is the most significant input controlling plant life. Overhead irrigation promotes development of early blight by increasing the leaf wetness period (Van der Waals *et al*., 2001). Early blight disease is a potential thread where tomatoes and potatoes are grown under irrigation or heavy dew (Van der Waals, 2001). Studies have shown that free water is required for disease development and the duration of leaf wetness can account for up to almost 90% of variability in disease development and severity (Kemmitt**,** 2002). Infections are most prevalent on poorly nourished or stressed plants. Maintaining good crop vigour throughout the season, with adequate water and nitrogen, helps plants resist early blight. Almost all tomato early varieties tend to be more susceptible. Good irrigation management of tomatoes can result in higher and more consistent yields, better quality, larger fruit, less bacterial disease occurrence.

Water in the form of high relative humidity, rainfall or dew accumulation can increase conidia germination and pathogen infection (Vloutoglou and Kalogerakis 2000).

Farmers in many countries are now faced with legislative restrictions on use of water which are being imposed to try to secure safe and adequate water supplies for domestic water users (Morison, 2007). Adequate irrigation management of tomatoes can result in more consistent higher yields, better quality, larger fruit, less fungal disease occurrence.

When water is a limiting factor for agricultural production, early blight invades the older, less vigorous leaves first, and moves up the plant to younger leaves. Irrigation with water deficit index provides greater economic return than total irrigation (Zegbe-Domíngues *et al*., 2003). When properly applied, the technique showed great potential to increase water use efficiency (Meric *et al*., 2011), especially in areas of low water availability (Lorite *et al*., 2007). Recent research on processing tomatoes in Ontario has shown yield increases of up to 81% on a range of soil types with the use of properly scheduled irrigation (Warner *et al*., 2003). The frequency, duration, amount and method of water application can affect pathogen survival and disease development in tomato production systems (Larkin *et al*., 2011; Ochola *et al*., 2015). Despite this rich knowledge on how water management can affect plant diseases and their development, this has not been carried out under the Limpopo conditions, especially with early blight disease. This information is necessary to improve productivity and food security especially under smallholder farming systems. Reduction in the indiscriminate use of pesticides can result in another positive outcome of the study.

CHAPTER 3

PREVALENCE AND DISTRIBUTION OF TOMATO EARLY BLIGHT IN GIYANI LIMPOPO PROVINCE

3.1 Introduction

Tomato is a major contributor to food security and improved livelihoods for farmers in the Limpopo province, especially in the Giyani area (Altman *et al.*, 2009). The crop is grown for both commercial and consumption purposes by both smallholder and emerging farmers in the area. Tomato as with any other crop, is susceptible to abiotic stress conditions such as drought, high and low temperature and salinity which further influences the occurrence and spread of pathogens, insects, and weeds (Coakley *et al*., 1999; McDonald *et al*., 2009; Ziska *et al*., 2010; Peters *et al*., 2014). The occurrence of both biotic and abiotic factors results in a significant reduction in crop quality and yield losses. Tomato diseases such as early blight caused by *A. solani* are highly prevalent in Limpopo due to prevailing climatic conditions (Mphahlele *et al*., 2018).

Since tomato is one of the main vegetable crop used for income generation by small scale entrepreneurs in the informal sector (Department of Agriculture Fishery and Forestry (DAFF), 2012), the presence of early blight negatively impacts on farmers' livelihoods. The crop is also highly nutritious, providing high content of vitamins A and C as well as lycopene, a natural antioxidant which is not found in other solanaceous crops (Chohan *et al*., 2015), which is important in fighting food insecurity among rural communities. However, the presence of early blight threatens crop quality and yields which results in food insecurity in smallholder farming communities. Inappropriate crop management practices, especially poor nutrient, soil and water management are also responsible for high early blight disease incidences and severity (Dawe *et al.*, 2000; Ladha *et al.*, 2003; Zhang *et al.*, 2007.

Tomato early blight is managed mainly by the application of synthetic fungicides, however most farmers lack resources and knowledge on application methods and their impact on the environment. Besides lack of knowledge on fungicides application, there are also reports on the existence of resistance *A. solani* races in the Giyani area (Van der Waals *et al*., 2003). Although there is confirmation on the presence of early blight disease and its causal pathogen in Limpopo Province, currently there are no reports on the extent of distribution as determined by farming practices and prevailing climatic conditions.

Early blight caused by *A. solani* is a serious disease among the important constraints in tomato production in Giyani. An understanding of the role of environmental conditions and its consequence on infections and survival of the pathogen by the farmers is needed to develop disease management practices (Chohan *et al*., 2015). The study is expected to bring knowledge and raise awareness on the prevalence of tomato early blight in the Greater Giyani municipality.

3.2 Description of study site

The study was carried-out in Giyani (Figure 3.1) within the lowveld regions in the sub-tropical zone of Southern Africa. The summer months (September to March) have long sunny days with occasional thunderstorms, while the winter (April to August) is mostly dry with mild temperature (M’Marete, 2003). Based on the information from South African explorer weather services, the region is the coldest during July when temperatures reach 8°C on average during the night. It is located in an area characterized by erratic low rainfall of about 450 - 500 mm per annum and minimum and maximum temperatures of 18°C and 39°C respectively.

Greater Giyani municipality is demarcated into three service centres namely Guwela, Mhlava Willem and Hlaneki service centers (Figure 3.1). At Guwela center, the main source of irrigation water is Greater Letaba and Klein Letaba River whilst Hlaneki receives their water supply from Klein Letaba and Nsami dam. However, due to occasional droughts water is normally applied in the Hlaneki area resulting in farmers relying on rainwater for crop irrigation.

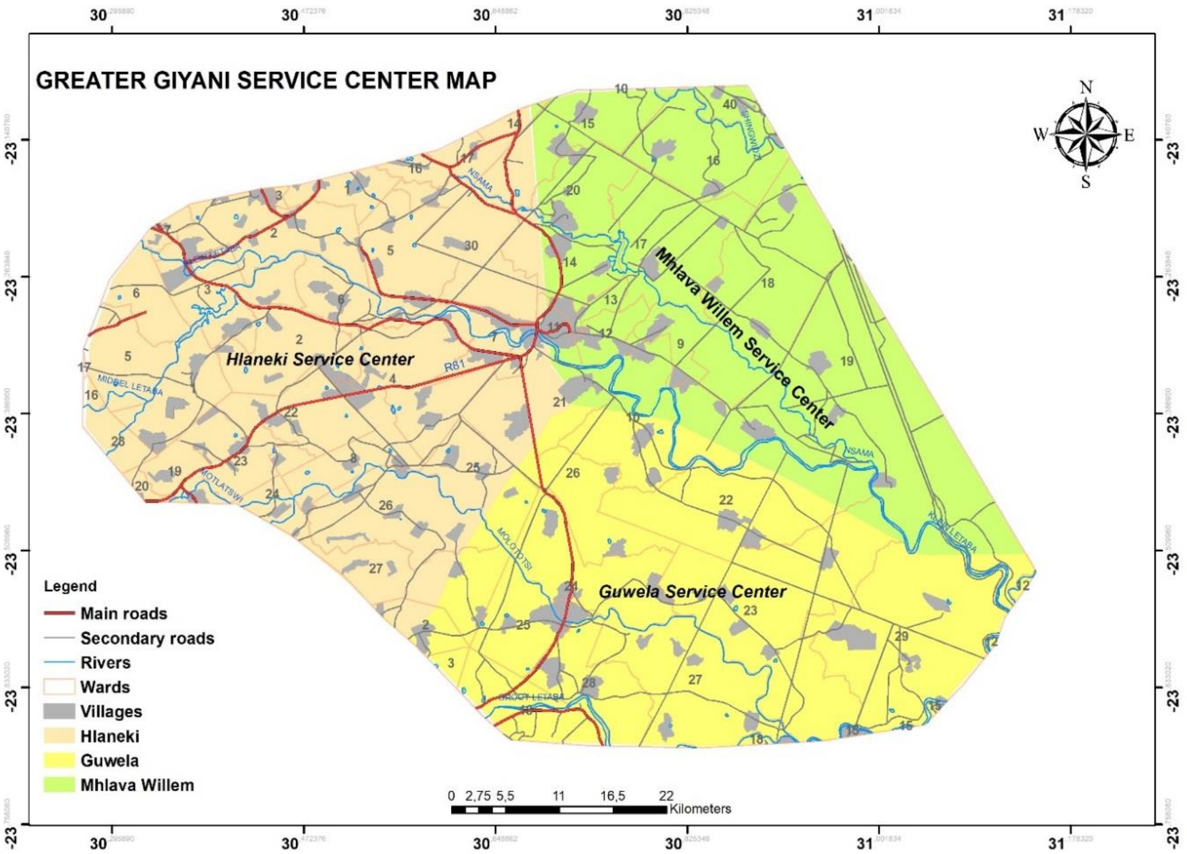


Figure 3.1 Giyani map showing three service centres where the survey was conducted

3.3. Materials and Methods

3.3.1 Early blight survey

Survey on early blight (EB) was conducted at three service centres of Greater Giyani Municipality namely Guwela, Hlaneki and Mhlava Willem (Figure 3.1). Twenty five potential tomato growers were identified from the records available at the local agricultural office. The farms were randomly selected based on the locations and production management strategies. Farms were selected in the three service centres allocations in the Greater Giyani Municipality and that they should be using drip irrigation system. The study will be comparing EB disease incidence and severity in the farms located in the three service centers of Giyani Municipality. EB survey was conducted during September to mid December 2016 to determine its prevalence and severity on grown Tomato Cultivars. Tomato plants were surveyed during early maturity stage and at harvest stage. Plants were randomly selected and early blight scored using a disease scale.

3.3.2 Data collection

Disease incidence

Determination of early blight incidence was done by using a stratified sampling method. A total number of twenty five (25) plants were randomly chosen from the corners of each field and also in the middle. From each plant, six leaves were randomly picked and assessed for early blight symptoms and the total number of leaves affected was recorded as a total percentage of infected plant. Percent disease incidence was determined using a formula by James (1974):

$$\text{Percentage Disease incidence} = \frac{\text{Number of diseased leaves}}{\text{Total number of leaves assessed}} \times 100$$

Disease severity

The same number of plants (25) were also selected to determine EB severity. Six leaves from each plant were randomly picked and assessed for early blight using the rating scale of 1-5 (Pandey *et al*., 2003) with slight modification as shown in Table 3.1 and Figure 3.2.

Percent disease severity was calculated as per the following formula:

$$\text{Percent Disease Severity} = \frac{\text{Sum of all diseased rating}}{\text{Total no. of rating x Maximum diseased grade}} \times 100$$

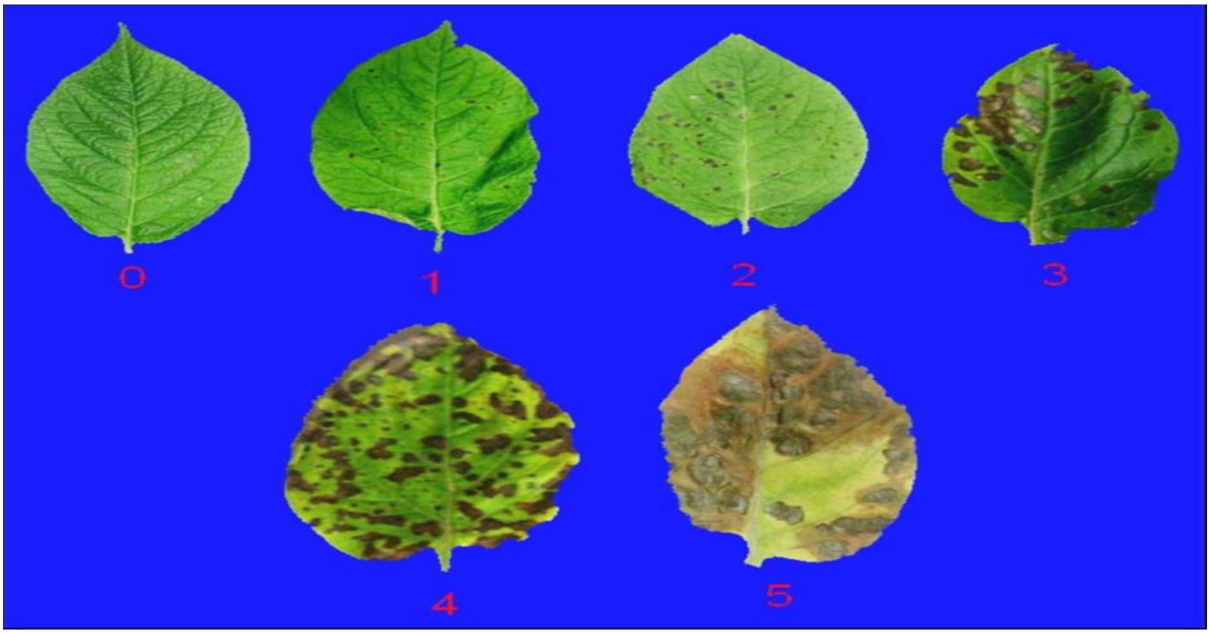


Figure 3.2. Scale (0-5) used for disease severity rating.

Table 3.1. The description of rating scale used to assess Early blight disease severity

Plant part	**Score**	**Description**
Leaves	0	Healthy
	1	One or two necrotic 1-5% spots on the leaf.
	2	Few isolates spot on the leaf covering nearly 6-20% of the surface leaf area.
	3	Many spots coalesced on the leaf covering 21-40% of the surface area of the leaf.
	4	Irregular, brightened with sunken lesions on the leaf covering 41-70% of the surface area.
	5	The whole leaves 71-100% infected.

3.3.3. Data analysis

Data obtained from the survey were subjected to analysis of variance (ANOVA) using Statistix 10.0 program for the significance of treatment effects. The Least Significant Difference (LSD) test was used to compare treatment means at 0.05% probability levels (Gomez and Gomez, 1984). The treatments to be compared are full and deficit irrigation treatments effects on early blight disease incidence and severity.

3.4. Results

3.4.1 Guwela Service center Disease incidence percentage and severity

The results on early blight incidence percentage and severity at Guwela Service Centre are shown in Table 3.2. The results showed that the highest tomato early blight disease incidence percentage was recorded at Green valley, Ntshovelo and Anakanya farms at 54% and 53% respectively. Whilst the lowest number of plant showing early blight symptoms was recorded in Mvhuleni (40%) followed by Tshulani with 35% disease incidence. All the other farms displayed early blight incidence ranging between 41 and 52%. On average, there was no significant difference between all the surveyed farms with regard to the occurrence of early blight.

The severity of early blight varied with each farm surveyed. The highest EB severity was recorded at Dzimuhluri and Tiyisela farms with a rating of 2.5 and 2.2 respectively. This was followed by Mvhuleni, Ntshovelo, and Seda farms with the disease rating of 1.8 and 1.9 respectively. The lowest disease severity was recorded at Green valley, Mzilela Cooperative and Vanyenge farms with a rating of 1.2, 1.3 and 1.4 respectively. There were no significant different ($P \geq 0.05$) on Dzimuhluri, Tiyisela and Malatjie farm. There were no significant different observed on Ntshovelo, Seda and Mvhuleni farm. Mzilela and Green valley were significantly different from Dzimuhluri. Maruping agric, Anakanya, Vanyenge, Mzilela coop and Green valley were not significantly different from each other.

Table 3.2 Early blight (EB) incidence and severity at Guwela service center

Farm name	**EB incidence (%)**	**EB severity**
Dzimuhluri	45	2.5^{b}
Tiyisela	50	2.2^{bc}
Tshulani	35	2.1^{bc}
Malatjie farmers coop	50	2.1^{bc}
Ntshovelo	53	1.9^{cd}
Seda	52	1.9^{cd}
Mvhuleni	40	1.8^{cde}
Maruping Agric	41	1.6d^{ef}
Anakanya	53	1.5d^{ef}
Vanyenge	51	1.4^{ef}
Mzilela coop	50	1.3^{f}
Green Valley	54	1.2^{f}

[a]Means followed by the same letter are not significantly different at ($P \leq 0.05$) according to Duncan's Multiple Range test. EB disease incidence did not differ significantly among farms. Disease severity was recorded on 1-5 scale where 0> Healthy, 1>One or two necrotic 1-5% spots on the leaf, 2>Few isolates spot on the leaf covering nearly 6-20% of the surface leaf area, 3>Many spots coalesced on the leaf covering 21-40% of the surface area of the leaf, 4>Irregular, brightened with sunken lesions on the leaf covering 41-70% of the surface area, 5>The whole leaves 71-100% infected.

3.4.2 Mhlava Willem Service Centre Disease incidence percentage and severity

The incidences and severity of early blight occurring in different farms at Mhlava Willem Service centre are shown in Table 3.3. In this area the highest early blight incidence was recorded at Shibonda farm at 55% of tomato plants showing disease symptoms. The lowest disease incidence was at Mucheneki farm (45%) followed by Sisimuka Gedle, Dyawu and Mabasa farms with a percentage ranging from 52%, 52% and 53% respectively.

The disease severity rating in this service center showed that early blight was severe in most of the surveyed farms. For example, out of the seven farms, early blight was more prevalent and severe in five farms. The highest disease severity was recorded at Makhensa ri xile and Mucheneki farms at 3.3 and 2.2 respectively. This was followed by Matoto, Mabasa, Sisimuka Gedle at 1.9 and Shibonda and Dyawu farms at 1.8.

Table 3.3 Early blight incidence and severity at Mhlava Willem Service Centre

Farm name	EB incidence (%)	EB severity
Makhensa Ri Xile	53	3.3^{a}
Matoto	50	1.9^{cd}
Mabasa	53	1.9^{cd}
Sisimuka Gedle	52	1.9^{cd}
Shibonda	55	1.8^{cde}
Dyawu	52	1.8^{cde}
Mucheneki	45	2.2^{bc}

[a]Means followed by the same letter are not significantly different at (P≤ 0.05) according to Duncan’s Multiple Range test. EB disease incidence did not differ significantly among farms. Disease severity was recorded on 1-5 scale where 0> Healthy, 1>One or two necrotic 1-5% spots on the leaf, 2>Few isolates spot on the leaf covering nearly 6-20% of the surface leaf area, 3>Many spots coalesced on the leaf covering 21-40% of the surface area of the leaf, 4>Irregular, brightened with sunken lesions on the leaf covering 41-70% of the surface area, 5>The whole leaves 71-100% infected.

3.4.3 Hlaneki Service Centre disease incidence percentage and severity

Early blight is more or less prevalent in every tomato field of Hlaneki s/c with varied incidence and severity from farm to farm (Table 3.4). The highest disease incidence percentage was recorded at Amata farm (50.5%) followed by G.S Maluleke (49.8%) and Mdunwázi (49.4) farm. The average disease incidence percentage was recorded at Hlayisi farm (48.3%). The lowest disease incidence percentage was recorded at A hi tirheni and M.T Agric farm at 47.8% and 47.8%.

The highest disease severity was recorded at A hi tirheni farm. The average disease severity was recorded at G.S Maluleke and Hlayisi farm. The minimum disease severity was recorded at Mdun'wazi farm. Mdun'wazi significantly difference from A hi tirheni, G.S Maluleke, Hlayisi and M.T Agric farm (Table 3.4). There was no significant different on A hi tirheni, G.S Maluleke, Hlayisi and M.T Agric farm .There was no significant different *($P \geq 0.05$)* on Amata and Mdun'wazi farm.

Table 3.4. Early blight incidence and severity at Hlaneki Service Centre

Farm name	EB incidence (%)	EB severity
A hi tirheni	47.8	2.2[bc]
G.S Maluleke	49.8	2.0[bc]
Hlayisi	48.3	1.9[cd]
M.T Agric	47.7	1.8[cd]
Amata	50.5	1.6[def]
Mdunw'azi	49.4	1.3[f]

[a]Means followed by the same letter are not significantly different at (P≤ 0.05) according to Duncan's Multiple Range test. EB disease incidence didn't differ significantly among farms. Disease severity was recorded on 1-5 scale where 0> Healthy, 1>One or two necrotic 1-5% spots on the leaf, 2>Few isolates spot on the leaf covering nearly 6-20% of the surface leaf area, 3>Many spots coalesced on the leaf covering 21-40% of the surface area of the leaf, 4>Irregular, brightened with sunken lesions on the leaf covering 41-70% of the surface area, 5>The whole leaves 71-100% infected.

3.5. Discussion

The survey of the disease was undertaken to reveal the incidence and severity of early blight in tomato growing areas of three service centers in Greater Giyani municipality areas. The results revealed that early blight disease incidence and severity was prevalent in all the three studied service centers. The highest EB incidence was recorded in Guwela Service Center as compared to Mhlava Willem and Hlaneki s/c as shown in Figure 3.3 (A). It was observed that most of the farms that were highly affected by EB disease were located near the rivers (Greater Letaba, Klein Letaba and Molototsi) and were using drip irrigation. These farms had a relatively high EB disease incidence than those located away from the rivers. Though farmers were using drip irrigation, leaf wetness tends to be higher under this conditions especially in the mornings due to dew. Other conditions such as high humidity accompanied by low night temperature and high day light intensity have shown to contribute to high disease incidence. The findings from the survey are similar to those reported by Rotem, (2004) that water in the form of high relative humidity, rainfall or dew accumulation can increase early blight conidia germination and pathogen infection. Van der Walls *et al*. (2001) also reported that alternating low and high humidity conditions favours disease development and severity.

The maximum disease severity was recorded in Mhlava Willem Service Center (Figure 3.3 A) which may be due to susceptibility of the cultivars, favourable environmental conditions (optimum temperature and relative humidity and moisture conditions) that must have favoured to build up of inoculum and showing increase in disease severity. Guwela service center was recorded less compared to other service centers. This may be due to unfavourable environmental conditions which might reduce the build-up of pathogen inoculum and thus reduce disease severity. The dry condition with less rainfall received on the area was not favourable for disease development. This is supported by Tsedaley, (2014) that favourable temperatures are required for spore germination and infection of plant tissues.

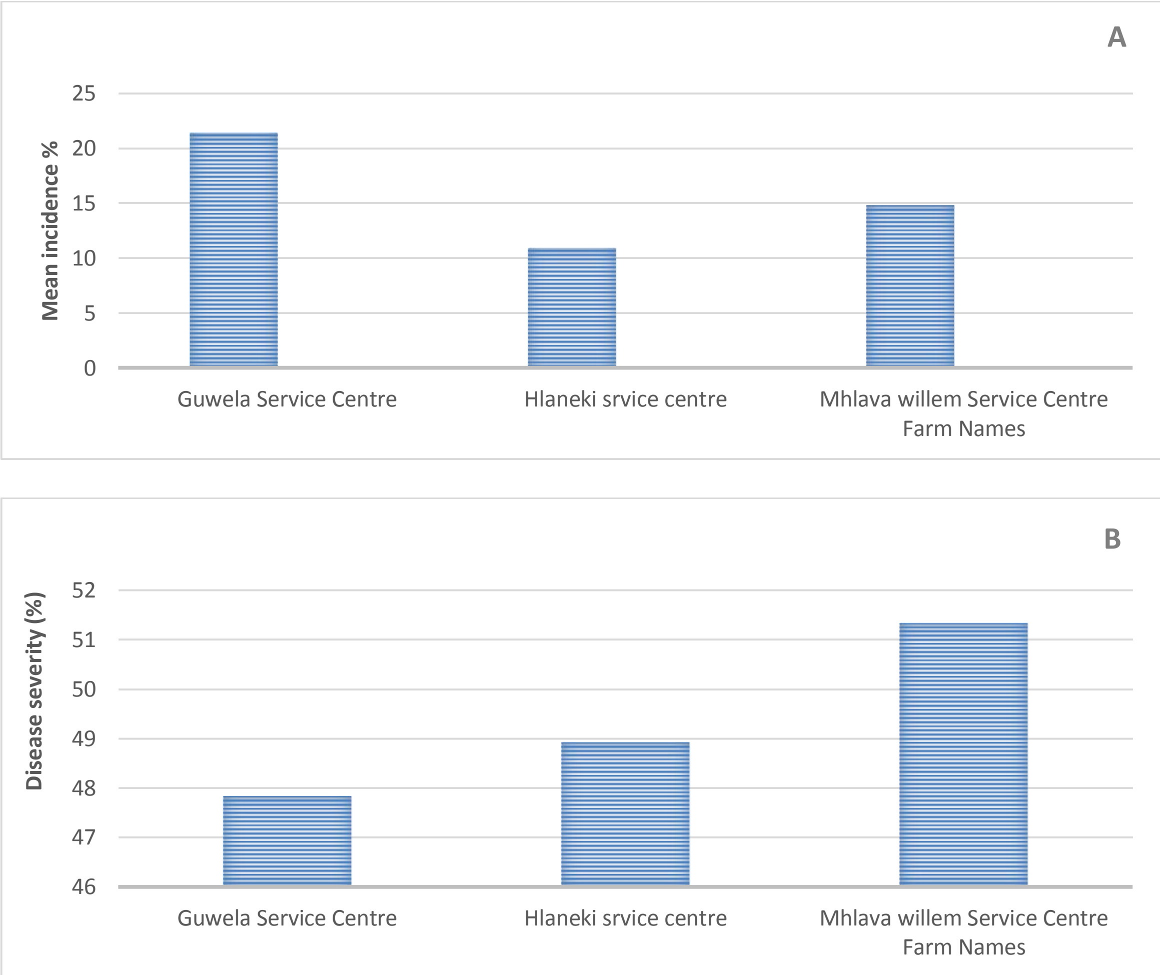


Figure 3.3 Early blight disease incidence (A) and severity (B) in Giyani Service Centers.

CHAPTER 4

OCCURRENCE OF TOMATO EARLY BLIGHT ON FOUR TOMATO CULTIVARS IN RESPONSE TO IRRIGATION MANAGEMENT

4.1 Introduction

Water constraints is one of the major challenges facing vegetable production in South Africa, including tomatoes. Tomato growing is considered a high risk activity due to the great variety of environments and systems in which it is grown; high susceptibility to pests and diseases; and high demand for inputs and services, which lead to high financial investment per unit area (José, 2013). Good productivity requires availability of water throughout the cycle, as the tomato plant is very sensitive to water stress (Lopes *et al*., 2005).

Irrigation management has a strong impact on the disease severity and epidemic progress rates of many plant pathosystems, ranging from leaf blights to vascular wilts (Café-Filho, 2018). The conditions that favour the majority of diseases are the existence of free water on the leaves, and high water content in the soil. Thus, irrigation by overhead sprinkler may aid dispersion and provide a micro environment which is favourable to infection by various pathogens that attack the shoots (Marouelli *et al*., 2013). Spores are initially splashed onto the lowest leaves, but frequent rain and overhead watering will spread the disease throughout the plant (Leonberger, 2016).

In some parts of the Limpopo province, including the greater Giyani Municipality area, low rainfall is a major challenge for crop production. This results in farmers using production systems which are heavily dependent on irrigation, as lack of water greatly affect the quality and quantity of production (Pires *et al*., 2009). Very little research has documented the impact of water management, especially mode of irrigation on early blight development under the Limpopo climatic conditions. Irrigation management may potentially influence early blight disease through reduced spore movement and germination under conducive conditions. This may lead to the control of early blight while reducing the application of fungicides and thus resulting in further reduction in pathogen fungicides resistance.

Drip irrigation technique is an efficient water saving technology and can significantly improve crop yield (Castellanos *et al*., 2013). A number of studies in various crops have validated the positive effect of drip irrigation in improving crop yields (Gideon, 2012). Drip irrigation has become one of the viable options in Giyani for its many advantages, such as the possibility to grow in areas of low water availability. Drip irrigation reduces water contact with crop aerial parts. Thus, disease development conditions become less favourable leading to high yield and improved fruit quality.

Unlike sprinklers, drip irrigation minimize the incidence of disease in the tomato shoots by not wetting the plants (Marouelli *et al.*, 2005). Free water is required for Alternaria spores to germinate; and spores will be unable to infect a perfectly dry leaf (Kemmitt, 2002). Although drip irrigation requires a high initial capital investment, it is one of the best techniques to use in applying water in vegetable production (Cetin *et al*., 2008). The objective of this chapter is to determine the effect of irrigation management practices on the occurrence of tomato early blight and tomato yield.

4.2 Materials and Methods

4.2.1 Site description

The study was conducted at two locations, approximately 50 km South of Giyani, with different farming practices namely: The first location was A Hi Tirheni Mqekwa Farm which is located at Daniel Ravalela Village (23°49' S; 29°41' E). The second location was Duvadzi Youth Organic Agricultural Co-operative Farm which is located at Loloka Village (23°.53'S; 30°.7'E) near Molototsi River (Figure 4.1). The river flows once or twice per annum in summer after major rainfall events. Both farms are located in an area characterized by erratic, low rainfall of about 450 - 500 mm per annum on average (predominantly summer rainfall from September to March), and minimum and maximum temperatures of 18°C and 31°C respectively.

A Hi Tirheni Mqekwa farm is located at a gentle slope towards the northern site where there is a dam for the village cattle water supply. Duvadzi farm is located next to Molototsi on a flat area with riparian stripe between the farm and the river. The predominant soil texture at A hi tirheni Mqekwa farm is loam. The predominant soil texture at Duvadzi farm is sandy loam with more clay occurring towards the Molototsi River.

Both farms have groundwater boreholes to access water for irrigation (Appendix 4.1). Duvadzi farm also uses water from the well in Molototsi River. Duvadzi Youth Organic Agricultural Co-operative Farm is situated near Molototsi River which flows once or twice per annum in summer after major rainfall events.

Both farms produce tomatoes for Johannesburg and local market depending on the market price. However, the presence of tomato early blight disease is negatively impacting on crop quality and quantity.

Figure 4.1. Google earth map of the experimental farm.

4.2.2 Experimental design and layout

The experiments on both farms were laid out as a randomized complete block design (RCBD) in a split plot arrangement with irrigation as the main plot treatment and tomato variety as the subplot treatment (Figure 4.2). Each treatment was replicated four times. The irrigation treatment consisted of:

i. Full soil profile was refilled with approximately 60 mm irrigation from the onset of the study, followed by 30 mm irrigations per week to refill the soil root zone depending on hydro probe readings.

ii. Soil profile was refilled up to 30 mm followed by 1-2 deficit irrigations (30 mm) per week to refill the root zone up to a soil water deficit of 15 mm, leaving “room for rain”.

The subplot treatment consisted of four tomato varieties namely: Rodade, Star 9006, Commander, and HTX 14. No Early blight management was applied in all treatments. Fertilizer application was based on soil analysis results from the laboratory.

Experimental layout.

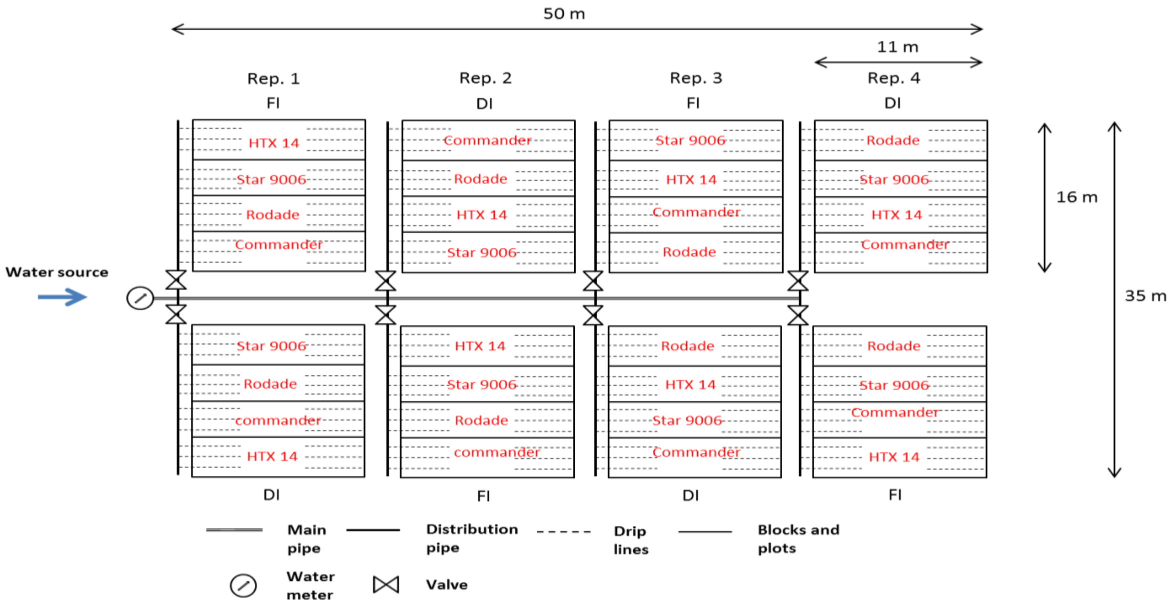


Figure 4.2. Experimental layout. The varieties of tomato in each block are shown in red. Two different irrigation treatments were applied in two blocks each (FI and DI).

4.3 Planting and pesticides application

Soil preparation was carried out using soil riper, disc plough and a ridger. Four weeks old healthy tomato seedlings were obtained from Khosouthopa Nursery. The first experiment at Duvadzi farm was established on the 29th December 2015 and the second was laid on the 20th October 2016. At A hi tirheni Mqekwa, first experiment planting was done on the 03rd March 2016 and the second planting was done on the 05th January 2017. Planting was done at the intra row spacing of 30cm and the inter row spacing of 1m (30 cm x 1 m). All varieties were trellised to support the plant and minimize fruits decay when touching the ground. Insect pests were controlled using possible pesticides such as Cypermethrin, Agromectin and Comite (Appendix 4.2). Pesticides were altered after seven days or on weekly basis based on the target pests and dosage for each was applied based on manufacturers' recommendations (Appendix 4.1).

4.4 Data collection

4.4.1 Soil properties

Soil properties such as nutrients status, texture and pH were determined before planting by taking soil samples at Duvadzi and A Hi Tirheni Mqekwa farm at the beginning of the experimental trial. Approximately 1 kg of soil was sampled using an auger from the top soil (0-30 cm) and sub soil (30-60 cm). The samples were put in a sealed plastic bags and taken to the laboratory for chemical and physical properties analysis as mentioned earlier.

4.4.2 Soil water content

Volumetric soil water contents were measured with the HydroSense II portable probe in all treatments at Duvadzi and A hi Tirheni Mqekwa farms. Measurements were taken in the top soil (0-15 cm), from the first week, once or twice per week for the full duration of crop growing period. At depths of 15-30 cm from the third week, two to three times per week after planting till the end of production period. The purpose was to schedule irrigations, to identify differences in soil water consumption and disease incidence between irrigation treatments and varieties, and to determine soil water storage for the calculation of Evapo transpiration (ET) with the soil water balance equation. Soil moisture measurements (16-30cm) for Duvadzi farm first planting was not included in the report due to water challenge experienced hence HydroSense II portable probe instrument readings were irregular.

4.4.3 Early blight incidence and severity

In both fields (Duvadzi and A hi Tirheni Mqekwa farm), eighteen plants were randomly selected using a stratified method from four corners and centre of the plot. All leaves were examined to determine appearance of the early blight symptoms. Percentage disease incidence were determined using a formula by James (1974):

Percent disease incidence = No. of diseased leaved/total no. of leaves examined x 100. Disease severity was determined using a scale developed by Pandey and Pandey (2003) as described in Chapter 3.

4.5 Results

4.5.1 Soil properties

Duvadzi farm

The predominant soil texture was found to be sandy loam with more clay occurring towards the Molototsi River. Soil pH for Duvadzi farm was slightly acidic on both 0-20cm and 16-30cm (Appendix 4.3). The observed pH can support the growth of most plant species. Bulk density was between 1.3 and 1.2 g cm^{-3}. The content of nutrients (N, P and K) and ions had slightly lower EC and PH. Electrical Conductivity (EC) was determined at 1:10 solution extract ranged from 17.6 to 17.7 mS m. The soil at Duvadzi farm was found to be predominantly rich in Ca and Mg.

A Hi Tirheni Mqekwa farm

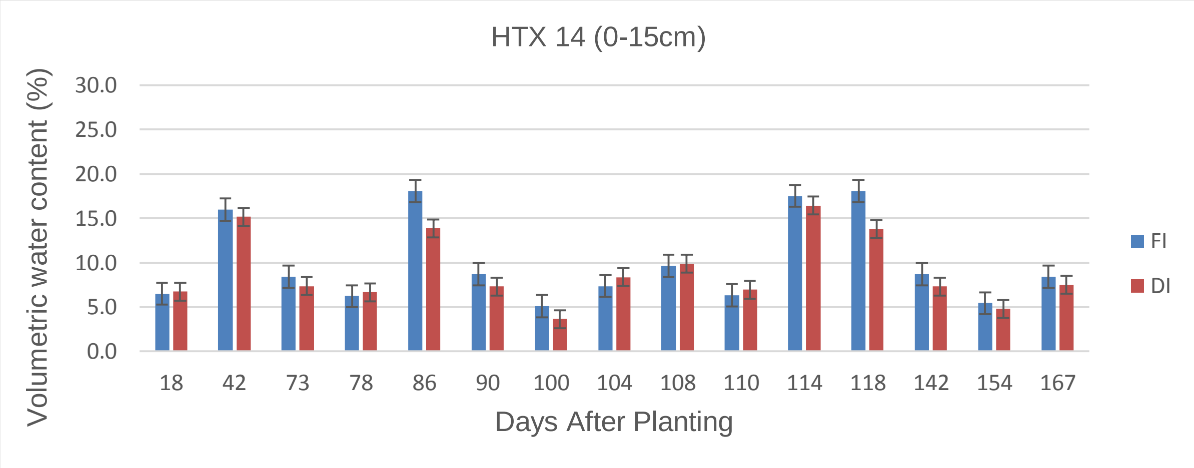
The soil at A Hi Tirheni Mqekwa Farm was found to be clay loamy with the pH value ranging between 6.0 and 7.0 on average (Appendix 4.4). Bulk density was 1.2 g cm^{-3} on both 0-20 and 30-50 cm. Electrical Conductivity (EC) was determined at 1:10 solution extract ranged from 43.6 to 47.0 mS m^{-1}. The soil was also found to be predominantly rich in Ca and Mg. The predominant soil texture at A hi Tirheni Mqekwa is sand clay loam.

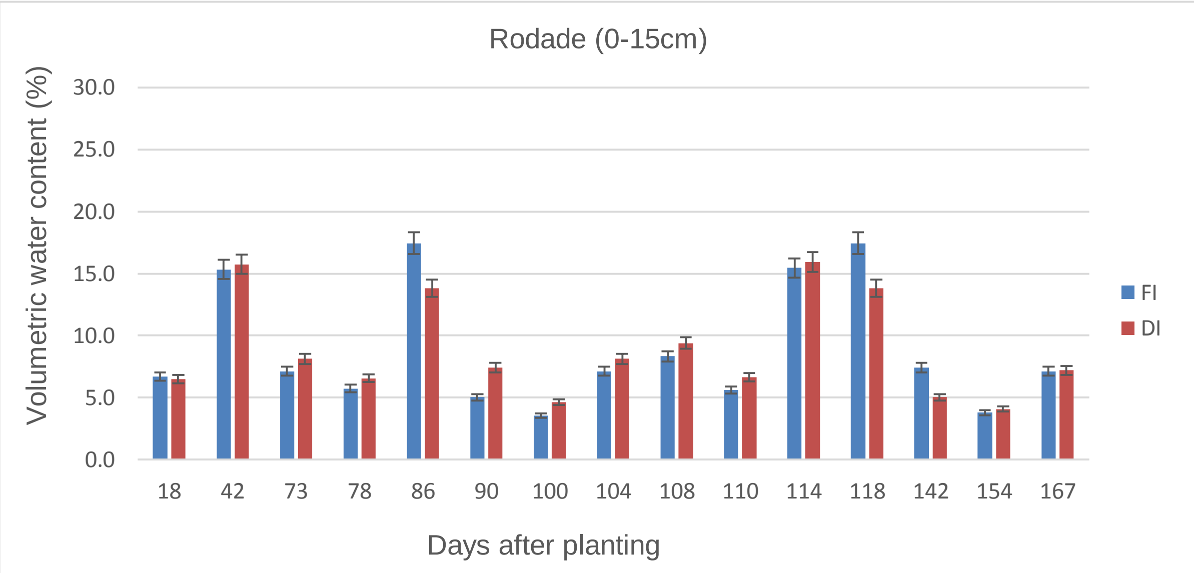
4.5.2 Soil water content

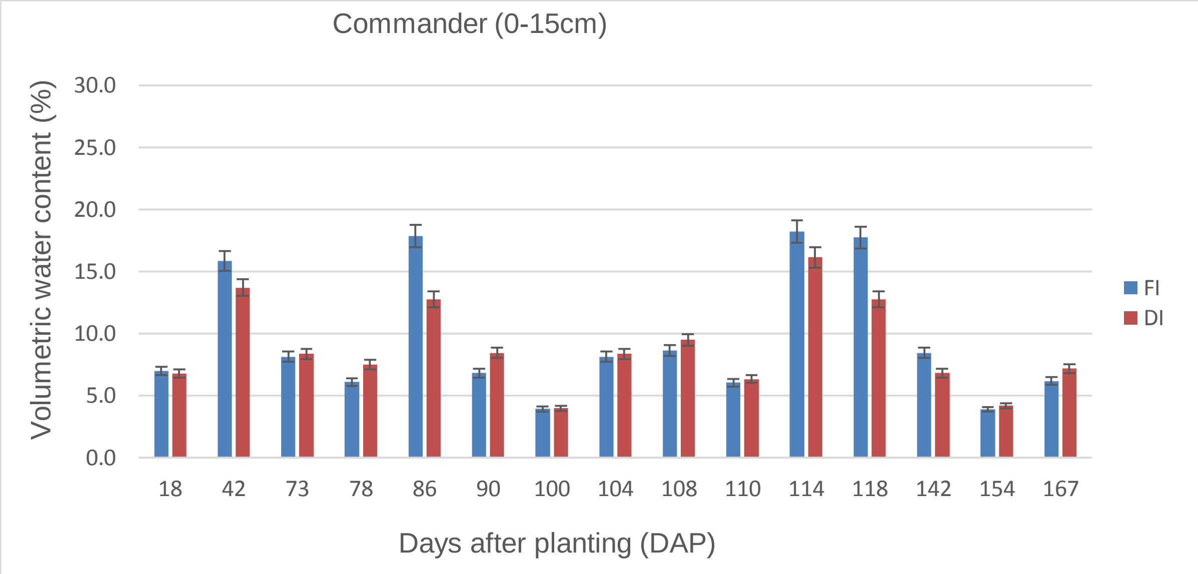
Duvadzi farm

In both irrigation treatments, VWC displayed varying response to different irrigation treatments based different soil measurement levels. The soil water content measurements for Duvadzi farm are shown in Figure 4.3 for the full irrigation (FI) treatment and the deficit irrigation (DI) treatment respectively. At 0 to 15cm, the highest soil water content in full irrigation treatments for all four varieties was at 42, 86, 114 and 118 DAP ranging from 15 to 20%. The lowest soil water content on HTX 14, Rodade, Commander and Star 9006 varieties recorded on 100 and 154 DAP VWC at the range of 0 to 5%. In deficit irrigation, the highest soil water content was recorded on 42 and 114 DAP at the range of 15 to 20% VWC and the lowest at 100 and 154 DAP at the range of 0 to 5% on all the varieties plots on trial.

There was no difference in terms of Volumetric Water Content (VWC) on average in all the variety treatments at Duvadzi farm during first planting season in both full and deficit irrigation (Figure 4.3). Low VWC % was recorded at 100 and 154 DAP, in all plots irrespective of irrigation treatment and cultivar planted (Figure 4.3). The same trend was recorded during late harvesting, 154 DAP where VWC was low on both full and deficit irrigation (Figure 4.3). On 114 and 118 DAP, there was an increase in VWC on both full and deficit irrigation and this was attributed to rainfall received during these days (Appendix 4.3).







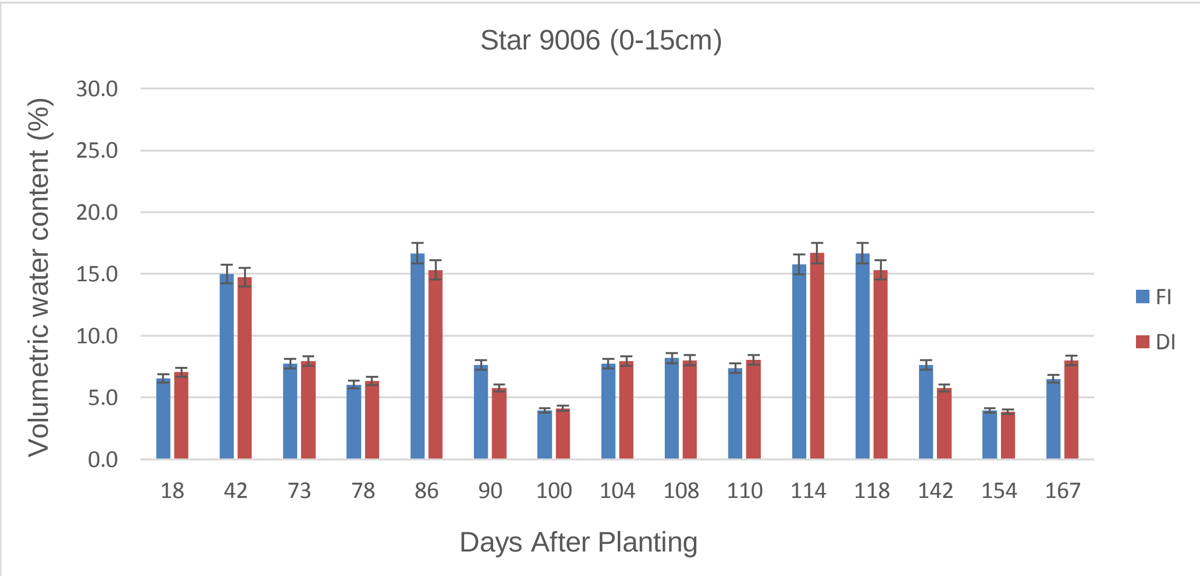
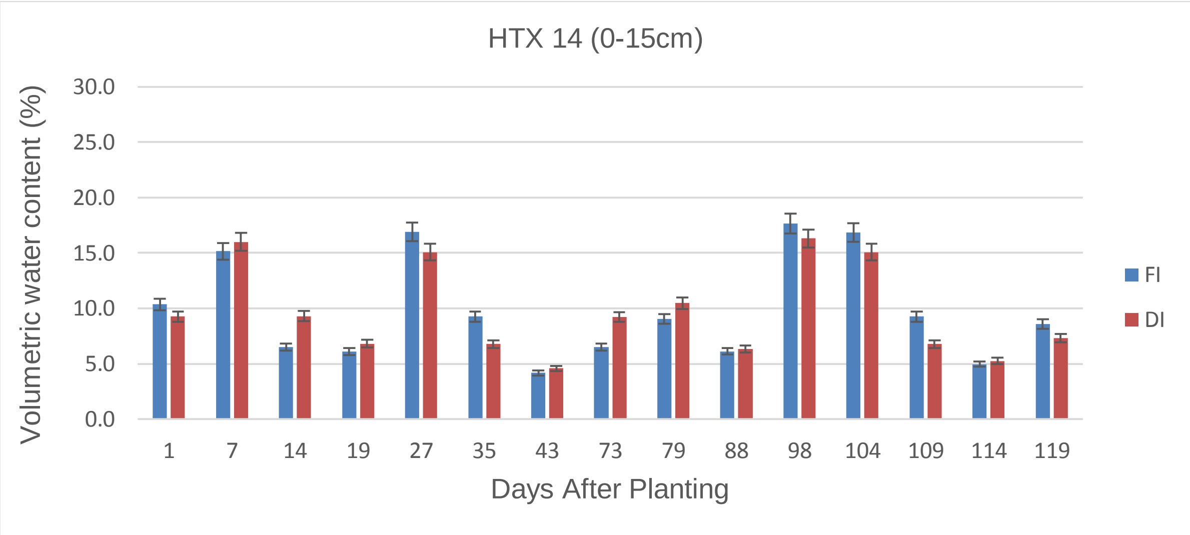
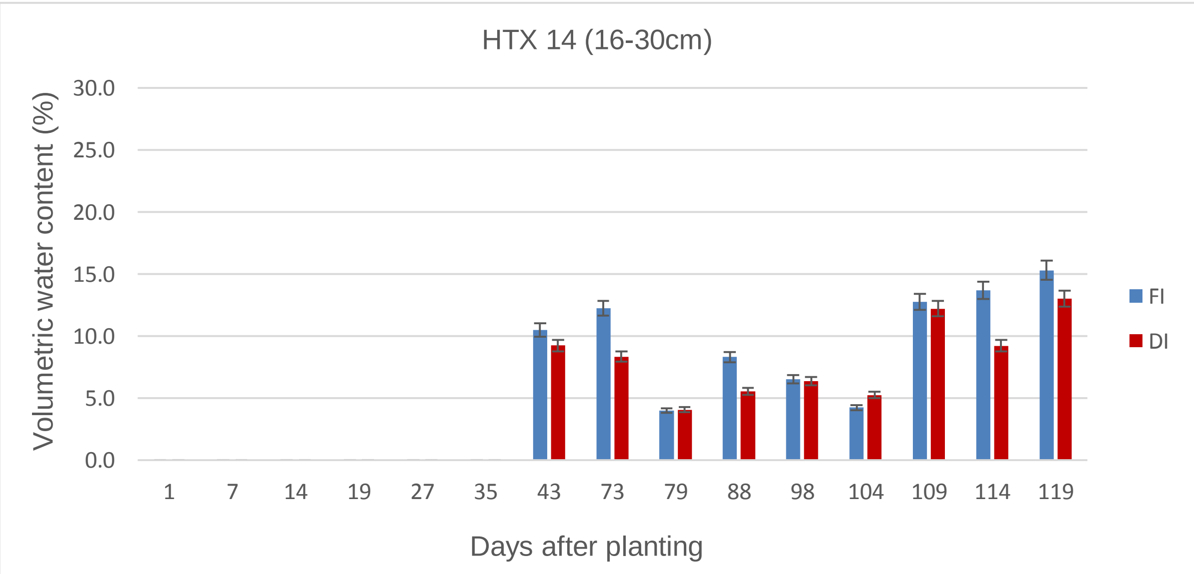


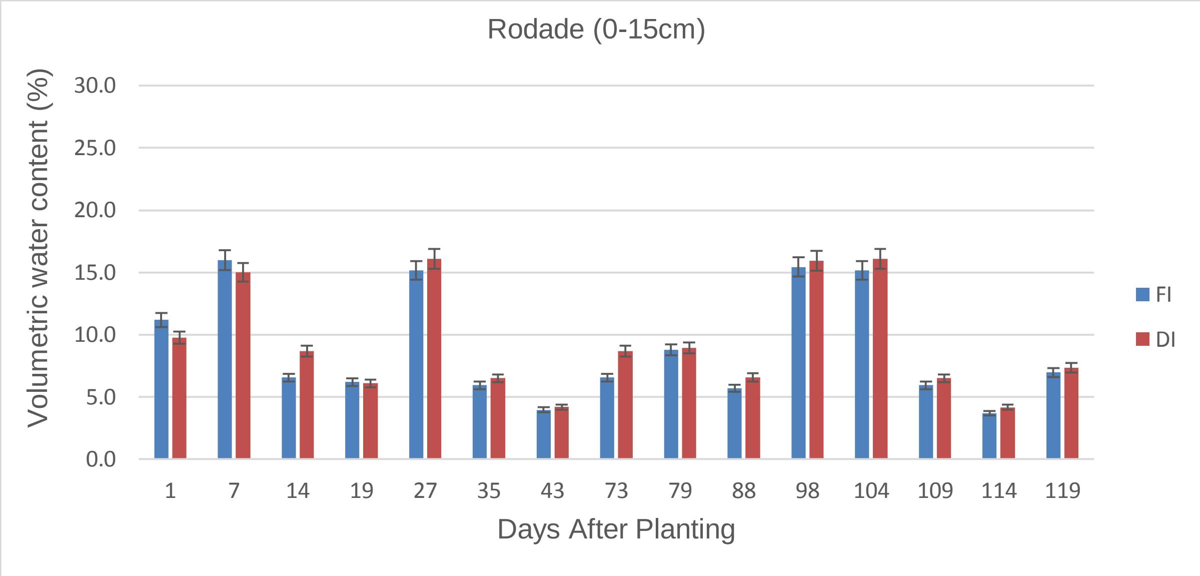
Figure 4.3. Volumetric soil water contents measured in the full irrigation (FI) and deficit irrigation (DI) plots of tomato varieties at Duvadzi farm, at two depths in the soil profile during the first cropping season.

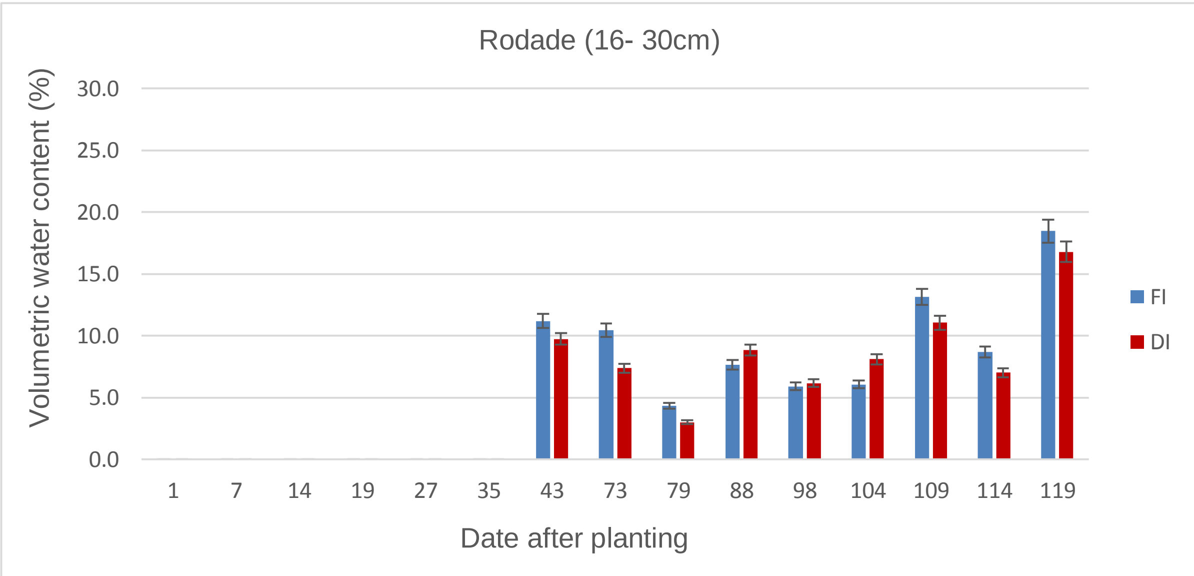
Volumetric water contents measured varied on Duvadzi farm throughout the second planting season as the results are shown on Figure 4.4. Under full irrigation (0-15cm), the highest VWC was recorded on 7, 27, 98 and 104 DAP at the range of 15 to 20% VWC at 0-15cm in all the varieties plots. The lowest was recorder on 43 and 114 DAP at 0-15cm in all the varieties plots (Figure 4.4).

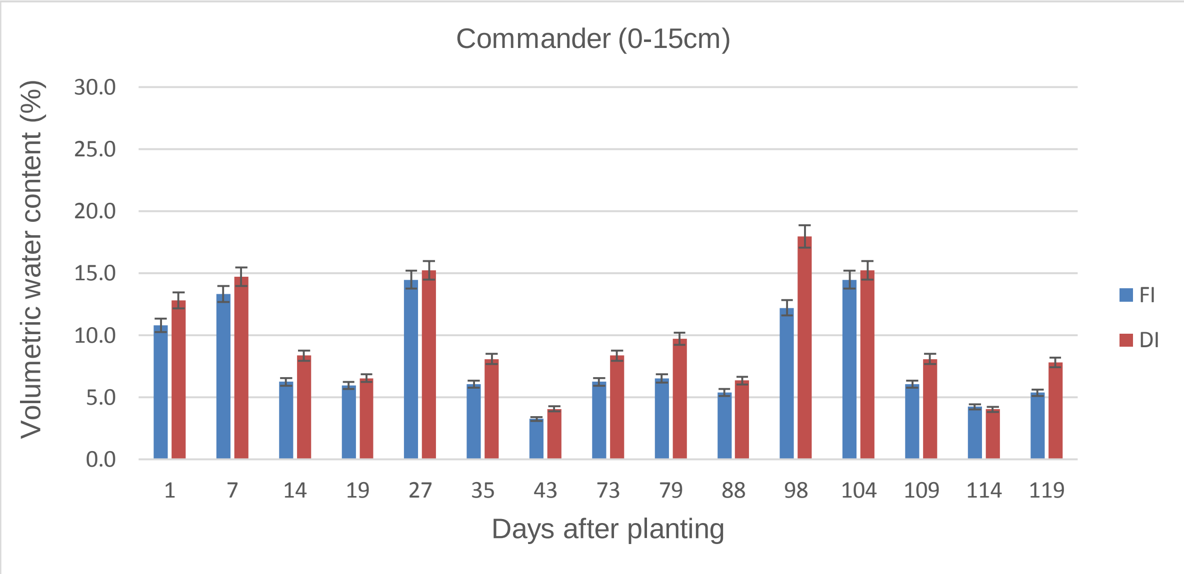
Soil moisture on 16-30cm was not significantly different as compared to the top part due to high evaporation encountered (Appendix 4.4). The soil moisture on 0-15cm was always higher on average as compared to 16-30cm due to irrigation**.** At 27, 98 to 104 DAP, rainfall was received and as a results the moisture content was high on both full and deficit irrigation and for all the varieties (Appendix 4.6). The highest records on deficit irrigation for HTX 14 plot, Rodade, Commander and Star plot (16 to 30cm) was on 7, 27, 98 and 104 DAP. The lowest irrigation measurements for the varieties plots were on 43 and 114 DAP. Volumetric water content for 16 to 30 cm was not recognised due as the instrument was recording out margin due very low moisture content.

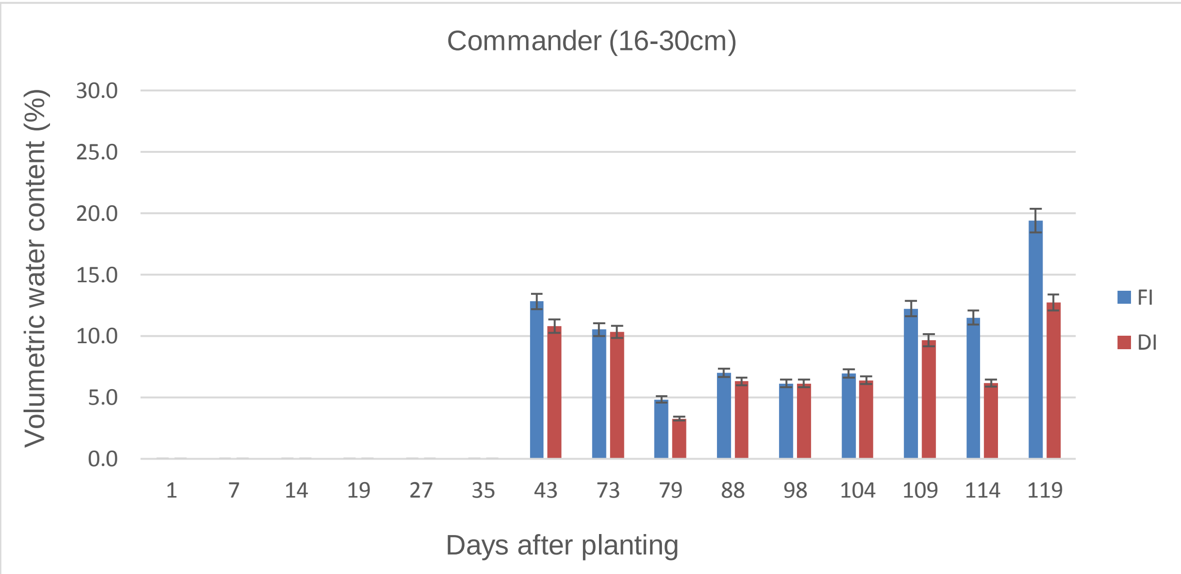


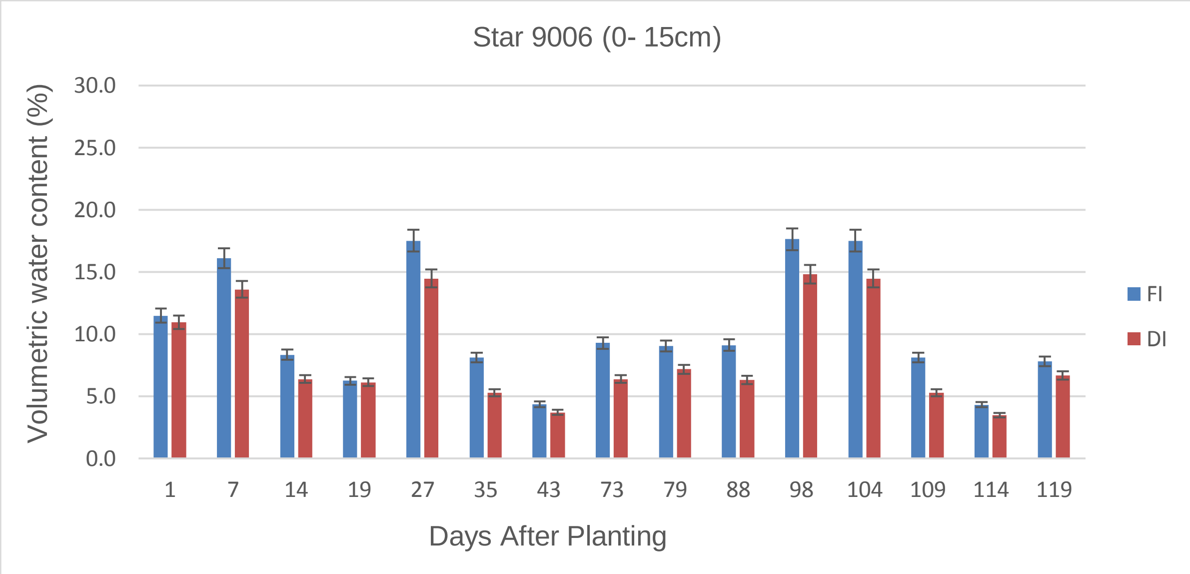



Rodade (0-15cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1
7
14
19
27
35
43
73
79
88
98
104
109
114
119
Days After Planting
FI
DI


Rodade (16- 30cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1
7
14
19
27
35
43
73
79
88
98
104
109
114
119
Date after planting
FI
DI


Commander (0-15cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1
7
14
19
27
35
43
73
79
88
98
104
109
114
119
Days after planting
FI
DI


Commander (16-30cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1
7
14
19
27
35
43
73
79
88
98
104
109
114
119
Days after planting
FI
DI



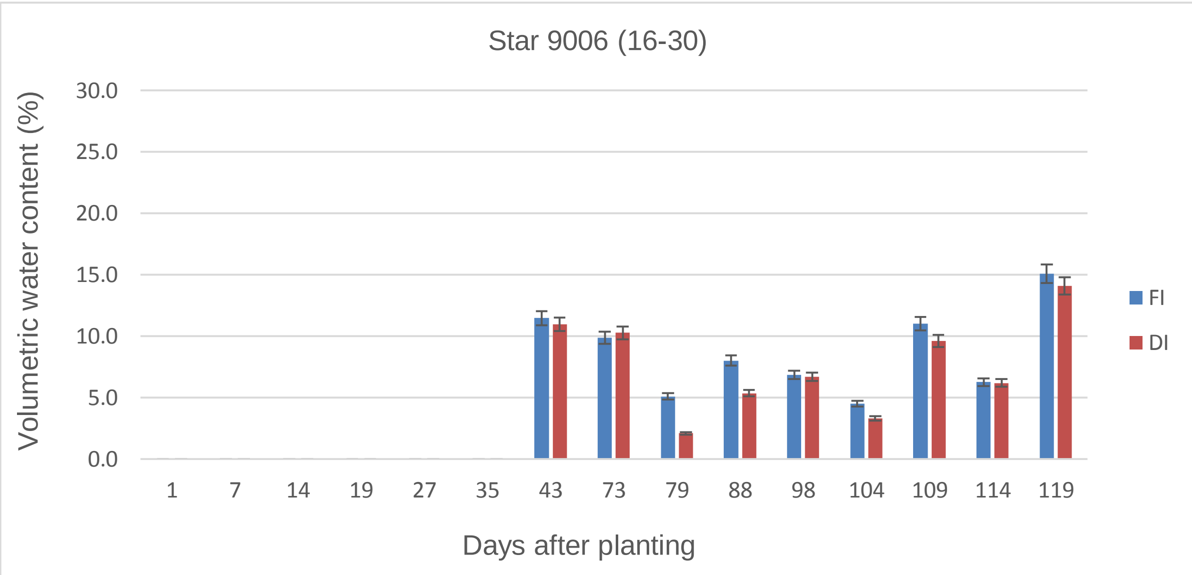
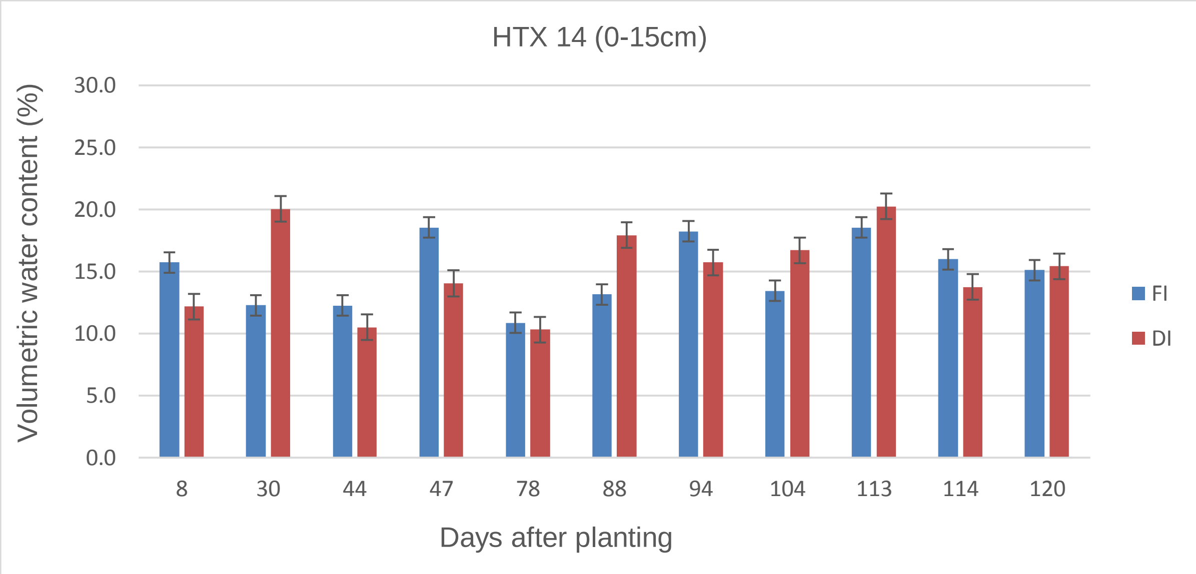


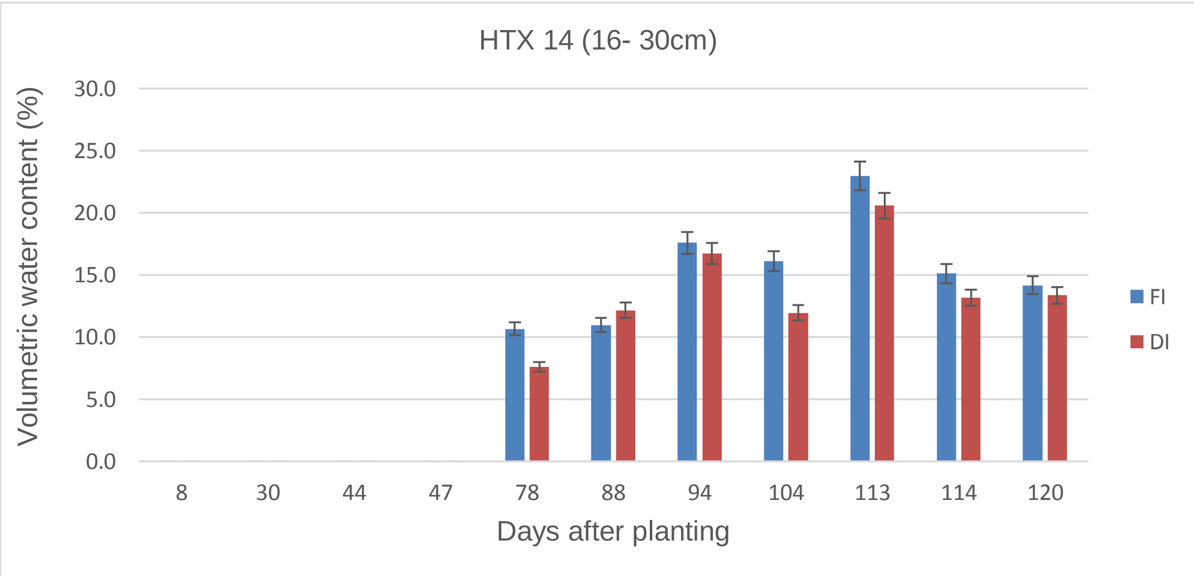
Figure 4.4 Volumetric soil water contents measured in the full irrigation (FI) and deficit irrigation (DI) plots of tomato varieties at Duvadzi farm, at two depths in the soil profile during the second cropping season.

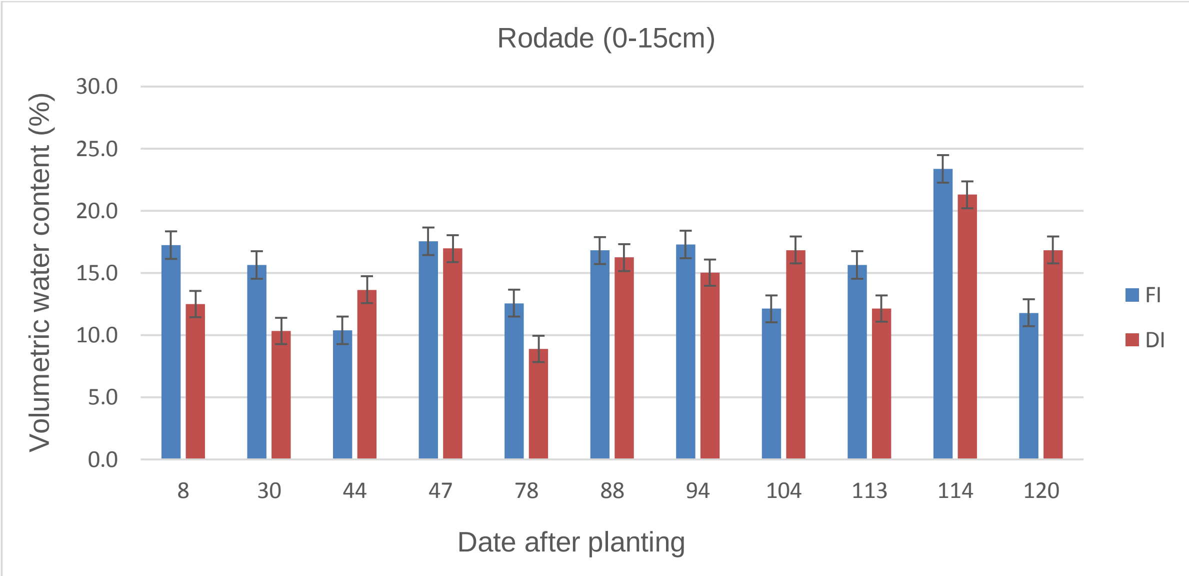
A hi tirheni Mqekwa farm

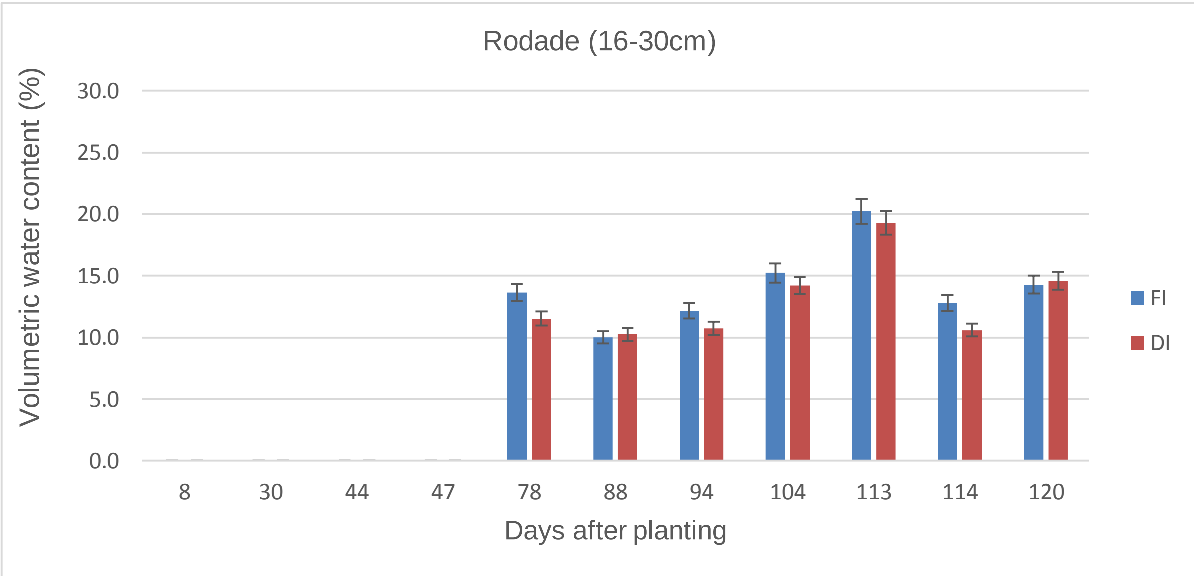
The volumetric water content at A hi tirheni Mqekwa under full irrigation at 0-15cm was seldom significantly higher that deficit irrigation, ''marginal'' (Figure 4.5). Soil moisture in 16-30cm was not significant different as compared to the top part (0-15cm) due to extreme high temperature and high evaporation encountered (Appendix 4.7). The soil moisture trend on both treatments were almost the same on the two (0-15cm and 16-30cm) irrigation levels. Under full irrigation, the highest VWC on HTX 14 was recorded on 113 DAP on both full and deficit irrigation. The highest Rodade VWC was recorded on 114 DAP (0-15 cm) and 113 DAP (16-30cm). The lowest record for HTX 14 plots were on 78 DAP, Rodade plots on 44 DAP, Commander plots on 30 and 120 DAP and Star 9006 8 and 113 DAP. Under deficit irrigation, HTX 14 plots recorded the highest VWC on 44 and 78 DAP, Rodade, Commander, Star 9006 recorded on 114 DAP.

During the first cropping season, measurements in 16 to 30cm were taken at 78 DAP when the roots development were at maximum in the required depth. Volumetric water content on 16 to 30cm showed no significant difference (P≥0.05) on all measured planting dates. On full irrigation on 113 DAP was recorded the highest VWC on all the varieties plots under investigation. The lowest record on HTX 14 plot was on 78 and 88 DAP, Rodade was on 88, 94 and 114 respectively, Commander on 104 DAP, Star 9006 on 120 DAP.

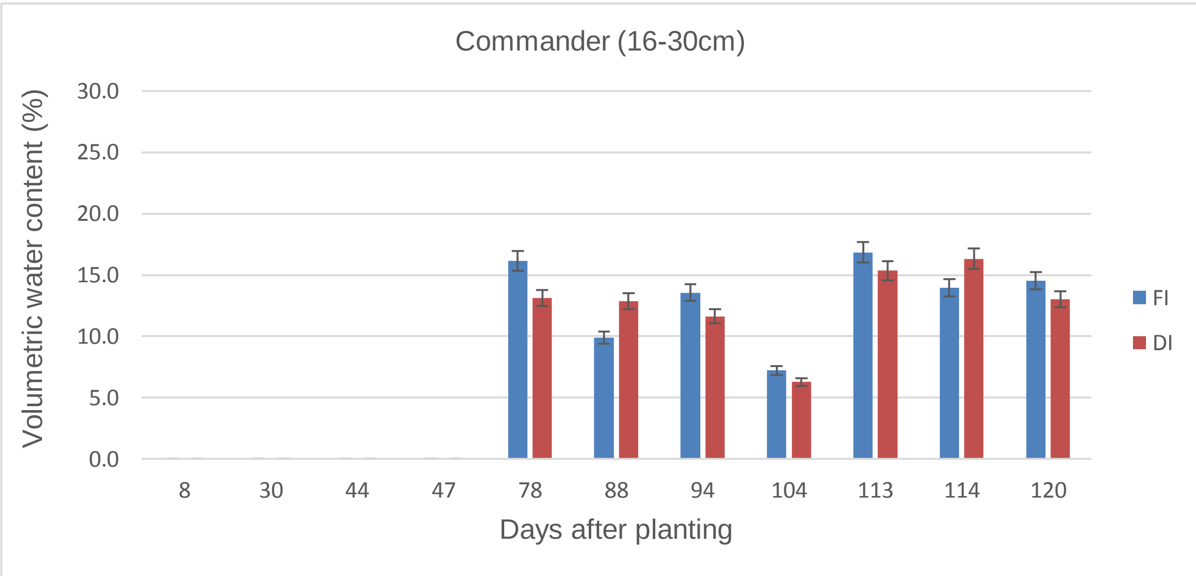

HTX 14 (0-15cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
8
30
44
47
78
88
94
104
113
114
120
Days after planting
FI
DI

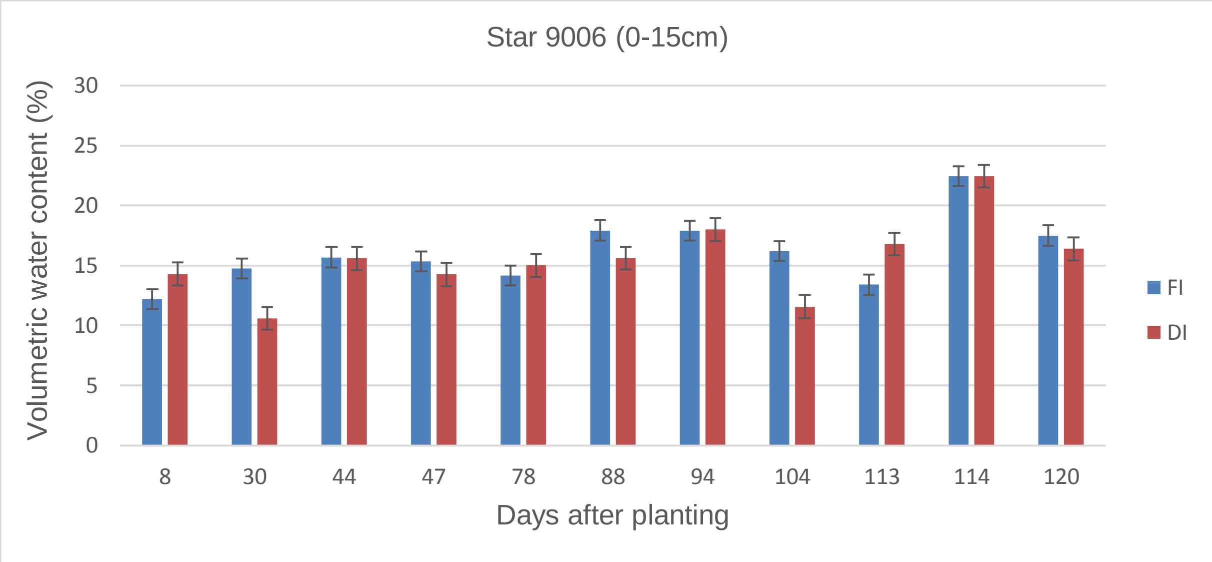

HTX 14 (16- 30cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
8
30
44
47
78
88
94
104
113
114
120
Days after planting
FI
DI


Rodade (0-15cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
8
30
44
47
78
88
94
104
113
114
120
Date after planting
FI
DI


Rodade (16-30cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
8
30
44
47
78
88
94
104
113
114
120
Days after planting
FI
DI


Commander (0-15cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
8
30
44
47
78
88
94
104
113
114
120
Days after planting
FI
DI


Commander (16-30cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
8
30
44
47
78
88
94
104
113
114
120
Days after planting
FI
DI



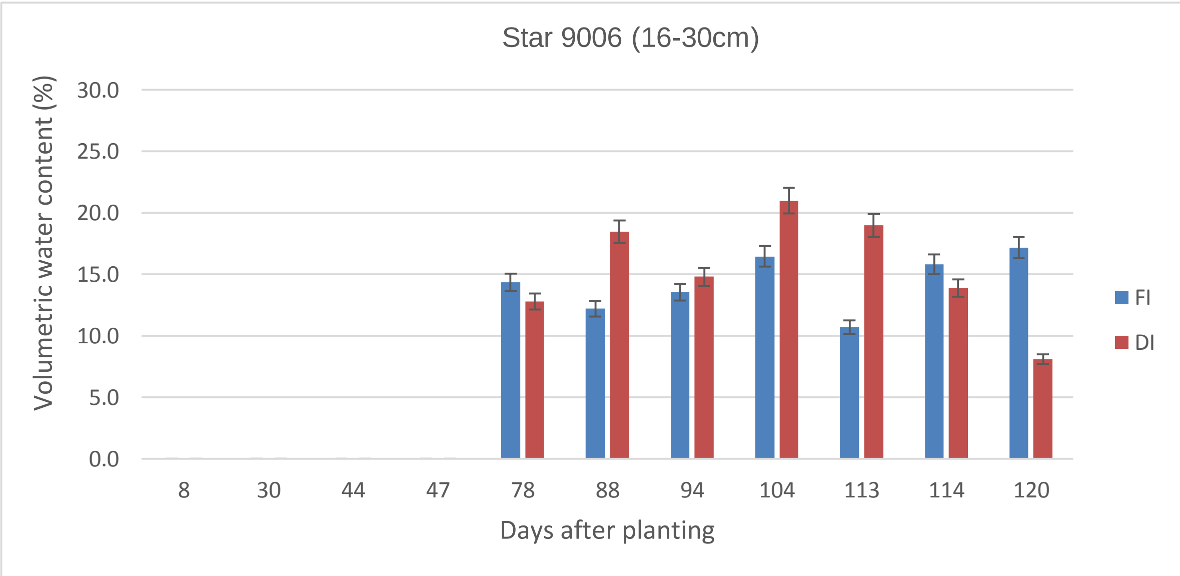
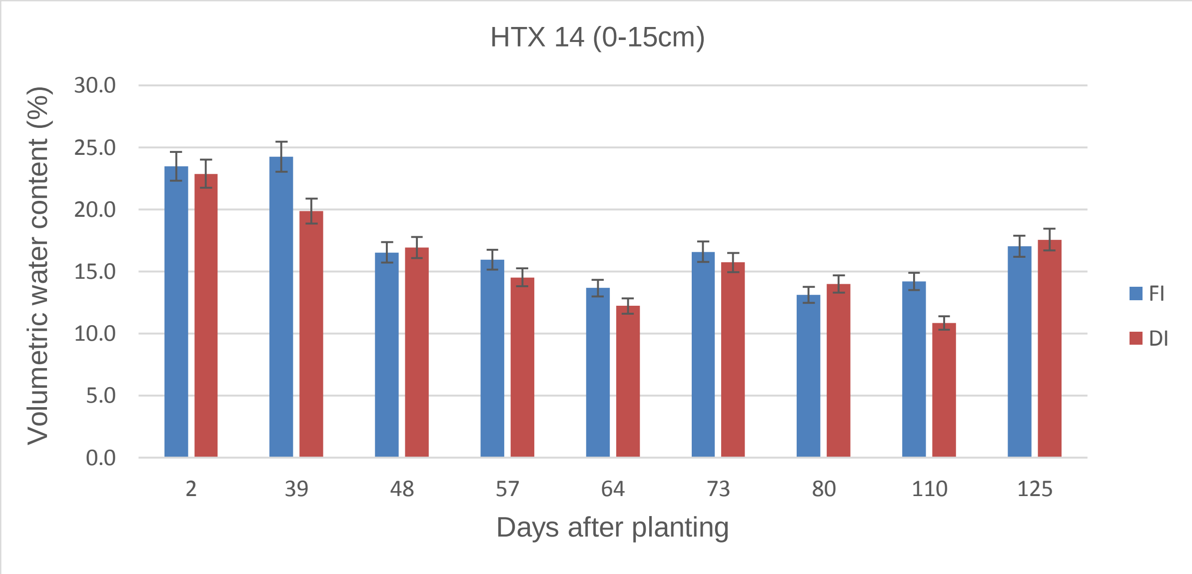


Figure 4.5 Volumetric soil water contents measured in the full irrigation (FI) and deficit irrigation (DI) plots of tomato varieties at A hi tirheni Mqekwa farm, at two depths in the soil profile taken during the first cropping season.

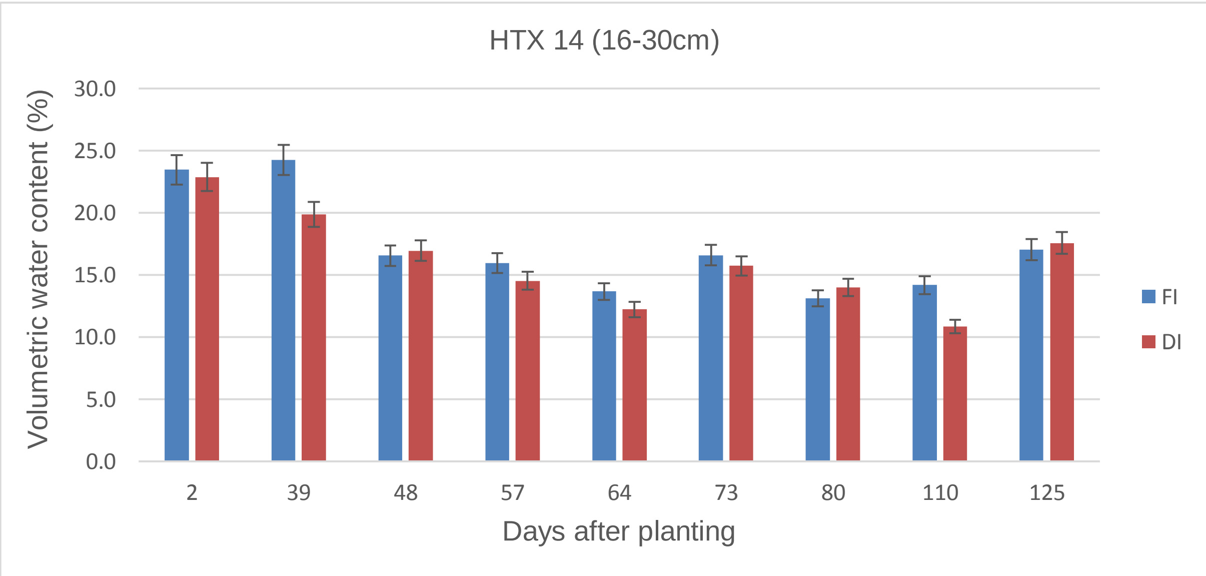
Rainfall in A hi tirheni Mqekwa farm was very irregular during the second cropping season with amounts ranging from 1 to 98 mm (Appendix 4.6). Very little amount of rainfall was received between March and May and it was difficult to maintain stable soil moisture due to high temperature and evaporation. Soil moisture in (0-15cm) was not significant different as compared to the lower part 16-30cm (Figure 4.6). Under full irrigation, 0-15 cm under HTX 14, Rodade plots and Commander had the highest VWC was recorded on 2 and 39 DAP and Star 9001 on 39 DAP. The lowest VWC at HTX 14 was recorded on 80 DAP, Rodade on 64 and 110 DAP respectively, Commander and Star 9006 on 110 DAP. On deficit irrigation (0-15cm) under HTX 14, the highest VWC record was on 2 DAP, Rodade and Commander on 2 and 39 DAP and Star 9006 on 2 DAP. The lowest VWC on HTX 14, Rodade, Commander and Star 9006 was recorded on 110 DAP.

During the second cropping season, at 16 to 30cm, the highest VWC was recorded in HTX 14 plot on 39 DAP under full irrigation and under deficit irrigation, Rodade, Commander on 2 and 39 and Star 9006 on 39DAP. The lowest record on HTX 14, Rodade, Commander was on 110 DAP and Star 9006 on 64 DAP.

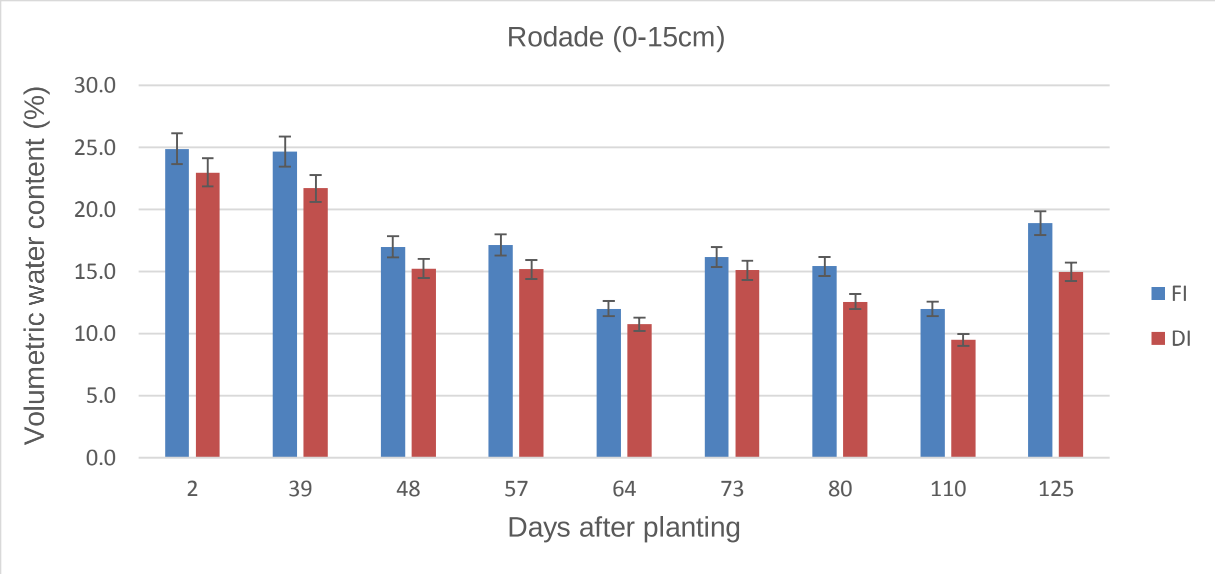
The VWC at A hi tirheni Mqekwa in full irrigation second season 0-15cm was lower as compared to 16-30cm in all the tomato varieties plots except in DAP 125 (Figure 4.6). This was observed from the 2 DAP to 125 DAP. There was no significant difference ($P \geq 0.05$) among the means on full and deficit irrigation treatments. The highest full irrigation volumetric water content % records on HTX 14 and Star 9006 was on 39 DAP, Rodade and commander on 2 and 39 DAP.

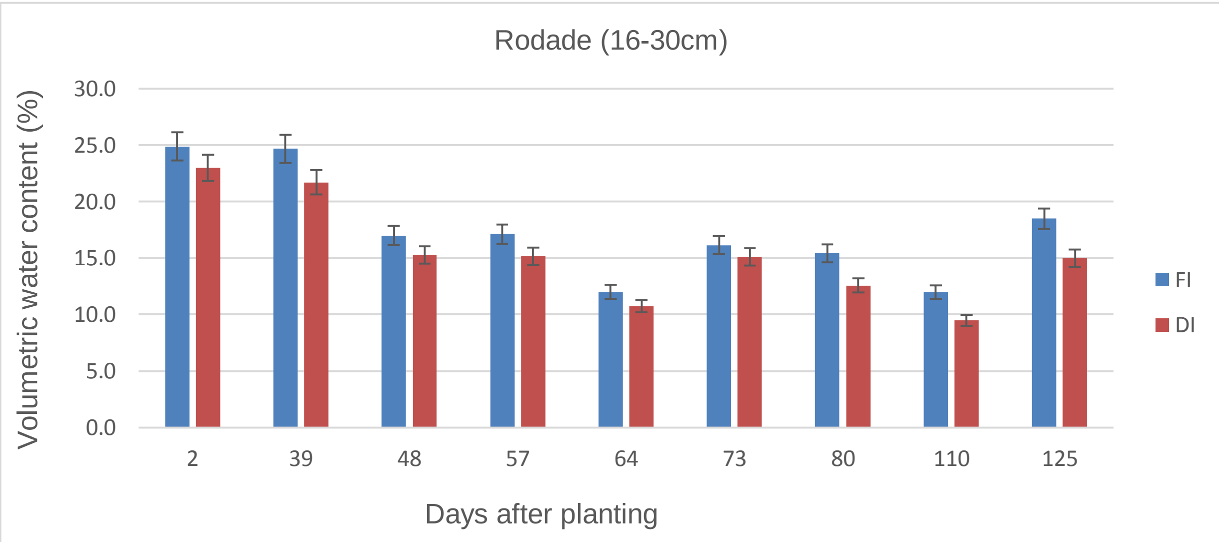


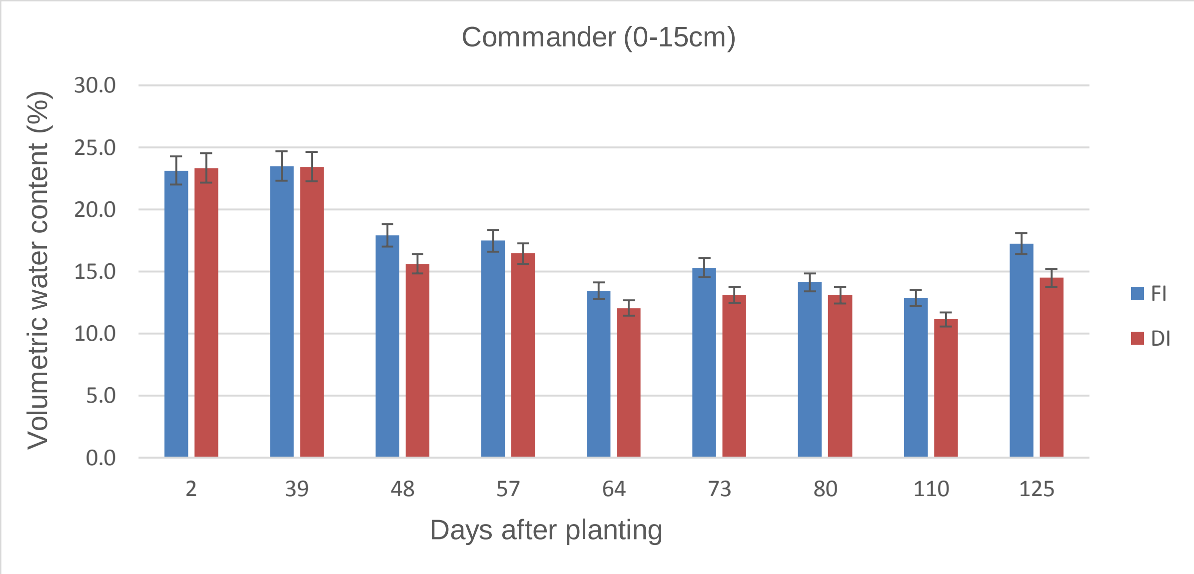
HTX 14 (0-15cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2
39
48
57
64
73
80
110
125
Days after planting
FI
DI

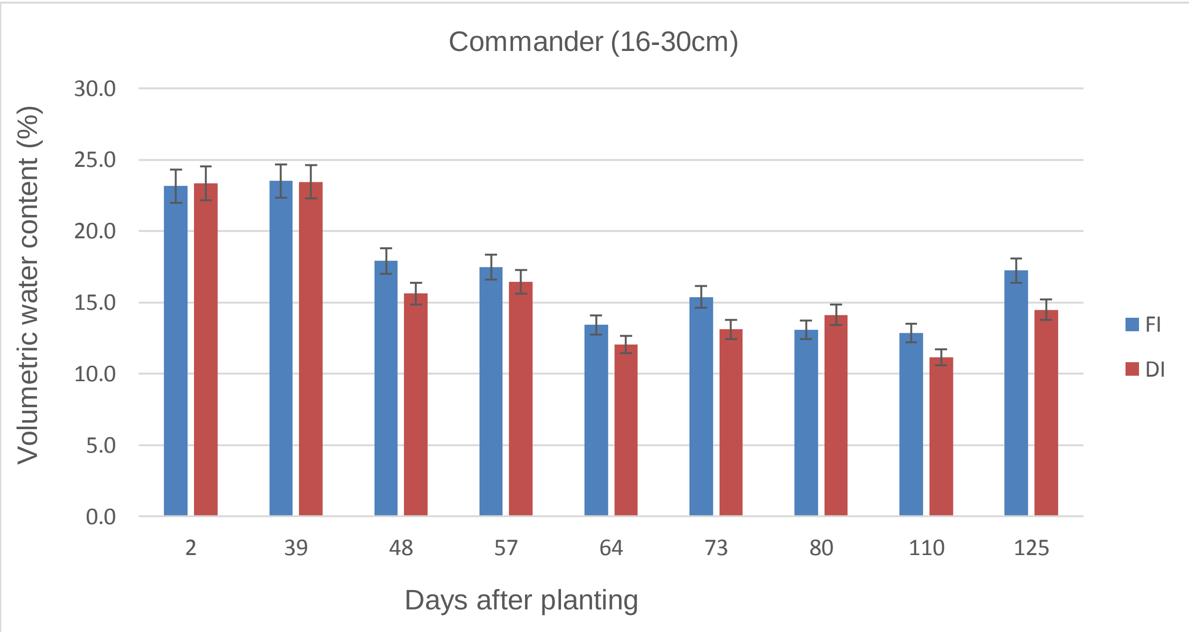


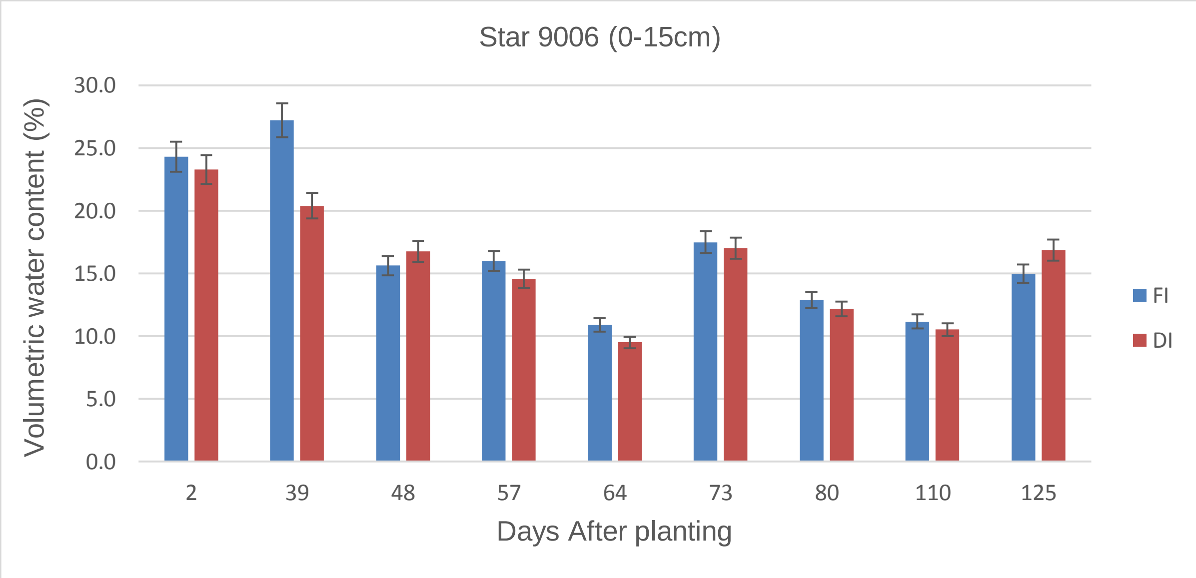
HTX 14 (16-30cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2
39
48
57
64
73
80
110
125
Days after planting
FI
DI


Rodade (0-15cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2
39
48
57
64
73
80
110
125
Days after planting
FI
DI


Rodade (16-30cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2
39
48
57
64
73
80
110
125
Days after planting
FI
DI


Commander (0-15cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2
39
48
57
64
73
80
110
125
Days after planting
FI
DI


Commander (16-30cm)
Volumetric water content (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2
39
48
57
64
73
80
110
125
Days after planting
FI
DI



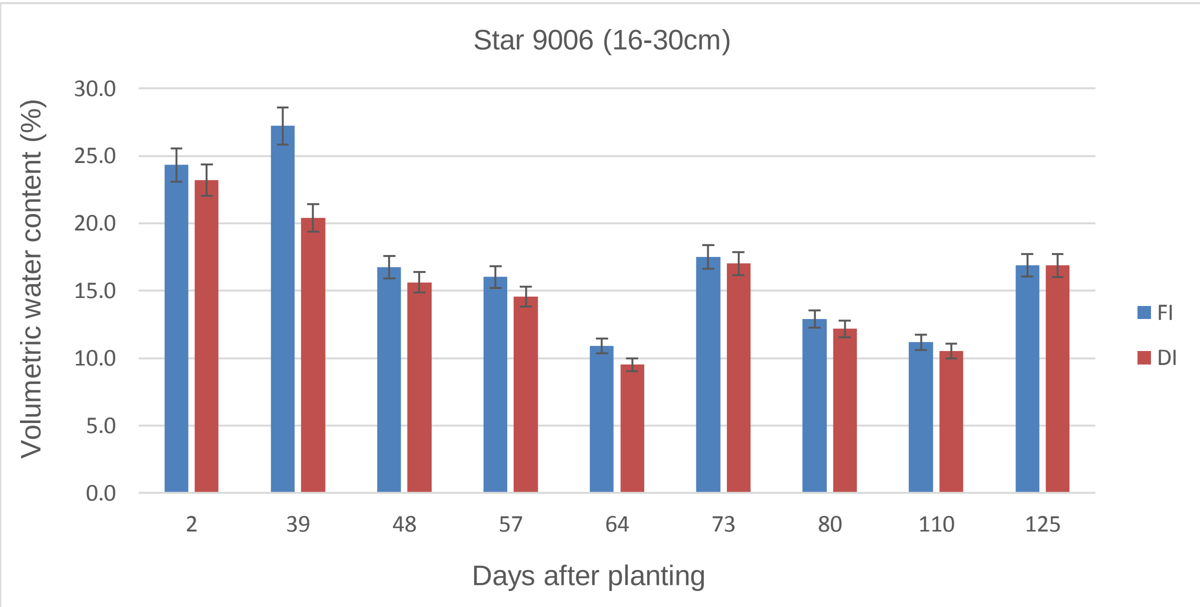


Figure 4.6: Volumetric soil water contents measured in the full irrigation (FI) blocks of tomato variety STAR 9006 A hi tirheni Mqekwa farms, at two depths in the soil profile second cropping season.

4.6 Disease incidence and severity

4.6.1 A Hi Tirheni Mqekwa farm

Disease incidence

During the first planting season, the disease incidence under full irrigation at A Hi Tirheni Mqekwa farm shows that HTX 14 and Rodade were the most affected varieties and the least affected variety was Star 9006 (Table 4.1). The average disease incidence under full irrigation for all the varieties was 28.8% (ranging from 21.1 % to 34.1%) (Table 4.1) during the first planting season. The average disease incidence under Deficit Irrigation was 26.85% (ranging from 26.0% to 34.9%). There was therefore significant difference between on the total number of plants showing early blight symptoms under full and deficit irrigation in this farm.

During the second planting season, the disease incidence under full irrigation at A hi tirheni Mqekwa farm shows that HTX 14 and Rodade were the most affected varieties and the least affected variety was Star 9006 (Table 4.2). The average disease incidence under full irrigation for all the varieties was 56.22% (ranging from 47.2 % to 59.7% indicated in Table 4.2) during the second season. There was a significant difference on the number of tomato plants infected with early blight under full and deficit irrigation.

The average disease incidence under deficit Irrigation was 53.45% (Ranging from 47.2% to 59.7%). The overall disease incidence, for all the varieties were higher under full irrigation than at deficit irrigation.

Disease severity

A significant difference ($P \leq 0.05$) was observed in all the cultivars investigated between the treatments especially during the first planting season (Table 4. 1). The most severely affected cultivar under full irrigation was HTX 14 and the least severely affected cultivar was Star 9006. The average disease severity under full irrigation was observed at 0.4 % (ranging from 0.3 to 0.5). The most affected variety under deficit irrigation was HTX 14, Rodade and Commander and the least affected variety Star 9006. The disease severity of affected leaves at A hi tirheni Mqekwa in full irrigation, first planting season was ranging from 0.3 to 0.5 for all the four verities (Table 4.1). The disease severity in deficit irrigation was ranging from 0.5 to 0.6.

A significant difference ($P \leq 0.05$) was observed on all the varieties between the two irrigation treatments during the second planting season (Table 4.2). It was observed that HTX 14 was the most highly severely affected cultivar and Star 9006 was the least affected cultivar in full irrigation. The disease severity of affected leaves at A hi tirheni Mqekwa in full irrigation, second planting season was ranging from 0.4 to 0.6 for all the four verities (Table 4.2). The disease severity in deficit irrigation was ranging from 0.6 to 0.7. Tomato Early blight was more severe on deficit irrigation than in full irrigation.

Table: 4.1 A hi tirheni Mqekwa farm early blight severity taken on the first planting season

Treatments	Tomato Variety	Disease Severity	Disease incidence %
Full irrigation	HTX 14	0.5bc[a]	34.1
	Rodade	0.3d	33.4
	Commander	0.4d	26.6
	Star 9006	0.3d	21.1
Deficit irrigation	HTX 14	0.6a	27.7
	Rodade	0.6ab	34.8
	Commander	0.6ab	34.9
	Star 9006	0.5c	26.0

[a]Means followed by the same letter are not significantly different at ($P \leq 0.05$) according to Duncan's Multiple Range test.

Table 4.2 Disease incidence and severity according to the scale of Pandey and Pandey (2003) with modifications at A hi tirheni Mqekwa farm second season

Treatments	Cultivars	Disease severity	Disease incidence %
Full irrigation	HTX 14	0.5b	59.7
	Rodade	0.4c	59.7
	Commander	0.4c	58.3
	STAR 9006	0.3c	47.2
Deficit Irrigation	HTX 14	0.7a	59.7
	Rodade	0.6ab	55.6
	Commander	0.6ab	55.6
	STAR 9006	0.6ab	47.2

[a]Means followed by the same letter are not significantly different at ($P \leq 0.05$) according to Duncan's Multiple Range test.

4.6.2 Duvadzi farm

Disease incidence

Disease incidence under full irrigation at Duvadzi farm shows that HTX 14 had the highest disease incidence and the least affected was Star 9006 (Table 4.3). The average disease incidence under full irrigation for all the varieties was 23.1% (ranging from 18.4 % to 27.8%) during the first planting season (Table 4.3). Disease incidence under deficit irrigation shows that HTX 14 had the highest disease incidence and the least affected was Star 9006. The average disease incidence under Deficit Irrigation was 31.85% (Ranging from 27.1% to 36.6%). The overall disease incidence for all the varieties was higher under deficit irrigation than at full irrigation.

Disease severity

First planting season, under deficit irrigation, disease severity in Commander was a significantly different (P≤ 0.05) from that in HTX 14 and Rodade but was not different from that in Star 9006. Under full irrigation, no statistical difference was observed among the four varieties under investigation. The most severely affected cultivar under full irrigation was HTX 14 and the least severely affected cultivar was Star 9006.

The most affected variety under deficit irrigation was HTX 14, Rodade and Commander and the least affected variety Star 9006 and Commander. The average disease severity under full irrigation was Star 9006 at 0.4 (ranging from 0.3 to 0.5).

Table 4.3 Disease incidence and severity according to the scale of Pandey and Pandey (2003) with modifications at Duvadzi farm first planting season.

Treatments	**Tomato Variety**	**Disease Severity**	**Disease incidence %**
Full Irrigation	HTX 14	0.6a	27.8
	Rodade	0.6a	22.5
	Commander	0.5a	27.0
	Star 9006	0.4abc	18.4
Deficit Irrigation	HTX 14	0.5ab	36.6
	Rodade	0.5ab	35.5
	Commander	0.3c	30.2
	Star 9006	0.3bc	27.1

[a]Means followed by the same letter are not significantly different at (P≤ 0.05) according to Duncan's Multiple Range test.

Disease incidence

The most affected cultivars at Duvadzi farm under full irrigation was HTX 14 and the least affected was Star 9006 (Table 4.4). The average disease incidence under full irrigation was Commander. Under deficit irrigation, Rodade and Commander were the highly affected cultivars and the least affected was Star 9006. The average disease severity under deficit irrigation was Rodade and Commander.

Disease severity

A significant difference ($P \leq 0.05$) was observed under full irrigation on HTX 14 as compared to Star 9006 and Rodade (Table 4.4). A significant different was observed in all the cultivars in between the full and deficit treatments. The average disease severity of affected plants at Duvadzi full irrigation was at 0.4 (ranging from 0.3 to 0.4). The most affected cultivar on deficit irrigation was HTX 14 and Commander and the least affected was Star 9006 and Rodade. The average severity on deficit irrigation was 0.5 (ranging from 0.5 to 0.6).

Table 4.4 Disease incidence and severity according to the scale of Pandey and Pandey (2003) with modifications at Duvadzi farms second season.

Treatments	**Cultivars**	**Disease severity**	**Disease incidence %**
Full irrigation	HTX14	0.4c	63.9
	Rodade	0.4de	62.5
	Commander	0.4cd	59.7
	Star 9006	0.3e	55.6
Deficit irrigation	HTX14	0.6a	58.3
	Rodade	0.5b	59.7
	Commander	0.6ab	59.7
	Star 9006	0.5b	52.8

[a]Means followed by the same letter are not significantly different at ($P \leq 0.05$) according to Duncan's Multiple Range test.

4.7 Discussion

Soil water content

Obtained results on both farms showed that there was no significant difference on all tested varieties at ($P \geq 0.05$) on both full and deficit irrigation management. This was due to extreme high temperature high water demand by plant and through the evapo-transpiration. Soil moisture content on both full and deficit irrigation was easily evaporated due to extreme high temperature during the experiments period. Although the initial plan was to maintain the soil water content in the FI treatment close to field capacity, this was not always possible because of mechanical challenges and the weather conditions. The soil moisture content during the first experiment at Duvadzi farm, 16-30cm was lower to such that the HydroSense II portable probe readings were out of range. During the first part of the season (September – November 2016), the water level in the well from where abstraction took place dropped. It resulted in reduced irrigation that manifested in low soil water contents. Following the onset of the rainy season in November 2016 and recharge of water in the river bed, usual irrigation resumed.

During the second growing season, at A hi tirheni Mqekwa farm, the lower part of the soil moisture was always higher as compared to deficit irrigation. The soil water contents were also kept relatively high with the tendency of soil water depletion during the course of the season, especially since the harvesting period. With the consideration of other factors on soil moisture deterioration, plants water consumption was higher during fruits developments; hence the water level trends were dropping to 5% on average.

Total seasonal irrigation at Duvadzi farm was 456.0 mm in the FI block and 434.7 mm in the DI block. Rainfall at Duvadzi was 120 mm and deep percolation was estimated to be 48 mm as rainfall in excess of field capacity in the root zone profile. At A Hi Tirheni Mqekwa, total seasonal irrigation was 436.8 mm in both FI and DI treatments, rainfall was 104 mm and deep percolation was estimated to be 43 mm.

Disease incidence

In general, early blight disease incidence at A hi tirheni Mqhekwa was not significant different ($P \geq 0.05$) between full and deficit irrigation treatments. However, disease incidence for cultivars in both planting seasons was higher under deficit irrigation than in full irrigation. The disease incidence results at A hi tirheni Mqekwa farm second planting showed that the two varieties (Commander and Rodade) responded differently between the two irrigation treatments. These varieties had high mean disease percentage in Deficit irrigation as compared to full irrigation. Generally, plants under full irrigation had high EB disease incidence as compared to deficit irrigation and it agrees with the conclusion by Adalberto *et al*., 2018 mentioning that water applied in excess or in deficit may result in the development of many fungal and bacterial plant diseases.

Disease severity

Early blight disease severity was significantly different ($P \leq 0.05$) between full and deficit irrigation treatments (Table 4.5) on the first season. There was no significant difference observed on the second season. The study revealed that all the four varieties under investigation were more affected under deficit irrigation as compared to those under full irrigation. Based on the outcome of the results, it shows that deficit irrigation has an influence on early blight disease development. The results agreed with the findings by Obreza *et al*., 1996 that early blight disease (caused by the fungus *Alternaria solani*) incidence was 50% more severe on deficit treatment compared with full irrigation. The results were also in agreement with the findings reported by Mercure (1998) that stressed plants are more predisposed to early blight.

In this study, the focus was more on irrigation management effect on early blight disease incidence and severity.

Disease incidence

The study revealed that all the four varieties under investigation were more affected under deficit irrigation as compared to those under full irrigation except only on the 2nd

season at Duvadzi farm (Table 4.5). The results are in agreement with the findings reported by Mercure (1998) that stressed plants are more predisposed to early blight.

Table 4.5 Disease severity comparison for irrigation treatments on the two farms.

A hi tirheni Mqekwa farm			Duvadzi farm	
Treatments	Overall Disease severity		Overall Disease severity	
	1st season	2nd season	1st season	2nd season
1	0.08b	0.50a	0.52a	0.50a
2	0.12a	0.49a	0.41a	0.42a

[a]Means followed by the same letter are not significantly different at ($P \leq 0.05$) according to Duncan's Multiple Range test. 1: Full irrigation 2: Deficit irrigation

Table 4.6 Disease incidence comparison for irrigation treatments on the two farms.

A hi Tirheni Mqekwa farm			**Duvadzi farm**	
Irrigation	**Overall Disease incidence %**		**Overall Disease incidence %**	
	1st season	2nd season	1st season	2nd season
1	31.19	28.77	23.93	60.43
2	30.46	30.84	32.35	57.63

1: Full irrigation 2: Deficit irrigation

CHAPTER 5

THE RESPONSE OF TOMATO CULTIVARS YIELD TO IRRIGATION MANAGEMENT

5.1 INTRODUCTION

Tomato production in South Africa relies heavily on irrigation under limited water availability which affect the plant growth. Worldwide, water use for irrigation accounts for about 70% of the global fresh water withdrawals and 90% of the consumptive water uses (Siebert *et al*., 2010; Dixon, 2015). Field water management practices are the most influential practices affecting crop yield particularly in irrigated agriculture in arid and semi-arid regions (Tiwari *et al*., 2003). Irrigation management directly affects crop performance and can lead to qualitative and quantitative improvements in vegetable production (Dukes *et al*., 2010). In recent years, tomatoes have rapidly become one of the most popular produce in the world including South Africa.

In many parts of the world, tomato is produced under irrigation (Grange, 1994). Therefore, irrigation management needs to be efficient also in order to help reduce environmental impact and promote sustainable use of resources (Montesano *et al*., 2015). Approximately one-third of agricultural land in the world experiences an inadequate water supply (Zhang *et al*., 2013). Tomato plants are sensitive to water stress and show high correlation between evapotranspiration and crop yield (Nuruddin *et al.*, 2003).

The predicted global warming, along with increased human food requirements, can be expected to alter the amount of irrigation needed worldwide to ensure food security, probably increasing it by 30% (Doll, 2002). Appropriate water management practices can help ensure the sustainability of agricultural and economic water related activities. Irregular and inadequate water supply reduced growth, yield, and quality of different tomato Cultivars. Nutrient and water supply affects tomato quality greatly and its highest demand for water is during flowering (Gideon, 2012).

Water management is one of the major factors affecting crop growth and productivity (Bernacchi, 2015; Qin, 2015). Crop yield and quality are very sensitive to appropriate water contents in the root zone of plants, which can improve the absorbing area and capacity of roots (He, 2014). The use of drip irrigation improves photosynthetic capacity of plants, maximizing yield whilst minimizing water usage and reducing environmental pollution (Abdelraouf *et al*., 2013). The proper use of irrigation is essential because water is the most limiting factor to crop yield (Sinclair, 2012) and its inadequate supply reduces food production (Cantero, 2016). Using irrigation systems properly is important for water conservation, economic efficiency and disease control (Goldy, 2013). The objective of this chapter is to determine the response of tomato cultivar to early blight under different irrigation water management.

5.2 Materials and methods

5.2.1 Site description and experimental design and layout

The study was conducted at two locations, approximately 50 km south of Giyani, with different farming practices namely: The locations were A hi tirheni Mqekwa farm and Duvadzi Youth Organic Agricultural Co-operative Farm as mentioned in chapter four. Experimental design and layout was done as stipulated in the previous chapter.

5.3 Data collection

5.3.1 Soil water content

Volumetric soil water contents were measured weekly with the HydroSense II portable probe in all treatments at Duvadzi and A hi Tirheni Mqekwa farms as explained in Chapter four.

5.3.2 Leaf chlorophyll content

Leaf chlorophyll measurements were taken during the second season of the experiment using a Chlorophyll Content Meter-300 (CCM-300) (Opti-Sciences Inc., USA). Eighteen plants out of total population of 112 per variety were randomly selected for sampling on each treatment per variety and plot. Chlorophyll content was measured on randomly selected three leaves from the upper, middle and lower canopy of each plant. At Duvadzi farm, the chlorophyll contents measurement was taken only during the vegetative stage of the plants due to the unavailability of chlorophyll content meter. During the second experiment, the measurements were taken during the flowering stage and on the fruit ripening stage of the plants on both farms.

5.3.3 Plant height and stem diameter

Plant height and stem diameter were measured in both first and second season of experimentation as indicators of crop growth. Plant height and stem diameter were measured with a tape measure and calliper. The measurements were done twice at flowering and fruit formation stages.

5.3.4 Irrigation volumes, evapotranspiration

Irrigation water volumes were recorded using water meters installed on the conveyance pipe at the access of the irrigated fields on both farms. Irrigations per plot were regulated using manual valves. Irrigation water volume readings were recorded by the farmers on dedicated sheets (Appendix 5.1) produced for this project. Crop water consumption was calculated with the field water balance equation:

$$ET = I + P - R - D - \Delta S$$

Where ET is actual evapotranspiration; I and P are irrigation and precipitation; R is runoff; D is deep percolation (or capillary rise); and ΔS is the soil water storage difference at the beginning as well as at the end of the measuring period (all in mm). Rainfall was read using manual rain gauges installed at each farm (Appendix 5.2) and the amount of irrigation applied was recorded with water meters (Appendix 5.3). Deep percolation was considered after high rainfall events as water refilling the soil in excess of field capacity in the 30 cm top soil where most of the roots occurred. Soil water storage was determined from soil water content records. Runoff was assumed to be 0 as land was cultivated in furrows and ridges. Crop water productivity (WP) was calculated as the ratio of the fresh yield of tomatoes (Y) and ET and expressed in kg per m^3 of water consumed: WP = Y / ET.

5.3.5 Crop yields

Harvesting was done twice per week for the period of three to four weeks. The fruits were harvested as they started to change colour from green to red. These was done to prolong the shelf life of the fruits after harvest. Harvesting was done on each treatment plot per variety. Harvested fruits of each variety in both treatments were weighed to determine the yield and the total yield per hectare was computed.

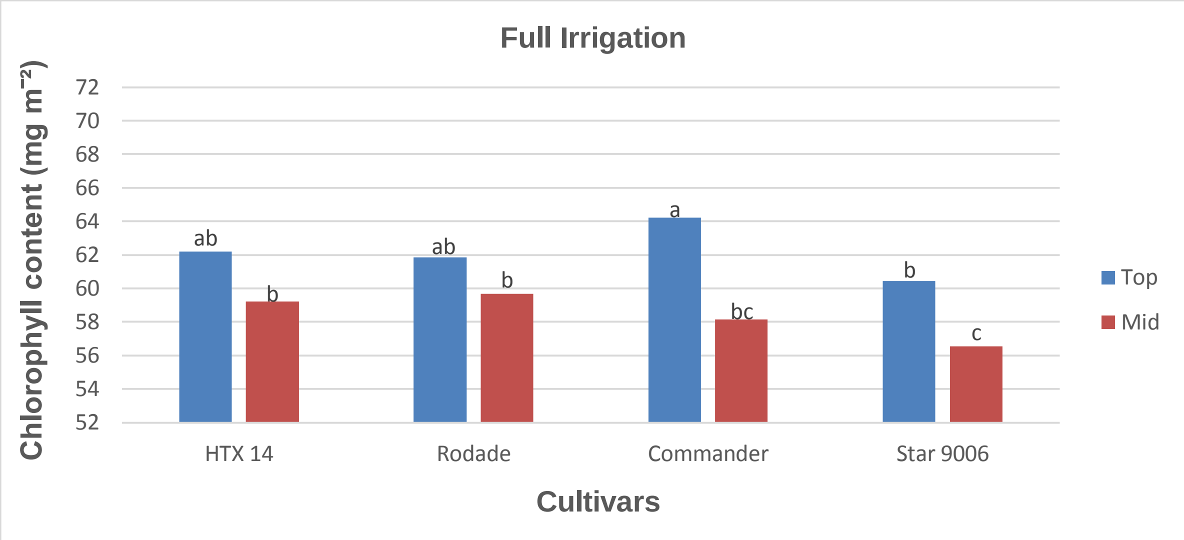
5.4 Results

5.4.1 Leaf chlorophyll content

Full irrigation treatments

At Duvadzi farm on full irrigation, Commander in the upper leaves had the highest chlorophyll content of 64 mg^{-2} (Figure 5.1). The minimum chlorophyll content for the leaves located in the lower part of the plant was on Star 9001 by 51.2 mg^{-2}. The minimum leaf chlorophyll content located on the lower canopy of the plants was taken during the vegetative growth stage of the plants. There were no significant difference ($P \geq 0.05$) among the means of leaf chlorophyll content on irrigation treatments and varieties (Figure 5.1). On harvesting period, the differences between canopy levels were small.

Second measurement at Duvadzi farm was taken at 102 Days after planting and it was during the harvesting period. At Duvadzi Farm on full irrigation, Star 9006 had the highest chlorophyll content of 62.8m on the upper leaves (Figure 5.1) of the plants. At deficit irrigation, the maximum chlorophyll content was obtained in Rodade Cultivar with 57.2mg^{m2}. The maximum chlorophyll content for the leaves located in the lower part of the plant under deficit irrigation was on Rodade at 57.2m. There were no significant difference ($P \geq 0.05$) among the means of leaf chlorophyll content on irrigation treatments and varieties (Figure 5.1 and 5.2).



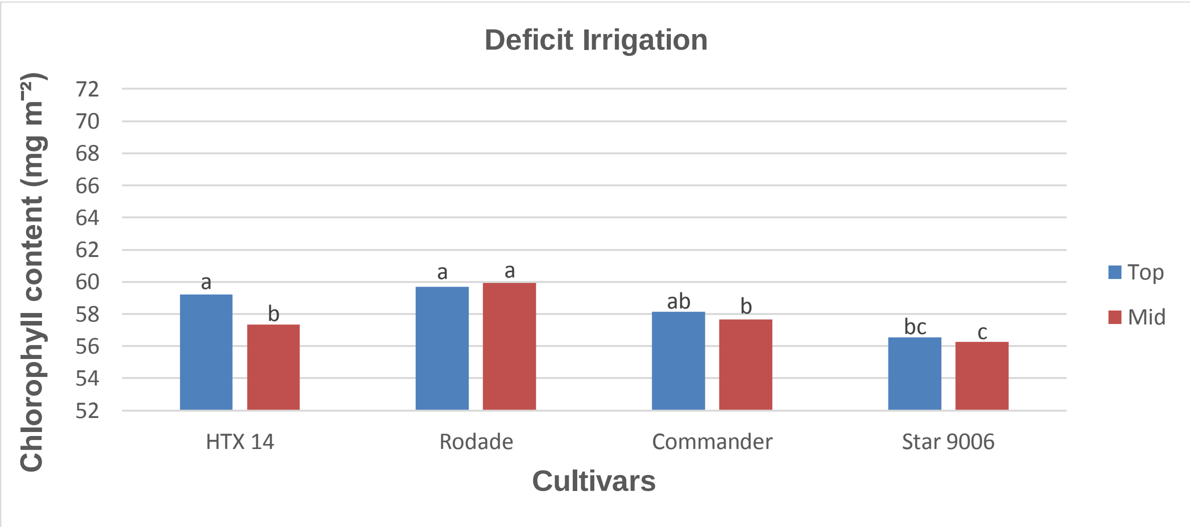
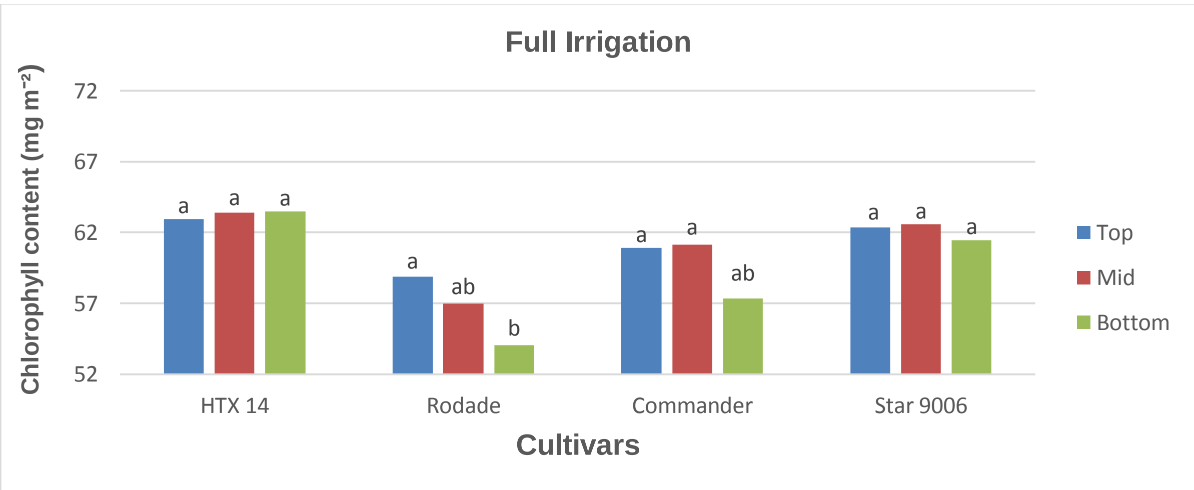


Figure 5.1 Chlorophyll meter readings (in the full and deficit irrigation treatments) of four tomato varieties at Duvadzi farm during vegetative stage.



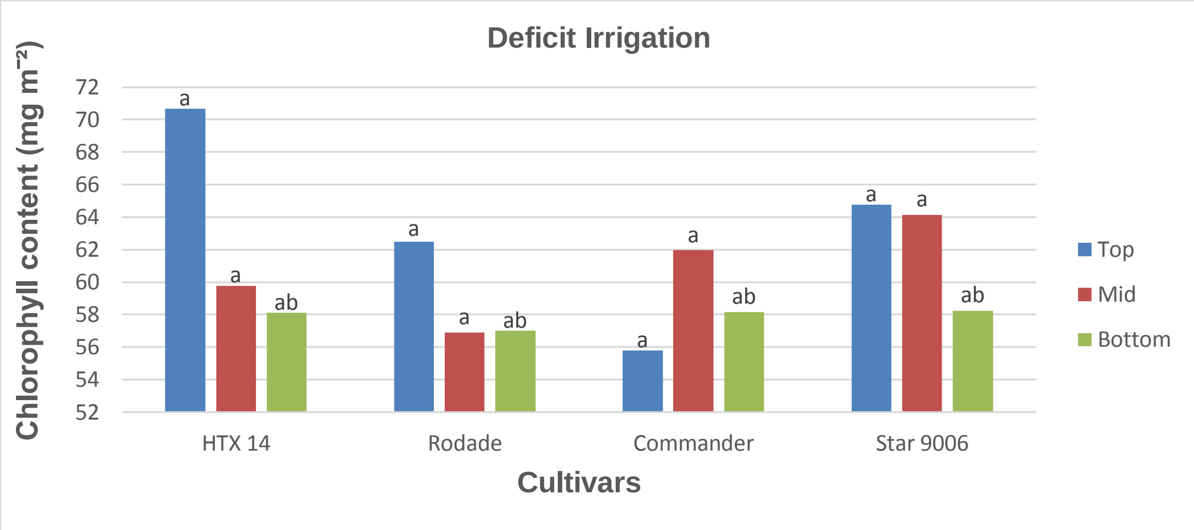


Figure 5.2 Chlorophyll meter readings (in the full and deficit irrigation treatments) of four tomato varieties at Duvadzi farm during harvesting.

At A hi tirheni Mqekwa, the measurements were taken on two occasions: during the vegetative stage (Figure 5.3) and during harvest (Figures 5.4). In general, chlorophyll content was the highest in the upper younger leaves when compared to the lower older leaves in all the cultivars. There was no marked difference between irrigation treatments and varieties (Figures 5.3 and 5.4). During the harvesting stage of the plants, chlorophyll content between canopy levels were ranging 49 to 66 mg m^{-2} in both full and deficit irrigation. This was possibly due to disturbance and exposure during harvesting (Figures 5.4) similar as in the Duvadzi experiment.

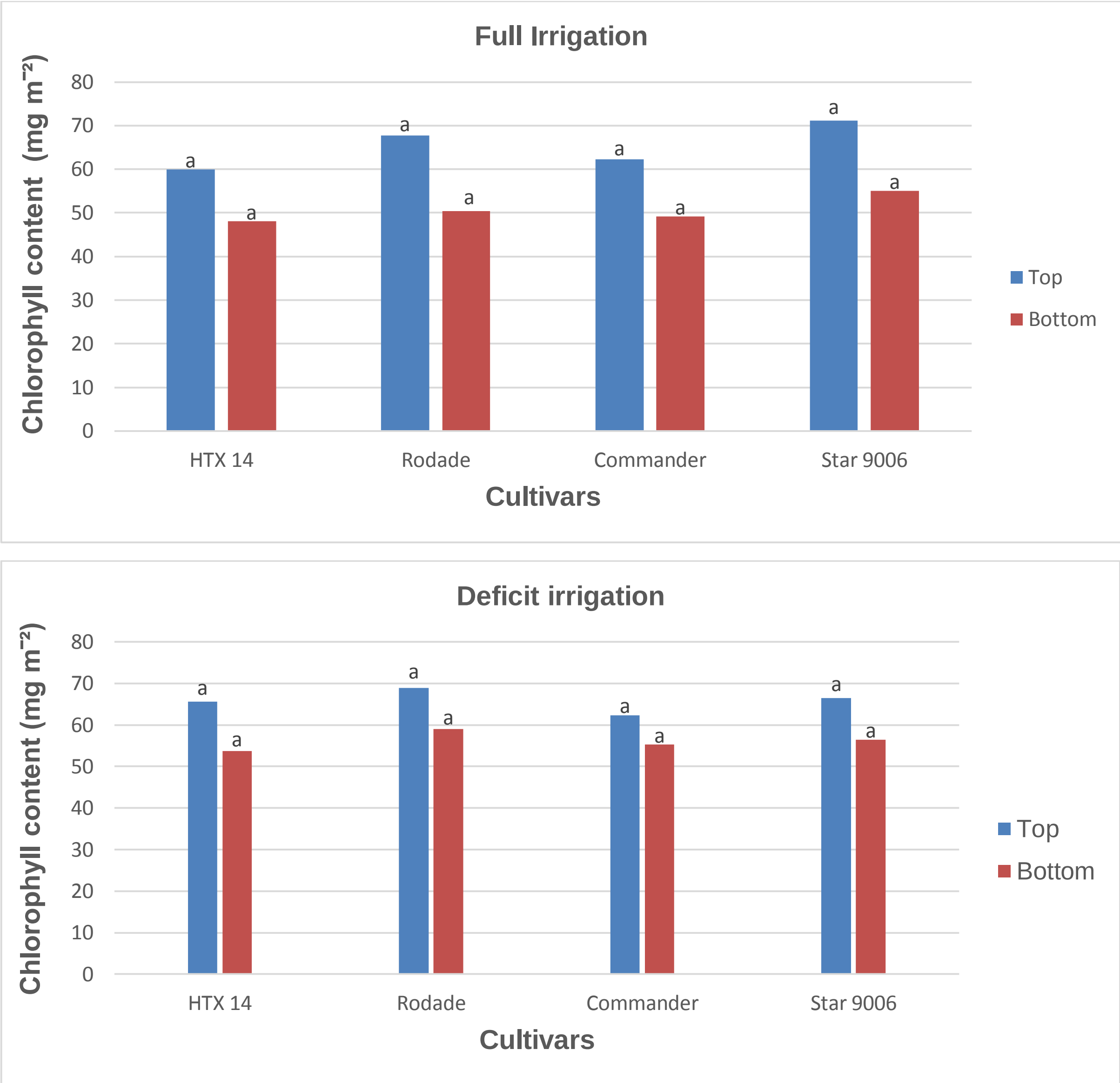


Figure 5.3 Chlorophyll meter readings in the full and deficit irrigation treatments of four tomato varieties at A hi tirheni Mqekwa farm during vegetative stage.

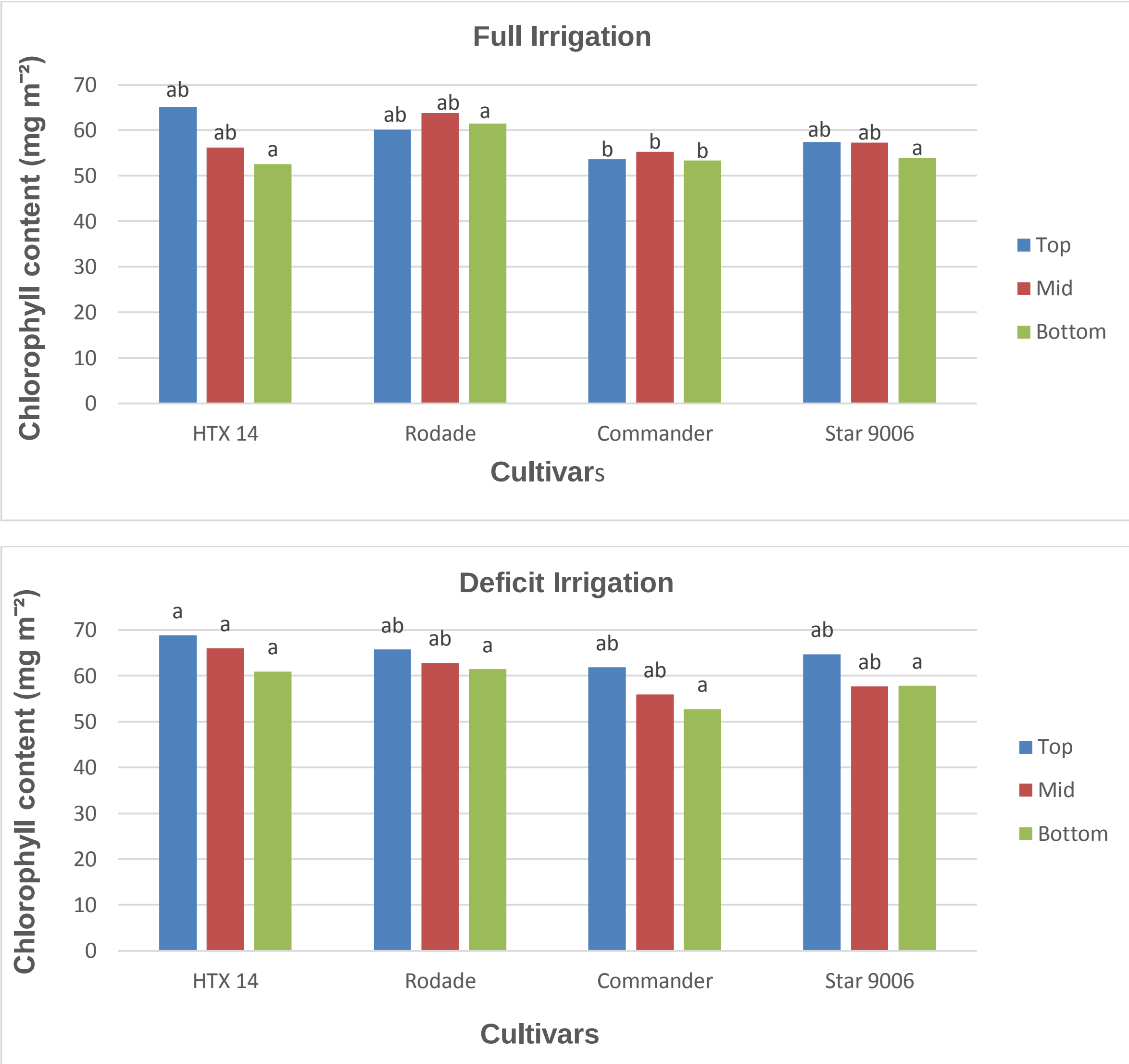


Figure 5.4. Chlorophyll meter readings in the full and deficit irrigation treatments of four tomato varieties at A hi tirheni Mqekwa farm during the harvesting stage.

5.4.2 Plant height and stem diameter

Duvadzi farm

Plant height and stem diameter were measured as indicators of crop growth under two different irrigation systems. During the plants development stage, Star 9006 at 1.9mm had the thickest stem size in full irrigation followed by Rodade and Commander at 1.8mm (Table 5.1). The minimum stem size was recorded on HTX 14 at 1.6mm. In

deficit irrigation, Star 9006 at 1.7mm had the highest stem size reading followed by Commander at 1.6mm. The minimum stem size was obtained on Rodade at 1.4mm.
Star 9006 at 11.2cm had the highest values on plant height under full irrigation followed by Rodade at 9.0mm. The minimum Plant height was obtained on HTX 14 at 5.3cm. There were no significant differences (P≥0.05) on all the varieties under trial.

During the fruit development stage, under full irrigation Star 9006 at 20.1cm had the highest record on plant height followed by Commander at 14.4cm (Table 5.2). The lowest figure was obtained on HTX 14 at 10.3cm. Under deficit irrigation, Star 9006 at 13.7cm had highest figure followed by Rodade at 10.9cm. The lowest record was obtained on HTX 14 at 5.3cm. There was no significant difference on plant height of all the varieties under both full and deficit irrigation.

Table 5.1 Plant height and stem diameter measured in full and deficit irrigation treatment at Duvadzi during development stage (32 DAP)

Blocks	**Cultivars**	**Plant height (cm)**	**Stem diameter (mm)**
Full irrigation	HTX14	5.3a	1.6a
	Rodade	9.0a	1.8a
	Commander	8.4a	1.8a
	Star9006	11.2a	1.9a
Deficit irrigation	HTX14	4.0a	1.5a
	Rodade	7.5a	1.4a
	Commander	6.3a	1.6a
	Star9006	8.0a	1.7a

[a] Means followed by the same letter are not significantly different at (P≤ 0.05) according to Duncan's Multiple Range test.

Table 5.2 Plant height and stem diameter measured in the full and deficit irrigation treatment of four tomato varieties at Duvadzi taken during fruit development of the plants (54 DAP).

Treatments	**Cultivars**	**Plant height (cm)**	**Stem diameter (mm)**
Full irrigation	HTX14	10.3a	2.4a
	Rodade	11.6a	1.8a
	Commander	14.4a	2.3a
	Star 9006	20.1a	1.9a
Deficit irrigation	HTX14	5.3a	1.7a
	Rodade	10.9a	3.0a
	Commander	7.1a	1.5a
	Star 9006	13.7a	2.8a

[a]Means followed by the same letter are not significantly different at ($P \geq 0.05$) according to Duncan's Multiple Range test.

A hi tirheni Mqekwa farm

The first measurement was taken on 18 DAP when the plants were on flowering stage and still vigorously growing. Rodade had the thickest stem diameter at 1.4mm in full irrigation followed by Star 9006 at 1.2mm (Table 5.3). The minimum stem size was recorded on Commander at 0.7mm. On Deficit irrigation, Rodade at 1.5mm was recorded the highest stem diameter followed by Star 9006 at 1.4cm. The minimum stem size obtained on Commander and HTX 14 at 0.9cm respectively.

Star 9006 were the tallest varieties on both full and deficit irrigation and there was no significant difference ($P \geq 0.05$) among the stem size means. Under deficit irrigation, Star 9006 was followed by Rodade at 1.4cm variety (Table 5.3). The stem diameter of the plants under full irrigation were less thick and taller as compared to those under deficit irrigation.

On the second measurement taken during fruit development stage, Star 9006 at 7.0cm variety recorded the highest plant height under full irrigation followed by Rodade at 5.8cm (Table 5.4). Commander at 5.5cm had the lowest plant height record on all the varieties under full irrigation. Rodade at 5.7cm had the highest plant height record under deficit followed by Commander at 5.6cm. Star 9006 had the lowest plant height record was at 5.2cm. There was no significant difference (P≥0.05) among the plants height means on both full and deficit irrigation. On full irrigation, Star 9006 at 1.6mm had the highest stem diameter record followed by Rodade and Rodade at 1.5mm respectively. The lowest stem diameter was recorded on Commander at 1.4mm. Under deficit irrigation, the highest stem size records were statistically the same and there was no any significant difference (P≥0.05) obtained.

Table 5.3 Plant height and stem diameter measured in the full and deficit irrigation treatment of four tomato varieties at A hi tirheni Mqekwa during Development stage of the plants (38 DAP).

Treatments	**Cultivars**	**Plant height (cm)**	**Stem diameter (mm)**
Full irrigation	HTX14	5.4bcd	0.8c
	Rodade	6.8ab	1.4a
	Commander	4.5d	0.7c
	Star9006	7.0a	1.2ab
Deficit irrigation	HTX14	5.2cd	0.9bc
	Rodade	6.3abc	1.5a
	Commander	4.1d	0.9bc
	Star9006	6.8a	1.4a

[a]Means followed by the same letter are not significantly different at ($P \leq 0.05$) according to Duncan's Multiple Range test.

Table 5.4. Plant height and stem diameter measured in the full and deficit irrigation treatment of four tomato varieties at A Hi Tirheni Mqekwa taken during fruit development stage of the plant (55 DAP)

Treatments	**Cultivars**	**Plant height (cm)**	**Stem diameter (mm)**
Full irrigation	HTX14	5.7a	1.5ab
	Rodade	5.8a	1.5ab
	Commander	5.5a	1.4b
	Star 9006	6.1a	1.6a
Deficit irrigation	HTX14	5.3a	1.5ab
	Rodade	5.7a	1.5ab
	Commander	5.6a	1.5ab
	Star 9006	5.2a	1.5ab

[a]Means followed by the same letter are not significantly different at ($P \leq 0.05$) according to Duncan's Multiple Range test.

5.4.3 Crop yields

Fresh yields of tomato fruits on both farms (Duvadzi and A Hi Tirheni Mqekwa) were measured by scale immediately after harvest yield determination. The results are shown in Figure 5.5. The highest yield was observed in Star 9006 on both irrigation treatments (32.4 t/ha). The lowest yield was observed in HTX 14 (17.9 t/ha).

At Duvadzi Farm, second experiment under full irrigation, there was no significant difference observed within the treatment in all four varieties under investigation (Figure 5.6). The highest yields were observed in Star 9006 in full and deficit irrigation. In deficit irrigation, the lowest yield was observed in HTX 14 and Commander (Figure

5.5). At deficit irrigation, the highest yields were recorded in Rodade variety and the least was HTX 14.

No significant differences (P≥0.05) in yields between cultivars were determined at Duvadzi farm (Figure 5.5). This was as the results of the effect of extreme high temperature experienced during the first experiment period. The high temperature also contributed to the large portion of the fresh tomatoes being of small fruit size as compared to the other varieties.

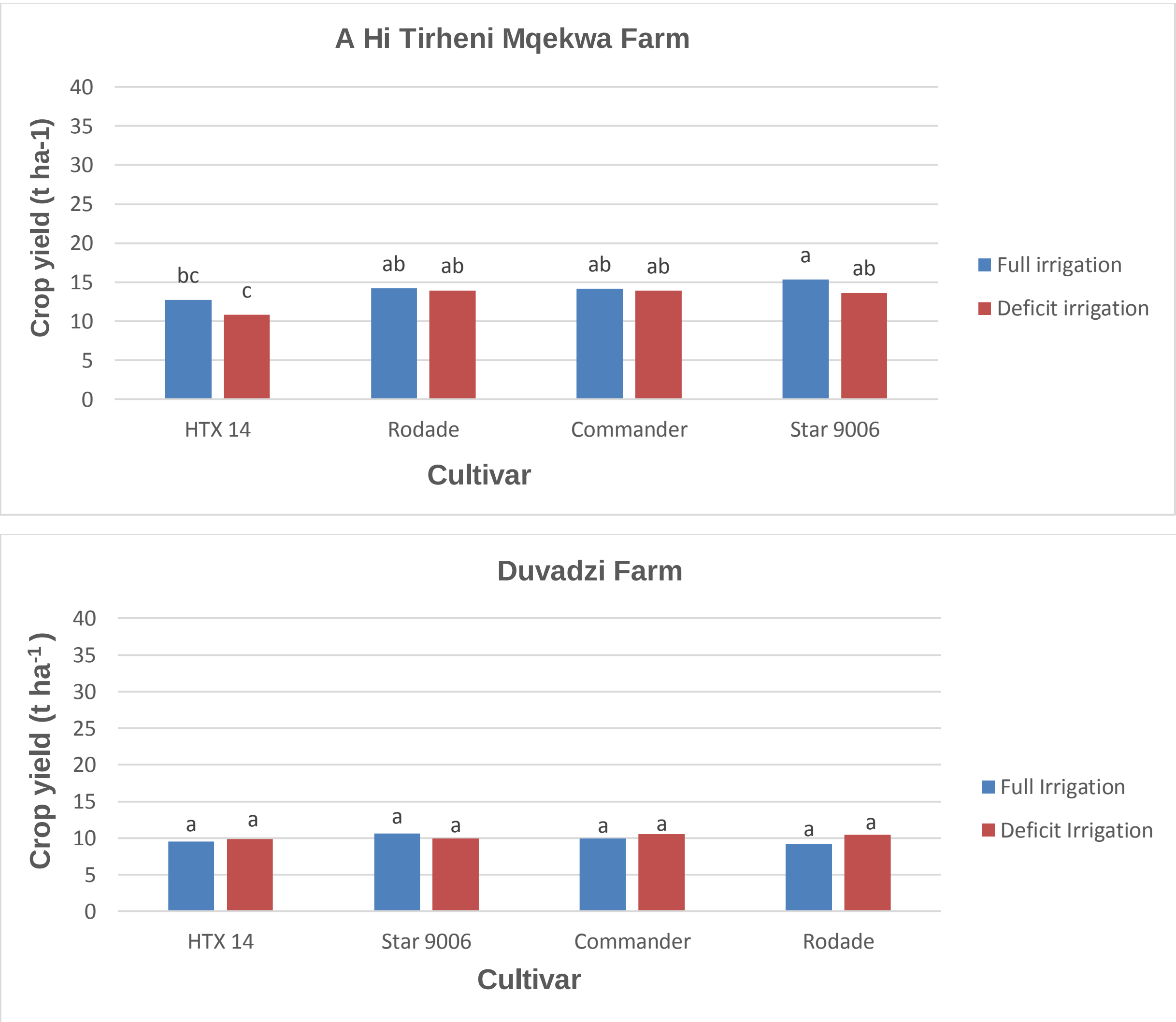
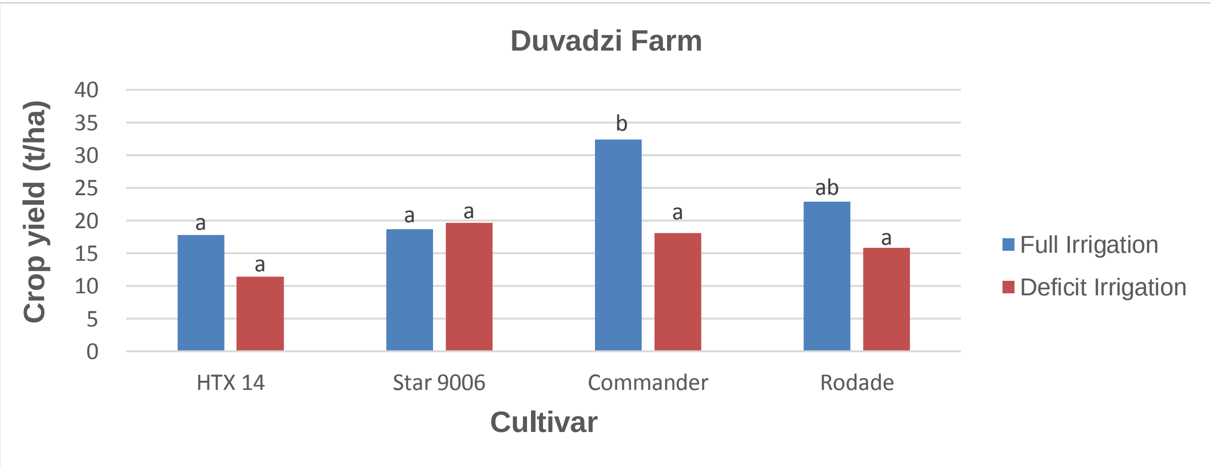


Figure 5.5. Tomato fresh yields of four varieties measured in the first experimental trial at Duvadzi and A hi tirheni Mqekwa farms.

At Duvadzi Farm, second experiment, there was no significant difference observed within the treatment in all the varieties (Figure 5.6). This was due to the high temperature experienced during the experiment period. Exception was variety Commander that yielded more in the FI treatment compared to the DI treatment, indicating that this variety may not be well adapted to drought conditions. The least performing cultivar under FI was observed in HTX 14. The highest yield under DI was observed in Star 9006. The least performing cultivar under DI was observed in HTX 14.

At A hi Tirheni Mqekwa farm, Star 9006 variety was the best performing variety under both FI and DI treatment (Figure 5.6). Under FI, a significant difference was observed at (P≤ 0.05) in HTX 14, Star 9006 and Rodade. The least performing cultivar under FI and DI was HTX 14.



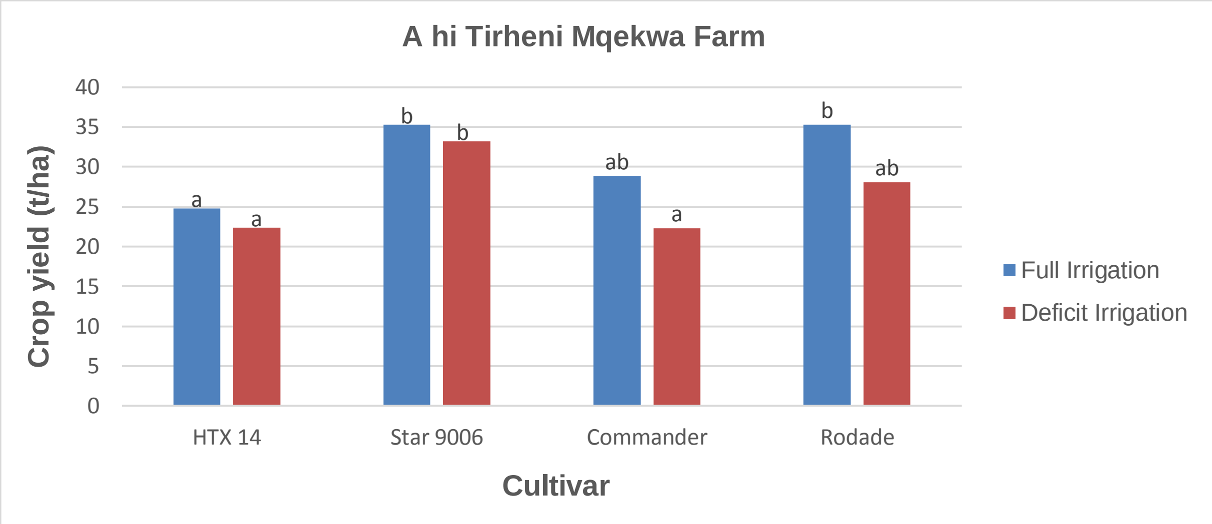


Figure 5.6. Tomato fresh yields of four varieties measured in the second experimental trial at Duvadzi and A hi tirheni Mqekwa farms.

5.5 Discussion

Leaf chlorophyll content

Leaf chlorophyll measurements were taken to monitor changes in the photosynthetic pigment content in the plant. Chlorophyll measurements with the CCM-300 indicated that younger leaves exposed to the sun on the top part of the canopy contain more chlorophyll than older leaves located on lower part of the plant canopy. The number of leaves per plant at different stages of crop growth was also significantly influenced by different irrigation levels. Chlorophyll content tended also to increase towards maturity compared to the vegetative and flowering stage, and then it dropped when leaf senescence occurred. There was no significant differences at ($P \geq 0.05$) between varieties and treatments. Typical chlorophyll content readings were between 40 and 60 mg m^{-2} at Duvadzi in the first experiment, and between 50 and 70 mg m^{-2} at both farms in the second experiment. Maximum leaf area index for all varieties at the given planting spacing was about 3 with canopy cover approaching 90%.

The results reflect that the amount of chlorophyll is generally higher in the leaves located in the upper part of the plant. This is due to more sunlight received that the middle and the lower leaves. However the results obtained from Duvadzi farm first season planting shows that the middle leaves had higher chlorophyll content than the top leaves. Although leaves located in the middle of the plants had slightly more and equal chlorophyll as the leaves located in the upper part of the plant in Duvadzi farm, there was no statistically significant different at ($P \geq 0.05$) level of confidence between measurement values. Leaves getting sunlight and leaves not getting much sunlight have different internal and external structures, tissues providing strength of plants growing in extensive light condition thrives and number of chloroplast is low but they are big and the amount of chlorophyll are too much (Kurtar, 2012).

Plant height and stem diameter

The overall results show that there was no significance difference ($P \geq 0.05$) observed on plants height and stem size between the treatments. The cultivars responded differently on the two irrigation treatments. Under deficit irrigation, a significant difference was observed between Star 9006 and Commander and HTX 14. Based on the results obtained, the means of all the varieties stem size under full irrigation were lower that the deficit irrigation. This shows that the cultivars on full irrigation had a lesser stem size and taller plant height as compared to deficit irrigation. Therefore, full irrigation treatment had a contribution on the plant and stem size. The results were in agreement with Zotz *et al.* (2001) who also reported that the differences in plant size may also be associated with changes on the leaf area which should be as results of water availability. The results show that Star 9006 and Rodade cultivars can tolerate water stress and still thrive better in terms of plant height than the other Cultivars.

At Duvadzi farm second season, no significant difference (P≥0.05) was observed in plant height under both irrigation treatments and among the cultivars. The insignificant difference of plant height between two irrigation patterns might be because the plants reduced the ineffective water consumption for crop due to extreme high temperature encountered. Other studies commend that on days when the soil is dry and the evaporative demand is high, there is a reduction in stem diameter, with only a partial recovery during the night. Under those conditions, the stem diameter can remain stable or even decrease from one day to the other, because the plant does not grow and becomes increasingly dehydrated (Silva *et al.*, 2018).

In the overall analysis at A hi tirheni Mqekwa farm, stem size did not show significant difference (P≥0.05) among the means on cultivars and on treatments. The difference was observed on HTX 14 that had a thicker stem in DI than FI with the difference of 0.1mm. The plants stem size in FI was lesser than the stem size in DI based on the obtained results.

Yield

There were no statistical significant differences (P≥0.05) in yield observed between treatments in the first growing seasons at Duvadzi farm and A hi tirheni Mqekwa farm. However, total yields at A hi tirheni Mqekwa were between 48 and 60 t ha^{-1}, which is in the range of potential yields obtained for these varieties in the area. At Duvadzi, the total yields ranged between 9 and 11 t ha^{-1}, which is well below potential, possibly due to the effects of the heat wave in the first part of the cropping season. Variety Star 9006 was also the best performing variety in the first experiment at Duvadzi farm that was conducted during a period of heat wave resulting in lower yields compared to the second experiment. From the perspective of varieties, Commander produced the highest yield in the FI treatment, and Star 9006 in the DI treatment. HTX 14 was the poorest performing variety in both FI and DI treatments.

There were no statistical significant differences (P≥0.05) in yield observed between treatments for the two growing seasons at A hi tirheni Mqekwa farm. The findings agreed with Anastasi *et al*., 2010 that irrigation deficit contributes to increments in yield, but plants not subjected to water deficit express their maximum productive potential, provided that other factors remain unchanged. This aspect can be explained by the occurrence of heat wave experienced during the first experiment that affected plants growth on both treatments. However, yields were generally higher at A hi tirheni Mqekwa compared to Duvadzi farm (Figure 5.5 and 5.6). In the second season, yields at A Hi Tirheni Mqekwa varied between 25 t ha^{-1} (DI treatment) and 35 t ha^{-1} (FI).

Though the statistic results did not show any significant different (P≥0.05) on yield, improvement was noticed. There was an increase in all the tomato cultivar yields under full irrigation compared to deficit irrigation at Duvadzi farm, second season. Similar results were also reported by Kirnak *et al.* (2001) where full water supply significantly increased fruit yield on eggplant. This indicates that deficit irrigation saved water but had an effect on yield reduction. Increasing the irrigation amounts resulted in increased total yield in general.

Crop yields in the second season improved at Duvadzi compared to the first season. However, they were lower than at A hi tirheni Mqekwa possibly due to the occurrence of pests. In general, the best performing cultivar at both farms was Star 9006, whilst HTX14 produced the lowest yields amongst the cultivars. In the second season at Duvadzi, cultivar Commander performed very well. Different reactions of our investigated cultivars to DI might be explained by different sensitivity of these cultivars to drought or moisture stress.

Generally, tomato yield decreased with the irrigation water reduction in the two growth seasons. This confirms the findings by other studies which showed that water deficit at certain levels decreased tomato yield (Zegbe-Domínguez *et al*., 2003; Kirda *et al.,* 2004; Patanè *et al.,* 2011), although to a different extent depending on the period and the degree of water stress (Nuruddin *et al.*, 2003). It is only at Duvadzi farm, first experiment where we had HTX 14, Commander and Rodade with higher yield in deficit than full irrigation but of low size and quality. Candido *et al*. (1999) also reported that water application positively influenced tomato productivity.

CHAPTER 6

SUMMARY, CONCLUSSION AND RECOMMENDATIONS

Tomato (*Lycopersicon esculentum* Mill) is one of the most produced and extensively consumed vegetable crops in the world (Grandillo *et al*., 1999). Early blight of tomato is a serious disease requiring control measures, including fungicide applications (Jackson, 2010). The disease occurs wherever tomato is grown, and can cause severe defoliation, resulting in fewer, smaller fruit. Many millions of dollars are spent on fungicides to control the disease. Various constraints, including abiotic and biotic stresses are responsible for yield reduction in tomato production (Abdel- Sayed, 2006). Among biotic factors, early blight caused by *Alternaria solani* is one of the major diseases of tomato causing major crop damage where the crop is produced (Chaerani *et al*., 2006). Control of tomato early blight has been almost exclusively based on the intensive application of protectant fungicides (Batista *et al*., 2006). However, their prolonged application and indiscriminate use has let to pathogen resistance resulting in loss of effectiveness (Batista *et al*., 2006). Manipulation of the agro-ecological conditions such as soil moisture, canopy humidity and rotation has been reported to suppress plant diseases of various crops (Pal, 2006).

Early blight disease incidence was not significantly difference ($P \geq 0.05$) between full and deficit irrigation treatments (Table 4.9). However, disease incidences for cultivars in both planting seasons were higher under deficit irrigation than in full irrigation.

Early blight disease severity was significantly different ($P \leq 0.05$) between full and deficit irrigation treatments. The study revealed that all the four tomato varieties under investigation were more affected by early blight disease under deficit irrigation as compared to those under deficit irrigation. There were no statistical significant differences (P≥0.05) in yield observed between treatments for the two growing seasons at Duvadzi farm and A hi tirheni Mqekwa farm (Figure 5.5 and 5.6). Generally, tomato yield decreased with the irrigation water reduction in the two growing seasons. Tomato can be irrigated with deficit irrigation without significant reduction in yield. The highest crop yields were obtained with variety Star 9006, although differences between varieties were mostly not significant. The effects of irrigation management and different varieties on early blight were mostly not significant because of the low incidence and severity of the disease during the unusually dry year.

Planting of tomato should be avoided in the hottest time of the year (January-February) due to high risk of heat wave in Giyani area. The majority of the farmers do not have knowledge about tomato EB disease and its management strategies. Most of the farmers usually apply fertilizers without testing of soil fertility status and have little knowledge on the other aspects of disease development. Farmer knowledge on EB disease is one of the most significant factors that guides on management strategies to be applied. Early blight (*Alternaria solani*) is a fungal disease that every tomato grower should know and be able to identify (Kerr, 2013). Early blight disease management strategies should be applied as yield losses will be proportionate to the level of infestation.

It is recommended deficit irrigation can be used without significant reduction in yield as compared to full irrigation. There was no significant difference in terms of early blight disease incidence and severity in both full and deficit irrigation. However, irrigation management cannot be the only strategic management that can be used to manage tomato early blight disease. However, it can be used based on varieties that such as Star 9006.

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APPENDICES

Appendix 4.1: Diesel pump (top left) and housed borehole with electricity supply (top right) at A hi tirheni Mqekwa farm; borehole from which abstraction occurs with a power generator (bottom left) and open well in the Molototsi river bed (bottom right) at Duvadzi farm.

Appendix 4.2: Pesticide applied on both farms for pest management

Pesticide	Pests	Dosage / 100L water
Cypermethrin EC	American Bollworm, Thrips, Aphids, Tomato looper and leaf miner	20ml
Methomex 200 SL		225ml
Mecti	Redspider mite	60ml
Makhromectin		60ml

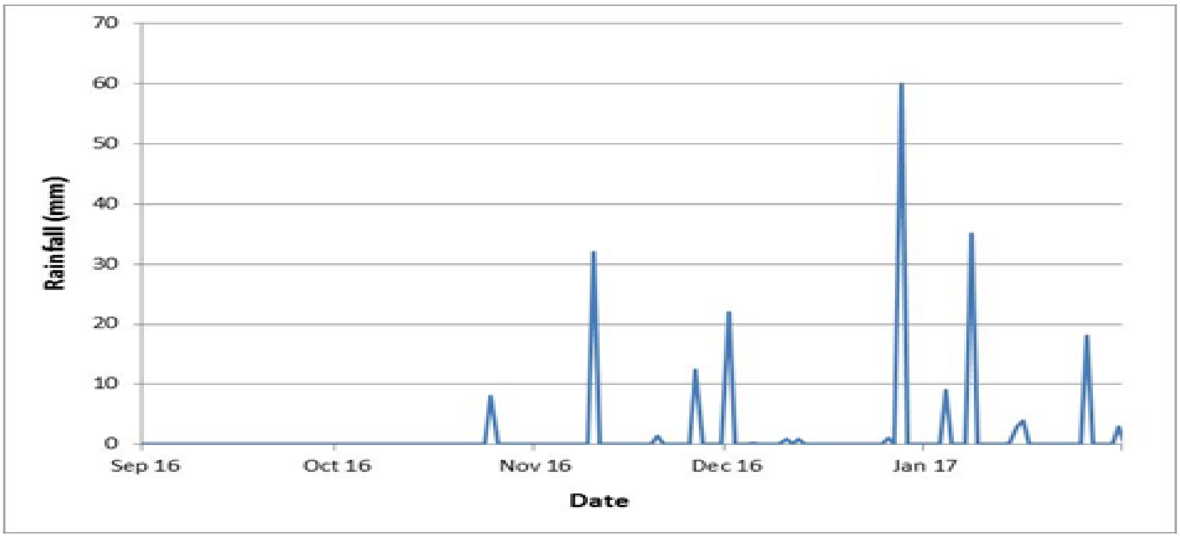
Appendix 4.3. Soil properties at the beginning of the experimental trial at Duvadzi farm.

Farm	Depth (cm)	pH (H2O)	P Bray (mg/kg)	K (mg/kg)	Na (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Ca (mg/kg)	Mg (%)	K (%)	Na (%)	Ca:Mg 1.5-4.5	(Ca+Mg) K 10.0-20.0	Mg:K 3.0-4.0	S-Value (Cmol(+)/kg	Na:K (Cmol(+) /kg	T (Cmol(+) /kg	Density (g/cm3)	S-AMAC (mg/kg)	NO3-N (mg/kg)	NH4-N (mg/kg)	EC (mS/m)
Duvadzi	0-20	6.0	3.5	241.9	61.4	607.6	313.9	47.0	39.2	9.7	4.1	1.2	9.1	4.1	6.6	0.4	6.5	1.3	11.6	14.4	0.5	17.6
	30-50	6.3	1.9	284.8	104.4	991.6	593.1	45.9	43.5	6.7	3.9	1.1	14.2	6.8	11.0	0.6	11.0	1.2	12.7	8.3	1.0	17.7

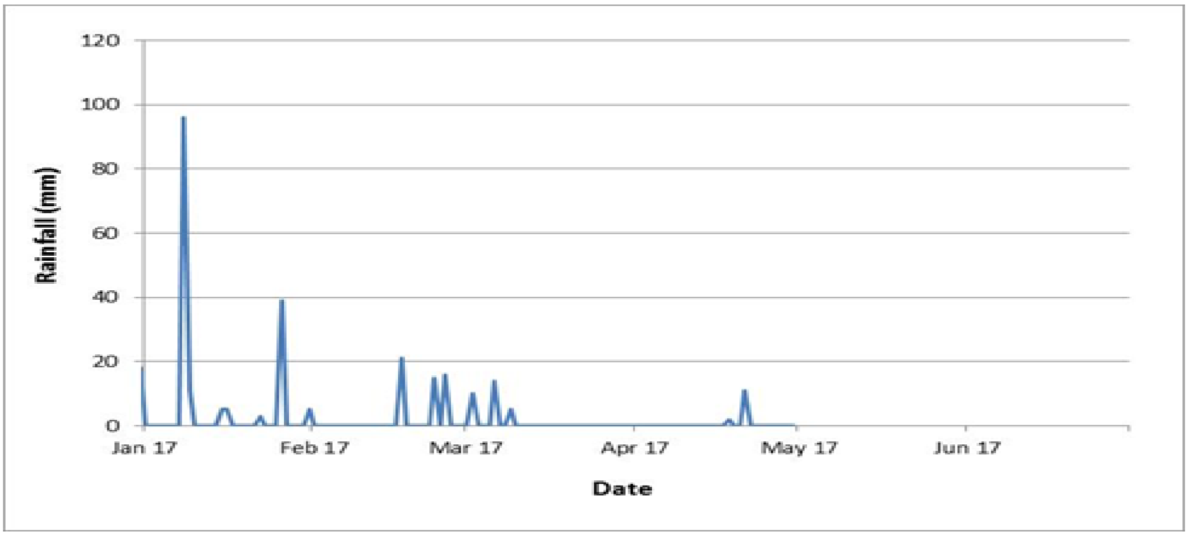
Appendix 4.4. Soil properties at the beginning of the experimental trial at A hi tirheni Mqekwa farm.

Farm	Depth (cm)	pH (H2O)	P Bray (mg/kg)	K (mg/kg)	Na (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Ca (mg/kg)	Mg (%)	K (%)	Na (%)	Ca:Mg 1.5-4.5	(Ca+Mg) K 10.0-20.0	Mg:K 3.0-4.0	S-Value (Cmol(+)/kg	Na:K (Cmol(+) /kg	T (Cmol(+) /kg	Density (g/cm3)	S-AMAC (mg/kg)	NO3-N (mg/kg)	NH4-N (mg/kg)	EC (mS/m)
A hi tirheni Mqekwa	0-20	7.1	13.4	193.5	133.6	1807.3	788.4	54.3	39.2	3.0	3.5	1.4	33.8	14.0	16.6	1.3	16.6	1.2	22.1	17.2	0.5	43.6
	30-50	7.2	9.5	174.1	136.1	2049.9	762.0	57.5	36.5	2.6	3.4	1.7	41.6	15.5	17.5	1.5	17.5	1.2	19.6	13.9	0.3	47.0

Appendix 4.5: Rainfall measurements at Duvadzi farm during September 2016-January 2017 cropping season

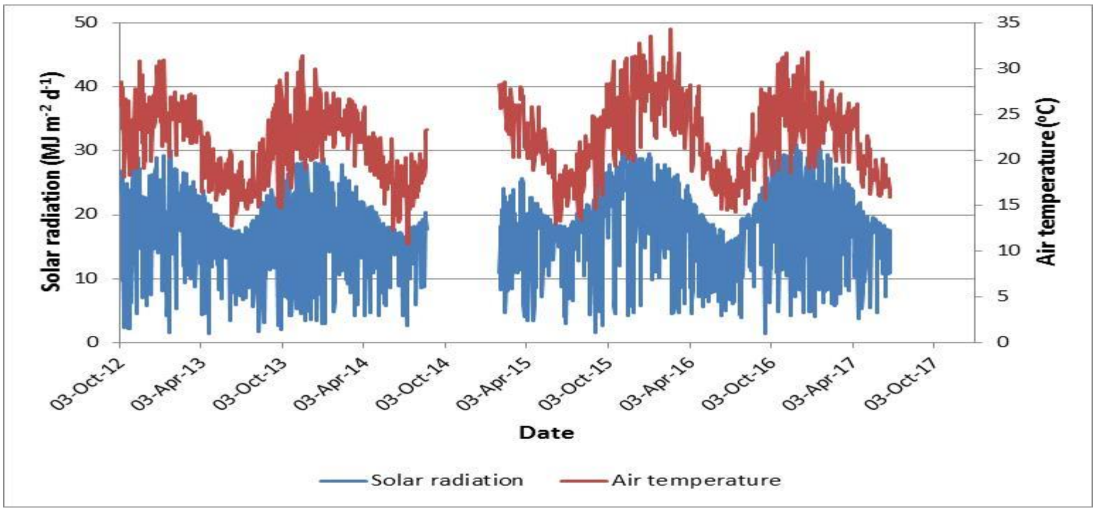


Appendix 4.6. Rainfall measurements at A hi tirheni Mqekwa farm during September 2016-January 2017 cropping season

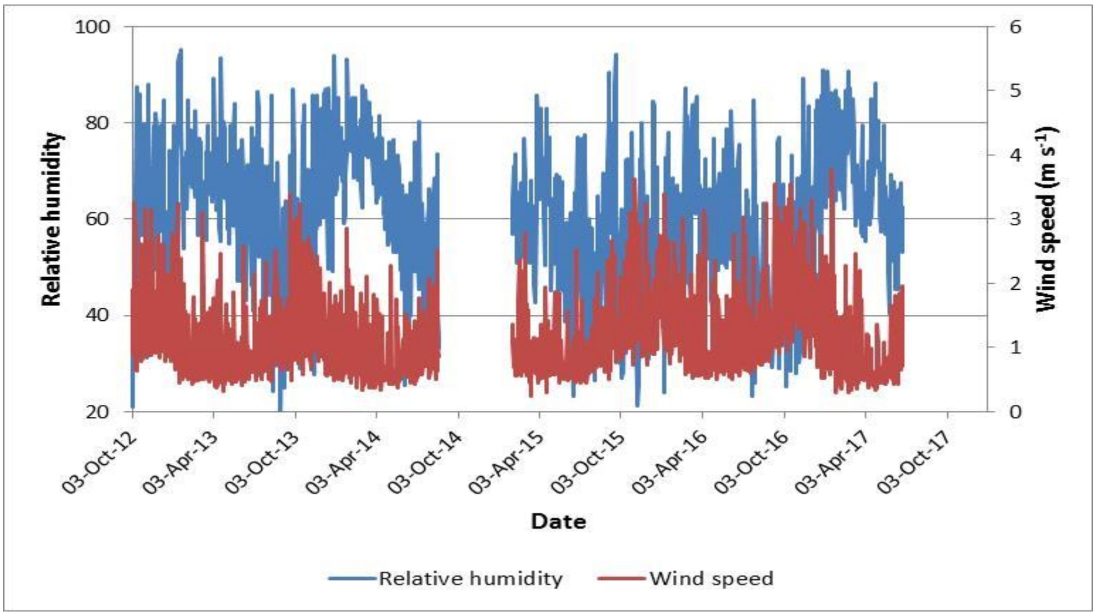


Appendix 4.7: Giyani weather data recorded from October 2012 to June 2017.

A

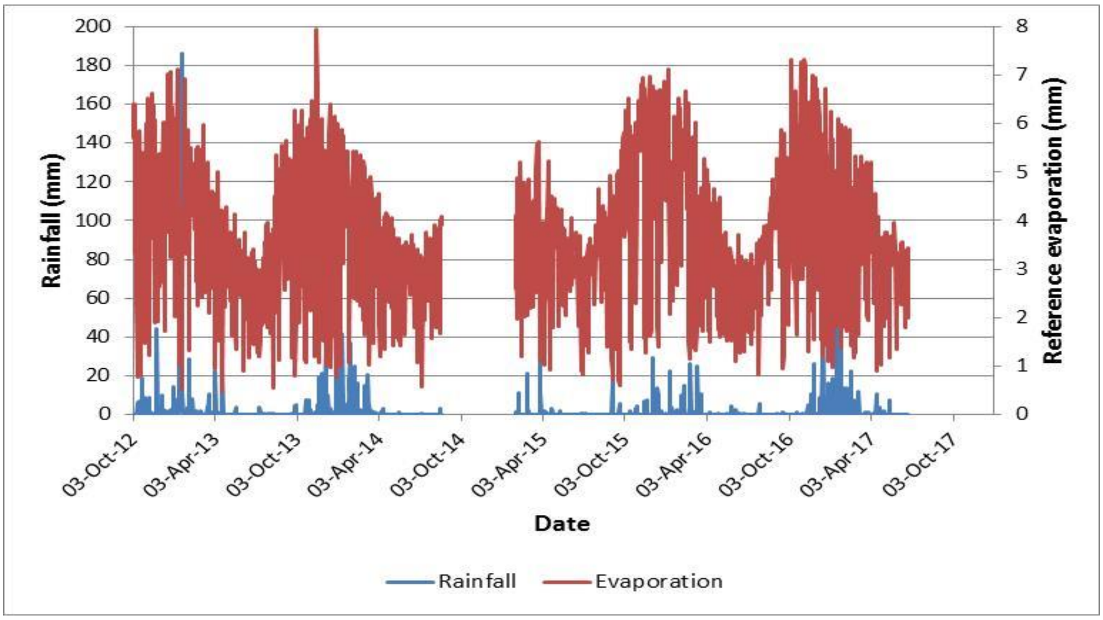


B



100
80
60
40
20
6
5
4
3
2
1
0
Relative humidity
Wind speed (m s-1)
03-Oct-12
03-Apr-13
03-Oct-13
03-Apr-14
03-Oct-14
03-Apr-15
03-Oct-15
03-Apr-16
03-Oct-16
03-Apr-17
03-Oct-17
Date
Relative humidity
Wind speed

C



200
180
160
140
120
100
80
60
40
20
0
8
7
6
5
4
3
2
1
0
Rainfall (mm)
Reference evaporation (mm)
03-Oct-12
03-Apr-13
03-Oct-13
03-Apr-14
03-Oct-14
03-Apr-15
03-Oct-15
03-Apr-16
03-Oct-16
03-Apr-17
03-Oct-17
Date
Rainfall
Evaporation

Appendix 5.1: Dedicated sheets used to record irrigation water volume readings

IRRIGATION RECORD SHEET																																			
	YEAR:2016					Duvadzi farm						Planting date:20161020						Crop:Tomato							Irrig:ation system:Drip										
Jan	Meter reading		FEB	Meter reading		MAR	Meter reading		APR	Meter readings		MAY	Meter reading		JUN	Meter reading		JUL	Meter reading		AUG	Meter reading		Sept	Meter reading		Oct	Meter reading		Nov	Meter reading		Dec	Meter reading	
Date	Op	Cl	Date	Op	Cl	Date	Op	Cl	Date	Op	Cl	Date	Op	Cl	Date	Op	Cl	Date	Op	Cl	Date	Op	Cl	Date	Op	Cl	Date	Op	Cl	Date	Op	Cl	Date	Op	Cl
1			1			1			1			1			1			1			1			1			1			1	648.6	652.6	1	740	745.2
2			2			2			2			2			2			2			2			2			2	320	325	2			2	745.2	747.8
3			3			3			3			3			3			3			3			3			3	325	328	3			3	747.8	752.1
4			4			4			4			4			4			4			4			4			4			4	652.6	656	4	747.8	752.1
5			5			5			5			5			5			5			5			5			5			5	656	678.2	5	752.1	756
6			6			6			6			6			6			6			6			6			6	352	359	6			6	756	757.1
7			7			7			7			7			7			7			7			7			7	359	363	7	669.4	667.8	7		
8			8			8			8			8			8			8			8			8			8	363	370	8	667.8	668.2	8		
9			9			9			9			9			9			9			9			9			9	370	373	9			9		
10			10			10			10			10			10			10			10			10			10			10			10		
11			11			11			11			11			11			11			11			11			11			11			11		
12			12			12			12			12			12			12			12			12			12	373	379	12			12		
13			13			13			13			13			13			13			13			13			13	379	382	13			13		
14			14			14			14			14			14			14			14			14			14			14			14		
15			15			15			15			15			15			15			15			15			15			15			15		
16			16			16			16			16			16			16			16			16			16			16			16		
17			17			17			17			17			17			17			17			17			17			17			17		
18			18			18			18			18			18			18			18			18			18			18	668.2	673.8	18		
19			19			19			19			19			19			19			19			19			19			19	673.8	675.4	19		
20			20			20			20			20			20			20			20			20			20			20	675.4	680	20		
21			21			21			21			21			21			21			21			21			21			21	680	682.5	21		
22			22			22			22			22			22			22			22			22			22			22	692.8	700	22		
23			23			23			23			23			23			23			23			23			23			23	700	702.5	23		
24			24			24			24			24			24			24			24			24			24			24	702.5	708.1	24		
25			25			25			25			25			25			25			25			25			25			25	708.1	711.3	25		
26			26			26			26			26			26			26			26			26			26			26	771.3	716.7	26		
27			27			27			27			27			27			27			27			27			27			27	716.7	720.1	27		
28			28			28			28			28			28			28			28			28			28			28	720.1	730.8	28		
29			29			29			29			29			29			29			29			29			29			29	730.8	731.6	29		
30						30			30			30			30			30			30			30			30			30	737	737.5	30		
31						31						31						31			31						31				739.5	744	31		

Appendix 5.2. Rain gauge placed at Duvadzi farm and A hi tirheni Mqekwa farm used to measure rainfall volumes.

Appendix 5.3 Layout of drip irrigation lines (left) and water volume meter used to measure irrigation volumes (right).