GROWTH, YIELD AND POSTHARVEST QUALITIES OF TOMATO (*Lycopersicon esculentum* M.) AS INFLUENCED BY SOIL MOISTURE LEVELS AND PACKAGING

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A Thesis submitted to the Graduate School in Partial Fulfilment for the Requirements of the Masters Degree in Horticulture of Egerton University

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DECLARATION AND RECOMMENDATION

DECLARATION

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

Signature ____________________ Date _________________

SIBOMANA IMANI CAROLINE

RECOMMENDATION

This research thesis has been submitted with our approval as university supervisors.

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DEDICATION

To my parents Charles-Borromée SIBOMANA NABANTU and Céline MUDAHAMA FURAHA for their love and to my fiancé, Bill BAHANE for his patience and encouragement.

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ABSTRACT

Tomato (*Lycopersicon esculentum* M.) is a fruit vegetable, and like most horticultural commodities is highly perishable. It is often exposed to stresses either imposed by other organisms (biotic) or arising from imbalance of environmental factors (abiotic). The effects of five different soil moisture levels [20%, 40%, 60%, 80% and 100% of the pot capacity (PC)] were studied in tomato (cv. 'Moneymaker') planted in plastic pots under greenhouse conditions, and then assessed for sustainable postharvest qualities including use of different types of packaging [non-packaged (control), perforated and non-perforated high density polythene bag (HDPE)]. The objective of this study was to determine the yield performance and the postharvest quality of tomato under varying soil moisture stress (water deficit). Field and laboratory trials were conducted at the Horticulture Research and Demonstration Field and Tissue culture laboratory respectively, Egerton University, from March to July 2010 (Trial 1) and from June to October 2010 (Trial 2). The experiments were carried out in a randomized complete block design (RCBD) and in a split-plot arranged in RCBD for both field and laboratory work respectively. Data collected was subjected to Analysis of Variance (ANOVA) and mean separations were done using Duncan Multiple Range Test (DMRT) at 5% level of significance. Water deficit stress resulted into decreased growth and yield of tomato but enhanced its post-harvest qualities. Plant height was affected by the amount of water applied, although inconsistently. Tomato fruit yield was also affected significantly by soil moisture levels. The highest fruit yield (70 ton/ha) was recorded in the well watered (control) plants; the highest flower abortion (80 - 94 %) and the smallest fruit diameter were observed in the severely stressed plants (20 % of PC). Soil moisture stress influenced tomato post-harvest qualities. The higher the water content, the higher the weight loss and the faster the fruit losses its firmness and develops a speedy fruit colour change. Fruit weight was reduced by 32 % in unpackaged fruits (control) while packaged fruits developed a faster fruit colour change and increased the fruit total soluble solids (5.5%). The fruit total soluble solid was decreased and the titrable acidity was higher in fruits from the well watered plants. Unpackaged fruits had the highest level of titrable acidity (12.6 -13.2%) and lost their firmness faster. Severe moisture stress improved tomato fruit quality in reducing fruit acidity and in increasing the fruit total soluble solids (5.8%) and preserving its firmness. Packaging positively influenced the tomato fruit quality and extended tomato shelf life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

ABA	Absicic acid
ASARECA	Association for Strengthening Agriculture Research in Eastern and Central Africa
CCM	Chlorophyll Content Meter
DAH	Days after harvest
DAP	Days after planting
DM	Dry mass
FAO	Food and Agriculture Organization
FM	Fresh mass
HDPE	High density polyethylene
Kgf	Kilogram-force
LRWC	Leaf relative water content
MAP	Modified atmosphere packaging
MSc	Master of Science
NP	Non-perforated
P	Perforated
PC	Pot capacity
RH	Relative humidity
RUFORUM	Regional Universities Forum for Capacity Building in Agriculture
SCARDA	Strengthening Capacity for Agricultural Research for Development in Africa
t/ha	Ton per hectare
TA	Titrable acidity
TSS	Total Soluble Solids
TM	Turgid mass
WS	Water Stress

CHAPTER ONE
INTRODUCTION

1.1. Background Information

Plants can respond to reduced soil water availability without experiencing any detectable change in shoot-water relations. Water is one of the most important inputs essential for the production of crops. Plants need huge quantities of water continuously during their life. Water profoundly influences photosynthesis, respiration, absorption, translocation and utilization of mineral nutrients, and cell division besides other processes (Anonymous, 2008).

Water deficits and insufficient water are the main limiting factors affecting worldwide crop production. While these are truisms, the importance and relevance of studying soil-plant-water relations are not diminished in the least. A better understanding of how soil-water deficits affect plant growth, nutrition, and water use is fundamental to the development of techniques to minimize the negative effects of the stress (Nuruddin, 2001).

Water stress in plants occurs when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use. Both water shortage and excess affect the growth and development of a plant directly and, consequently, its yield and quality. Many environmental stresses, such as heat, salinity, low temperature, drought, and developmental processes, such as seed maturation, cause water deficit in plants. Of the various physiological processes in the plant, growth is the most sensitive to water stress (Bradford and Hsiao, 1982).

Soil moisture requirements differ with the crop and stage of the crop development; its availability varies with the amount of water in the soil and the type of soil. Watering plants merits a considerable attention in order to supply the plants with the appropriate amount of this vital nutrient. Water is vital for plant growth and development. Water deficit stress, permanent or temporary, limits the growth and the distribution of natural vegetation and the performance of cultivated plants more than any other environmental factors do (Hong-Bo *et al*., 2009).

Low water availability can also cause physical limitations in plants. Stomata are plant cells that control movement of water, carbon dioxide, and oxygen into and out of the plant. During low moisture stress, stomata close to conserve water. Water is important for growth and survival of plants and how much water to apply depends on many factors including soil characteristics, plant species and climatic conditions. Plants will not thrive and provide good colour if they are under moisture stress. Irrigation should take into consideration the relationship between soil's water holding and storage capacities and the plant water use. Also moisture conservation practices such as mulching (black/ clear polythene) are critical in deciding irrigation frequency.

Adequate soil moisture during the Preharvest period is essential for the maintenance of postharvest quality. According to Shewfelt and Prussia (1993), water stress during the growing season can affect the size of the harvested plant organ, and lead to soft or dehydrated fruit that is more prone to damage and decay during storage. On the other hand, vegetables experiencing an excess of water during the growing season can show a dilution of soluble solids and acids, affecting flavour and nutritional quality. A significant impact of globalization on horticulture has been an increasing demand for quality improvement and the wider adoption of quality standards for fruit, vegetable and salad commodities (Harold *et al*., 2007).

Vegetables are 80 to 90 % water. Because they contain so much water, their yield and quality suffer very quickly from drought. Thus, for good yield and high quality, irrigation is essential for the production of most vegetables. When it comes to crops, plant water deficit stress can lower yields and possibly lead to crop failure. Moderate water stress reduces fruit size and increases soluble solids content, acidity, and ascorbic acid content (Obreza *et al*., 2001). On the other hand, excess water supply to plants results in cracking of fruits (such as cherries, plums, and tomatoes), excessive turgidity leading to increased susceptibility to physical damage (such as oil spotting on citrus fruits), reduced firmness, delayed maturity, and reduced soluble solids content (FAO, 2009).

Meaza *et al*. (2007) indicate in their work that postharvest qualities of tomatoes partly depend upon preharvest factors such as cultural practices, genetic and environmental conditions. Quantitative and qualitative losses occur in tomatoes as in many other horticultural commodities between harvest and consumption. Qualitative losses, such as loss in edibility, nutritional quality, caloric value, and consumer acceptability of fresh produce, are much more difficult to assess than are quantitative losses.

Postharvest losses vary greatly across commodity types, with production areas and the season of production. Reduction of postharvest losses can increase food availability to the growing world population, decrease the area needed for production, and conserve natural resources (Kader, 1986). Postharvest losses in horticultural fruit crops are mainly related to handling, from harvest to retail. Losses are caused by mechanical injuries, inadequate storage, inappropriate handling and transport, and on-display time in the retail market (Marcos *et al*., 2005).

Although minimizing postharvest losses of already produced food is more sustainable than increasing production to compensate for these losses, less than 5% of the funding of agricultural research and extension programs worldwide is devoted to activities related to maintenance of produce quality and safety during postharvest handling. This situation must be changed if success is to be achieved in reducing postharvest losses of horticultural perishables (FAO, 2009).

1.2. Statement of the problem

Horticultural crops are characterized by peculiar problems; they are highly seasonal, perishable and bulky in nature. Insufficient soil moisture due to lack or poor water management and other field practices (e.g. insufficient nutrient supply) lead to a decline in crop production (growth, yield and quality), especially vegetables, including tomato. Tomato fruits are very susceptible to loss in quality when the field practices and other preharvest factors are not well managed. Postharvest handling practices, including packaging may also increase tomato shelf life. Poor postharvest handling may lead to rapid decay of fruits unless appropriate preventive measures are taken. Postharvest losses in vegetables are estimated at about 35-45% as the product moves from farm to the ultimate consumers (Muhammad, 2000). Preventing postharvest losses that occur in horticultural products is more difficult compared to other crops. This is because the tissue composition of horticultural products, especially those of vegetables, is to a large extent more than 90% water. Tomato is one of the most widely grown vegetables in the world. The popularity of tomato among consumers has made it an important source of vitamins A and C in diets. Losses that are observed in tomato after harvest reduce the income to farmers and retailers. At peak harvest, the farmers are forced to sell off their produce at very low prices or risk losing the whole lot due to spoilage (Mathooko and Nabawanuka, 2003). There is lack of documentation on the optimum amount of water for tomato production, poor harvest management practices and lack of infrastructure facilities, results in huge losses (Mir *et al*., 2007).

1.3. Objectives

1.3.1. General objective

The goal of this study was to determine the yield performance and the postharvest quality of tomato under varying soil moisture stress (water deficit).

1.3.2. Specific objectives

The specific objectives were to:

1. Determine the effects of soil moisture levels on growth and fruit yield of tomato.
2. Determine the effects of soil moisture levels on the postharvest qualities of tomato.
3. Determine the effects of packaging on the postharvest qualities of tomato.
4. Determine the interactive effects of packaging and soil moisture levels on postharvest qualities of tomato.

1.4. Hypotheses

1. Soil moisture levels have no effect on growth and fruit yield of tomato.
2. Soil moisture levels have no effect on postharvest qualities of tomato.
3. Packaging has no effect on postharvest qualities of tomato.
4. There are no interactive effects between packaging and soil moisture levels on postharvest qualities of tomatoes.

1.5. Justification

Worldwide production of fruits and vegetables has been increasing over the years, partly in response to population growth but also due to rising living standards in most countries and active encouragement to consume fruits and vegetables by government health agencies (Wills, 2007). The tomato is commercially important worldwide both for fresh fruit market and processed food industries. Because of its commercial importance, millions of dollars are now spent on imparting and improving desirable characteristics, either through classical breeding programs or by genetic manipulation (Opiyo, 2005).

The tomato (*Lycopersicon esculentum* M.) is one of the most commonly grown fresh market vegetables despite being highly perishable. Due to poor handling and inadequate infrastructure, postharvest losses in horticultural crops (including tomato) are estimated to be in the tune of 25 to 40% which is a major setback in expansion of the industry. Postharvest losses in tomato are a prime factor affecting the quantity and quality of tomato fruits in the market (Meaza *et al*., 2007).

Options to avert these losses are limited, and thus there is need to design research studies that are geared to developing such strategies. All year round availability of tomato in the market is very important for farmers as well as consumers because the tomato is a vegetable par excellence; it is found in every meal and can be eaten raw as salad. This is now even more critical as more and more producers adopt greenhouse technology where tomato is the crop of choice.

The manipulation of field practices such as proper watering might reduce field losses and enhance the quality of the tomato, and may also result in higher yield. Good storage and packaging might also influence the fruit quality and its shelf life. Tomato subjected to different levels of water regimes can behave differently in terms of postharvest qualities. The losses observed from harvesting time to consumption may therefore be reduced depending on the water regimes adopted.

1.6. Expected outputs

The expected outputs of this study are:

1. Optimum water level for enhanced growth and yield of tomato will be established,
2. Growing conditions (field and environmental conditions) that would extend the tomato's shelf life after harvest established and documented,
3. Come up with recommendations of packaging type to extend storage periods of tomato fruit,
4. MSc degree in Horticulture realised,
5. Publish and present the results of the study in referred journals and conference.

CHAPTER TWO
LITERATURE REVIEW

2.1. General information on tomato

Tomato (*Lycopersicon esculentum* Mill) is the second most important vegetable crop after potato (*Solanum tuberosum*). Based on the FAO world data (2004), the total acreage is approximately 2.8 million hectares with yearly worldwide fruit production of 84.7 million metric tons. Fresh tomatoes and other processed tomato products make a significant contribution to human nutrition owing to the concentration and availability of several nutrients in these products and to their widespread consumption. Composition tables show that ripe tomato contains 93-95% water and low levels of solid matter.

Tomato varieties are divided into several categories, based mostly on shape and size. The most cultivated varieties in Africa are 'Floradel', 'Marglobe', 'Heinz 1370', 'Rio Grande', 'Roma VF', 'Moneymaker', 'Anna F_1', 'Marmande', etc. Factors influencing selection of tomato varieties include market demands, resistance to disease pathogens, suitability to production systems, and regional adaptability (Diver *et al*., 1999).

Tomatoes are adapted to a wide range of environmental conditions, but in temperate areas low temperatures and short growing seasons can limit growth. Tomatoes prefer slightly acidic soils with a pH of 6.0 to 6.8 (Cox and Tilth, 2009). The tomato plant requires significant quantities of water, but not in excess, since tomato roots will not function under water-logged (anaerobic) conditions.

Sufficient moisture must be maintained to establish the plant and carry it through to fruit production. When the moisture level surrounding the roots is too high, epinasty, poor growth, late flowering, fewer flowers and lower fruit set occurs. Fruit disorders such as cracking and blossom-end-rot are common when water availability is inconsistent. Even under moderate water stress, photosynthesis is slowed because the movement of gases through the stomata is restricted and the movement of water up the xylem is slowed (Benton, 2008).

The tomato plant needs a controlled supply of water throughout the growing period for optimal quality and higher yield. Tomatoes are very sensitive to water deficits during and immediately after transplanting, at flowering and during fruit development (Doorenbos and Kassam, 1979). Nyabundi and Hsiao (1989a) reported that when tomato plants were subjected to different levels of water stress under field conditions, vegetative growth was inhibited but flower retention and fruit development were enhanced and led to early fruit ripening. However, the duration of reproductive growth was much shorter in water stressed plants leading to formation of fewer flower trusses and lower tomato fruit yield. The early fruit ripening observed in water stressed plants was also attributed to early cessation of reproductive growth in water stressed plants.

Deficit irrigation (deliberate under-irrigation) is likely to reduce yield or quality of horticultural crops, with severe economic consequences. Providing 60-80% of the normal water requirement during fruiting can improve flavour (Cox and Tilth, 2009). It has been widely reported that irrigation deficit in the 1st growth period reduces the number of flowers leading to a decrease in the number of fruits and in the marketable yield.

Nuruddin *et al*. (2003) also found that water deficits improved the quality of fruits, increased soluble solids and acidity and that water stress throughout the growing season significantly reduced yield and fruit size, but plants stressed only during flowering showed fewer but bigger fruits than completely non-stressed plants.

2.2. Water stress and tomato growth and yield

2.2.1. On tomato growth

It has been reported that when tomato plants are subjected to different levels of water stress under field conditions, vegetative growth was inhibited but flower retention and fruit development were enhanced and lead to early fruit ripening (Nyabundi and Hsiao, 1989b)

2.2.2. On tomato yield

It has been reported that water deficit stress increases the flower abortion, thus affects the fruits settings. The low marketable fruit yield obtained for some tomato varieties might be due to non-development of flowers. It was observed that only 50% of the flowers produced developed into fruits, thus sink size was a limiting factor to fruit production in tomato (Olaniyi *et al*., 2010).

2.3. Postharvest qualities of tomato

The term ‘quality’ is regarded as a complete and objective definition. For a consumer of horticultural produce, quality is a highly subjective judgment related to learned criteria. Tomato (*Lycopersicon esculentum* M.) fruit quality covers a number of different characteristics among which more attention has been paid to fruit grade. Tomato quality components include appearance (colour, size, shape, freedom from defects and decay), firmness, flavour, and nutritional value. Colour, firmness, flavour, nutritive value, and safety of tomatoes are related to their composition at harvest and compositional changes during postharvest handling (Kader, 1986). Deterioration in quality can be caused by a variety of stress factors that may be grouped into four general but often inter-related categories: metabolic stress, transpiration (water) stress, mechanical injury stress and microbial damage stress.

Tomato fruits are often harvested at the mature green stage to minimize the damage during post-harvest handling. The fruits may later ripen spontaneously or after treatment with ethylene before shipment to retailers. Losses often occur from excessive deterioration during holding and marketing of tomatoes. This problem is especially acute with tomatoes harvested when at the breaker or more advanced stages of ripeness (Moneruzzaman *et al*., 2008).

Apart from physical losses in quality, serious losses also occur in the essential nutrients, vitamins and minerals. Improper stage of maturity, ripening conditions and lack of proper storage facilities cause a glut during the peak period of harvest and a large portion of fruits is sold at throw away prices. The need to reduce post harvest losses is therefore of paramount importance. Suitable stages of fruit maturity and optimum ripening conditions for quality and longer storage of tomato has not yet been developed for developing countries (Moneruzzaman *et al*., 2009).

2.3.1. Tomato fruit colour

Colour is an important component of visual appearance. Differentiation between individual fruits and vegetables by consumers is based primarily upon appearance, which often influences purchase (Gnanasekharan *et al*., 1992). The analysis of colour is frequently an important consideration when determining the effectiveness of the variety for postharvest treatments (McGuire, 1992). The colour of tomatoes is a very important marketing factor that affects the consumer preference and is also a very important quality attribute for the processing industry (Arias *et al*., 2000).

Colour change during ripening involves the conversion of chloroplasts to chromoplasts with the degradation of chlorophyll. During ripening, the chlorophylls gradually disappear and become undetectable 7 days after the breaker and/or turning stage. Tomato fruits change in colour from green, typical of chlorophylls, through pink-orange to bright red, owing to the development of carotenoids (Jongen, 2000). Different varieties have different pigmentations and the main pigments are β-carotene (yellow) and lycopene (red); and so the tomato colour is considered to be the main function for fruit ripeness (Hobson *et al*., 1983).

2.3.2. Tomato flavour, sweetness and sourness

Of all the aspects of tomato quality, flavour (organoleptic properties) is one of the most important to consumers and it frequently influences the purchases of certain fruit types and sources. Flavour is comprised of taste and aroma. Taste is due to sensations felt on the tongue while aroma is due to stimulation of the olfactory senses in the nose by volatile organic compounds.

Flavour quality of tomatoes is largely determined by the sugar (estimated by soluble solids content) and acid composition of the fruit (Table 1). Tomato flavour depends upon sweetness and sourness and each of them is correlated with the other (Stevens and Kader, 1979). The palatability of fruits depends on Total Soluble Solids (TSS) and acidity ratio.

Table 1. Influence of sugar content and acidity on tomato flavour

Acidity	Sugar content	Flavour
High	High	Good
High	Low	Tart
Low	High	Bland
Low	Low	Tasteless

Sweetness of tomato is mainly dependent upon the levels of total sugars; reducing sugars like glucose, and non-reducing sugars like sucrose. Sourness is mostly due to the level of Titratable Acidity (TA), like citric acid; and it usually masks sweetness (Mustafa, 1994).

2.3.3. Tomato firmness

Firmness is an important factor to take into account since most, if not all, fruits exhibit a substantial change in firmness during the process of ripening. From the producers and the fruit processors' point of view, firmness can be an indication of the shelf life of the product (Anonymous, 2008).

2.3.4. Water stress and postharvest qualities of tomato

Adequate soil moisture during the pre-harvest period is essential for the maintenance of postharvest quality. Water deficit stress during the growing season can affect the size of the harvested plant organ and lead to soft or dehydrated fruit that is more prone to damage and decay during storage.

The effects of pre-harvest factors on postharvest qualities are often overlooked and underestimated. However, many of the decisions that are made during crop production can greatly influence the postharvest qualities of crops. It is critical to remember that vegetable quality can only be improved at the pre-harvest stage; and is maintained during the harvest and postharvest stages. Thus, it is of utmost importance to consider the pre-harvest factors that allow us to maximize the quality of the vegetables going into storage. These factors encompass production and management decisions concerning soil fertility, variety selection, irrigation, and pest management.

Transpiration, the loss of water from plant tissue by evaporation, can also result in rapid loss in quality and a direct loss in saleable weight. Water loss mainly affects appearance, through wilting and shriveling, and texture. However, water loss can also affect nutritional quality. Excess moisture at the pre-harvest stage can also increase the incidence of postharvest diseases (Benton, 2008).

2.4. Packaging

The principal purpose of packaging is to reduce damage in transport; it protects the produce from mechanical injury, and contamination during marketing. Another purpose is to keep the produce in a sensibly sized unit for handling and marketing purposes. Packaging maintains fruit weight, prolongs shelf life, protects the produce from mechanical injury and contamination during marketing and minimizes fungal infection (Kader and Rolle, 2004).

Shelf life is the most important aspect in loss reduction biotechnology of fruit and vegetables. It is reported that the shelf life of fresh fruits and vegetables is affected by various factors such as the quality of the raw material, postharvest handling conditions, processing conditions, packaging system, and storage (Mudahar, 1997). Food producers should attempt to choose packaging conditions and materials (the choice of packaging materials can affect shelf life) that will maximize the product’s shelf life because packaging materials differ in permeability to atmospheric and respiratory gases.

Plastic and brown paper bags are the common packages used for fresh tomato in research and experiments, however, tomato fruits can be packaged in boxes or baskets, plastic tubes and/or plastic clamshells. Temperature plays a very important role in the preservation of recently-harvested products (Teruel *et al*., 2004). Storage life will be enhanced if the temperature during the postharvest period is kept as close to the optimum as feasible for a given commodity.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Experimental site

The tomato plants were grown in plastic pots under polythene covered greenhouse at the Horticulture Research and Demonstration Field, in Egerton University. The site is situated within Rift-valley Province and is located approximately 175 km North-West of Nairobi. The farm lies at a latitude of 0^o23'S, longitude 35^o35'E and an altitude of 2238m. The experimental site receives a minimum annual rainfall of 907 mm, and temperatures of 26.4^oC (max) and 7.8^oC (min) (Kere *et al*., 2003; Wambua, 2008). The postharvest experiment was conducted at the department of Horticulture's laboratory.

3.2. Greenhouse Experiment

3.2.1. Field establishment and treatment application

In the greenhouse experiment, 120 pots (20.32 x 35.56 cm in size) each containing 10 kg of air dried soil (a mixture of sand, top soil and manure at the ratio of 1:2:0.5) arranged in a randomized complete block design (RCBD) were used for the 2 trials. Each treatment was replicated four times and had 6 plants per replicate.

3.2.2. Plant material and growth conditions

The tomato seeds (cv. 'Moneymaker') were sown in plastic pots and seedlings were watered daily for two weeks before initiating treatments in order to improve root development. Thereafter, the plants were subjected to 5 levels of water treatments until harvesting. The containers were covered with black plastic to prevent evaporation. The pots were put on top of a plastic paper to avoid direct contact with the soil surface. The water amounts were determined based on the percentage of pot water capacity. Treatments included: WS_1 (100% of PC) or control (3000 ml), WS_2 (80% of PC), WS_3 (60% of PC), WS_4 (40% of PC) and WS_5 (20% of PC). Water-stressed plants were receiving 80% (80% of PC), 60% (60% of PC), 40% (40% of PC) and 20% (20% of PC) of the amount of water applied to the control plant.

3.2.2.1. Transpiration

Plant transpiration was studied by monitoring plant weight loss over a given time interval once evaporative losses were prevented. According to Kirnak *et al*. (2001), the gravimetric method is easily adapted for potted plants since the volumes of water applied to the root zone and the volumes of water drained from the pots are known. Transpiration rates were calculated based on a water balance approach. The evaporation was negligible because the pots were covered. The transpiration was measured by weighing each container using a portable weighing scale with an accuracy of ±5 g. The biweekly measurements were taken from April to June 2010 and from July to September 2010.

3.2.2.2. Leaf relative water content (LRWC)

Relative Water Content (RWC) is defined as the water volume of a leaf divided by the maximum water volume. The leaf relative water content (LRWC) was calculated based on the methods of Yamasaki and Dillenburg (1999). The leaves were picked from the mid-section of branches. A leaf sample was made up of four leaves, collected from the same branch, and then weighed to obtain the fresh mass (FM). The turgid mass (TM) was recorded when the same leaves were floated in distilled water inside a closed Petri-dish for 24 hours and after gently wiping the water from the leaf surface with tissue paper. After the imbibition period, the dry mass (DM) was taken after the leaf samples were placed in a pre-heated oven at 80^{o}C for 48 h. All mass measurements were made using an analytical scale, with precision of 0.001 g. Values of FM, TM, and DM were used to calculate LRWC, using the equation:

$$LRWC(\%) = [(FM - DM)/(TM - DM)] \times 100$$

3.2.2.3. Chlorophyll content

Leaves from two plants were randomly picked for the determination of chlorophyll content per plot. The chlorophyll content meter (CCM-200) was used to measure chlorophyll content of tagged leaves (four leaves on the second node from the top). The CCM measures chlorophyll content through remote sensing without destruction of leaf tissue. Using the readings from the chlorophyll meter, chlorophyll content of each plot was taken by averaging the readings from the two plants.

3.2.2.4. Flower abortion

The number of flowers /truss/plant was recorded and tagged to help in the determination of the percentage of flowers that aborted. This was obtained through the formula given below:

$$\text{Flower abortion (\%)} = \frac{\text{Total number of flowers - Number of aborted flowers X 100}}{\text{Total number of flowers}}$$

3.2.2.5. Other parameters

Other parameters measured included the height of the plants (cm) from the pot- ground to the tip of the plant; the stem diameter (mm) was measured 10 cm from the pot-ground and the internode length was measured as the distance between flower trusses. Data on these parameters were taken on a weekly basis.

3.2.3. Data analysis

The data collected was subjected to Analysis of Variance (ANOVA) using SAS version 9.1. Significant means were separated using the Duncan Multiple Range Test (DMRT) at $\alpha \leq 0.05$. The statistical model was as follow:

$$Y_{ij} = \mu + \Gamma_i + \beta_j + \varepsilon_{ij}$$

Where:

i= 1, 2,3,4,5 and j=1, 2, 3, 4

μ= overall mean

Γ_i = effect of ith water levels in jth blocks

β_j = effect of jth blocks or replications

ε_{ij} = random error component

Y_{ij} = observation of the ith treatments and the jth replications

3.3. Laboratory Experiment

3.3.1. Postharvest treatments

The variables described below were assessed when the fruits from the control plot (100% PC) treatments and/or non-packaged fruits showed signs of shrivelling. The fruit weight loss, fruit colour change, total soluble solids (TSS), titratable acidity (TA) and fruit firmness were recorded 3 times per week. Fruits were kept in a cold chamber at a temperature of 21 ± 2 ºC. The type of packaging used was the polybags, commonly used in the market: (0.22 x 6.37 cm of size; 0.02 mm of thickness). The polybags were then perforated with a punch (Model: Kangaro Punch DP 520-8cm of 2.5mm punching probe).

3.3.1.1. Fruit weight

The weight of 5 fruits per treatment per replicate was determined using an electric weighing balance (Model: *HangPing JA 2003*) and weight loss (%) was calculated by differences between initial weights and final weights divided by initial weights (Moneruzzaman *et al.*, 2009).

$$\text{Weight loss (\%)} = \frac{\text{Initial fruit weight - Final fruit weight x 100}}{\text{Initial fruit weight}}$$

3.3.1.2. Fruit colour change

Fruit colour change was determined using the tomato colour chart as demonstrated by Abdullah *et al*. (2004).

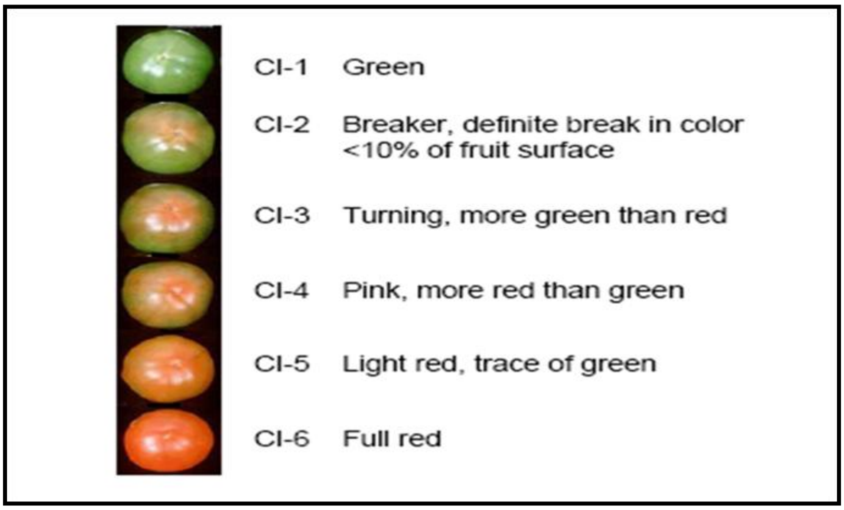

Figure 1. Tomato colour chart corresponding to stages of fruit ripeness

3.3.1.3. Fruit firmness

Fruit firmness was determined on two fruits per treatment per replication using a hand-penetrometer [Fruit pressure tester, Model: *FT 327* (*1-12 Kg*), with 0.7 x 0.92 mm of probe's size]. Fruit firmness (kgf) was recorded at the equatorial surface for each individual fruit using a destructive technique. Fruits were harvested at the breaker stage. The firmness readings were taken at harvest (day 0) and at 2-day intervals until the termination of the experiment.

3.3.1.4. Total Soluble Solids (TSS)

The Total soluble solids content was measured using a hand-held refractometer [Model SKU: MT- 032 (Brix, 0-32%)]. Determination was done by calculating the average TSS for the 2 fruits per treatment for each replicate. The final value was obtained by determining the average of the replicate for each treatment.

3.3.1.5. Titratable Acidity (TA)

Two fruits per treatment per replicate were used to determine titratable acidity (%). Fruit juice (5ml) was titrated with 0.1N NaOH to pH 8.1 using phenolphthalein as an indicator. Percentage of titratable acidity (TA) was calculated using the following formula by Monash Scientific (2003):

$$TA\ (g/l) = \frac{T \times M \times 0.75}{V \times 10 \times 0.1}$$

Where,

M= Molarity (M) of 0.1M NaOH

V= Volume (ml) of sample

T= Titre (ml) of 0.1 M NaOH

3.3.1.6. Tomato shelf life

The fruit shelf life was considered to have elapsed when the fruits lost 75% of their initial weight (Marcos *et al*., 2005) and/or started showing signs of shrivelling and decay.

3.3.2. Experimental Design

The experimental design was a split-plot experiment arranged in a randomized complete block design (RCBD) with packaging as the main treatment and water levels being the sub treatments. The water treatments were constituted of 5 levels (WS1: 100% of PC, WS2: 80% of PC, WS3: 60% of PC, WS4: 40 % of PC and WS5: 20% of PC) whereas packaging had 3 levels [Perforated (P), Non-Perforated (NP) and non-packaged or control (C)] and were replicated three times. Two trials were conducted, the first trial running from June to July 2010, and the second trial from August to October 2010.

3.3.2.1. Data analysis

The data obtained were subjected to Analysis of Variance (ANOVA) using SAS version 9.1. Significant means were separated by mean differences Tukey-HSD at $\alpha \leq 0.05$. The observations were described by the following linear statistical model:

$$Y_{ijk} = \mu + \alpha_i + R_j + \alpha R_{ij} + \beta_k + \alpha\beta_{ik} + \varepsilon_{ijkl}$$

Where:

i= 1, 2, 3 j= 1, 2, 3, 4, 5 and k= 1, 2, 3

μ = overall mean effect

R_j = replications

α_i = effect of the ith level of factor A (Packaging)

β_j = effect of the jth level of factor B (Water levels)

αR_{ij} = effect of the interaction between the α_i and R_j

$\alpha\beta_{ik}$ = effect of the interaction between the αi and β_k

ε_{ijkl} = random error component

CHAPTER FOUR

RESULTS

4.1. Field Experiment

4.1.1. Growth parameters

Changes in plant height, stem diameter and internode length were used to study the effects of water deficit stress on the growth of tomato. In this study, variable effects of water stress on growth parameters were observed.

4.1.1.1. Height

In the first trial, there was no significant difference for plant height, however, in the second trial, plant height was affected by the amount of water applied, although inconsistently. For example, while there were no significant effects observed within the first 64 DAP and 14 days to the termination of the data collection, the height of plants subjected to WS_5 was reduced by between 14% to 22% within the period of 78 DAP to 85 DAP when compared to the well watered (WS_1) plants in both trials (Table 2).

Table 2. Influence of soil moisture levels on plant height (cm) of tomato *cv.* ‘money maker’ grown in the greenhouse (Trials 1 and 2).

Trial 1	Days after planting						
Water Levels	45	52	59	66	73	80	87
WS_1	14.17a*	18.75a	22.88a	28.70a	37.95a	44.78a	53.85a
WS_2	18.13a	22.18a	26.25a	32.23a	40.23a	51.73a	59.73a
WS_3	17.75a	22.90a	28.30a	34.93a	44.38a	53.88a	60.35a
WS_4	16.50a	20.35a	23.85a	27.93a	36.20a	43.38a	49.70a
WS_5	16.13a	20.70a	26.40a	30.03a	39.43a	46.73a	53.38a
Trial 2	Days after planting						
	57	64	71	78	85	92	99
WS_1	26.76a	39.38a	50.95ab	62.25a	74.45a	83.78a	91.35a
WS_2	26.08a	41.10a	52.80a	61.95a	74.05a	84.73a	91.05a
WS_3	24.80a	38.53a	53.15a	61.30a	69.28b	80.55a	85.63a
WS_4	24.08a	36.55a	46.88b	54.25b	63.50c	73.03b	75.75a
WS_5	21.58a	36.13a	46.80b	52.43b	58.45d	65.08c	83.88a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

4.1.1.2. Stem diameter

Water deficit stress influenced the stem diameter of the tomato plants. The smallest stem diameter was observed in the most stressed plants (WS_5) where the highest reduction observed was between 11.2% (78 DAP) and 17.7% (87 DAP) compared to the controls in the two trials (Table 3).

Table 3. Influence of soil moisture levels on stem diameter (mm) of tomato plants *cv.* 'money maker' grown in the greenhouse (Trials 1 and 2).

Trial 1	Days after planting						
Water Level	45	52	59	66	73	80	87
WS_1	5.00a*	6.25a	5.38a	6.00a	6.88a	7.75a	7.75a
WS_2	4.88a	6.13a	5.63a	6.00a	7.00a	8.00a	8.13a
WS_3	5.13a	6.13a	5.50a	5.75a	6.88a	7.75a	7.50ab
WS_4	4.13a	6.00a	5.00a	5.50a	6.63a	6.75a	7.50ab
WS_5	4.13a	6.25a	5.25a	5.13a	5.88a	6.88a	6.38b
Trial 2	Days after planting						
	57	64	71	78	85	92	99
WS_1	6.00a	8.13a	9.00a	10.0a	10.25a	10.88a	10.88a
WS_2	6.13a	7.38a	8.88a	9.5ab	10.00a	10.25a	10.25a
WS_3	6.00a	7.38a	9.00a	9.4ab	9.88a	10.50a	10.50a
WS_4	5.50a	6.75a	8.25a	9.0ab	9.88a	10.25a	10.25a
WS_5	5.25a	7.13a	8.63a	8.88b	9.50a	9.38a	9.88a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

4.1.1.3. Internode length

Significant differences were observed in the internode length in both trials. In trial 1, the internode length was reduced by 9.5 cm in the stressed plants (WS_5) compared to the moderate water stressed plants (WS_3). In the 2^{nd} trial, the internode length in the most stressed plants (WS_5) was reduced between 4.6- 6.7 cm compared to the well watered plants (Table 4).

Table 4: Effects of soil moisture levels on internode length (cm) of tomato plants *cv*. 'money maker' grown in the greenhouse (Trials 1 and 2).

	Trial 1				Trial 2			
	Truss distances							
	1	2	3	4	1	2	3	4
WS_1	14.15a*	17.50a	17.18a	13.33ab	13.25a	19.38a	16.00a	16.00a
WS_2	16.63a	17.25a	16.75a	09.68ab	15.63a	18.00ab	16.13a	18.00a
WS_3	19.25a	18.13a	15.88a	15.13a	16.00a	14.75bc	14.63a	13.38a
WS_4	18.00a	17.38a	15.50a	12.00ab	17.00a	16.60abc	13.70a	12.93a
WS_5	17.25a	18.25a	15.25a	5.63b	17.25a	12.68c	12.50a	16.13a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

4.1.2. Physiological parameters

The degree of plant water stress was determined by measuring a number of physiological variables such as chlorophyll content, stomatal conductance, leaf temperature, Relative humidity (RH) and Leaf relative water content (LRWC).

4.1.2.1. Chlorophyll content

In trial 1, differences in chlorophyll content were observed after 73 DAP. The highest chlorophyll contents were observed in WS_4 (40% PC) tomatoes at 73 and 80 DAP and at 87 DAP; the highest chlorophyll content was in WS_3 (60% PC) tomatoes. In the 2nd trial, at 92 and 99 DAP, the highest chlorophyll content was observed in the WS_5 (20% PC) (Table 5).

Table 5. Effects of soil moisture levels on chlorophyll content (mg m^{-3}) of tomato leaves *cv.* 'money maker' from two trials conducted in the greenhouse.

Trial 1	Days after planting						
Water Level	45	52	59	66	73	80	87
WS_1	11.43a*	16.43a	18.30a	22.85a	26.55b	19.50b	51.65ab
WS_2	16.50a	18.60a	20.53a	25.63a	25.93b	25.00b	52.08ab
WS_3	15.03a	18.88a	19.40a	25.70a	32.70ab	23.80b	61.45a
WS_4	14.45a	15.30a	18.80a	23.30a	39.38a	33.93a	46.75ab
WS_5	16.10a	18.98a	23.20a	28.18a	31.93b	24.50b	41.85b
Trial 2	Days after planting						
	57	64	71	78	85	92	99
WS_1	31.53a	41.85ab	40.50a	55.53a	48.75a	41.25b	51.40c
WS_2	34.38a	36.58bc	42.40a	39.82b	44.68a	43.98b	60.73b
WS_3	29.80a	36.03bc	35.38a	42.98b	50.43a	58.88a	53.03bc
WS_4	33.75a	46.38a	42.65a	47.13ab	56.75a	51.6ab	69.15a
WS_5	31.40a	32.08c	47.23a	45.58ab	52.35a	56.13a	72.45a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

4.1.2.2. Stomatal conductance

Soil moisture stress influenced stomatal conductance of the tomato plants. In trial 1, the stomatal conductance was not affected by water deficit stress from 45 to 73 DAP. However, 80 DAP up to the harvest; differences in stomatal conductance were observed. At 80-87 DAP, the lowest stomatal conductance in tomatoes at 60% PC (WS_3). In trial 2, differences in stomatal conductance were observed at 64 and 71 DAP. The highest stomatal conductance were observed in 20% PC (WS_5) at 64 DAP and in 60% PC (WS_3) at 71 DAP while the lowest stomatal conductance was in 40% PC tomatoes (WS_4) at 71 DAP (Table 6).

Table 6. Effects of soil moisture levels on stomatal conductance (µmol/m^2s) of leaves from tomato plants *cv*. 'money maker' grown in the greenhouse (Trials 1 and 2).

Trial 1	Days after planting						
Water Level	45	52	59	66	73	80	87
WS_1	320.50a*	552.30a	224.00a	377.40a	290.38a	227.50a	191.75ab
WS_2	420.30a	195.50a	132.35a	169.30a	241.13a	157.63ab	228.63ab
WS_3	243.50a	143.00a	153.25a	188.40a	289.00a	94.00b	165.38b
WS_4	188.40a	243.80a	131.25a	180.40a	258.13a	110.13ab	266.00ab
WS_5	127.60a	244.10a	121.38a	274.90a	346.75a	202.38ab	311.50a
Trial 2	Days after planting						
	57	64	71	78	85	92	99
WS_1	138.75a	161.88b	185.75ab	271.00a	250.38a	176.13a	339.88a
WS_2	110.58a	136.13b	193.75ab	209.13a	192.00a	290.5a	282.38a
WS_3	150.88a	159.38b	222.50a	175.75a	185.40a	193.00a	292.63a
WS_4	132.63a	191.13b	131.25b	254.75a	243.00a	284.25a	369.88a
WS_5	129.38a	279.38a	166.88ab	223.75a	266.88a	280.88a	368.00a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

4.1.2.3. Leaf temperature

Leaf temperature was not affected by any of the water treatments in trial 1. However, in trial 2, plants from the moderate (WS_3) and severe water stressed (WS_5) were slightly cooler by about 1.8°C at 64 DAP compared to the control (Table 7).

Table 7. Effects of soil moisture levels on leaf temperature (ºC) of tomato plants *cv.* 'money maker' grown in the greenhouse (Trials 1 and 2)

Trial 1	Days after planting						
Water Levels	45	52	59	66	73	80	87
WS_1	28.90a*	34.10a	27.95a	28.18a	18.78a	27.93a	22.18a
WS_2	29.03a	35.40a	27.93a	28.70a	18.78a	28.58a	22.65a
WS_3	29.08a	34.25a	28.85a	28.55a	18.60a	28.33a	22.33a
WS_4	29.43a	35.05a	28.75a	28.48a	18.70a	28.25a	22.18a
WS_5	29.50a	33.75a	28.50a	28.40a	18.08a	28.40a	21.70a
Trial 2	Days after planting						
	57	64	71	78	85	92	99
WS_1	27.58a	31.15a	28.13a	25.13a	19.88a	29.30a	24.25a
WS_2	28.33a	29.75ab	27.90a	25.58a	20.15a	29.25a	24.20a
WS_3	27.65a	29.40b	28.10a	25.38a	20.38a	28.98a	24.40a
WS_4	27.80a	29.65ab	28.13a	25.35a	19.80a	29.30a	24.30a
WS_5	28.33a	29.38b	28.08a	25.35a	20.30a	29.33a	23.95a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

4.1.2.4. Relative humidity

The results showed significant differences among water treatments as the plant grew. The severe stressed plants (WS_5), in trial 1, had low RH of 6% compared to the plants of the moderate water stress (WS_3) at 66 DAP. In trial 2, RH was reduced by 3.2% in the plants that received 20% of PC (WS_5) compared to the control treatment (100% of PC) at 85 DAP (Table 8).

Table 8. Influence of water levels on relative humidity (%) of tomato leaves (Trials 1 and 2)

Trial 1	Days after planting						
Water Levels	45	52	59	66	73	80	87
WS_1	74.90a*	69.35a	75.63b	73.73ab	81.45a	76.53a	79.93a
WS_2	72.33a	71.53a	77.78ab	73.78ab	82.68a	76.40a	79.93a
WS_3	74.68a	73.18a	79.93a	75.80a	75.98a	77.28a	79.50a
WS_4	74.32a	71.18a	76.25ab	72.72ab	82.08a	77.00a	78.40a
WS_5	75.33a	73.35a	77.6ab	71.28b	83.45a	74.10a	78.95a
Trial 2	Days after planting						
	57	64	71	78	85	92	99
WS_1	75.95a	71.55a	67.93ab	70.33a	83.50a	70.73a	74.58ab
WS_2	73.83a	72.43a	67.9a0b	71.30a	83.28a	68.2ab	74.70a
WS_3	73.40a	70.30a	66.63b	72.85a	82.35ab	69.65a	72.43ab
WS_4	73.68a	69.70a	70.03a	70.63a	82.23ab	67.85ab	72.48ab
WS_5	73.88a	70.23a	68.13ab	71.00a	80.85b	65.65b	71.38b

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

4.1.2.5. Leaf Relative Water Content (LRWC)

The leaf relative water content (LRWC) was reduced by 13.8% in the most stressed plants (WS_5) compared to the control (WS_1) at 78 DAP in trial 1 whereas in trial 2, only 7.7% of reduction in the LRWC was observed in the 2 treatments at 106 DAP as shown in Table 9.

Table 9. Influence of soil moisture levels on leaf relative water content (%) of tomato plants *cv*. 'money maker' grown in greenhouse (Trials 1 and 2).

Trial 1	Days after planting					
Water Level	50	57	64	71	78	85
WS_1	77.93a*	80.95a	83.98b	75.83a	81.23a	85.73a
WS_2	79.78a	75.55b	84.70ab	74.83a	81.05a	84.58ab
WS_3	82.70a	80.95a	87.00a	78.13a	77.70a	78.90c
WS_4	78.83a	80.85a	84.43b	78.20a	78.73a	78.35c
WS_5	81.30a	79.15a	83.73b	82.70a	70.05b	80.18bc

Trial 2	Days after planting					
	78	85	92	99	106	113
WS_1	79.12ab	77.31a	70.78a	75.59a	75.73a	72.04a
WS_2	82.42ab	76.73a	72.29a	73.82a	74.82ab	69.47a
WS_3	85.26ab	74.61a	74.61a	73.14a	76.58a	66.81a
WS_4	77.05b	74.76a	74.69a	69.76ab	74.76ab	69.89a
WS_5	85.77a	74.41a	68.86a	65.14b	69.91b	70.74a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

4.1.2.6. Transpiration rate

There was no significant difference in transpiration rates among the treatments in trial 1. However, in trial 2, a reduction in transpiration with increase in water stress was observed at 95 DAP (Table 10).

Table 10. Influence of soil moisture levels on transpiration rate (gm^{-2}) of tomato plants *cv*. 'money maker' grown in greenhouse (Trials 1 and 2).

	Trial 1					Trial 2				
	Days after planting									
	62	69	74	78	83	74	81	86	90	95
WS_1	0.40a*	0.60a	0.85a	0.30a	0.63a	0.48a	0.55a	0.90a	0.45a	0.45ab
WS_2	0.40a	0.63a	1.20a	0.13a	0.50a	0.45a	0.73a	1.30a	0.25a	0.55ab
WS_3	0.50a	0.63a	0.93a	0.15a	0.40a	0.45a	0.63a	0.83a	0.38a	0.43b
WS_4	0.25a	0.35a	1.05a	0.2a	0.65a	0.40a	0.48a	1.20a	0.48a	0.70ab
WS_5	0.45a	0.35a	0.90a	0.25a	0.50a	0.60a	0.63a	1.15a	0.40a	0.90a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

4.1.3. Yield parameters

The results obtained show that soil moisture deficit had an influence on yield parameters which were observed during the experiment. The parameters observed were abortion rate, fruit expansion rate, fruit diameter, number of fruits per plant, yield per plant and yield per hectare.

4.1.3.1. Flower abortion

The results in table 11 show that there were significant differences in flower abortion among the treatments on the 3rd and the 4th trusses. In trial 1, the most stressed plants (WS_5) recorded a higher flower abortion of 80.3 - 93.5% (on the 3rd truss) and 72.2 - 80.5% (on the 4th truss) compared to the well watered plants (WS_1 and WS_2) respectively, whereas in trial 2, only 65.7% (3rd truss) and 77.8% (4th truss) of flower abortion was recorded in the most stressed plants (WS_5) compared to the plants of the control (WS_1).

Table 11. Influence of soil moisture levels on flower abortion (%) of tomato *cv.* 'money maker' grown in greenhouse (Trial 1 and 2).

	Trial 1				Trial 2			
	Truss number							
	1	2	3	4	1	2	3	4
WS_1	1.32a*	4.45a	4.69bc	13.75b	5.05a	3.57a	6.65b	9.73b
WS_2	0.00a	6.64a	1.56c	9.62b	3.95a	5.92a	5.45b	5.99b
WS_3	1.25a	9.05a	15.31abc	24.68ab	3.45a	6.16a	2.78b	13.56b
WS_4	1.47a	7.98a	20.28ab	20.89b	5.27a	8.65a	18.15a	11.93b
WS_5	5.13a	9.52a	23.88a	49.40a	3.57a	8.66a	19.38a	43.83a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

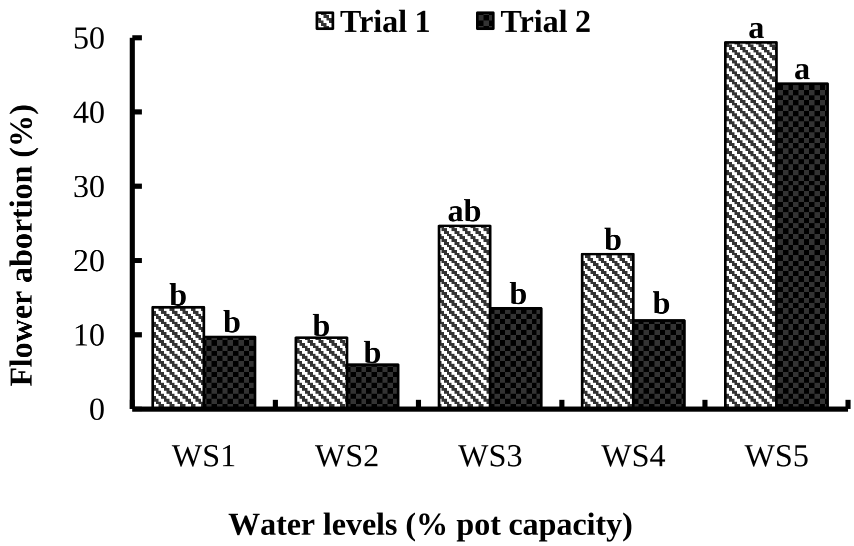

Figure 2. Effects of water levels on abortion of tomato flowers (truss 4) as influenced in two trials (bars with the same letters are not significant different according Duncan Multiple range Test (DMRT) at P≤ 0.05).

4.1.3.2. Other yield parameters

Other yield parameters recorded were the total number of fruits per plant, fruit diameter and fruit yield per plant and/or per hectare. The results given below (Table 12) indicate the reduction in total fruit number, fruit diameter and fruit yield/ha.

4.1.3.2.1. Total fruit number

Soil moisture levels influenced fruit number per plant in both experiments. The fruit number from the well watered plants was 163 (average of 24 plants/treatment) in trial 1 and later increased in the 2nd trial by 260 (average of 24 plants/treatment). Fruit number for the severe stressed plants had 171-229 (average of 24 plants/ treatment) fruits in trial 2, compared to the well water plants.

4.1.3.2.2. Fruit diameter

Significant differences were noted between the treatments regarding the fruit diameter in trial 1. There was 13-17.1% (4.4-5.7 mm) reduction in the fruit diameter of stressed plants (WS_5 and WS_4) compared to the fruits of the moderate water stressed plants (WS_2) (Table 12).

4.1.3.2.3. Total fruit yield per hectare

Total fruit yield was affected by the different water regimes in both trials. The highest fruit yield equivalent to 69.5 t/ha was recorded in plants subjected to WS_1 in the 2nd trial.

However, the severe stressed plants (WS_5) had a reduction in fruit yield of 12 and 44.3 t/ha compared to the well watered plants (WS_1) in trial 1 and trial 2 respectively.

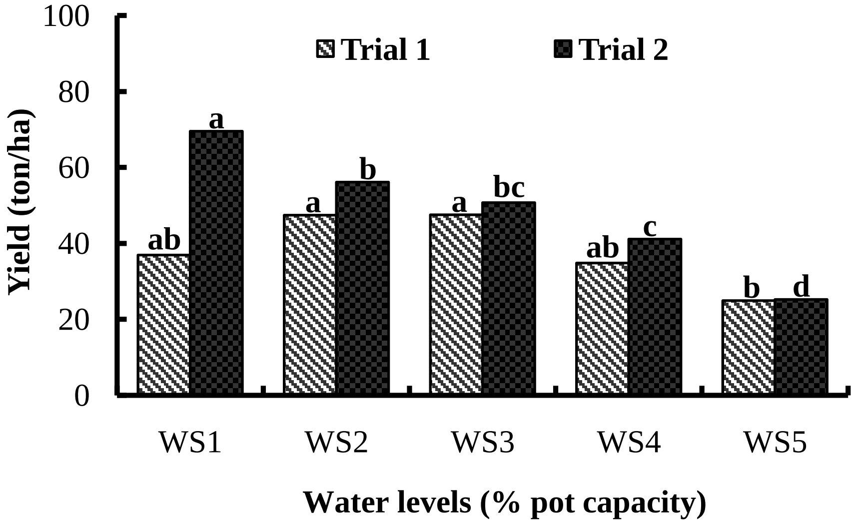

Figure 3. Influence of soil moisture levels on the fruit yield of tomato plants in trials 1 and 2. (Bars with the same letters are not significantly different at $P \leq 0.05$ according to Duncan multiple range test)

Table 12. Influence of soil moisture levels on the fruit yield parameters of tomato *cv.* 'money maker' grown in greenhouse (Trials 1 and 2).

Trial 1				
Water Levels	Total fruits[a]	Fruit/plant	Fruit dia. (mm)	Yield/plant (kg)
WS_1	163.50b[b]	34.50a	31.29abc	0.84ab
WS_2	240.50a	41.30a	33.38a	1.08a
WS_3	228.30a	46.00a	32.25ab	1.08a
WS_4	204.30ab	40.00a	29.01bc	0.79ab
WS_5	201.80ab	37.50a	27.66c	0.57b
Trial 2				
	Total fruits[a]	Fruit/plant	Fruit dia. (mm)	Yield/plant (kg)
WS_1	260.75a[b]	48.00a	33.43a	1.58a
WS_2	241.50ab	41.75a	32.73a	1.27b
WS_3	215.50ab	43.50a	30.54a	1.15bc
WS_4	229.00ab	40.25ab	29.37a	0.93c
WS_5	171.00b	31.25b	26.99a	0.57d

[a] The total number of fruits was based on the average of 24 plants per treatment
[b] Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

4.2. Laboratory experiment

4.2.1. Fruit weight loss

Soil moisture levels had significant effects on the fruit weight. In trial 1, up to 12 DAH the weight loss (g) in fruits subjected to WS_5 was significantly lower than in all other treatments. Up to 12 DAH, there was no significant difference between fruits of WS_4 and WS_5 water levels, both of which were significantly lower than WS_1 and WS_3. No significant difference was observed between WS_1 and WS_3 (Table 13). In trial 2, up to 16 DAH, all treatments were significantly different. From 20-24 DAH, WS_1 and WS_2 fruits did not exhibit any significant differences in weight (Table 13).

There were no significant difference between packaging treatments from the start of the experiment up to 8 DAH and 12 DAH in trial 2 and 1 respectively, weight loss for fruits in non-perforated package was significantly lower compared to the control (non-packaged fruits) at 16 and 24 DAH although there were no significant differences in the perforated and non-perforated packaged fruits (Figure 4). In trial 2, there were significant differences in the fruits from the non-perforated and perforated package where the non-perforated packaged fruits had significantly lower fruit weight loss (g) compared to perforated packaged fruits (Figure 5).

Interactive effects between the water levels and packaging were significant in both trials 1 and 2. In trial 1, fruits from WS_1, WS_2 and WS_3 in non-perforated packages and fruits from WS_2 in perforated packages had a significantly lower weight loss compared to unpackaged (control) fruits from WS_5 at 16 DAH (Table 14). In trial 2, fruit weight loss in WS_1 non-perforated packaging was significantly lower than fruits from WS_3 (for both the control and perforated package), WS_4 and WS_5 for all the packaging treatments at 8 DAH; and at 16 DAH for all the packaging treatments for WS_3, WS_4 and WS_5 (Table 15).

Table 13. Fruit weight (g) of tomato *cv.* 'money maker' as influenced by soil moisture levels (Trials 1 and 2)

Trial 1	Days after harvest						
Water Level	0	4	8	12	16	20	24
WS_1	40.59b*	39.35b	38.51b	37.89b	32.80b	28.41b	21.84ab
WS_2	51.15a	49.61a	48.75a	48.02a	47.32a	41.42a	28.98a
WS_3	40.19b	39.06b	38.45b	37.89b	31.87b	27.43b	17.18bc
WS_4	26.68c	25.70c	25.26c	24.85c	24.20c	23.91b	19.37bc
WS_5	21.69c	21.07c	20.69c	20.38c	15.40d	15.02c	12.32c
Trial 2	Days after harvest						
	0	4	8	12	16	20	24
WS_1	59.13a	58.05a	57.41a	56.80a	56.25a	55.66a	54.65a
WS_2	54.09b	53.29b	52.76b	52.20b	51.73b	51.30a	50.75a
WS_3	41.30c	40.63c	40.21c	39.79c	39.37c	39.04b	38.61b
WS_4	35.13d	34.56d	34.19d	32.82d	33.44d	33.12c	32.60c
WS_5	27.00e	26.47e	26.15e	25.83e	25.51e	25.24d	24.69d

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

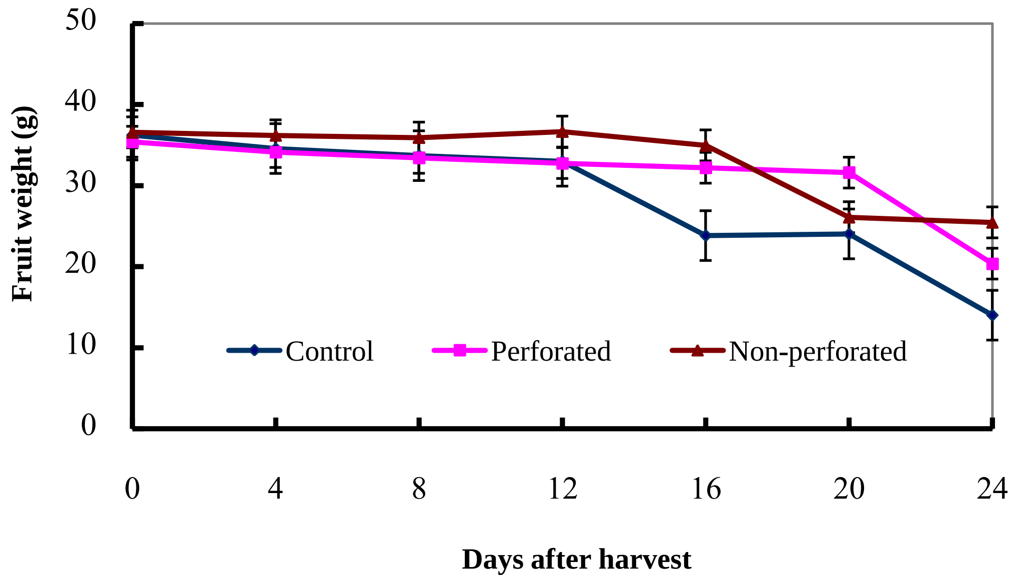

Figure 4. Effects of packaging on weight of tomato fruits obtained from trial one

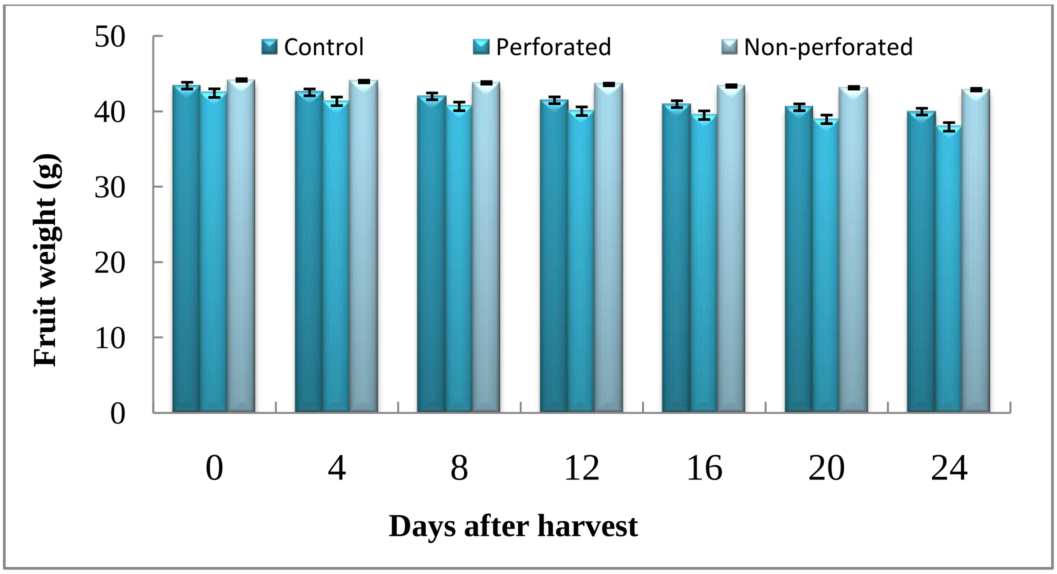

Figure 5. Effects of packaging on weight of tomato fruits obtained from trial two.

Table 14. Interactive effects of water levels and packaging on fruit weight (g) of tomato *cv*. 'money maker' (Trial 1)

	Packaging											
DAH	0			8			16			24		
WS	C	P	NP	C	P	NP	C	P	NP	C	P	NP
WS_1	39.3abcd*	40.1abcd	42.3abc	36.5abcde	37.6abcde	41.4abcd	21.4ab	36.2ab	40.8a	12.8a	24.4a	28.2a
WS_2	50.5a	52.2a	50.7a	46.9ab	49.4a	50.0a	45.1a	47.5a	49.4a	12.8a	42.8a	31.3a
WS_3	39.7abcd	37.1abcd	43.8ab	37.1abcde	35.0abcde	43.2abc	20.1ab	33.7ab	41.8a	12.9a	12.3a	26.3a
WS_4	27.7bcd	26.2bcd	26.1bcd	25.3bcde	24.8cde	25.7bcde	24.2ab	24.0ab	24.4ab	23.4a	10.8a	23.9a
WS_5	23.9bcd	21.4cd	19.8d	22.6cde	20.2de	19.3e	8.3b	19.6ab	18.3ab	8.1a	11.4a	17.5a

*Means with the same letter(s) within a column and/or a row (within a given period) are not significantly different at $P \leq 0.05$

Table 15. Interactive effects of water levels and packaging on fruit weight (g) of tomato *cv*. 'money maker' (Trial 2)

	Packaging											
DAH	0			8			16			24		
WS	C	P	NP	C	P	NP	C	P	NP	C	P	NP
WS_1	60.7a*	56.4ab	60.3a	58.5ab	53.9abc	59.8a	57.0ab	52.3abc	59.3a	55.8ab	49.4abc	58.8a
WS_2	53.8abc	54.7abc	53.8abc	52.3abc	52.5abc	53.4abc	51.1abc	51.1abc	53.0abc	50.0abc	49.7abc	52.2abc
WS_3	38.9bcd	42.6abcd	42.4abcd	37.6cde	41.0bcde	42.0abcd	36.7cde	39.9bcde	41.6bcd	35.8cde	38.9bcd	41.1bcd
WS_4	33.3d	34.1d	37.9cd	32.3de	32.8de	37.6cde	31.5de	31.7de	37.1cde	30.7de	30.5de	36.7cde
WS_5	30.3d	24.2d	26.4d	29.3de	23.1e	26.1de	28.5de	22.4e	25.7de	27.5de	21.3e	25.3de

*Means with the same letter(s) within a column and/or a row (within a given period) are not significantly different at $P \leq 0.05$

4.2.2. Colour change

Water level treatments significantly influenced colour change of the tomato fruits in both trials. In trial 1, fruits from the WS_3 developed colour at a faster rate compared to fruits from WS_5 at 8-16 DAH. In trial 2, at 8 DAH, fruits from WS_4 had a significant increase in the colour development compared to fruits from WS_1 and WS_3. The fruit colour index was significantly higher in fruits subjected to WS_2 water level compared to those from WS_3 at 12 DAH and to all other water levels at 16 DAH (Table 18).

Packaging influenced fruit colour change in trials 1 and 2. In trial 1, packaged fruits (perforated and non-perforated) exhibited a faster colour change compared to the unpackaged fruits at 16 DAH, and the control fruits were discarded. In trial 2, fruits packaged in non-perforated bags developed colour faster than those in perforated packages and the control. From 4-16 DAH, significant differences were observed between the perforated and non-perforated packaging. At 16 DAH, significant differences were observed between all treatments with the colour index being highest in fruits packaged in non-perforated bags (Figure 6).

No interactive effect between water levels and packaging treatments was observed in trial 1 with respect to fruit colour change (Table 19). In trial 2, the interaction between water levels and packaging treatments was significant. At 12 DAH, non-perforated fruits from WS_4 had a significantly higher fruit colour development than control (unpackaged) fruits from WS_3 (Table 34). The colour change in fruits from WS_1 in perforated bags was significantly slower compared to all other treatments in control and non-perforated packages and fruits from the WS_2 and WS_3 in the perforated bags at 16 DAH (Table 20).

Table 16. Influence of moisture levels on fruit colour change of tomato *cv.* 'money maker' grown in the greenhouse (Trials 1 and 2).

Trial 1	Days after harvest				
Water Level	0	4	8	12	16
WS_1	2.11ab*	3.22a	4.56ab	5.33a	5.11a
WS_2	2.00b	3.00a	3.89ab	4.78ab	5.56a
WS_3	2.22ab	3.33a	4.67a	5.22a	4.89a
WS_4	2.22ab	3.00a	4.00ab	4.33b	4.67a
WS_5	2.33a	3.00a	3.56b	4.11b	3.56b
Trial 2	Days after harvest				
	0	4	8	12	16
WS_1	2.00a*	2.22a	3.22b	4.78ab	5.22b
WS_2	2.00a	2.22a	3.67ab	5.11a	5.89a
WS_3	2.00a	2.33a	3.33b	4.33b	5.22b
WS_4	2.00a	2.56a	4.89a	5.00ab	5.22b
WS_5	2.00a	2.22a	3.67ab	4.89ab	5.33b

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

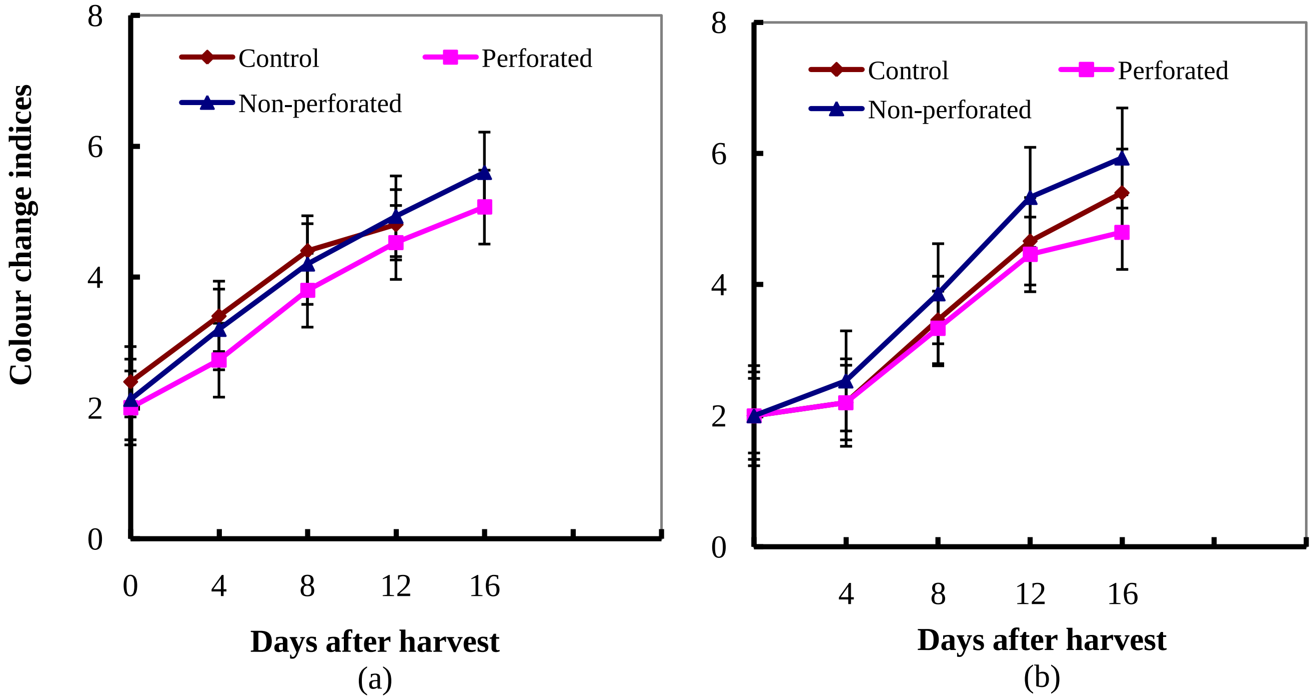

Figure 6. Influence of packaging on tomato fruit colour change: Trial 1 (a) and Trial 2 (b)

Table 17. Interactive effects of water levels and packaging on fruit colour change (Trial 1)

	Packaging														
DAH	0			4			8			12			16		
WS	C	P	NP	C	P	NP	C	P	NP	C	P	NP	C	P	NP
WS_1	2.3a*	2.0a	2.0a	3.7a	2.7a	3.3a	4.7a	4.3a	4.7a	5.3a	5.3a	5.3a	3.7a	5.7a	6.0a
WS_2	2.0a	2.0a	2.0a	2.7a	3.0a	3.3a	4.0a	3.7a	4.0a	4.7a	4.3a	5.3a	5.0a	5.7a	6.0a
WS_3	2.7a	2.0a	2.0a	2.7a	3.0a	3.0a	5.0a	4.7a	4.3a	5.3a	5.3a	5.0a	3.7a	5.7a	5.3a
WS_4	2.0a	2.0a	2.7a	2.7a	2.7a	3.7a	3.3a	3.7a	5.0a	3.3a	4.3a	5.3a	4.0a	4.3a	5.7a
WS_5	2.0a	2.0a	2.0a	4.0a	2.3a	2.7a	5.0a	2.7a	3.0a	5.3a	3.3a	3.7a	1.7a	4.0a	5.0a

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*Means with the same letter(s) within a column and/or a row (within a given period) are not significantly different at P ≤ 0.05

Table 18. Interactive effects of water levels and packaging on fruit colour change (Trial 2)

	Packaging														
DAH	0			4			8			12			16		
WS	C	P	NP	C	P	NP	C	P	NP	C	P	NP	C	P	NP
WS_1	2.0a*	2.0a	2.0a	2.0a	2.0a	2.7a	3.3a	3.0a	3.3a	5.3ab	4.0ab	5.0ab	6.0a	4.0d	5.7ab
WS_2	2.0a	2.0a	2.0a	2.3a	2.0a	2.3a	3.7a	3.3a	4.0a	4.7ab	5.0ab	5.7ab	6.0a	5.7ab	5.3abc
WS_3	2.0a	2.0a	2.0a	2.0a	2.7a	2.3a	3.0a	4.0a	3.0a	3.7b	5.0ab	4.3ab	6.0a	5.3abc	5.7ab
WS_4	2.0a	2.0a	2.0a	2.7a	2.3a	2.7a	4.0a	3.3a	4.3a	5.0ab	4.0ab	6.0a	5.3abc	4.3cd	6.0a
WS_5	2.0a	2.0a	2.0a	2.0a	2.0a	2.7a	3.3a	3.0a	4.7a	4.7ab	4.3ab	5.7ab	5.3abc	4.7bcd	6.0a

*Means with the same letter(s) within a column and/or a row (within a given period) are not significantly different at P ≤ 0.05

4.2.3. Fruit firmness

Water treatments had significantly influenced fruit firmness in both trials. In trial 1, fruits from WS_4 were firmer than fruits from WS_2 at 2 DAH. In trial 2, however, significant differences were observed in fruit firmness between fruits from WS_2 and WS_3 and WS_4 at 2 DAH; and WS_3, WS_4 and WS_5 at 4 DAH. At 8-10 DAH, fruits from WS_5 were significantly firmer than fruits from WS_2 (Table 21). In trial 1, unpackaged (control) fruits were firmer compared to fruits from the non-perforated package at 4-8 DAH, though the differences were not significant in fruits from the perforated package. In trial 2, unpackaged and non-perforated packaged fruits were firmer than those packaged in perforated bags at 2 DAH. At 6 DAH, significant differences were observed in unpackaged (control) fruits and packaged fruits, although no significant differences were observed between the packaged treatments (perforated and non-perforated). At 10 DAH, control fruits were significantly softer compared to packaged fruits in perforated bags (Table 22). Interaction between the 2 treatments was observed at 2 DAH in the 2nd trial, where control fruits from WS_3 and WS_4 and non-perforated fruits from WS_3 were firmer (6-6.4 kgf) than perforated fruits from WS_2 (2.2 kgf) (Table 24).

Table 19. Influence by soil moisture levels on tomato fruit firmness (kgf) from (Trials 1 and 2).

Trial 1	Days after harvest					
Water Level	0	2	4	6	8	10
WS_1	4.16a*	3.61ab	2.82a	3.58a	3.13a	2.57a
WS_2	5.24a	3.56ab	3.56a	3.50a	3.08a	2.69a
WS_3	4.71a	3.26b	3.13a	3.61a	3.89a	3.30a
WS_4	5.09a	4.81a	3.64a	3.66a	3.74a	2.96a
WS_5	4.04a	4.50ab	3.81a	3.42a	3.88a	2.54a
Trial 2	Days after harvest					
	0	2	4	6	8	10
WS_1	5.53a*	4.60ab	4.04bc	4.23a	4.69ab	3.88ab
WS_2	6.03a	3.98b	3.23c	4.30a	3.47b	3.24b
WS_3	5.94a	5.50a	4.90ab	4.69a	4.36ab	4.40ab
WS_4	5.30a	5.32a	5.46a	4.40a	4.29ab	3.71b
WS_5	5.52a	4.57ab	4.72ab	4.34a	5.12a	5.22a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Table 20. Fruit firmness (kgf) as influenced by packaging (Trials 1 and 2).

Trial 1	Days after harvest					
Packaging	0	2	4	6	8	10
Control	4.79a*	4.03a	4.13a	4.17a	3.96a	3.17a
Perforated	4.33a	3.84a	3.37ab	3.53ab	4.00a	2.99a
Non-perforated	4.83a	3.97a	2.68b	2.95b	2.69b	2.28a
Trial 2	Days after harvest					
	0	2	4	6	8	10
Control	5.61a*	5.39a	4.63a	5.03a	4.63a	3.43b
Perforated	5.86a	3.84b	4.33a	4.25b	4.71a	4.86a
Non-perforated	5.53a	5.15a	4.45a	4.45b	3.81a	3.98ab

*Means with the same letter(s) within a column are not significantly different at P ≤ 0.05

Table 21. Interactive effects of water levels and packaging on fruit firmness (kgf) (Trial 1)

	Packaging																	
DAH	0			2			4			6			8			10		
WS	C	P	NP	C	P	NP	C	P	NP	C	P	NP	C	P	NP	C	P	NP
WS_1	5.2a*	3.5a	3.8a	3.9a	3.8a	3.1a	4.7a	2.0a	1.9a	5.0a	4.3a	1.4a	3.6a	3.4a	1.5a	3.5a	2.9a	1.3a
WS_2	6.0a	3.6a	6.2a	3.3a	3.4a	3.9a	4.2a	4.0a	2.5a	3.6a	3.0a	4.0a	2.4a	4.1a	2.8a	3.6a	2.4a	2.1a
WS_3	4.3a	5.2a	4.6a	3.2a	3.0a	3.6a	4.5a	2.5a	2.4a	3.7a	4.7a	2.4a	4.1a	4.0a	3.5a	3.7a	3.7a	2.4a
WS_4	4.4a	5.0a	6.0a	4.1a	4.4a	5.5a	3.5a	4.6a	2.8a	3.8a	3.0a	4.3a	5.0a	3.3a	2.9a	2.6a	3.6a	2.7a
WS_5	4.1a	4.4a	3.6a	5.2a	4.5a	3.8a	3.9a	3.8a	3.8a	4.7a	3.0a	2.6a	4.7a	4.3a	2.7a	2.5a	2.2a	2.9a

*Means with the same letter(s) within a column and/or a row (within a given period) are not significantly different at $P \leq 0.05$

Table 22. Interactive effects of water levels and packaging on fruit firmness (kgf) (Trial 2)

	Packaging																	
DAH	0			2			4			6			8			10		
WS	C	P	NP	C	P	NP	C	P	NP	C	P	NP	C	P	NP	C	P	NP
WS_1	6.3a*	5.0a	5.3a	5.8ab	4.1ab	3.9ab	4.1a	3.6a	4.7a	4.7a	4.6a	3.4a	5.5a	5.5a	3.1a	3.6a	4.1a	3.9a
WS_2	6.2a	5.4a	6.2a	4.3ab	2.2b	5.5ab	3.1a	3.4a	3.3a	4.8a	3.9a	4.2a	4.1a	3.1a	3.3a	2.9a	4.2a	2.6a
WS_3	6.3a	6.4a	5.2a	6.0a	4.1ab	6.4a	5.5a	5.3a	3.9a	5.0a	4.3a	4.8a	4.5a	4.5a	4.1a	4.2a	4.4a	4.6a
WS_4	4.1a	5.5a	6.3a	6.3a	5.0ab	4.7ab	6.0a	5.3a	5.1a	5.3a	4.2a	3.7a	4.9a	5.2a	2.8a	2.6a	5.4a	3.2a
WS_5	5.2a	7.0a	4.4a	4.7ab	3.8ab	5.3ab	4.5a	4.2a	5.5a	5.4a	4.2a	3.5a	4.3a	5.2a	5.8a	3.9a	6.2a	5.6a

*Means with the same letter(s) within a column and/or a row (within a given period) are not significantly different at $P \leq 0.05$

4.2.4. Fruit Total Soluble Solids (TSS)

There were significant differences in fruit TSS among the water level treatments in both trials. In general, the highest levels of TSS were observed in fruits from the plants subjected to WS_5. In trial 1, TSS content in fruits from WS_5 was significantly higher (5.72%) than in fruits from other water levels at 2, 6 and 10 DAH. At 4 and 8 DAH, fruits from WS_5 had significantly higher TSS than those in WS_1, WS_2 and WS_3, but not WS_4 (Table 25). In the 2nd trial, no significant difference was observed in the fruit TSS for fruits from WS_4 and WS_5 at 2, 8 and 10 DAH. Fruits from WS_5 were not significantly different in TSS content compared to fruits from WS_3 only at 0 and 8 DAH. Significant difference in TSS content between WS_3 and WS_4 were observed, though there was no significant difference among the 2 water treatments from 0-6 DAH (Table 25).

Packaging had no influence on the fruit TSS in trial 1. In trial 2, significant difference was observed at 8 and 10 DAH where fruits in non-perforated packaging had a significantly higher TSS content compared to fruits in perforated packaging though no significant difference was observed in unpackaged (control) fruits and the non-perforated packaged fruits (Table 26).

Significant effects were observed in the interaction of both water and packaging treatments in trial 1 and 2. In the 1st trial, TSS content of unpackaged fruits from WS_5 was highly significant (5.9%) compared to fruits from WS_2 in non-perforated bags (3.9%) at 2 DAH. Fruits packaged in perforated bags from WS_5 had higher level of TSS (6.1%) than perforated fruits from WS_1 (4%) at 6 DAH. Control (unpackaged) fruits and perforated packaged fruits from WS_5 had significantly higher levels of TSS content than fruits packaged in non-perforated bags from WS_1 and unpackaged fruits from WS_2 at 10 DAH (Table 27). In the 2nd trial, higher TSS levels were observed in unpackaged fruits from WS_1 and perforated packaged fruits from WS_5 compared to packaged fruits (perforated and non-perforated) from WS_1 at 2 DAH. Unpackaged fruits and non-perforated packaged fruits from WS_1 had significantly lower TSS than fruits from WS_5 in non-perforated bags at 6 DAH. Similarly, unpackaged fruits from WS_1 had significantly lower value of TSS content compared to fruits from WS_2, WS_4 and WS_5 from non-perforated bags and unpackaged fruits from WS_3 and WS_5 at 6 DAH. Control fruits from WS_5 had significantly higher TSS content than fruits from WS_1 packaged in perforated, non-perforated and control packages and fruits from WS_3 packaged in non-perforated bags at 10 DAH. TSS content was significantly higher in non-perforated fruits from WS_4 compared to those from WS_1 packaged in control, perforated and non-perforated packages and in perforated bags from WS_2 and WS_3 at 10 DAH (Table 28).

Table 23. Effects of moisture levels on percent total soluble solutes of tomato fruit (Trials 1 and 2).

Trial 1	Days after harvest					
Water Level	0	2	4	6	8	10
WS_1	4.58bc*	4.48bc	4.63bc	4.43b	4.22b	4.30c
WS_2	4.28c	4.32c	4.38c	4.51b	4.21b	4.31c
WS_3	4.69bc	4.54bc	4.90b	4.67b	4.58b	4.48c
WS_4	5.00ab	4.94b	5.12ab	4.98b	5.11a	5.17b
WS_5	5.34a	5.72a	5.59a	5.94a	5.37a	5.78a
Trial 2	Days after harvest					
	0	2	4	6	8	10
WS_1	4.06c*	4.46c	4.37d	4.28c	4.71c	4.28d
WS_2	4.42c	4.71bc	4.94c	5.03b	5.15b	5.16c
WS_3	4.93b	5.12ab	5.68ab	5.33ab	5.31b	5.43bc
WS_4	5.38b	5.43a	5.52b	5.28b	5.78a	5.82a
WS_5	5.90a	5.52a	6.08a	5.79a	5.81a	5.63ab

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Table 24. Influence of packaging on percent total soluble solutes of tomato Fruit (Trial 1 and 2).

Trial 1	Days after harvest					
Packaging	0	2	4	6	8	10
Control	4.95a*	4.82a	4.87a	4.97a	4.85a	4.83a
Perforated	4.73a	4.85a	5.07a	4.97a	4.70a	4.95a
Non-perforated	4.65ass	4.73a	4.83a	4.79a	4.54a	4.64a
Trial 2	Days after harvest					
	0	2	4	6	8	10
Control	4.87a*	5.04a	5.38a	5.15a	5.35ab	5.36a
Perforated	4.96a	5.10a	5.27a	5.07a	5.15b	5.05b
Non-perforated	4.99a	5.00a	5.30a	5.21a	5.55a	5.39a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Table 25. Interactive effects of water levels and packaging on fruit total soluble solids (%) (Trial 1)

	Packaging											
DAH	0			2			6			10		
WS	C	P	NP	C	P	NP	C	P	NP	C	P	NP
WS_1	4.7a*	4.4a	4.7a	4.3ab	4.6ab	4.5ab	4.8ab	4.0b	4.5ab	4.4ab	4.4ab	4.1b
WS_2	4.3a	4.6a	3.9a	4.6ab	4.5ab	3.9b	4.7ab	4.4ab	4.5ab	4.1b	4.4ab	4.4ab
WS_3	5.4a	4.5a	4.6a	4.6ab	4.8ab	4.7ab	4.7ab	5.0ab	4.3ab	4.7ab	4.4ab	4.3ab
WS_4	5.4a	4.7a	4.9a	4.8ab	4.7ab	5.4ab	4.8ab	5.4ab	4.7ab	5.0ab	5.5ab	5.0ab
WS_5	5.4a	5.2a	5.4a	5.9a	5.6ab	5.7ab	5.9ab	6.1a	5.9ab	5.9a	6.0a	5.4ab

*Means with the same letter(s) within a column and/or a row (within a given period) are not significantly different at $P \leq 0.05$

Table 26. Interactive effects of water levels and packaging on fruit total soluble solids (%) (Trial 2)

	Packaging											
DAH	0			2			6			10		
WS	C	P	NP	C	P	NP	C	P	NP	C	P	NP
WS_1	3.9d*	4.1cd	4.3bcd	5.0a	4.1b	4.3b	4.0c	4.5abc	4.4bc	4.2d	4.2d	4.5cd
WS_2	4.7abcd	4.2bcd	4.3bcd	4.6ab	4.6ab	4.9ab	5.3abc	4.7abc	5.1abc	5.5abc	4.9bcd	5.1abcd
WS_3	4.6abcd	5.2abcd	5abcd	5.3ab	5.1ab	5.0ab	5.9ab	5.1abc	5.0abc	5.6abc	5.0bcd	5.7abc
WS_4	5.5abc	5.4abcd	5.2abcd	5.5ab	5.4ab	5.4ab	4.9abc	5.4abc	5.6ab	5.7abc	5.5abc	6.3a
WS_5	5.7abc	5.8ab	6.2a	4.9ab	6.2a	5.4ab	5.7ab	5.7ab	6.0a	6.0ab	5.6abc	5.3abcd

*Means with the same letter(s) within a column and/or a row (within a given period) are not significantly different at $P \leq 0.05$

4.2.5. Titratable Acidity (TA)

Soil moisture levels had significant effects on the fruit TA in both trials 1 and 2. In trial 1, fruits from WS_5 had the lowest acidity content than the other water treatments (at 4 DAH), though there were no significant differences in fruits from WS_5 and WS_4 throughout the experiment. The highest titratable acidity content was observed in fruits from WS_3; however, no significant difference was observed in fruits from WS_1, WS_2 and WS_3. In trial 2, the highest TA content observed was from WS_2 fruits and the lowest acidity content observed was from WS_5 fruits, though no significant difference was observed between WS_3, WS_4 and WS_5 except at 8 DAH (Table 29).

Significantly lower levels of TA were observed in fruits from the non-perforated bags than in control packages in trials 1 and 2, respectively at 10 and 2, 6 and 10 DAH. Perforated packaged fruits had significantly higher level of TA compared to non-perforated packaged fruits at 2 and 10 DAH (Table 30).

Interactive effects between water levels and packaging treatments on TA were observed in the 2nd trial. Non-perforated fruits from plants subjected to WS_5 had significantly lower TA content than fruits packaged in control and perforated packages from plants subjected to WS_2 at 2, 6 and 10 DAH and fruits packaged in perforated bags from WS_1 at 10 DAH (Table 32).

Table 27. Fruit titratable acidity (%) as influenced by soil moisture levels (Trials 1 and 2)

Trial 1	Days after harvest					
Water Levels	0	2	4	6	8	10
WS_1	9.08ab*	9.98a	7.87a	7.92ab	6.04bc	6.64a
WS_2	8.10ab	9.45ab	8.04a	9.79a	8.88ab	8.80a
WS_3	9.50a	7.95abc	8.04a	8.82ab	7.92abc	8.8a
WS_4	6.36bc	6.08c	7.58a	8.03ab	9.31a	7.10a
WS_5	5.19c	7.25bc	5.01b	7.82b	5.56c	7.57a

Trial 2	Days after harvest					
	0	2	4	6	8	10
WS_1	7.90a*	9.80b	10.14ab	10.82b	11.08a	11.07ab
WS_2	6.36ab	13.23a	12.79a	14.34a	10.99a	12.62a
WS_3	5.06b	8.49bc	8.38b	10.24bc	12.70a	9.74abc
WS_4	5.65b	8.17bc	7.84b	10.74bc	7.32b	8.96bc
WS_5	5.57b	6.41c	8.42b	7.44c	8.69b	7.24c

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Table 28. Fruit titratable acidity (%) as influenced by packaging (Trials 1 and 2)

Trial 1	Days after harvest					
Packaging	0	2	4	6	8	10
Control	7.33a*	7.15a	7.13a	8.71a	7.44a	8.74a
Perforated	7.78a	9.06a	7.79a	8.20a	7.56a	8.27ab
Non-perforated	7.82a	8.21a	7.00a	8.51a	7.63a	6.49b

Trial 2	Days after harvest					
	0	2	4	6	8	10
Control	5.34a*	10.63a	10.40a	12.09a	10.82a	9.76ab
Perforated	6.94a	10.08a	9.83a	11.18ab	9.69a	11.55a
Non-perforated	6.04a	6.95b	8.31a	8.87b	9.96a	8.47b

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Table 29. Interactive effects of water levels and packaging on fruit titratable acidity (%) (Trial 1)

	Packaging											
DAH	0			2			6			10		
WS	C	P	NP	C	P	NP	C	P	NP	C	P	NP
WS_1	6.9a*	9.8a	10.6a	6.8a	12.0a	11.2a	8.5a	7.0a	8.2a	6.9a	7.4a	5.6a
WS_2	7.7a	9.3a	7.4a	9.6a	10.8a	8.0a	10.7a	8.5a	10.2a	10.4a	9.3a	7.5a
WS_3	7.1a	12.5a	8.5a	9.5a	8.8a	5.6a	10.1a	7.2a	8.8a	9.4a	9.1a	7.9a
WS_4	8.6a	4.3a	6.2a	4.9a	6.0a	7.4a	6.1a	10.4a	7.6a	7.2a	8.1a	6.0a
WS_5	6.4a	3.1a	6.1a	5.1a	7.8a	8.9a	8.1a	7.5a	7.8a	9.8a	7.4a	5.5a

*Means with the same letter(s) within a column and/or a row (within a given period) are not significantly different at $P \leq 0.05$

Table 30. Interactive effects of water levels and packaging on fruit titratable acidity (%) (Trial 2)

	Packaging											
DAH	0			2			6			10		
WS	C	P	NP	C	P	NP	C	P	NP	C	P	NP
WS_1	4.6a*	8.0a	11.1a	11.3ab	8.1ab	10.0ab	11.6ab	10.8ab	11.1abc	10.0ab	14.8a	8.4ab
WS_2	4.3a	10.0a	4.8a	15.6a	16.4a	7.6ab	15.3a	14.9a	11.8ab	13.2a	13.8a	10.9ab
WS_3	4.7a	6.5a	4.0a	10.8ab	8.1ab	6.7ab	10.9ab	13.9ab	11.5abc	10.0ab	12.0ab	7.3ab
WS_4	8.4a	4.0a	4.5a	8.8ab	9.6ab	6.1ab	12.3ab	9.6ab	9.4abc	7.8ab	8.5ab	10.7ab
WS_5	4.7a	6.3a	5.7a	6.6ab	8.2ab	4.4b	10.4ab	6.7ab	6.5bc	7.8ab	8.7ab	5.2b

*Means with the same letter(s) within a column and/or a row (within a given period) are not significantly different at $P \leq 0.05$

4.2.6. Tomato Shelf life

Although fruits did not attain 75% of weight loss throughout the period of the experiment, the shelf life was determined when the fruits started showing signs of shrivelling and decay. Water levels influenced the fruit shelf life with the highest percentage in fruit weight loss observed in fruits from WS_3 (Trial 1) and WS_5 (Trial 2) at 24 DAH; the lowest percentage weight loss was observed in fruits from WS_4 (Trial 1) and WS_2 (Trial 2), though no significant difference was observed in the water treatments in Trial 2 (Figure 7).

Non-packaged fruits (control) had lost 34.23 % of their initial weight at 16 DAH compared to the packaged fruits (9.06% in perforated and 4.43% in non-perforated packages). At the end of the experiment (24 DAH), unpackaged fruits had lost 61.34% of their initial weight, though no significant difference was observed among the packaging treatment (Figure 8).

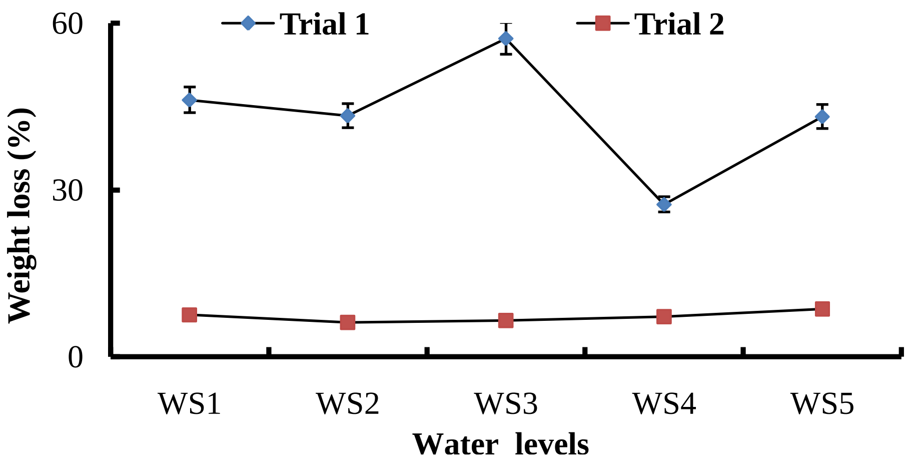

Figure 7. Percentage fruit weight loss of tomato fruits as influenced by water levels

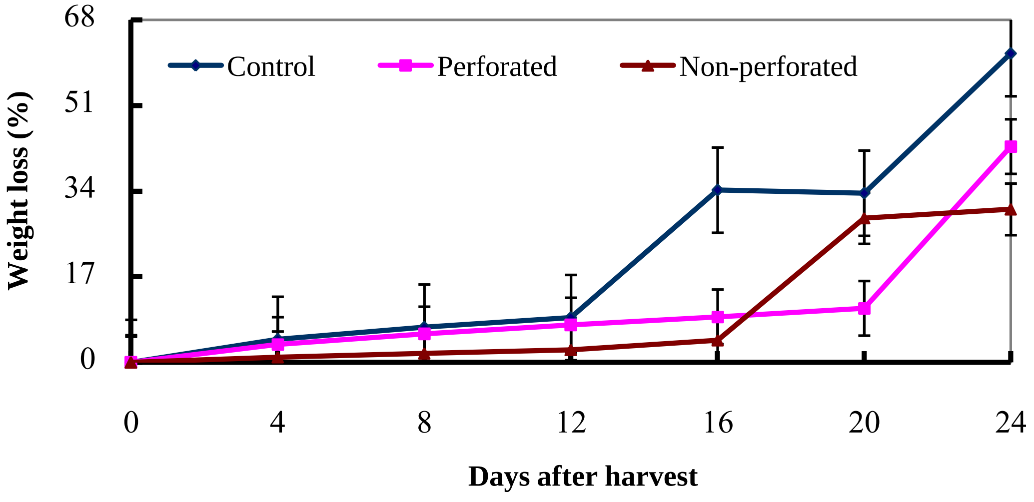

Figure 8: Percentage fruit weight loss of tomato fruits as influenced by packaging (Trial 1)

CHAPTER FIVE
DISCUSSION

5.1. Growth parameters

Water deficit usually has morphological effects on the growth of plants, which eventually results in yield reduction. Moisture stress does not affect all aspects of plant growth and development equally. When water deficit develops slowly enough to allow changes in developmental processes, water stress has several effects on growth (Taiz and Zeiger, 1998). In this experiment, it was evident that tomato plants that received less amount of water were shorter than those that were grown under adequate moisture supply. Consequently, the plants under moisture stress exhibited small stem diameter and short internodes. Results from this study are similar to those found by Kinark *et al*. (2001) where plant height and stem diameter of water stressed plants were smaller than the equivalent component in the well-watered plants, water deficit causes decrease in plant height, stem diameter and total dry matter (Bilibio *et al*., 2011), and severe water deficit was found to delay stem elongation in *Penium maximum* (Luvaha *et al*., 2010). Similar effects of water stress were observed on dry matter in Kiwifruit (Chartzoulakis *et al*., 1993) and muskmelon (Zeng *et al*., 2008). It has been demonstrated that plants growing under high water stress tend to suffer from significant growth and yield reductions (Dorais *et al*., 2001), and that irrigation deficit decreases all aspects of growth parameters, with major reductions in levels of 60% of water deficit (Bilibio *et al*., 2011).

The quantity and quality of plant growth depend on cell division, enlargement and differentiation which are affected by water deficits but not necessarily to the same extent (Nahar *et al*., 2011). The low increase in plant height under extreme water deficit may be due to reduced cell turgor, which affects cell division and expansion, though cell division was found to be less sensitive to water deficit than cell expansion or enlargement (Luvaha *et al*., 2010). Stem and plant growth may be inhibited at low water potential despite complete maintenance of turgor in the growing regions as a result of osmotic adjustment (Bradford and Hsiao, 1982). However, Klepper *et al*. (1971) indicate that stem diameter changes reflect changes in stem tissue hydration; and it could also be possible that part of the immediate change in volume results from changes in xylem vessel cross-sectional area, which might occur with changes in xylem tension.

In this study, well watered plants showed an increase in internode length compared to the moderate and severe stressed plants. It is well known that when soil water availability is limited, plant growth is usually decreased. It has been reported that when tomato plants are subjected to different levels of water stress under field conditions, vegetative growth is inhibited (Nyabundi and Hsiao, 1989).

5.2. Physiological parameters

The study shows that water stress in the pot-grown tomatoes produced significant reduction in physiological parameters such as chlorophyll content, stomatal conductance, leaf temperature, relative humidity, leaf relative water content and transpiration rate. These observations concur with the findings reported by Nuruddin *et al*. (2003). Photosynthesis and transpiration of plants subjected to water stress are inhibited but gradually recovered under continuous stress treatment. Water deficit exerts a negative effect on relative water content, thus the ability of the plant to survive severe water deficits depends on its ability to restrict water loss through the leaf epidermis after the stomata have attained minimum aperture because more water is absorbed during imbibition (El Jaafari, 2000). Transpiration rate gradually decreased with increasing of water stress. An explanation to this reduction could be that when the soil dries, the rate of absorption by roots falls short of transpiration rate by the plant. It has been reported that plants under water deficit reduce transpirational water losses by reducing stomatal conductance; moreover, water stress hinders leaf internal transport of CO_2, enzyme activity and hence photosynthetic capacity (Manzoni *et al*., 2011). It was shown that the transpiration rate of wilted plants is reduced by 40% of the control and that a smaller reduction in transpiration rate (20%) is observed when a substantial part of the root system (75%) is subjected to moisture stress in tomato plants (Das, 1997).

In this study, it was noted that the leaf temperature decreased by 1.8^{o}C in the moderate (WS_3) and severe water stressed (WS_5) plants compared to the control plants. However, Klepper *et al*. (1971) found that water deficits increased leaf temperature by to 3-4^{o}C, and when water stress limits transpiration, the leaf heats up (Taiz and Zeiger, 1998). High leaf temperature in water-stressed plants could be related to decreased transpiration rate and LRWC values (Kinark *et al*., 2001). According to this study, the decrease in leaf temperature could be due to the difference in the greenhouse temperatures where the trials were conducted. Moreover, it should be noted that canopy temperature is dependent on climatic parameters and internal plant water status.

5. 3. Yield parameters

Water deficit stress influenced abortion rate, fruit size, total fruit number, fruit diameter and total yield per hectare. The highest flower abortion (70-85%) observed in severely stressed plants could be due to the fact that as the water stress increases, the number of ovules per floret decreases. According to Doorenbos and Kassam (1979), the reproductive stage is particularly susceptible to water deficit stress and the highest demand for water is during flowering. The effects of water stress on floral initiation are little known, but evidence suggests that drought conditions reduce the number of flowers. Irrigation deficit in the 1st growth period reduces the number of flowers leading to a decrease in the number of fruits and in the marketable yield. The results of this study agrees with the findings of Turner (1993) who stipulated that water stress increased floret abortion and premature death of whole flower heads.

An increase in the fruit size was observed in the moderately stressed plants; and fruits from the stressed plants were fewer in number. Birhanu and Tilahun (2010) mentioned that the number of fruits per plant is affected both by water deficit level and cultivars and that the fruit size as well as number of fruits per plant is reduced with reduction in the amount of irrigation water applied for the tomato plants. According to Erdal *et al*. (2007), plants having sufficient water, form bigger fruits and at the same time get more nutrients under water supplied conditions, thus plants grow well and fruit quality increases. It was found that the rate of fruit growth is highly correlated with the soil water content (Mingo *et al*., 2003). Soil drying and/or watering tomato plants in such a way that only part of the root system is allowed to dry can limit fruit expansion rate and the final size of the fruit.

In this study, a reduction in fruit yield in water stressed plants was observed. The results showed that the reduction in fruit weight and diameter under stress conditions may contribute to the reduction in fruit yield. Our results agree with the findings of Kirnak *et al*. (2001) who found significant reductions in fruit yield in the water-stressed plants compared to the unstressed plants. Similar effects of water stress on fruit yield and/or biomass reduction for a range of other agricultural and horticultural crops including sorghum, tomato, peach and strawberry. It was also observed that the total yield and marketable yields decrease as the water deficit level increase (Birhanu and Tilahun, 2010).

The low fruit yield obtained could be attributed to the failure of flowers to develop into fruits. It was observed that only 50% of the flowers produced developed into fruits because sink size was a limiting factor to fruit production in tomato and that the poor fruit set may be as a result of high temperatures that are not conducive for good fruit set (Olaniyi *et al*., 2010). The optimum moisture regime for tomato cultivation ranges from field capacity to 50% of soil available water and the application of irrigation water during the period of fruit development has a favourable influence on yield as well as on the efficiency of water utilization since the fruit set of tomato is highly sensitive to water stress (Nuruddin, 2001). Irrigation during the period of fruit set and fruit development increase fruit yield by 53 t/ha compared to non-irrigated plants, water stress decreases yield, flower number, percent fruit set and dry matter production and the photosynthetic rate, transpiration rate and leaf water potential as well as the water use efficiency (WUE) are reduced but the leaf temperature and stomatal resistance were increased by the water stress (Rahman *et al*., 1999).

Although there have been many studies on the effects of water deficit on yield, few have addressed the relationship among yield, vegetative growth, and physiological responses to different irrigation regimes. Water deficit stress (drought) is catastrophic to crop growth and production and its effects are much more conspicuous on the physical appearance. Plants under water stressed regimes predispose them to insect infestation and disease infection. Consequently, application of water to tomato plants will result in realization of optimal yield. From this study, it was evident that water regimes at different growth stages influenced productivity of tomato plants.

5.4. Post-harvest qualities

Tomato quality changes continuously after harvesting. Significant differences in fruit weight loss, colour change, fruit firmness, total soluble solids and titratable acidity observed clearly indicate that degradation of fruits commence after harvesting. The highest fruit weight loss was recorded in fruits from 60% of PC (WS_3) in trial 1 and in fruits from 20% of PC (WS_5) in trial 2. Unpackaged fruits resulted in higher fruit weight loss than packaged fruits. It is well known that most fresh fruits and vegetables contain so much water (80-90%), thus their quality suffer very quickly from water loss, especially loss of salable weight. Fruit weight loss is normally due to senescence or desiccation of tomato fruits (Batu and Thompson, 1998) and is mostly dependent on the transpiration driving force (vapour pressure deficit: VPD).

In fruits from WS_5, the higher percentage weight loss could have been the result of higher rates of CO_2 production that were observed in plants growing under a water deficit which may also reduce the fruit shelf life by increasing respiration and accelerating senescence

(Dorais *et al*., 2001). Thus, the higher the respiration rate, the faster the water loss and the higher the weight loss. The highest percentage in fruit weight loss was observed in unpacked fruits because packaging restricts the air movement around the produce, hence minimising fruit weight loss (Abdullah *et al*., 2004). The use of packaging creates an environment similar to modified atmosphere. The effectiveness of a modified atmosphere in reducing weight loss has been attributed to its inhibitory effect on both respiration and transpiration (Kader, 1986). It is expected that a lower respiration and transpiration rate would result in reduced weight loss as observed in the present study. In this study, fruit weight loss could be due to the modified atmosphere packaging (MAP) that creates water saturated or near saturated atmosphere around the fruit which reduces water loss and shrinkage.

In this study, no significant colour change was observed within the first 4 DAH in all the water treatments. Fruit that are harvested at stages prior to full ripeness show an increase in lycopene content during postharvest ripening. Lucille and Grierson (2003) mentioned that at the breaker stage of tomato ripening, lycopene begins to accumulate and its concentration increases. However, ethylene is the dominant trigger for ripening in climacteric fruits, thus it is responsible for initiating fruit ripening and also colour change. The amount of ethylene produced increases with the stage of development, and non water-stressed plants are likely to develop faster compared to water stressed plants and produce more ethylene. This could be the reason why faster colour development was observed in the moderate watered plants.

It has been shown that controlled or modified atmospheres delay fruit ripening at 12.8°C and that modified atmospheres resulting from the enclosure of mature green tomatoes in polyethylene or other forms of plastic packaging may also delay fruit ripening (Harold *et al*., 2007). In contrast, this study demonstrated that colour change was fast in packaged fruits (especially in the non-perforated package). Our results are distinct from the findings of Harold *et al*. (2007) since our tomatoes were harvested at the breaker stage and kept at 21± 2^{o}C. When fruits are packaged, they are initially subjected to stress due to the reduction in O_2. This may result in an initial increase in respiration and ethylene production. The ethylene may accumulate in the package and this accelerates colour change. Polythene packaging has been reported to result in better early ripening and colour development in mature green tomatoes and maintains the best physicochemical quality of fruit during storage to marketing (Moneruzzaman *et al*., 2009).

In this study, fruits from the water stressed plants were firmer compared to those from the well watered plants (WS_1 and WS_2). Generally, when plants are well watered (without stress), the water concentration in their fruits increase and tend to make the fruits softer during the period of storage. This might explain the higher levels of firmness observed in fruits from the water stressed plants. It has been reported by Crookes and Grierson (1983) that as ripening progresses, the cell wall becomes increasingly hydrated and as the pectin riches middle lamella, it is modified and partially hydrolysed. The change in cohesion of the pectin gel governs the ease with which one cell can be separated from another, which in turn affects the final texture of the ripe fruit. This process occurs early at ripening stage in soft fruit such as tomato.

Packaging influenced the tomato fruit firmness. Non-perforated packaged fruits were firmer than perforated packaged fruits because MAP inhibits the synthesis and accumulation of cell wall degrading enzymes by slowing down their activities that cause fruit tissue softening. It has been also reported that low oxygen levels in modified or controlled atmospheres inhibit polygalacturonase activity, thus reducing the rate of fruit softening (Kapotis *et al.,* 2004).

This study showed that higher levels of TSS were found in fruits from stressed plants and in fruits packaged in non-perforated bags. It has been widely shown that reduced soil moisture and salt stress increase sugar content in tomatoes (Obreza *et al*., 2001; Hanson and May, 2003; Birhanu and Tilahun, 2010). Although water stress resulted in decreased yield in tomatoes, it increased brix values (Shinohara *et al*., 1995). According to Birhanu and Tilahun (2010), the reduction of fruit size under deficit irrigation is mainly attributed to reduction of water, and this may explain why the fruit total soluble solid content is often higher in the stressed plants. The lowest TSS observed in fruits from the well and moderate water stressed plants (WS_1, WS_2 and WS_3) can be attributed to the higher water uptake by the plants and therefore lead to the dilution of the concentration of TSS.

A general trend of increasing TSS with time though not significant for the first 6 DAH was noticed. The only significant difference in TSS throughout the period of experimentation was between perforated and non-perforated packaging at 8 DAH where non-perforated packaged fruits had significantly higher TSS than perforated packaged fruits. Similar observations were made by Nasrin *et al*. (2008), who found that changes of TSS were lower in fruits packed in perforated polyethylene bag. The higher TSS observed in non-perforated packages could be due to increase in respiration and high CO_2 levels (Kere *et al*., 2000). In this study, fruit titrable acidity was found to be significantly higher in fruits from WS_2 plants and in non-packaged fruits. There is an inverse relationship between the TSS and TA; as the value of sugar content (TSS) increases, that for the acidity (TA) decreases.

Finally, the results of this study confirm that packaging helps in extending tomato shelf life and this complement the findings of Moneruzzaman *et al*. (2009) who suggested that the use of controlled atmosphere for tomato fruit storage would be of considerable benefit for the long-term storage of fruit. Batu and Thompson (1998) have reported the extension of the shelf life by packaging in polyethylene films which slows the ripening process of tomato. Also, MAP results in accumulation of CO_2 and depletion of O_2 around the fruits, which may increase its storage life. According to Nasrin *et al*. (2008), shelf life of tomato can be extended at ambient temperature up to 17 days without excessive deterioration in quality by treating the fruits with chlorine, and packaging in perforated polyethylene bags.

The differences observed in the various parameters in trial 1 and trial 2 could be due to the difference in the planting time and different greenhouses. In trial 1, seeds were sown in plastic pots and seedlings were watered daily for two weeks before initiating treatments in order to improve root development; unlike in trial 2 where seeds were first raised in a nursery then transplanted in the pots, and after that, water treatment application started 2 weeks after transplanting. It is known that exposure to moisture stress at the seedling stage confers some degree of hardening against current and later drought periods (Luvaha *et al*., 2007). According to Shamsul *et al*. (2008), water stress at earlier stages of growth (20 days after planting) is more inhibitory compared to the later stage (30 days after planting) when the plant is well established and therefore able to cope with moisture stress.

CHAPTER SIX
CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

6.1.1. Field experiment

The goal of this study was to determine the performance of tomato under varying soil moisture stress (water deficit). Soil moisture levels influenced growth and yield of tomato (*Lycopersicon esculentum* M., cv. 'Moneymaker') in both trials though the differences were much more obvious in the 2nd trial. From the results of this study, the conclusion is that water deficit affects the plant growth parameters by reducing them as it increases. It therefore influences growth through its effect on the physiological parameters; thus crop maturity and productivity are both affected by low moisture levels during its vegetative stage. Restricting water levels (20-60% of PC) resulted in significant differences among growth and physiological parameters. Plant height was affected by the amount of water applied, although inconsistently. Stem diameter, internode length, leaf temperature, relative humidity, leaf relative water content and transpiration rate decreased in the stressed plants unlike chlorophyll content and stomatal conductance. Tomato yield was also affected significantly by soil moisture levels. The highest fruit yield was recorded in plants from the well watered (control) plants, whereas the highest abortion rate and the smallest fruit diameter were observed in the severe stressed plants.

6.1.2. Laboratory Experiment

Water levels and packaging significantly influenced the postharvest qualities (fruit weight loss, colour change, fruit firmness, total soluble solids and titratable acidity) and tomato shelf life was extended in packaged fruits. Severe moisture stress improved the tomato fruit quality by reducing the fruit acidity (TA), in increasing the fruit total soluble solids (TSS) and preserving its firmness. From the results of this study, it is concluded that the higher the water content, the higher the fruit weight loss and the faster the fruit losses its firmness and develops fruit colour change faster. Packaging also influenced positively the tomato fruit quality. Reduced weight and firmness, and short shelf life were observed in unpackaged fruits while packaged fruits had developed a faster fruit colour change and increased the fruit total soluble solids. There were interactive effects among the water levels and packaging treatments regarding the postharvest qualities of tomato. Unpackaged fruits from moderate water stressed plants had a higher weight loss; non-perforated fruits from water stressed plants had their sugar content increased, their firmness preserved and acidity reduced.

6.2. Recommendations

Understanding the effects of water deficit stress on physiological parameters such as photosynthesis, transpiration, stomatal conductance, leaf temperature and vapour pressure deficit could be of great help in understanding crop yield response to irrigation. Tomato needs a controlled supply of water throughout the growing period for optimal fruit quality and higher yield. Water must be applied at an optimum level to achieve maximum yields. Abiotic stresses (water, salt, heat, environmental stress) and the timely application of inputs need to be considered; they have a significant impact not only on tomato fruit yield, but also in increasing fruit quality. This would then allow a more rational choice of irrigation regimes as well as more efficient water use. High water stress (deficit irrigation) causes lower yield but enhances the fruit quality.

From the present study, good results were obtained from well water plants on growth and physiological parameters of the tomato plant of which we considered to be the optimum irrigation (80-100% of PC). The high fruit yield was from the control plants (100% of PC) although it did not increase some of the postharvest qualities. Thus, we recommend the following:

1. Field experiments to be conducted for maximum yield and fruit quality production though in case of scarcity, deficit irrigation provides high water use efficiency and field production might be difficult in terms of water requirements per plant and yet greenhouse tomato production is costly.

2. There is need of proper continuation in supplying water throughout the production for better yield in tomato production and having adequate soil moisture during the preharvest period is essential for the maintenance of postharvest quality.

3. Introduce packaging after harvest for storage of tomato fruit to avoid fruit weight loss and to maintain longer shelf life, also to increase the sugar content. The choice on which type of package (perforated or non-perforated) to use depends with the interest of the retailer and/or consumer and at what extend the produce will be kept in storage.

4. Further researches in the area of post-harvest studies of horticultural commodities concerning the impact of preserving the quality of fruits and vegetables although the degree to which currently available techniques may be further improved to provide a significant commercial impact is unclear.

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APPENDICES

Appendix 1: Layout in a randomized complete block design (RCBD)

BLOCK 1	WS_1	WS_3	WS_4	WS_5	WS_2
BLOCK 2	WS_5	WS_4	WS_1	WS_2	WS_3
BLOCK 3	WS_2	WS_1	WS_5	WS_3	WS_4
BLOCK 4	WS_3	WS_5	WS_2	WS_4	WS_1

Key:

WS_1:100% of PC; WS_2: 80% of PC; WS_3: 60% of PC;

WS_4: 40% of PC; WS_5: 20% of PC

Appendix 2: Layout of split-plot in a randomized complete block design (RCBD)

WS_1	WS_2	WS_3	WS_4	WS_5	WS_5	WS_1	WS_4	WS_2	WS_3	WS_3	WS_5	WS_1	WS_4	WS_2
CONTROL (non-packaged)					NON-PERFORATED					PERFORATED				
WS_2	WS_4	WS_1	WS_5	WS_3	WS_3	WS_2	WS_1	WS_4	WS_5	WS_1	WS_4	WS_5	WS_2	WS_3
PERFORATED					CONTROL (non-packaged)					NON-PERFORATED				
WS_4	WS_5	WS_2	WS_3	WS_1	WS_2	WS_1	WS_5	WS_3	WS_4	WS_5	WS_2	WS_3	WS_1	WS_4
NON-PERFORATED					PERFORATED					CONTROL (non packaged)				

Key:

WS_1:100% of PC; WS_2: 80% of PC; WS_3: 60% of PC;

WS_4: 4s0% of PC; WS_5: 20% of PC

Appendix 3: Interactive effects of water levels and packaging on fruit weight (g) (Trial 1)

	Days after harvest	0	4	8	12	16	20	24
Water Levels	Packaging							
	Control	39.3abcd*	37.7abcd	36.5abcde	35.7abcde	21.4ab	21.1a	12.8a
WS_1	Perforated	40.1abcd	38.7abcd	37.6abcde	36.8abcde	36.2ab	35.7a	24.4a
	Non-perforated	42.3abc	41.7abc	41.4abcd	41.1abcd	40.8a	28.5a	28.2a
	Control	50.5a	48.1a	46.9ab	45.9ab	45.1a	44.3a	12.8a
WS_2	Perforated	52.2a	50.4a	49.4a	48.5a	47.5a	46.9a	42.8a
	Non-perforated	50.7a	50.3a	50.0a	49.7a	49.4a	33.1a	31.3a
	Control	39.7abcd	38.0abcd	37.1abcde	36.5abcde	20.1ab	22.8a	12.9a
WS_3	Perforated	37.1abcd	35.7abcd	35.0abcde	34.4abcde	33.7ab	33.1a	12.3a
	Non-perforated	43.8ab	43.5ab	43.2abc	42.9abc	41.8a	26.5a	26.3a
	Control	27.7bcd	26.0bcd	25.3bcde	24.7bcde	24.2ab	23.9a	23.4a
WS_4	Perforated	26.2bcd	25.2bcd	24.8cde	24.3cde	24.0ab	23.7a	10.8a
	Non-perforated	26.1bcd	25.9bcd	25.7bcde	25.5bcde	24.4ab	24.2a	23.9a
	Control	23.9bcd	23.0bcd	22.6cde	22.2cde	8.3b	8.2a	8.1a
WS_5	Perforated	21.4cd	20.7cd	20.2de	19.9de	19.6ab	18.7a	11.4a
	Non-perforated	19.8d	19.6d	19.3e	19.1e	18.3ab	18.2a	17.5a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Appendix 4: Interactive effects of water levels and packaging on fruit weight (g) (Trial 2)

	Days after harvest	0	4	8	12	16	20	24
Water Levels	Packaging							
	Control	60.7a*	59.2ab	58.5ab	57.8ab	57.0ab	56.5ab	55.8ab
WS_1	Perforated	56.4ab	54.9abc	53.9abc	53.0abc	52.3abc	51.4abc	49.4abc
	Non-perforated	60.3a	60.0a	59.8a	59.6a	59.3a	59.1a	58.8a
	Control	53.8abc	52.9abc	52.3abc	51.7abc	51.1abc	50.7abc	50.0abc
WS_2	Perforated	54.7abc	53.3abc	52.5abc	51.7abc	51.1abc	50.5abc	49.7abc
	Non-perforated	53.8abc	53.6abc	53.4abc	53.2abc	53.0abc	52.8abc	52.5abc
	Control	38.9bcd	38.1cde	37.6cde	37.1cde	36.7cde	36.3cde	35.8cde
WS_3	Perforated	42.6abcd	41.6bcd	41.0bcde	40.1bcde	39.9bcde	39.4bcde	38.9bcd
	Non-perforated	42.4abcd	41.2abcd	42.0abcd	41.8abcd	41.6bcd	41.4bcd	41.1bcd
	Control	33.3d	32.6de	32.3de	31.9de	31.5de	31.1de	30.7de
WS_4	Perforated	34.1d	33.3de	32.8de	32.2de	31.7de	31.3de	30.5de
	Non-perforated	37.9cd	37.7cde	37.6cde	37.4cde	37.1cde	36.9cde	36.7cde
	Control	30.3d	29.7de	29.3de	28.9de	28.5de	28.1de	27.5de
WS_5	Perforated	24.2d	23.5e	23.1e	22.7e	22.4e	22.1e	21.3e
	Non-perforated	26.4d	26.2de	26.1de	25.9de	25.7de	25.5de	25.3de

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Appendix 5: Interactive effects of water levels and packaging on fruit colour change (Trial 1)

	Days after harvest	0	4	8	12	16	20	24
Water Levels	Packaging							
	Control	2.3a*	3.7a	4.7a	5.3a	3.7a	4.0a	
WS_1	Perforated	2.0a	2.7a	4.3a	5.3a	5.7a	4.0a	
	Non-perforated	2.0a	3.3a	4.7a	5.3a	6.0a	4.0a	
	Control	2.0a	2.7a	4.0a	4.7a	5.0a	6.0a	
WS_2	Perforated	2.0a	3.0a	3.7a	4.3a	5.7a	6.0a	
	Non-perforated	2.0a	3.3a	4.0a	5.3a	6.0a	4.0a	
	Control	2.7a	2.7a	5.0a	5.3a	3.7a	4.0a	
WS_3	Perforated	2.0a	3.0a	4.7a	5.3a	5.7a	5.7a	
	Non-perforated	2.0a	3.0a	4.3a	5.0a	5.3a	4.0a	
	Control	2.0a	2.7a	3.3a	3.3a	4.0a	5.0a	
WS_4	Perforated	2.0a	2.7a	3.7a	4.3a	4.3a	5.3a	
	Non-perforated	2.7a	3.7a	5.0a	5.3a	5.7a	6.0a	
	Control	3.0a	4.0a	5.0a	5.3a	1.7a	2.0a	
WS_5	Perforated	2.0a	2.3a	2.7a	3.3a	4.0a	4.7a	
	Non-perforated	2.0a	2.7a	3.0a	3.7a	5.0a	5.7a	

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Appendix 6: Interactive effects of water levels and packaging on fruit colour change (Trial 2)

	Days after harvest	0	4	8	12	16	20	24
Watering levels	Packaging							
WS_1	Control	2.0a*	2.0a	3.3a	5.3ab	6.0a	6.0a	
	Perforated	2.0a	2.0a	3.0a	4.0ab	4.0d	5.3a	
	Non-perforated	2.0a	2.7a	3.3a	5.0ab	5.7ab	6.0a	
WS_2	Control	2.0a	2.3a	3.7a	4.7ab	6.0a	6.0a	
	Perforated	2.0a	2.0a	3.3a	5.0ab	5.7ab	6.0a	
	Non-perforated	2.0a	2.3a	4.0a	5.7ab	5.3abc	6.0a	
WS_3	Control	2.0a	2.0a	3.0a	3.7b	6.0a	6.0a	
	Perforated	2.0a	2.7a	4.0a	5.0ab	5.3abc	6.0a	
	Non-perforated	2.0a	2.3a	3.0a	4.3ab	5.7ab	6.0a	
WS_4	Control	2.0a	2.7a	4.0a	5.0ab	5.3abc	6.0a	
	Perforated	2.0a	2.3a	3.3a	4.0ab	4.3cd	5.7ab	
	Non-perforated	2.0a	2.7a	4.3a	6.0a	6.0a	6.0a	
WS_5	Control	2.0a	2.0a	3.3a	4.7ab	5.3abc	5.3ab	
	Perforated	2.0a	2.0a	3.0a	4.3ab	4.7bcd	5.3ab	
	Non-perforated	2.0a	2.7a	4.7a	5.7ab	6.0a	6.0a	

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Appendix 7: Interactive effects of water levels and packaging on fruit firmness (Trial 1)

	Days after harvest	0	2	4	6	8	10
Watering levels	Packaging						
WS_1	Control	5.2a	3.9a	4.7a	5a	3.6a	3.5a
	Perforated	3.5a	3.8a	2.0a	4.3a	3.4a	2.9a
	Non-perforated	3.8a	3.1a	1.9a	1.4a	1.5a	1.3a
WS_2	Control	6.0a	3.3a	4.2a	3.6a	2.4a	3.6a
	Perforated	3.6a	3.4a	4.0a	3.0a	4.1a	2.4a
	Non-perforated	6.2a	3.9a	2.5a	4.0a	2.8a	2.1a
WS_3	Control	4.3a	3.2a	4.5a	3.7a	4.1a	3.7a
	Perforated	5.2a	3.0a	2.5a	4.7a	4.0a	3.7a
	Non-perforated	4.6a	3.6a	2.4a	2.4a	3.5a	2.4a
WS_4	Control	4.4a	4.1a	3.5a	3.8a	5.0a	2.6a
	Perforated	5.0a	4.4a	4.6a	3.0a	3.3a	3.6a
	Non-perforated	6.0a	5.5a	2.8a	4.3a	2.9a	2.7a
WS_5	Control	4.1a	5.2a	3.9a	4.7a	4.7a	2.5a
	Perforated	4.4a	4.5a	3.8a	3.0a	4.3a	2.2a
	Non-perforated	3.6a	3.8a	3.8a	2.6a	2.7a	2.9a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Appendix 8: Interactive effects of water levels and packaging on fruit firmness (Trial 2)

	Days after harvest	0	2	4	6	8	10
Watering levels	Packaging						
WS_1	Control	6.3a	5.8ab	4.1a	4.7a	5.5a	3.6a
	Perforated	5.0a	4.1ab	3.6a	4.6a	5.5a	4.1a
	Non-perforated	5.3a	3.9ab	4.7a	3.4a	3.1a	3.9a
WS_2	Control	6.2a	4.3ab	3.1a	4.8a	4.1a	2.9a
	Perforated	5.4a	2.2b	3.4a	3.9a	3.1a	4.2a
	Non-perforated	6.5a	5.5ab	3.3a	4.2a	3.3a	2.6a
WS_3	Control	6.3a	6.0a	5.5a	5.0a	4.5a	4.2a
	Perforated	6.4a	4.1ab	5.3a	4.3a	4.5a	4.4a
	Non-perforated	5.2a	6.4a	3.9a	4.8a	4.1a	4.6a
WS_4	Control	4.1a	6.3a	6.0a	5.3a	4.9a	2.6a
	Perforated	5.5a	5.0ab	5.3a	4.2a	5.2a	5.4a
	Non-perforated	6.3a	4.7ab	5.1a	3.7a	2.8a	3.2a
WS_5	Control	5.2a	4.7ab	4.5a	5.4a	4.3a	3.9a
	Perforated	7.0a	3.8ab	4.2a	4.2a	5.2a	6.2a
	Non-perforated	4.4a	5.3ab	5.5a	3.5a	5.8a	5.6a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Appendix 9: Interactive effects of water levels and packaging on fruit total soluble solids (TSS) (Trial 1)

	Days after harvest	0	2	4	6	8	10
Watering levels	Packaging						
WS_1	Control	4.7a	4.3ab	4.5a	4.8ab	4.7a	4.4ab
	Perforated	4.7a	4.6ab	4.9a	4.0b	4.1a	4.4ab
	Non-perforated	4.4a	4.5ab	4.5a	4.5ab	3.9a	4.1b
WS_2	Control	4.3a	4.6ab	4.7a	4.7ab	4.5a	4.1b
	Perforated	4.6a	4.5ab	4.2a	4.4ab	4.2a	4.4ab
	Non-perforated	3.9a	3.9b	4.2a	4.5ab	3.9a	4.4ab
WS_3	Control	5.4a	4.6ab	5.0a	4.7ab	4.7a	4.7ab
	Perforated	4.5a	4.8ab	5.1a	5.0ab	4.7a	4.4ab
	Non-perforated	4.6a	4.7ab	4.6a	4.3ab	4.4a	4.3ab
WS_4	Control	5.4a	4.8ab	4.7a	4.8ab	5.0a	5.0ab
	Perforated	4.7a	4.7ab	5.4a	5.4ab	5.3a	5.5ab
	Non-perforated	4.9a	5.4ab	5.2a	4.7ab	5.0a	5.0ab
WS_5	Control	5.4a	5.9a	5.4a	5.9ab	5.3a	5.9a
	Perforated	5.2a	5.6ab	5.8a	6.1a	5.3a	6.0a
	Non-perforated	5.4a	5.7ab	5.6a	5.9ab	5.5a	5.4ab

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Appendix 10: Interactive effects of water levels and packaging on fruit total soluble solids (TSS) (Trial 2)

	Days after harvest	0	2	4	6	8	10
Watering levels	Packaging						
	Control	3.9d	5.0a	4.3c	4.0c	4.6de	4.2d
WS_1	Perforated	4.1cd	4.1b	4.6bc	4.5abc	4.1e	4.2d
	Non-perforated	4.3bcd	4.3b	4.3c	4.4bc	5.4abcd	4.5cd
	Control	4.7abcd	4.6ab	5.1abc	5.3abc	5.3abcd	5.5abc
WS_2	Perforated	4.2bcd	4.6ab	4.3c	4.7abc	4.7cde	4.9bcd
	Non-perforated	4.3bcd	4.9ab	5.4abc	5.1abc	5.5abcd	5.1abcd
	Control	4.6abcd	5.3ab	6.0ab	5.9ab	4.9bcde	5.6abc
WS_3	Perforated	5.2abcd	5.1ab	5.7abc	5.1abc	5.6abcd	5.0bcd
	Non-perforated	5.0abcd	5.0ab	5.3abc	5.0abc	5.5abcd	5.7abc
	Control	5.5abc	5.5ab	5.6abc	4.9abc	6.2a	5.7abc
WS_4	Perforated	5.5abcd	5.4ab	5.3abc	5.4abc	5.4abcd	5.5abc
	Non-perforated	5.2abcd	5.4ab	5.7abc	5.6ab	5.7abc	6.3a
	Control	5.7abc	4.9ab	6.0ab	5.7ab	5.9ab	6ab
WS_5	Perforated	5.8ab	6.2a	6.5a	5.7ab	5.9ab	5.6abc
	Non-perforated	6.2a	5.4ab	5.8abc	6.0a	5.6abcd	5.3abcd

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Appendix 11 : Interactive effects of water levels and packaging on fruit titratable acidity (TA) (Trial 1)

	Days after harvest	0	2	4	6	8	10
Watering levels	Packaging						
WS_1	Control	6.9a	6.8a	7.4a	8.5a	5.0a	6.9a
	Perforated	9.8a	12.0a	8.3a	7.0a	6.8a	7.4a
	Non-perforated	10.6a	11.2a	7.9a	8.2a	6.5a	5.6a
WS_2	Control	7.7a	9.6a	7.6a	10.7a	10.6a	10.4a
	Perforated	9.3a	10.8a	8.5a	8.5a	7.9a	9.3a
	Non-perforated	7.4a	8.0a	8.0a	10.2a	8.2a	7.5a
WS_3	Control	7.1a	9.5a	8.8a	10.1a	7.8a	9.4a
	Perforated	12.5a	8.8a	9.0a	7.2a	8.7a	9.1a
	Non-perforated	8.9a	5.6a	6.4a	8.8a	7.3a	7.9a
WS_4	Control	8.6a	4.9a	6.9a	6.1a	7.9a	7.2a
	Perforated	4.3a	6.0a	8.4a	10.4a	9.9a	8.1a
	Non-perforated	6.2a	7.4a	7.6a	7.6a	10.1a	6.0a
WS_5	Control	6.4a	5.1a	5.3a	8.1a	5.9a	9.8a
	Perforated	3.1a	7.8a	4.8a	7.5a	4.7a	7.4a
	Non-perforated	6.1a	8.9a	5.3a	7.8a	6.1a	5.5a

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Appendix 12: Interactive effects of water levels and packaging on fruit titratable acidity (TA) (Trial 2)

	Days after harvest	0	2	4	6	8	10
Watering levels	Packaging						
WS_1	Control	4.6a	11.3ab	11.8ab	11.6ab	8.9abc	10.0ab
	Perforated	8.0a	8.1ab	11.1ab	10.8ab	13.2a	14.8a
	Non-perforated	11.1a	10.0ab	7.6ab	10.1ab	11.1abc	8.4ab
WS_2	Control	4.3a	15.6a	16.2a	15.3a	12.5ab	13.2a
	Perforated	10.0a	16.4a	10.8ab	14.9a	8.7abc	13.8a
	Non-perforated	4.8a	7.6ab	11.4ab	12.8ab	11.8ab	10.9ab
WS_3	Control	4.7a	10.8ab	9.2ab	10.9ab	14.5a	10.0ab
	Perforated	6.5a	8.1ab	7.5ab	13.9ab	13.2a	12.0ab
	Non-perforated	4.0a	6.7ab	8.4ab	6.0ab	11.5abc	7.3ab
WS_4	Control	8.4a	8.8ab	5.9b	12.3ab	7.5abc	7.8ab
	Perforated	4.0a	9.6ab	9.3ab	9.6ab	4.6c	8.5ab
	Non-perforated	4.5a	6.1ab	8.4ab	10.4ab	9.9abc	10.7ab
WS_5	Control	4.7a	6.6ab	8.9ab	10.4ab	11.6abc	7.8ab
	Perforated	6.3a	8.2ab	10.5ab	6.7ab	8.8abc	8.7ab
	Non-perforated	5.7a	4.4b	5.9b	5.2b	5.6bc	5.2b

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$

Appendix 13: Analysis of variance for fruit weight loss in a split plot design at different days after harvest (Trial 1)

Source	df	Mean squares (MSS)						
		0 DAH	4 DAH	8 DAH	12 DAH	16 DAH	20 DAH	24 DAH
Rep	2	420.42	414.88	47.45	400.19	940.21	2040.87	3473.44
Package	2	5.37	17.75	28.34*	38.48*	504.07**	228.89*	493.48
Rep*package (error a)	4	43.10	37.74	36.53*	36.33*	144.87	371.79	318.05
CV (%)		18.21	17.58	17.61	17.83	39.70	70.79	93.86
Water	4	1258.89 **	1190.99**	1148.65**	1115.92**	1254.50**	816.26**	340.35
Water*package	8	13.40	14.46	15.52	16.21	73.48	69.48	201.94
Error b	24	27.17	25.69	24.86	24.22	36.04	67.01	87.26
CV (%)		14.46	14.50	14.52	14.56	19.80	30.05	46.85
R^2		0.90	0.91	0.91	0.91	0.91	0.86	0.85
Mean		36.06	34.95	34.33	33.81	30.32	27.24	19.94

$\alpha = 0.05$

Appendix 14: Analysis of variance for fruit weight loss in a split plot design at different days after harvest (Trial 2)

Source	df	Mean squares (MSS)						
		0 DAH	4 DAH	8 DAH	12 DAH	16 DAH	20 DAH	24 DAH
Rep	2	258.00	224.97	234.92	228.19	223.07	215.54	190.34
Package	2	11.50	25.94	36.78	47.64	56.60	67.08	92.18
Rep*package (error b)	4	14.82	16.26	17.28	17.61	17.69	18.76	23.89
CV (%)		8.88	9.45	9.86	10.07	10.19	10.60	12.14
Water	4	1582.72**	1533.86**	1503.67**	1475.64**	1456.13**	1429.31**	1396.73**
Water*package	8	16.62	15.97	16.00	15.71	15.34	15.96	18.10
Error b	24	22.80	22.18	22.07	21.88	21.24	21.26	21.93
CV (%)		11.02	11.01	11.15	11.22	11.17	11.28	11.63
R^2		0.93	0.93	0.93	0.93	0.93	0.93	0.92
Mean		43.33	42.60	42.14	41.69	41.26	40.87	40.26

$\alpha = 0.05$

Appendix 15: Analysis of variance for fruit colour change in a split plot design at different days after harvest (Trial 1)

Source	df	Mean squares (MSS)						
		0 DAH	4 DAH	8 DAH	12 DAH	16 DAH	20 DAH	24 DAH
Rep	2	0.42	6.96	4.47	2.02	4.62	35.49	60.02
Package	2	0.62**	1.76	1.40	0.62	16.09**	3.29	29.62**
Rep*package (error a)	4	0.22	0.06	0.17	0.56	6.22*	3.32	6.62
CV (%)		21.52	7.88	9.98	15.72	52.76	38.85	80.91
Water	4	0.14	0.22	1.97	2.58*	5.02*	4.08	1.09*
Water*package	8	0.34**	0.92	1.57	1.68	1.01	3.76	5.29
Error b	24	0.09	0.61	1.18	0.71	1.66	3.68	3.92
CV (%)		14.11	25.01	26.32	17.73	27.10	40.93	62.32
R^2		0.74	0.64	0.54	0.65	0.70	0.61	0.76
Mean		2.18	3.11	4.13	4.76	4.76	4.69	3.18

$\alpha = 0.05$

Appendix 16: Analysis of variance for fruit colour change in a split plot design at different days after harvest (Trial 2)

Source	df	Mean squares (MSS)						
		0 DAH	4 DAH	8 DAH	12 DAH	16 DAH	20 DAH	24 DAH
Rep	2	0.00	0.16	0.62	1.76	0.29	0.16	0.00
Package	2	0.00	0.56	1.16	3.09	4.82	0.56	0.00
Rep*package(error a)	4	0.00	0.66	0.19	0.22	0.19	0.69	0.00
CV (%)		0.00	35.17	12.24	9.73	8.10	14.37	0.00
Water	4	0.00	0.19	0.67	0.81	0.76	0.28	0.00
Water*package	8	0.00	0.22	0.85	1.23	1.07	0.36	0.00
Error b	24	0.00	0.13	0.31	0.54	0.17	0.08	0.00
CV (%)		0.00	15.47	15.55	15.22	7.59	5.00	0.00
R^2		0.00	0.68	0.65	0.65	0.85	0.74	0.00
Mean		2.00	2.31	3.56	4.82	5.38	5.78	6.00

$\alpha = 0.05$

Appendix 17: Analysis of variance for fruit firmness in a split plot design at different days after harvest (Trial 1)

Source	df	Mean squares (MSS)					
		0 DAH	2 DAH	4 DAH	6 DAH	8DAH	10 DAH
Rep	2	34.13	41.25	56.65	46.21	38.65	13.37
Package	2	1.13	0.14	7.85**	5.59*	8.41*	3.29
Rep*package (error a)	4	2.87*	5.21*	7.05**	2.90	3.15	6.67**
CV (%)		36.43	57.79	78.32	47.97	50.00	91.91
Water	4	2.61*	4.04*	1.48*	0.08	1.42	0.91
Water*package	8	2.65*	0.90	2.09*	3.84*	1.98	1.32
Error b	24	2.77	1.77	1.39	1.59	1.99	1.67
CV (%)		35.81	33.75	34.80	35.50	39.77	46.02
R^2		0.63	0.75	0.84	0.79	0.73	0.65
Mean		4.65	3.95	3.39	3.55	3.55	2.81

$\alpha = 0.05$

Appendix 18: Analysis of variance for fruit firmness in a split plot design at different days after harvest (Trial 2)

Source	df	Mean squares (MSS)					
		0 DAH	2 DAH	4 DAH	6 DAH	8DAH	10 DAH
Rep	2	8.50	2.15	4.87	0.81	1.87	0.39
Package	2	0.45	10.45	0.34	4.95	3.69	7.77
Rep*package (error a)	4	1.03	1.10	6.88	0.99	0.46	2.99
CV (%)		17.90	21.90	58.68	22.66	15.48	42.28
Water	4	0.87	3.45	6.59	0.28	3.35	5.13
Water*package	8	2.94	2.29	1.12	0.57	2.47	1.38
Error b	24	0.69	1.51	1.32	0.69	1.69	2.04
CV (%)		14.62	25.57	25.69	18.84	29.64	39.91
R^2		0.75	0.63	0.70	0.56	0.53	0.55
Mean		5.67	4.79	4.47	4.39	4.38	4.09

$\alpha = 0.05$

Appendix 19: Analysis of variance for fruit TSS in a split plot design at different days after harvest (Trial 1)

Source	df	Mean squares (MSS)					
		0 DAH	2 DAH	4 DAH	6 DAH	8DAH	10 DAH
Rep	2	1.60	2.18	1.21	0.31	1.04	0.93
Package	2	0.37	0.06	0.23	0.16	0.37	0.36
Rep*package (error a)	4	0.38**	0.15	0.20	0.46	0.38	0.24
CV (%)		12.90	8.07	9.09	13.81	13.12	10.18
Water	4	1.50	2.85**	1.95**	3.42**	2.47**	3.79**
Water*package	8	0.18	0.31	0.20	0.28	0.19	0.15
Error b	24	0.30	0.28	0.25	0.42	0.30	0.33
CV (%)		11.52	11.11	10.25	13.19	11.64	11.88
R^2		0.64	0.74	0.68	0.65	0.69	0.72
Mean		4.78	4.80	4.92	4.91	4.70	4.81

$\alpha = 0.05$

Appendix 20: Analysis of variance for fruit TSS in a split plot design at different days after harvest (Trial 2)

Source	df	Mean squares (MSS)					
		0 DAH	2 DAH	4 DAH	6 DAH	8DAH	10 DAH
Rep	2	0.42	0.26	0.45	0.12	0.99	0.54
Package	2	0.06	0.03	0.46	0.07	0.60	0.55
Rep*package (error a)	4	0.76	0.12	0.26	0.36	0.17	0.25
CV (%)		17.64	6.86	9.58	11.67	7.71	9.49
Water	4	4.85**	1.88	4.02**	2.78**	1.87**	3.26**
Water*package	8	0.20	0.52	0.47	0.40	0.57	0.25
Error b	24	0.21	0.35	0.27	0.26	0.13	0.12
CV (%)		9.31	11.74	9.81	9.91	6.73	6.66
R^2		0.83	0.60	0.77	0.72	0.82	0.86
Mean		4.94	5.05	5.32	5.14	5.35	5.27

$\alpha = 0.05$

Appendix 21: Analysis of variance for fruit TA in a split plot design at different days after harvest (Trial 1)

Source	df	Mean squares (MSS)					
		0 DAH	2 DAH	4 DAH	6 DAH	8DAH	10 DAH
Rep	2	117.92	110.68	9.66	19.13	5.62	9.84
Package	2	1.15	13.67	2.68	0.98	0.13	21.21
Rep*package (error a)	4	7.27	5.90	6.53	7.73	5.75	6.38
CV (%)		35.29	29.84	34.96	32.79	31.80	32.26
Water	4	30.17*	22.88*	15.14	6.29	25.38	10.02
Water*package	8	15.11	11.03	1.67	5.94	4.13	1.72
Error b	24	8.58	6.42	6.90	4.01	8.62	8.61
CV (%)		38.33	31.13	35.94	23.63	38.92	37.45
R^2		0.71	0.75	0.43	0.60	0.45	0.41
Mean		7.64	8.14	7.31	8.48	7.54	7.83

$\alpha = 0.05$

Appendix 22: Analysis of variance for fruit TA in a split plot design at different days after harvest (Trial 2).

Source	df	Mean squares (MSS)					
		0 DAH	2 DAH	4 DAH	6 DAH	8DAH	10 DAH
Rep	2	7.17	64.41	11.04	0.19	3.85	8.91
Package	2	9.57	59.00	17.54	41.35	5.21	35.76
Rep*package(error a)	4	19.01	20.80	5.93	5.68	7.31	1.51
CV (%)		71.36	49.47	25.61	22.23	26.61	12.37
Water	4	10.97	58.41	36.93	54.32	31.06	37.74
Water*package	8	18.98	13.55	13.17	10.29	18.06	9.69
Error b	24	4.49	8.27	9.49	11.58	5.52	7.39
CV (%)		34.69	31.18	32.38	31.75	23.14	27.38
R^2		0.74	0.77	0.59	0.59	0.73	0.65
Mean		6.11	9.22	9.51	10.72	10.16	9.93

$\alpha = 0.05$

Appendix 23: SAS procedures used to analyse the laboratory split-plot experiment

```
title;
data fruit;
input REP $     Water $ PACKAGE   day0    day4    day8    day12  day16  day20  day24;
cards;

data

;
proc glm;
class Rep water package;
model day0 day4 day8 day12 day16 day20 day24=Rep package Rep*package water water*package/ss3;
test h=package E=Rep*package;
means package water/lsd;
means water*package;
run;
```