UNIVERSITY OF GHANA, LEGON

GROWTH, YIELD AND QUALITY OF HEAT TOLERANT TOMATO AS INFLUENCED BY DIFFERENT WATERING REGIMES

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DEPARTMENT OF CROP SCIENCE

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DECLARATION

I hereby declare that this thesis has not been submitted for a degree to any other university. It is entirely the student's own account of his research, except that for references to other people's work which have duly been cited.

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DEDICATION

I dedicate this work to the Almighty God.

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ABSTRACT

The need for regular production of high quality tomatoes in times of drought to meet the ever increasing demand of consumers has become critical as a means to reduce the importation of both fresh and processed tomatoes. Two experiments were conducted with a heat tolerant tomato (CLN2001A (Renamed Nkansah Heat Tolerant)) variety and a popularly grown variety (Pectomech) as a control. The design used was the Completely Randomized Design (CRD) with three replications. Watering stress treatments used were 250 ml, 500 ml, 750 ml, 1,000 ml and 1,250 ml. Each treatment had 36 plants.

The effects of induced drought /irrigation on growth parameters; Relative Growth Rate (RGR), Net Assimilation Rate (NAR), Specific Leaf Area (SLA), Leaf Weight Ratio (LWR), relative water content, plant stem diameter, plant height, number of leaves and chlorophyll content were studied. Yield parameters studied included number of fruits and fruit weight per plant whilst fruit quality parameters determined included fruit sugar content (brix) and pH at the University of Ghana farm.

The result indicated that, among the treatments, the 500 ml and the 750 ml produced the highest fruit yield and quality. The low and higher treatments of 250 ml and 1,250 ml recorded the least performance in terms of growth and yield for the CLN2001A cultivar. In terms of weight, however, the 1,000 ml treatment performed better than all the treatments.

The heat tolerant variety performed better at 500 ml and 750 ml in terms of yield compared with the non-heat tolerant variety that performed better at 1,000 ml and 1,250 ml.

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CHAPTER ONE

1.0 INTRODUCTION

Tomato (*Solanum Lycopersicon L*) belongs to the family *Solanaceae* and originated in Peru-Ecuador region of South America and is now cultivated widely throughout the world (van der Vossen *et al*., 2004)

Tomato is consumed in diverse ways including raw, as an ingredient in many dishes, sauces, salads, soups, stews, garnish and drinks. The fruit which is rich in lycopene has beneficial health effects and is the second most important vegetable used worldwide in terms of its vitamins and mineral contribution to diets (Sozzi and Fraschinal, 1997). Tomato cultivation also serves as a source of income and employment to many farming communities and households.

Currently, world production is about 100 million tons fresh fruit produced on 3.7 million hectares. China is the world's leading producer of tomatoes in both hectares of harvested production (1,255,100 hectares) and weight of fruit produced (30,102,040 Mt). The other top leading fruit-producing countries are the United States, Turkey, Italy and India (FAOSTAT Database, 2004). Production in Ghana in relation to demand is generally low. Available data suggest that overall production doubled between the 1970s/80s and the 1990s. In the 1970s and early 1980s tomato production fell from around 100,000 tons per year to around 50,000 tons per year. This increased in the late 1980s to around 100,000 tons. During the 1990s production expanded again, averaging around 200,000 tons per year by the end of the decade. However, there is a gradual decline in recent times. (IFPRI, 2010)

The major areas of production in Ghana include Navrongo, Pwalugu and Bolgatanga in the Upper East Region, Bontanga, Gulinga and Libga in the Northern region, Tuobodom in the Brong Ahafo

Region and Asante Akim, Akomadan in the Ashanti Region. Most of the cultivars commonly grown include Petomech, Yaqui, Henz, No name and Burkina. Production of these cultivars is hampered by high temperatures which lead to low fruit set and low yield. Availability or inadequate water supply to the plants also hampers growth and yield. In order to overcome high temperatures that result in low fruit set and low yields, Nkansah *et al.,* (2006) in a work on breeding for heat tolerance in tomatoes in Ghana using several tomato lines received from AVRDC, selected a heat tolerant tomato line CLN 2001A (aka Nkansah HT). Further agronomic studies in terms of nutrition, spacing and water requirements need to be effected using the selected heat tolerant tomato line before it is released to farmers especially in the dry season when there is insufficient water and the temperatures are high.

Heat tolerance in tomatoes is the ability to set fruits at night temperatures above 21^0C (Villareal and Lai, 1978; Nkansah and Ito 1994) and must have a higher net photosynthetic rate at 30-35^0C than a sensitive variety (Bar-Tsur *et al.*, 1985).

Tomato growth aside the temperature effect is also influenced by several environmental factors such as availability of water or drought, salinity and nutrition. Water stress is one of the most important limiting factors for agricultural and vegetable crops production as it affects the growth of the plants, reduces yield by lowering the quality, number and size of fruits, seed and other plant organs. (Pak, 2009)

In Africa and for that matter Ghana, most vegetable farmers depend on the rainfall for the supply of water for their crops. The privileged few who have access to irrigation facilities have little or no knowledge about the rudiments of crop water requirement such as the right amount, time and for maximum productivity.

Ironically, tomato cultivation is best in the dry periods when water supply is also a challenge to production. Availability of water has been observed to be a major limiting factor in tomato cultivation in Ghana particularly between January and March where the day and night temperatures exceed the recommended growth range. Consequently, most farmers are not able to make the best out of their lots during this period of the year and this has compelled the country to spend huge amounts of high currency to import tomatoes in order to meet the ever increasing domestic demand.

Water supply is a major constraint to crop production in Ghana. Efficient use of water by irrigation is becoming increasingly important and alternative water application and scheduling water application is very critical to make the most efficient use of any watering system, as excessive watering reduces yield, while inadequate water application causes water stress and reduces production. On the other hand, the intensity of the operation requires that the soil water supply be kept at the optimal level to maximize returns to the farmer. High-frequency water management by drip irrigation minimizes soil as a storage reservoir for water, provides at least daily requirements of water to a portion of the root zone of each plant, and maintains a high soil metric potential in the rhizosphere to reduce plant water stress.

For high yields, an adequate water supply and relatively moist soils are required during the total growing period. Reduction in water supply during the growing period in general has an adverse effect on yield and the greatest reduction in yield occurs when there is a continuous water shortage until the time of first picking. The period at the beginning of the flowering period is most sensitive to water shortage and soil water depletion in the root zone during this period should not exceed 25% (Ismael, 2010)

Water shortage just prior to and during early flowering reduces the number of fruits. The effect of water deficit on yield during this period is greater under conditions of high temperature and low humidity. Controlled irrigation is essential for high yields because the crop is sensitive to both over and under irrigation (Al-Harbi *et al.*, 2008). Therefore, apportioned water for agriculture has to be utilized in an efficient and rationalized manner especially for tomato production in the dry seasons. More so, the utilization among tomato cultivars need to be known in order to recommend to farmers the watering regimes of cultivars like the heat tolerant and non-heat tolerant types for the various growing season. This work was carried out to study the effect of different watering levels or regimes on growth, physiological characters, yield and fruit quality of heat tolerant and non-heat tolerant or tropical tomato cultivars.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Ecology and Climatic Requirement of Tomato

Tomato (*Solanum lycopersicum L.*) is a warm season crop and requires a well-drained, fertile soil with good water holding capacity with high level of organic matter. Tomato plant is very sensitive to temperature variations and regimes. Whilst low soil temperatures retard seedling growth and mineral uptake, high temperatures above 27^{o}C induce pollen sterility and high night temperatures are injurious to the productivity of the plant as it adversely affect flower initiation. The plant is largely self-pollinated but high temperature combined with high relative humidity is known to also hamper pollen dispersal (Tindall, 1988).

Air temperature variation of 6^{0}C, from a daily mean of 18.7 ^{0}C is considered necessary for optimum growth and development (De Konings, 1990).

This is particularly related to the maintenance of an adequate carbohydrate/nitrogen balance in the plant and functioning of enzymes regulatory system in promoting both growth and fruit setting (Tindall, 1988).

Night temperature of about 16-20^{o}c are considered adequate for most cultivars as temperatures below 13^{o}c impart negatively on pollination and fertilization resulting in alternate flower abortion. Ercan and Vural (1994) attributed low fruit set in tomato to low temperatures due to a decreased pollen count and viability.

High temperatures, on the other hand, may cause splitting of the staminal cone and also leads to fasciation of the style (Heuvelink, 2005) thereby hampering self pollination. Ercan and Vural (1994) who also had a low fruit set at low temperatures due to a decreased pollen count and viability.

Excessive rainfall and high relative humidity can be harmful to the plant, particularly if unstaked, due to the proliferation of diseases during humid conditions. Erratic irrigation may produce fruit cracking and splitting calcium or Potassium in the soil water may lead to physiological disorder known as blossom-end-rot (Tindall, 1988).

Light intensity has also been identified to be an important factor in determining the ascorbic acid content of tomato fruits. It is known that under low light intensities, the ascorbic acid is much lower than under high intensities. Hammer *et al.*, (1943) found out that there was an increase of 66% ascorbic acid content of tomato fruits when the plants were transferred from shade to sunshine at the time the fruit was mature green.

Some of the common tomato varieties cultivated in Ghana include Roma, Petomech, Royal, Burkina, NA, Power (Khor, 2006)

2.2.0 CROP WATER USE

Sixty to ninety-five percent of any physiologically active plant is made of water and tomato fruit is made up of 94.1% water (Kramer *et al.*, 1992). The ecological importance of water to plants is as a result of its physiological relevance. Almost every life process that takes place in the living plant is directly or indirectly affected by water availability. Water is required by plant for such processes as digestion, photosynthesis, transport of minerals and photosynthates, structural support (turgidity), growth and transpiration (James, 1988).Water forms an important constituent of the protoplasm. Water also serves as a solvent in which gases, minerals and other important solutes are dissolved and moved from one part to the other (Kramer, 1988)

2.2.1 Water as a constituent of the cytoplasm

Water is important both qualitatively and quantitatively, consisting between 80-90% of the fresh weight of woody plants. Water forms an important part of the protoplasm as the protein and lipid molecules which constitute the protoplasmic framework, and the reduction of water content below some critical level is accompanied by changes in structure and ultimately death (Kramer, 1955)

The membrane binding the outside of the cytoplasm is the plasmalemma which is highly permeable to water but only slowly and selectively permeable to solutes. The cell wall outside the plasmalemma is porous and permits water and solutes of low molecular weight to make rapid flow to and from the plasmalemma. Organelles in the cytoplasm such as the vacuoles, mitochondria, nucleus and plastids are also bound by a membrane similar to that of the plasmalemma and are capable of allowing the exchange of water and solutes with the surrounding cytosol. The high concentration of solutes with the surrounding cytosol dilutes the internal water compared to the outside and water enters in response causing the cell to swell and become turgid. Cells lose water when the solute concentration are high outside or when evaporation occurs and they shrink as the volume of water decreases inside (Boyer, 1995).

2.2.2. Consumptive water use (Transpiration)

Transpiration, defined as the evaporation of water from a living surface, accounts for 99% of water use by plant (Wilson *et al.*, 1962). The process of transpiration involves the transformation of water from the liquid to gaseous state. The process occurs when the vapour pressure within the leaf exceeds that of the surrounding air and stomata are open to permit the absorption of carbon dioxide into the plant for photosynthesis. Relative high level of water deficits and low leaf water potentials can occur within relatively short period of time, even less than an hour when transpiration is rapid and fast (Barrs and Klepper, 1968)

The rate of transpiration is given by $$T = \frac{^{e}\mathrm{leaf}-{}^{e}\mathrm{air}}{^{r}\mathrm{leaf}+{}^{r}\mathrm{air}}$$

Where;

T= transpiration
^{e}leaf=vapour pressure within the leaf;
^{e}air=vapour pressure of air
^{r}leaf=resistance to vapour flow through the stomata
^{r}air=resistance to vapour flow through the air boundary layer around the leaf.

Transpiration is facilitated with the opening of the stomata as ^{e}leaf usually exceeds ^{e}air. It is commonly assumed that the vapour pressure within the leaf equals the saturation vapour pressure for the temperature within the leaf, since there is usually at least some water in the leaf even if it is wilted (James, 1988)

The resistance term ^{r}air depends primarily on air movement as higher winds tend to break up the boundary layer surrounding the leaves and reduce ^{r}air. The resistance term ^{r}leaf for a given plant is mainly related to the degree of stomatal closure, that is, ^{r}leaf increases as stomata closes.

Water passes freely through the stomata when they are opened and the lost may be rapidly as though it were evaporating from a free water surface instead of through many small pores (Brown and Escombe 1900). Sayre, (1926) on the other hand, has shown that the rate of transpiration depends more on the perimeter of the opening, than on its area.

For continuous growth and development of the plant, it will have to extract water from the soil through the roots to replenish what is lost through transpiration. The plant achieves this by activating the process referred to as the passive absorption whereby water moves through the soil into the roots, up the xylem vessel and into the leaves due to a water potential gradient between the leaf and the soil (James, 1988)

$$Q = \frac{\Psi_{leaf} - \Psi_{soil}}{{}^{r}plant + {}^{r}soil}$$

Q=rate of flow

$_{leaf} = \Psi_{T} + \Psi_{\pi}$

Where

Q= rate of flow, Ψ_{leaf} = total water potential in the leaf, Ψ_{soil} = total water potential in the soil

Ψ_{T} = turgor pressure within the plant, Ψ_{π} = osmotic pressure within the plant

^{r}plant = resistance to water movement into the roots, up the xylem, and into the leaf

^{r}soil = resistance to water movement in the soil, the term ^{r}soil can also be written as ^{r}soil = 1/k

Where, K is the hydraulic conductivity of the soil (James, 1988)

2.2.3 Application of Water to the Plant

To ensure the optimum use of water for increased crop productivity, it is important to identify the right time to apply water. The methods used are generally classified into three indicators namely; Plant indicators, Soil indicators, Water budget technique (James, 1988)

Water budge technique; the plant and soil indicators pertains to observing the plant and soil in order to ascertain the most appropriate time to provide water to the crop. Of these two, the plant monitoring method is the most direct and commonest method used (James, 1988). Key indicators used in this method are; the appearance and growth of the plant; it is perhaps the simplest method and a visual indicator which takes into consideration leaf and shoot freshness and wilting status as well as the colour of the leaf. Visible wilting of the plant as indicator for the need to irrigate is, however, limited by the fact that by the time wilting becomes apparent substantial proportion of yield might have been lost already (Slatyer, 1967).

Measurement of the diameter and stem of the plant can also be made over time to determine the rate of growth whereby the need for water will be indicated by a low growth rate. However, appearance of the crop as a means of determining when to apply water must be done with caution since other conditions such as disease and insufficient nutrient in the soil may also produce changes in plant appearance similar to those associated with water stress (James, 1988)

Leaf temperature; sufficiently large air vapour pressure deficit results in cooling leaf canopy below ambient temperature. A reduction in soil water also results in lowering transpiration rate and thereby accounting for rising leaf temperature.The relative ease with which canopy temperature is measured by infrared thermometry, and the dominant influence of the vapor pressure deficit of the air on the difference between canopy and ambient temperature led to the development of a crop water stress index by Idso *et al*., (19782b) and Jackson *et a*l., (1977). The method is based on monitoring canopy temperature which results from the interaction of plant transpiration with the evaporative demand of the atmosphere (Jackson, 1982).

Leaf water potential; this method is a destructive one that involves the removal of the plant leaf and placing it in a pressurized chamber (called a pressure bomb). The pressure in the chamber is slowly increased until fluid is forced from the leaf stem. The pressure required is a measure of the moisture potential of the leaf. Challenges with this method are that leaf age, leaf exposure to sunlight, and time of day can significantly affect the result thereby giving a misleading indication on water requirement of the plant (James, 1988)

Stomatal resistance; it is an index to the need for water, since it is related to the degree of stomatal opening and the rate of transpiration. Whilst high resistance indicates significant stomatal closure, reduced transpiration rates signify the need for water. Challenges associated with this method are that it requires large amount of time and high skill level to make and interpret stomatal resistance James (1988).

2.2.4 Water stress and plant growth

Plant water stress, which can vary in degrees from a small reduction in water that can only be detected by the use of instruments to permanent wilting point leading to final plant death, occurs when plant cells and tissues are less than fully turgid (Kramer, 1969). Hsiao, (1973) also defined plant water stress as the condition where plant water potential and turgor pressure reduces sufficient enough to adversely affect the normal growth and function of the plant.

Plant water stress has been identified to be a very important problem that has over the years reduced crop plants productivity all over the world. The effects of severe cases of water stress on the photosynthetic ability of the plant are quite complex and may include a combination of processes associated with stomatal closure and ultimate decrease in plant growth (Chaves, 1991;

Sharkey, 1990). The closure of the Stomata occurs when the two guard cells surrounding the stomatal opening lose turgor pressure and close the opening (Outlaw, 2003). The reduction in photosynthetic ability of the plant which negatively affects other physiological activities of the plant is observed.

Yield losses due to water stress probably exceed losses from other sources depending on severity and duration (Barnabas *et al.*, 2008). Boyer, 1982, stated that water stress largely compromises plants development and productivity worldwide. Water stress reduces lint yield in cotton basically as a result of reduced boll production due to the production of fewer flowers and bolls (Stockton *et al.*, 1961). High ABA is has been identified as an important factor in pollen sterility in barley, wheat and rice (Saini and Westgate, 2000). Guin *et al.*, (1976) observed that, water stress increased the abscisic acid (ABA) content in young cotton bolls.

2.2.5 Plants Adaptation to Water Stress

In order for the plant to survive the harsh conditions of water deficiency and other forms of stress, some plants are known to have evolved means of adapting to water stress. Based on this, plants have been classified into three categories as follows; adaptation by acquired hardiness, adaptation by morphological xerophytism and adaptation by tolerance, (Leopold, 1964)

Adaptation by acquired hardiness; continuous exposure of plant to stress environments like drought, salinity, cold and high temperature hardens them for future introduction to similar conditions. Clement (1937) studied the changes found in leaves of plants that have been identified to perform well upon being subjected to dry conditions and found that there were changes in hemi-cellulose contents which he attributed the resistance attribute to. He observed that, plant developed constituents which help them to serve and retain water and therefore become drought resistant (Leopold, 1964).

In contrast to this cytological level of adaptation, Clark and Levitt (1956) produced evidence that plant drought hardiness could be attributed to a feature of the epidermis of the leaf. They observed that when soybean leaves were hardened and compared with their rates of water loss after excision with the water loss of unhardened leaves, leaves experienced slower water loss after hardening but that if they were sliced up, thus minimizing the epidermal influence, there was no longer a slower rate of water loss. Consequently, they suggested that the hardening was as a result of the accumulation of waxes in the cuticles associated with the drought experience.

Xerophytim; this a morphological adaptation of plants to dry conditions characterized by reduction in leaf size. Reduced plant size, leaf area and reduced leaf area index (LAI), have been identified to be important mechanisms adopted by plants in moderating water use and reducing injury under water stress (Mitchell *et al.*, 1998)

Plants with this type of adaptation are morphologically adapted to avoid dehydration by reducing the water loss per unit of leaf volume, others may also develop water-storage tissues inside the leaf or stem. In plants like sorghum, that are adapted to drought prone areas, older leaves are selectively killed in order to allow remaining younger leaves to maintain some level of turgidity, stomatal conductance and assimilation (Blum and Arkin 1984). Maximov (1929) observed that the morphological xerophytes transpired at about the same rates per unit surface as mesophytes when water was readily available but at slower rate during periods of poor water availability. Xerophytes are known to be plants that are able to withstand water stress by the use of internal photosynthetic utilization of CO_2 thereby permitting some assimilatory activity when gas exchange is limited (Leopold, 1964).

Dehydration; tolerance to dehydration is commonly observed in seeds. McIlrath *et a.,* (1963) studied the loss of water from tomato seeds during ripening of the fruits and found that the seeds actively lose about 50% of their free water during ripening. In seeds and resting plant parts, resistance to water stress appears to involve a binding of the cytoplasm associated with a nearly suspended respiratory activity. In vegetative parts, morphological devices permit the folding of cell walls around the cytoplasm during the drying process, avoiding the tearing of the cell structure or excessive cytoplasmic abrasion while the water shortage develops.

The flow of water through plants has evolved as a necessary means of their adaptation to terrestrial habitats. As multicellular plants extend their leaves into the air, transpirational flow occurs, sometimes over along vertical distances. At the cellular level, water stress exerts tremendous effects to the functions of the cells. Reactive oxygen species produced during water-deficit stress can damage many cellular components including lipids, proteins, carbohydrates and nucleic acids (Monk *et al*., 1987). Berlin *et al*., (1982) observed that subjecting plants to water stress led to significant changes in the grana and stroma lamellae, palisade cell walls, the number and size of chloroplasts and the structure of the mitochondria. Bondada and Oosterhuis (2002) also observed loss of chloroplast membrane integrity as a result of plant water stress.

Gaff, (1966) reported that dehydration of protein from cabbage leaves caused changes in the amount of reactive sulfhydryl which he attributed to changes in configuration of the protein.

2.3.0 Soil Water Forces and Forms

Between the particles of a soil are a complex interstitial channels and voids which provide space for moisture, air and soil organisms. The movement of Water in the soil is closely linked with storage because water potential is a function of water content (Richards 1931). The rate of water flow is also a function of the potential energy gradient and the ease with which water is transmitted through the pores within the soil, termed saturated hydraulic conductivity, is governed by pore size distribution and the myriad of its flow paths (Childs and Collis-George 1950)

Soil moisture, which basically is the amount of water above the water table, can be categorized into three main classes namely gravitational, capillary and hygroscopic. Of these, gravitational water is the part of water that remains above the water table shortly after rains or heavy irrigation before it drains under the force of gravity. This water takes a short time of a day or less and in clay it could take three or four days. The maximum amount of water remaining in the soil after gravitational water has drained away is the field capacity of the soil. This water content, usually expressed in millimeters, is very important for plant growth and development and defined as the moisture content of a deep, permeable, well-drained soil a few hours to several days after a thorough wetting. As a soil constantly drains and soils differ in the rate at which it happens there is not really a constant amount of water held against gravity. There are however few challenges such as restricting layers, high water table, surface evaporation, consumptive use by crops which affect its determination. To attempt to standardize definitions, the field capacity is defined as the quantity of water held at a particular suction pressure forty-eight hours after wetting, (Carruthers and Clark, 1981)

Hygroscopic water on the other hand is that water held tightly to the surface of the grains by adsorption and forms the water which is held by soil particles on soil surface. The water is held tightly around the soil particles due to cohesive and adhesive forces (Tindall, 1988). It is these forces that greatly reduce the water potential and thus not available to plant although some xerophytes may be able to draw this water in extremis (Wiesner, 1970)

Capillary water is held by surface tension around soil particles in smaller pore spaces and fissures. In the smaller pores of the soil, water is held against the force of gravity by capillary forces. This form of water is most important to plants and constitutes the only available source of water to plants. Capillary water can creep above water table to height determined by the soil texture and composition of the soil (Barrow, 1987)

2.3.1 Soil physical properties influencing irrigation

For irrigation to be successful and for that matter produce the ultimate result, there is the need to consider certain fundamental soil properties that determine the success or otherwise of the huge investment in irrigating the crop. Key among these factors are soil depth, soil texture, soil infiltration, soil moisture content, bulk density and soil porosity (Aragüés *et al.*, (2011). Soil organic matter has also been proved to influence water holding capacity of the soil, infiltration and porosity and soil compactibility (Carter, 2002).

2.3.2 Infiltration of water into the soil

Infiltration rate determines how long it will take rainfall or irrigation to water a plot of land for example a soil with 20mm/h infiltration rate will take four hours to absorb 80mm of water per unit area. When infiltration is slow, rainfall or water applied to the soil may be wasted by flowing away and possibly causing erosion or forming puddles from which evaporation losses become high (Barrow, 1987). To the extent that water infiltrates into and through the soil, it does not run off (Radcliffe and Rasmussen 2002). The infiltration rate refers to how fast water soaks into the soil and it is an important property of soils that affects the growth and development of the plant growing on it and the level of soil erosion. Generally, the lower the infiltration rate the greater the surface runoff, and thus the greater the potential for soil erosion occur. Movement of water into the soil is controlled by gravity, capillary action, and soil porosity. Of these factors soil porosity is most important. A soil's porosity is controlled by its texture, structure, and organic content. Coarse-textured soils have larger pores and fissures than fine-grained soils and therefore allow for more water flow. However, infiltration into some sandy soils is hindered because the particles are covered with a hydrophobic coating that prevents wetting (Jamison, 1946).

2.3.3. Soil Texture

The relative proportions of sand silt and clay determines the soil texture. This factor can be determined from grain-size distribution using textural classification chart. The size of pore spaces created in the soil matrix is mostly determined by the textural classification of soil. The soil texture, therefore, influences considerably the other phases (water and air) contained in the spaces of soil matrix. Relatively, sandy soil is characterized by its loose and non-cohesive nature and low water holding capacity. These features predispose such soils to the formation of relatively simple capillary systems, through which water and soil circulate in the soil thereby ensuring good drainage and aeration. Coarse textured soils are more prone to erosion by running water, thereby reducing the ability of the soil to retain water for a long time. Sandy soils are coarse textured and have high rate of permeability.

The clay particles, on the other, is characterized by its ability to hold more water and minerals due the facts that its it has large surface area resulting from its plate-like shape coupled with the fact that its particles are usually aggregated together into complex granules. Other features that play an important part in irrigation are the pore space, the bulk density and the water content (Seyed *et al*., 2011).

2.3.4 Soil Structure

Soil structure is the arrangement and binding together of soil particles into larger clusters, called aggregates or 'peds.' Aggregation of the particles enhances its stability against erosion, for maintaining porosity and soil water movement, and for improving fertility and carbon sequestration in the soil (Nichols *et al*., 2004). The aggregation is also important for increasing stability against erosion, for maintaining porosity and soil water movement, and for improving fertility and carbon sequestration in the soil (Nichols *et al*., 2004).

An important factor that exerts a tremendous influence on soil-water relation in plants growth and development is the way individual soil particles are arranged with respect to each other. The size of aggregates of the soil is a valuable criterion of soil structure determination. For example, sand-sized aggregates are believed to be more favorable for plant growth than very small and very large ones. This is explained by the fact that soils made up exclusively of silt-size aggregates cannot be drained by gravity, since the pores are too small. Large pores induce aeration and infiltration, medium-sized pores facilitate capillary conductivity, and small pores induce greater water holding capacity. Studies by Baver (1948) and also Nelson and Baver (1940) have shown that the percolation rate of water through soil is largely related to the quantity of large pores in the soil.

2.3.5 Permanent Wilting Point (PWP)

Leeper and Uren (1993) defined permanent wilting as the soil water condition at which the leaves undergo a permanent reduction in their water content (wilting) because of a deficient supply of soil water, a condition from which the leaves do not recover in an approximately saturated atmosphere overnight.

Wilting depends on the rate of water use, depth of root zone and water holding capacity of the soil. It is the lower end of available moisture range. As moisture is lost from the soil it reaches a point, called permanent wilting point, at which the force with which the remaining moisture adheres to soil particles exceeds that exerted by plant roots making it difficult for the growing plant to absorb water from the soil and as a result wilts to the point of not being able to recover overnight (Taiz and Zeiger, 1991). Miller and Donohue, (1995) defined permanent wilting point as the difference between soil water held at -33kpa. Richards and Wadleigh (1952) found that many herbaceous plants reach their permanent wilting point when the soil water potential ranges from 1.5-2.0MPa. However, Slatyer (1957) pointed out that permanent wilting point is not constant because wilting really depends on the potential at which leaf cells lose their turgor.

2.3.6 Plant Water up-take

Water absorption by plant occurs with the help of energy in the form of ATP, which is released due to metabolic activities of root cells such as respiration. Absorption takes place against concentration gradient - even when the concentration of cell sap is lower than that of soil water.

Water tends to move from the soil mass to root surfaces, then through the plant and into the atmosphere along a gradient of decreasing water potential. In some segments of this pathway, however, the effective driving force causing flow is not necessarily a simple gradient of total potential, and different component potentials may be responsible for disproportionate amount of flow, particularly when the flow water is accompanied by flows of heat, electricity or solutes Slatyer (1967).

Active or osmotic absorption occurs in slowly transpiring plants where the roots behave as osmometers whereas passive absorption occurs in rapidly transpiring plants where water is pulled in through the roots, which act merely as absorbing surfaces (Renner, 1912; Kramer, 1932).
Most of the solutes are moved into the root xylem by an active ion transport system, but some may be released by the disintegration of protoplasts in maturing xylem vessels (Hylmo, 1953; Kevekordes *et al., (*1988) and some are carried into roots by the transpiration stream. Cortes (1992) speculated that ions are released in the root interior because of the decreased membrane potential across the cortex.

Soil condition and properties also affect the availability of water and nutrients to the plants. Soil is composed of solid particles, water and air. The interactions between these give rise to two main mechanisms by which water is retained in the soil. These mechanisms involve forces emanating from either the liquid-air or solid-liquid interfaces of soil-water systems and their relative importance depends on largely on the degree to which to which the soil shrinks as water is removed from it (Slatyer, 1967).

Soil water affects plant growth directly through its controlling impact on plant water status and its effect on transpiration, digestion, photosynthesis, growth, transport of minerals and photosynthates, transpiration and structural support plant (James, 1988). Soil water content affects nutrient transport to the root surface by affecting the rate of diffusion and mass flow of water to the roots. In the mass flow, ions like nitrates, which are entirely soluble, are completely from the solution the mass flow of water. Barber *et al*, (1963) observed that mass flow can account for most of the transport of major elements like Ca, Mg and N.

2.3.7 Factors that determine Plant water Requirements

Tomato water requirements are affected by soil, plant, climatic and management factors.

2.3.8 Soil factors

The soil, and for that matter the growing medium, has a very fundamental influence that must be considered in designing planning amount of water to supply to the tomato plant. Key soil factors include water intake rate and available water holding capacity of soils with varying textures. In general, finer textured soils release water more gradually than those of course texture, because of a lower proportion of large pores. In sand soils, virtually all the water drains at soil water potential values close to zero predominantly because of large pores. Soils of intermediate texture on the other hand may retain more water between soil water potential values of -0.3bars to -15 bars than fine textured soils Slatyer (1967).

2.3.9 Morphological plant factors influencing crop water use

There are wide differences among plants of different species with respect to the depth, spread, and amount of branching and therefore the extent of root surfaces. The larger the volume of soil occupied by the root, the larger the volume of water available to it and the longer the plant can survive without replenishment of soil water by rain or irrigation. Miller (1916) attributed the greater drought resistance of sorghum to the fact that it has nearly twice as many fine roots as corn. Slatyer (1955) likewise reported that sorghum has better-developed root system than cotton or peanuts. Sorghum also maintains a higher level of turgor than cotton or peanuts when subjected to drought. This presumably is largely because sorghum has a more extensive absorbing surface, although better control of water loss may also be a factor Kramer (1969).

Taylor *et al*., (1934) concluded that plants can absorb enough water to replace transpiration losses if one-fourth to one-half of the root system is in soil above permanent wilting percentage.

Plant rooting depth and density are among the main drought avoidance traits identified to confer seed yield in chickpea under terminal drought environments (Subbarao *et al*., 1995).Shallow rooted plants like tomatoes require relatively frequent water supply for optimum crop yield. Solar radiation, temperature, wind, and relative humidity are the driving forces behind evapo-transpiration and therefore determine water use by plants. In the rain fed environments, plant rooting depth is often cited as an important factor because it has a major influence in determining the potential supply of water from the deep soil and thus improves yield Krishnamurthy *et al*., (2003). Over a wide range of climatic conditions, the simple product of air temperature and radiation can be used to estimate maximum tomato water use (Tan, 1980).

Plants with certain unique morphological traits and features that make them cope better to stress conditions and such plants are known to withstand heat stress better. Firstly, plant factor of extreme importance in determining its level of water stress resistance is the nature of the rooting system. Some plants develop long root length which has good ability to uptake water and nutrients from the soil surface. Kamoshita *et al*., (2000) in a pot experiment observed that genotypes with higher root length density at a depth of 30 to 40 cm extracted more soil water from deeper soil during drought.

Others develop deep rooting systems also under water stress. Where some roots extend beyond the bulk of the root system and absorb water against low soil moisture stresses, they may mask the effects of relatively high soil moisture stresses occurring over the remaining part of the root system.

Secondly, a key morphological feature of some plants like tomato that makes them withstand a varying degree of drought is its apparent hairiness which can make it check transpiration to some extent (Martin and Juniper, 1974). Thirdly, plants with small leave size are also known to be better at withstanding stress by resisting water loss resulting from evaporation through shortening of its stomata. Reduced plant size, leaf area and leaf area index are important adaptation mechanisms by plants in enhancing water use efficiency and reducing injury in drought conditions (Mitchel *et al.*, 1998)

Lastly, other plants tend to survive harsh periods by changing the intensity of the physiological processes and the position of organs or by rolling their leaves as may be found in grasses (Fernandez and Castrillo, 1999; Kadioglu and Terzi, 2007; Saglam *et a*l., 2008). Richards *et al.*, (2002), suggested that leaf rolling during period of drought may be important in maximizing photosynthesis by reducing plant water loss.

2.4. 0 Heat tolerance and Biochemical Mechanisms for Heat Tolerance

Generally, the ability of an organism to survive heat stress within its tissues is known as heat tolerance. The heat tolerance of higher plants differs directly with their natural habitat. Heat tolerance in tomato is defines as the ability to set fruits under night temperatures above 21^{o}C (Villareal and Lai, 1978; Nkansah *et al*, 1994). In other crops like cabbage, the definition is based on genetic basis which is said to be the ability to produce compact heads under mean temperatures not less than 25^{o}C (Opena and Lo, 1979).

Plants are subjected in one way or the other to several stress conditions that go a long way to impede their smooth growth and development. Whilst some of these stresses on growth may be due to biological factors such as diseases and pests conditions, others are as a result of abiotic factors such as nutrient deficiencies, drought and salinity. Wang *et al*., 2003, observed that drought and salinity were becoming particularly widespread in many parts of the world and have the tendency to cause serious salinization of more than 50% of all arable lands by the year 2050. Abiotic stress resulting from drought, salinization, flooding and high temperatures has been reported to be one of the major causes of crop loss worldwide, reducing average yields for most major crop plants by more than 50% (Wang *et al*., 2003). Among these stress factors, the impact of water stress is very critical as it leads to reduced photosynthesis, respiration and ion uptake, changes in the metabolic and growth patterns in the plant and in several cases results in plant death (Jaleel, *et al*., 2009a)

Plants have developed several responses that involve a series of physiological, biochemical and molecular processes resort to during these unfavorable periods.

Acquired stress tolerance in plant is often a result of various stress-response mechanisms that act coordinately or synergistically to prevent cellular damage and to reestablish cellular homeostasis Wang (2003).

Elucidating the various mechanisms of plant response to stress and their roles in acquired stress tolerance is thus of great practical and basic importance. Much research is devoted to some of the major tolerance mechanisms, including ion transporters, osmoprotectants, free-radical scavengers, late embryogenesis abundant proteins and factors involved in signaling cascades and transcriptional control Wang (2003).

In order to survive various stresses that a plant may be subjected to, the plant has various mechanisms. One of the most important mechanisms adopted by plants is the production of various compounds like plant hormones among which is abscicic acid (ABA).

ABA is a naturally occurring compound in plants which is partially produced via the mevalonic pathway in chloroplasts and other plastids. It is a sesquiterpenoid (15-carbon). The production of ABA is stimulated by stresses such as water loss and freezing temperatures. Kermode (2005) also attests to the roles played by Abscisic acid during periods of stress when he defined its function as mediating plant responses to abiotic stresses, including drought, salinity, and low temperature, and acts with other phytohormones to regulate plant growth.

Davies, 1995; Raven, 1992; Salisbury and Ross, 1992 suggested some physiological responses known to be associated with the production of abscisic acid by plant as follows; stimulation of the closure of stomata emanating from water stress; inhibition of shoot growth and under certain circumstances may even promote growth of roots for extraction of moisture further away from the normal root zone; induction of seed dormancy; induction of gene transcription especially for proteinase inhibitors in response to wounding. All these processes are important mechanisms that facilitate plant tolerance for various stress conditions.

2.4.1 Effect of Abscisic Acid (ABA) and xylem sap pH in Plant Drought Resistance

Abscicic acid plays primary regulatory roles in plant's response to stress, especially water stress. It also interacts with auxin, cytokinin, gibberellins and ethylene, usually as an antagonist, to influence many aspects of development and the response to stress Bacon (2004)

Levels of ABA fluctuate dramatically in specific tissues during development or in response to changing environmental condition, whether or not this is 'stressful'. Almost all cells can synthesis ABA (Culter and Krochko, 1999), and it is transported around the plant via both xylem and the phloem. As soils dries around the root these synthesis ABA. ABA in stressed roots do not only maintain their growth rates such that they can continue to access water from the soil (Munns and Sharp, 1993), but also increases root hydraulic conductivity (Glinka and Reindolf, 1971) by ,modifying root membrane properties such that they can take up more water per unit surface area. Both effects of ABA in the root can lead to an increase in water use efficiency. Some of the ABA synthesized in the roots is transported to the shoot with the xylem to accumulate in the leaves.

ABA can also be synthesized in the leaves experiencing soil drying-or air-drying-induced changes in water status. This can accumulate in the leaf and/or be transported down to the root in the phloem, and back to the shoot via the xylem. In the leaf, ABA induces stomatal closure, which is one of the most important factors controlling transpirational water loss and one of the most important factors controlling transpiration water loss and water use efficiency under stressful conditions. Mutants that lack the ability to synthesize ABA, exhibit permanent wilting because of their inability to close their stomata. These have been termed *wilty mutants*, and examples include *flacca* in tomato and Az34 in barley. The applications of exogenous ABA to such mutants restores stomatal closure and shoot water status to wild-type levels (Imber and Tal, 1970).

ABA also induces reduction in leaf and stem growth rates, reducing the transpirable leaf surface area and preserving water. ABA also greatly accelerates the senescence of leaves (Zacarias and Raid, 1990), while ethylene induces their abscission. Both processes reduce the leaf surface area over which water can be lost, thereby improving water use efficiency. ABA can also reduce the xylem osmotic potential to increase water flux across the root or stem (Glinka, 1980). This helps to prevent xylem embolism in stressed plants. ABA is arguably the most important stress response hormone involved in the modulation of water use efficiency in plants.

2.4.2 How the ABA/pH signal works

An increase in xylem sap and/or bulk leaf ABA concentration is often associated with soil and/or air water deficit and found to be required for the water-retentive response that occurs in the shoot (stomatal closure or reduced leaf growth). However, in reality the ABA-based chemical signally system is much more complex than a simple up-regulation of root (or shoot) ABA biosynthesis and xylem ABA transport to the leaf. Decreases in stomatal aperture and leaf growth rate frequently occur before any increase in the total, or bulk leaf ABA content can be measured (Cornish and Zeevaart, 1985) and even before increases in xylem sap, ABA can be observed. Despite this the response observed are still dependent on the presence of ABA in plant. This is because, the strength of the ABA signal perceived at its final site of action (taking the stomatal guard-cell membrane as a particular example) is influenced in many ways along its journey from root to shoot (and shoot to root), and does not always reflect coarser measurement of ABA concentration. This means that arbitrary measurements of, for example, xylem sap ABA concentrations, are often not indicative of the ABA concentration at its ultimate site of action, i.e. of that to which the stomata respond. This has been elegantly demonstrated by Zhang and Outlaw (2001a), who were able to measure the ABA concentration at its ultimate site of action, the tiny volume of liquid-filled space around as single guard cell pair (the guard cell apoplast) as a separate sub-component of the bulk-leaf apoplastic ABA concentration (this being a sub-component of the total bulk tissue ABA concentration) These authors found that mildly stressing *Vicia faba L*. roots could increase the apoplastic guard-cell ABA concentration in the absence of a change in total bulk leaf or xylem sap ABA concentration and even in the absence of a change in the bulk apoplastic ABA concentration. The apoplastic guard cell ABA concentration correlated with changes in stomatal aperture most effectively. Such localized changes in ABA are the result of factors that affect the extent to which the cells of the leaf area able to 'filter out' a portion.

The ABA carried into the leaf by xylem vessels is less readily filtered out of the apoplast by the cells of the leaf that it encounters on its passage towards guard cells. The concentration of ABA that remains in the transpirational stream by the time it reaches the guard is cell is less affected, and remains high enough to induce stomatal closure. All this can occur without an increase in ABA input anywhere in the system. Thus, the pH change that occurs as soil (or air) dries can function as a root (or leaf) sourced chemical signal that alerts the shoot of the need to conserve water and increase its water use efficiency, and provides means by which to do so. As stress develops further, a combination of increased xylem ABA and sap alkalinzation will provide an even stronger signal to the shoot than either signal could have done alone (Bacon, 2004).

As well as increasing the residence time of xylem-sourced ABA in the leaf apoplast (by reducing the ability of leaf cells to remove ABA from the transpiration stream), a pH change can increase the local (ABA) at the guard cells apoplast in other ways. A change in pH of the xylem sap can gradually increase the ABA concentration in the xylem sap before it reaches the leaf in the absence of *de novo* ABA synthesis, Bacon (2004). This comes about because the increase in sap alkalinity induces ABA stored in the stem parenchyma to be released into the xylem lumen (Sauter and Harting, 2002). It may also be the case that the greater proportion of the ABA synthesized in the root (or transported to the root from the shoot) will enter the xylem vessels when the pH of the xylem cell sap is higher. There is indirect evidence to support this hypothesis (Slovik *et al.* 1995). In addition, root dehydration has been shown to increase the ability of the root cell to release the ABA that they contain/synthesize, by causing cytoplasmic acidification (Daeter *et al,* 1993). This may change the pH gradient over the root cell membrane in favour of ABA release to the root apoplast, from where ABA can more easily enter the xylem vessels.

There is also some evidence to suggest that an increase in leaf apoplastic alkalinity will reduce the export of ABA out of the leaf via the phloem, as loading of ABA into this transport conduit will also depend on pH gradients (Jia and Zhang, 1997; Wilkinson and Davies, 2002). Some work provides evidence to suggest that the increased pH of the leaf apoplast actually causes the release of ABA from stores in leaf mesophyll cells (Hartung *et al.*, 1983), to enrich the ABA in the apoplast sourced from the root, the stem and the xylem. However this may only occur under more severe stress when leaf-water deficits occur and leaf cell cytoplasm becomes acidified (Kaiser and Hartung, 1981). This may be one way in which chemical and hydraulic signals interacts. The net result of all these pH-dependent processes is an accumulation of ABA to physiologically active concentrations in the leaf apoplast adjacent to the guard cells, often in the absence of measurable increases in the bulk tissue or even of xylem sap (ABA), and before shoot water status is affected by the stress. In addition, non-pH mediated stress-induced increases in the ABA signal all contribute to the raised guard cell apoplastic concentration. The obvious inclusion here is *de novo* ABA synthesis in the root(or leaf), but there is also some evidence for a stress induced reduction in the ability of the cells of both the root and the leaf to catabolise ABA(Liang *et al.*, 1997)

In addition, stress-induced pH changes may be more pronounced when leaf apoplastic sap is sampled, as opposed to xylem sap sourced from closer to the root system (Hoffmann and Kosegarten, 1995). Liu *et al*. (2003) sampled sap from de-topped root. Measurement of xylem sap pH in earlier studies in which de-toppd roots were sampled also have resulted in under-estimations of the stress-induced pH change (Bacon *et al*., 1998).

2.4.3 Accumulation of proline in tissues as means of adjusting to water stress.

Wilson *et al*., 2009, observed that most plants adapt to low water potential (ψw) that occur during various forms of stress by resorting to several changes in their metabolite levels and the activity of specific metabolic pathways. Much research work has been done in this area of plant response to stress. Proline is known to accumulate in many plant species under a broad range of stress conditions such as drought, salinity, and high-radiation intensity, heavy metals, and oxidative stress. Proline accumulation can also be observed with other stresses such as high temperature and under starvation (Sairam *et al*., 2002). The accumulation of proline in plant tissues is also a clear marker for environmental stress, particularly in plants under drought stress (Routley, 1966).

Proline is an amino acid that is produced by higher plants in response to stress in their growing environment and its accumulation is one of the main metabolic responses to abiotic stress in plants. Work done by Kaplan *et al*., (2007); Sharma and Verslues, (2010) showed that high levels of Proline accumulation are typically seen in response to low water potential whilst reduced levels are observed in direct response to salt or cold. Ben-Hassine *et al*., (2008); Parida *et al*., (2008); Evers *et al.*, (2010) also reported that Ecophysiological observations confirm the role of proline in drought adaptation by heat tolerant plants. During periods of stress, this compound provides intracellular protection against water loss, a process of profound economic and agronomic importance. Stressed plants proline accumulation is believed to take place primarily in cytosol in order to offset the imbalances in the osmotic potential of the vacuoles in which non-compatible solutes like inorganic ion (particularly potassium ions) are impounded.

The importance of drought-induced proline accumulation by plants in times of drought and how it facilitates drought resistance has attracted the attention of many research works. Traditionally, proline has been thought of mainly as a compatible solute that accumulates as part of osmotic adjustment (Voetberg and Sharp, 1991)

Szabados and Savoure,(2010) found out that proline is involved in redox buffering and the storage of energy and reductance. These vital roles are, however influenced by some vital factors such as the spatial and temporal control of the synthesis and metabolism, which indicate whether there will be a take-up or release of a reductance and energy at the requisite part of the plant and also time to satisfy plants need (Sandeep, *et al*., 2010)

Proline synthesis is also thought to be a mechanism to regenerate $NADP^+$ in the chloroplast and thus prevent photoinhibition caused by a lack of appropriate electron acceptors (Hare and Cress, 1997), there is strong evidence to support such a role in the root growth zone at low ψw (Voetberg and Sharp, 1991).

In Arabidopsis seedlings at low ψw, osmotically significant levels of Pro (50–100 µmol g−1 fresh weight, roughly equivalent to 50–100 mm) are routinely observed in our laboratory (Sharma and Verslues, 2010). Such osmotic roles, as well as other potential roles in protecting cellular structure or ROS detoxification, depend on high bulk levels of Proline and have led to a "more-is-better" strategy of generating transgenic plants that constitutively overexpress P5CS1 or suppress PDH1 to increase Proline contents and, presumably, salt or drought resistance (Kishor *et al*., 1995; Zhu *et al*., 1998; Nanjo *et al*., 1999a; Hong *et al*., 2000; Sawahel and Hassan, 2002; Parvanova *et al*., 2004; Vendruscolo *et al*., 2007).

There are proposed roles, which depend on spatial and temporal control of Pro synthesis and catabolism to either take up or release reductant and energy at the correct place and time to meet the plant's needs and do not lend themselves as well to the more-is-better theory of Pro accumulation, that are known to be performed by Proline during periods of drought. Notable among them are redox buffering and storage or transfer of energy and reductant (Szabados and Savouré, 2010; Sharma and Verslues , 2010). Of particular interest is the fact that both P5CS1 and Δ1-PYRROLINE-5-CARBOXYLATE REDUCTASE (P5CR), which catalyzes the second step of Pro synthesis, prefer NADPH to NADH as an electron donor (Zhang *et al*., 1995; Murahama *et al*., 2001). It has been suggested that Pro synthesis could be a mechanism to regenerate NADP+ in the chloroplast and thus prevent ROS production and photoinhibition caused by a lack of appropriate electron acceptors (Hare and Cress, 1997; Hare *et al*., 1998; Szabados and Savouré, 2010; Verslues and Sharma, 2010).

2.5.1. Effects of High Temperature on Photosynthesis

High temperature has been known to play critical roles in the growth and yield of plants by speeding up chemical reactions within the plant. Certain plants are better performers under relatively adverse temperature environments such as that above or below the optimum required for important physiological functions in plants. Heat tolerant tomatoes are cultivars which have the ability to set fruits at night temperatures not lower than 21^{0}C (Nkansah and Ito, 1994). Bar-Tsur *et al*., (1985a) observed that heat tolerant tomato varieties have higher photosynthetic ability than sensitive cultivars. The effects of high temperature on the photosynthetic functions of plants are felt on its rate of chemical reactions and structural reorganization. Berry and Bjorkman, (1980) reported that high temperatures are responsible for changes in the thylakoid membrane, altering not only its physicochemical properties, but also its functional organization. High temperatures alter the functioning of the oxygen-evolving system (Yamashita and Butler, 1968), resulting in the release of functional manganese ions from the complex (Nash *et al.*, 1985). Thomson *et al*., (1989) attributed this release to the reduction by peroxides or superoxides.

2.5.2 Effects of Temperature on Photosynthesis, Respiration and Transpiration

Photosynthesis is highly temperature sensitive, and biomass and yield are proportional to the potential for crop photosynthesis (Loomis and Williams, 1963; Tollenaar and Bruulsema, 1988a). Stomatal conductance is a process that is directly responsible for the ingress of carbon dioxide to the leaf and may therefore be seen as the first point of control of crop photosynthesis. Temperature induced stomatal closure does not appear to reduce photosynthesis as shown by the fact that changes in stomatal conductance are not consistent with the response to of photosynthesis to temperature (Slatyer, 1977); that is, stomatal conductance increases at temperatures that are high enough to irreversibly damage photosynthesis (Bjorkman, *et al*,. 1975).

Although stomatal conductance does not directly appear to affect photosynthesis, it does help regulate transpiration, which is most likely to affect the response of photosynthesis to heat stress by modifying leaf temperature. In crops with an adequate supply of, moisture, canopy temperatures may be as much as 8^0C below the ambient as a result of transpirational cooling (Reynold *et al.*, 1994). This is in sharp contrast with stress resulting from drought or crops exposed to high temperature, where leaf temperatures may be up to 15^0c above the ambient (Altschuler and Mascarenhas, 1982). As a matter of fact, high temperatures will result in greater stress if accompanied by drought induced stomatal closure.

The impact of high temperature in the yield and quality attributes of crops could be enormous depending on the duration of exposure and the intensity. Most determinants of potential grain number in wheat are highly sensitive to temperature and are reduced in proportion to duration of preanthesis development. The number of tillers, and consequently ears per plant is reduced by elevated temperature (Rawson, 1986), and both spikelets per ear and the number of florets per spikelet tend to decrease as temperature rises above about 15^0c in the preanthesis period (Fischer and Mauwer, 1976; Shpiler and Blum, 1986). Consequently, the potential number of grains/m^2 is significantly reduced by increased temperature, and this generally results in severe yield losses, as the reduction in grain number does not appear to be compensated for by an increase in individual Kernel mass (Wardlaw *et al*., 1980)

Elevated temperatures may reduce crop yield by three main mechanisms:

a. If the increase in rate of organ production at elevated temperature is not as great as the increase in rate of development, then elevated temperature may result in fewer organs or phytomers being produced in each developmental phase.

b. If at elevated temperature, the increase in rate of growth of a given phytomer or yield component is not commensurate with increase in rate of development , then the organ or yield component will be reduced in size; and

c. Biomass and yield are frequently related to the total amount of radiation intercepted by the crop (Loomis and Williams, 1963; Hunt and Pararajasin-ham, 1995), and by reducing the duration of crop growth, and elevated temperatures reduce the time over which radiation can be absorbed and, hence, cumulative radiation interception.

CHAPTER THREE

3.0 MATERIALS AND METHODS

Two experiments were conducted in a greenhouse at the University of Ghana Forest and Horticultural Crops Research Centre (FOHCREC), Kade between September 2012 and May, 2013. FOHCREC-Kade is in the forest zone which is 114m above sea level on latitude 60.0854’N and longitude 00.5400’W and located in the Kwaebibrim District of the Eastern region of the republic of Ghana. The dominant soil of the centre is the Haplic Acrisol (FAO/UNESCO, 1990). The area which lies in the deciduous forest has an annual rainfall ranging between 1300-1800mm (Nkansah *et al*., 2007: Ofosu-Budu, 2003). The area is subjected to marked wet and dry season with a bimodal rainfall pattern. The two rainfall peaks make two growing seasons possible. There is heavy rainfall in May-July, which is interrupted by a dry period of about two weeks in August; this is followed by another period of heavy rainfall from September to October. Dry season length is between 120 -130 days. Temperature ranges between 25-38^{0}C. The experiment was conducted in screen house with two different tomato varieties, the control (Pectomech) and a heat tolerant variety (CLN 2001A/Nkansah Heat tolerant). The research was conducted twice with the first one from September, 2012 to January 2013 and the second one from February 2013 to May, 2013, which happens to fall within periods of high temperatures. The minimum and maximum temperatures recorded in the screen house during the growing period was between 25 and 31^{o}C respectively.

3.1.0 Experimental Design and Layout

One hundred and eighty plants each of the control variety and heat tolerant tomato varieties were used. Five water treatments were adopted. These include 250 ml, 500 ml, 750 ml, 1,000 ml and 1,250 ml /plant /week.

3.1.1 Planting and agronomic practices

In each of the experiments, seedlings were raised in seed boxes filled with a mixture of carbonated rice husk and haplic acrisol soil series in a ratio of 1:3. Seedlings of uniform size and height were transplanted into the poly bags when they were 3 weeks old.

The plants were grown in poly bags of 30 cm x 25 cm size filled with 6kg haplic acrisol soil series from the University of Ghana Forest and Horticultural Crops Research Centre at Kade. The growing medium had the following composition: Clay = 27.10%, silt = 29.92%, sand = 41.45%, organic matter = 1.53%, p^H = 5.10, N = 0.13%, Total P = 26.5 Mg/kg, available P= 10.18 Mg/kgCa = 2.40 Cmol/kg, K = 0.54 Cmol/kg, Mg = 0.80 Cmol/kg and Electrical Conductivity = 291.00 µS/cm. The plants were then arranged in a Completely Randomized Design.

In the first experiment, which was conducted between 28th September 2012 and 4th January 2013, sowing was done on 28th September 2012 and transplanted on the 19th of October, 2012. Application of 15:15:15 NPK fertilizer at the rate of 3.00 g per plant was done on 26th October 2012. The plants were staked on 2nd November, 2012. First Harvesting and Weighing of fruits were done on 24th December, 2012.

In the second experiment sowing of the seed was done on 4th February, 2013 and transplanted on 25th February 2013. Application of 15:15:15 NPK fertilizer at the rate of 3.00 g per plant was done on 18th March, 2013. Each plant was staked on the 25th of March, 2013. First harvesting and weighing of fruits were done on 27th April, 2013.

3.1.3 Determination of relative water content

Five matured leaves from newly developed and expanded leaves per treatment were used. The fresh weight per leaflet was recorded after which the leaves were floated on distilled water at light compensation point at room temperature for at least 24 hours. They were then blotted dry and their turgid weights determined. They were then oven- dried under a temperature of 75^0c for 48hours and their dry weights recorded.

The relative water content (%) was calculated from the formula below:

$$RWC(\%) = \frac{Wf - Wd}{Wt - Wd} \text{x } 100$$

Where,

RWC= relative water content, W_f = Leaf fresh weight (g), W_d= leaf dry weight (g)

W_t= leaf turgid weight (g)

3.1.4 Determination of plant height, diameter and leaf number

Plant height (cm) was measured with a measuring tape, stem diameter with a verneer caliper (cm) and number of leaves counted. Measurements were done four weeks (vegetative stage) and nine weeks (flowering stage) after transplanting.

3.1.5 Determination of chlorophyll content

Ten plants per treatment were selected for the chlorophyll content determination. The chlorophyll meter was employed in recording 10 leaves per plant after which the average was recorded.

3.1.6 Determination of Relative growth rate (RGR), Net Assimilation Rate (NAR), Leaf Weight Ratio (LWR), Specific Leaf Area (SLA) and Leaf Area Ratio (LAR)

Three destructive samplings were conducted whereby the fresh weight of the plant was taken before being oven-dried for 76hours. The dry weight of the plants was then recorded after oven drying. The leaf area of the plants was determined using a Leaf Area Meter (Leaf area meter, YMJ-A, Japan)

The following formulae were used to calculate the different growth indices;

$$\text{RGR}=\frac{lnWf-lnWi}{t2-t1} \qquad NAR=\frac{Wf-Wi}{t2-t1}X\frac{lnAf-lnA1}{Af-Ai} \qquad \text{LAR}=\frac{\text{L.A}}{TPDW}$$

$$\text{SLA}=\frac{\text{LA}}{LDW} \qquad \text{LWR}=\frac{\text{LDW}}{TPDW}$$

Where;

RGR= Relative Growth Rate, NAR= Net Assimilation Rate, LAR= Leaf Area Ratio, SLA= Specific Leaf Area, LWR= Leaf Weight Ratio, W_f= final dry weight, W_i= initial dry weight

A_f=leaf area at reproductive stage, A_i =Leaf area at vegetative stage

$T_2 - T_1$= Time lapse between the vegetative stage and reproductive stage.

3.1.7 Determination of shoot:root ratio

Five plants each from the five respective treatments were taken and the loose soil completely washed from the roots. The plants were then blotted remove water from the roots after which the root was severed, at the soil line, from the shoot. The individual roots and shoots were bagged separately and oven-dried for 76 hours at a temperature of 75^{o}C. The dried roots and shoots were then weighed on weighing scale and the weights recorded accordingly. The shoot:root ratio was determined as the ratio of shoot/root.

3.1.8 Determination of fruit number and fruit weight

Fruit weight (kg) and fruit number were recorded each time harvesting was done. Ten fruits plants per treatment per replication for both varieties were used. The mean of the ten plants was used to determine the fruit weight and number of fruits per plant. The fruit weight was determined by selecting 10 fruits per treatment each time harvesting was done and weight determined on the weighing scale and the average weight recorded.

3.1.9 Fruit quality determination

3.1.10 Sample preparation

Ten fruits per treatment per replication for both the heat tolerant variety and the control were randomly selected. The selected fruits were then cleaned, cut opened and macerated in a blender. Samples from the macerated material were used for the determination of the fruit quality parameters: pH and Soluble solids.

3.1.11 Determination of soluble solids content

A thin film of the macerate tomato samples was smeared on a brix Hand Refractometer and the soluble solids content read as percentage sugar.

3.1.12 Determination of pH

A thin film of the macerated fruits applied on the pH meter whereby the pH readings recorded accordingly.

3.1.13 Determination of free proline

Tomato leaves and roots were used for proline analysis in this study. Free proline in the plant parts was determined with method according to Bates *et al*., (1973) with some modifications. 0.1g of leaves and roots of the tomatoes were weighed and put in a test tube. 10ml of $CaCl_2$ was added to each test tube and put into water baths at different temperatures (4, 25, 35 and 45^0C) for 24 hours. Samples were then harmonized with 1ml of 3% (w/v) sulfosalicyclic acid 0.5 ml of the supernatant 0.5ml of acid ninhydrin and 0.5 ml of glacial acetic acid were mixed in a test tube and reacted in water bath/heater at 100^0C for I hour. The reaction was completed by cooling in an ice bath. 1ml of toluene was added to the mixture. The mixture was then shaken vigorously and left for a while. 1ml of the upper layer was collected and measured with a spectrophotometer at A_{520}.

3.1.14 Determination of Number of Seeds per fruit/seed quality

Ten fruits per treatment per replication were randomly selected and the seeds extracted and the number recorded. 50 seeds per treatment were subjected to germination test and the number of seeds that germinated per treatment also recorded to assess the germination percentage as a measure of seed quality.

3.1.15 Germination test

Seeds were extracted from twenty fruits per treatment and then fermented in pulp and juice at ambient temperature for two days after which the seeds were dried on tissue paper. Germination test was conducted by placing 25 seeds each form the various treatments in each petri dish on two layers of Whatman No.1 filter paper moistened with deionized water and covered. The germination of seeds was counted daily for 8 days. Seed germination count started from the 8th day after sowing and a seed was considered as germinated when 3-4 cm long radicle was visible outside the seed coat (Fernandez and Johnston 1995).

3.1.15 Statistical analysis

Data was subjected to analysis of variance (ANOVA) using the statistical program GenStat® version 11.1. Treatment means were separated using Fisher's protected T-test least significant difference (LSD) at 5% level of significance.

4.0 CHAPTER FOUR

4.11 Comparisons of Relative Growth Rate (RGR), Net Assimilation Rate (NAR), Specific Leaf Area (SLA), Leaf Weight Ratio (LWR) and Leaf Area Ratio (LAR).

The results in Tables 1, 2, 3, 4 and 5 indicate that different watering regimes significantly affected RGR, NAR, SLA, LWR and LAR of the heat tolerant and non-heat tolerant tomato cultivars. There were significantly differences between the two cultivars. Pectomech had significantly higher RGR, NAR, SLA, LWR and LAR compared to the heat tolerant cultivar (Tables 1, 2, 3, 4 and 5).

The effect of different watering regimes on RGR, SLA, NAR and LAR in the heat tolerant variety follows a unique trend. It was observed that the secondary response variables increased from 250 ml treatment to 750 ml and decreased with increased water application. The least values was recorded at the maximum watering regime of 1,250 ml. This trend is in a sharp contrast with the control (Pectomech) that generally followed a trend of increasing growth which finally peaked at the highest watering regime of 1000 - 1,250 ml (Tables 1, 2, 4 and 5) with the exception of NAR which peaked at 750 ml treatment (Table 3). Significant interactions were observed between cultivars and watering regimes.

The heat tolerant variety appears to perform badly under high water regimes unlike the control that responded favourably and even perform better with increasing water supply. This can be attributed to the fact that the control (Pectomech) had higher leaf area compared to the heat tolerant cultivars hence more light interception leading to the higher growth rates of the former and also of the fact that the growing conditions favoured the control than the heat tolerant cultivar. The minimum and maximum temperature recorded during the growing period was between 25^{o}C and 31^{o}C. Heat tolerant tomatoes are reported to grow best at temperatures between 30^{o}C -35^{o}C and night temperatures above 21^{o}C (Nkansah, 1994). The growing conditions may have accounted for the lower growth rates of the heat tolerant cultivar.

The interplay of RGR, NAR, SLA, LAR and LWR in determining plant growth has been well researched into with thrilling results. Correlation between LAR and RGR has been found to be very tight. As plant invests more in leaf area development (LAR), the higher the total carbon gains hence a faster growth (RGR). Konings (1989) also explained that an increase in NAR may require an increased rate of photosynthesis by extra investment in photosynthetic apparatus thereby decreasing SLA. Low SLA values reduces the amount of leaf area thereby impeding the light interception and ultimately photosynthetic carbon gain with a resultant low RGR.

High RGR observed in the Pectomech could be attributed to varietal differences as the Pectomech was characteristically bigger leave size and taller than the CLN2001A. It was observed that the RGR had a close link with the NAR as any increase observed in the RGR resulted in corresponding increase in LAR (Tables 1 and 2). The close association identified between RGR and NAR is attributed to a positive relationship between RGR and photosynthetic rate per unit leaf area (Konings, 1989)

Table 1 Means of relative growth rate of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato variety (Pectomech) cultivars at different watering regimes.

Watering regime (ml)	RGR (mg g^{-1} day^{-1})	
	CLN2001A	Pectomech
250	0.20	0.31
500	0.37	0.53
750	0.31	0.60
1,000	0.25	0.56
1,250	0.18	0.61
LSD (5%)	***0.04***	

Table 2 Means of Net Assimilation Rate of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato variety (Pectomech) cultivars at different watering regimes.

Watering regime (ml)	NAR (gcm^{-2} day $^{-1}$)	
	CLN2001A	Pectomech
250	2.32	3.87
500	4.09	4.51
750	4.52	6.71
1,000	1.04	7.53
1,250	1.47	8.38
LSD (5%)	***0.83***	

Table 3 Means of Specific Leaf Area of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato variety (Pectomech) cultivars at different watering regimes.

Watering regime (ml)	SLA (cm^2 g^{-1})	
	CLN2001A	Pectomech
250	2.32	3.86
500	4.09	4.51
750	4.52	6.70
1,000	1.07	7.53
1,250	1.47	8.71
LSD (5%)	***0.06***	

Table 4 Means of Leaf Weight Ratio of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato variety (Pectomech) cultivars at different watering regimes.

Watering regime (ml)	LWR	
	CLN2001A	Pectomech
250	0.48	0.37
500	0.55	0.55
750	0.49	0.47
1,000	0.43	0.58
1,250	0.37	0.58
LSD (5%)	***0.11***	

Table 5 Means of Leaf Area Ratio of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato variety (Pectomech) cultivars at different watering regimes.

Watering regime (ml)	LAR	
	CLN2001A	Pectomech
250	1.44	2.16
500	2.16	2.08
750	2.34	3.78
1,000	4.62	2.93
1,250	3.33	3.96
LSD (5%)	***0.83***	

4.1.2 Comparisons of means of proline contents in the root and the leaf of heat tolerant tomato and non-heat tolerant tomato cultivars

Tables 6 and 7 show that different watering regimes significantly affected the level of proline accumulation in the leaf and roots of both the heat tolerant and non-heat tolerant tomato cultivars. Proline accumulation decreased with increased watering regimes in the root of both the heat tolerant and the control cultivars (table 6) while the leaf proline decreased from 250 ml to 1,000 ml and increased at 1,250 ml treatment (table 7). It was highest at 250 ml treated plants compared with the other treatments. In both the leaf and the root, higher amounts of proline were recorded in the plants supplied with the least volume of water whilst those provided with the highest water volume produced the least proline content with the exception of leaf at treatment 1,250 ml. In the roots, the 250 ml applied to heat tolerant (CLN2001A) tomato produced 0.52 mg/ml of proline as against the 0.32 mg/ml accumulated with the application of the 1,250 ml treatment. Generally, from the study, proline accumulation in the roots was much higher than that of leaves for both cultivars. This could be explained by the fact that the root is the first plant part to sense conditions of different watering regimes in the growing environment. It is a common knowledge that, plants under various forms of stress response produce significant amount of osmo-protectant like proline.

During the process of adjustment, the expression level of the gene encoding pyrroline-5-carboxylate synthetase (P5CS), a component of proline synthetic pathway, is also increased (Ishitani *et al*. 1995). Proline content in plants under different watering regimes is frequently observed in several species (Clifford *et al*., 1998; Bajji *et al*., 2001) and may act as a regulatory or signaling molecule to activate multiple responses that are part of the adaptation process (Maggio *et al*., 2002; Claussen,2005).

Table 6 Means of means of proline accumulation in the root of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato variety (Pectomech) cultivars at different watering regimes.

Watering regime (ml)	Root proline (mg/ml)	
	CLN2001A	Pectomech
250	0.52	0.50
500	0.47	0.47
750	0.46	0.38
1,000	0.46	0.38
1,250	0.32	0.29
LSD (5%)	***0.04***	

Table 7 Means of means of proline accumulation in the leaf of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato variety (Pectomech) cultivars at different watering regimes.

Watering regime (ml)	Leaf proline (mg/ml)	
	CLN2001A	Pectomech
250	0.32	0.24
500	0.26	0.25
750	0.25	0.22
1,000	0.21	0.20
1,250	0.26	0.23
LSD (5%)	***0.07***	

4.1.3 Comparisons of means of relative water content at 4 and 9 weeks after transplanting in heat tolerant and non-heat tolerant tomato cultivars at different watering regimes.

Data in tables 8 and 9 indicate that there were no significant differences between the watering regimes of 500 ml to 1,250 ml. They (500 ml to 1,250 ml) were all significantly different from the 250 ml watering regime. The same applies to the varieties. Pectomech had lower relative water content than the CLN2001A. The heat tolerant variety, CLN2001A, has proved to be able to retain higher amount of relative water in situation of water stress. This is consistent with findings by Besset *et al.*, (2001) when he reported that drought resistant crop varieties showed consistently higher leaf water potential in their tissues than susceptible types under soil moisture deficit.

Plant leaf water status, as measured by relative water content, plays vital functions in metabolism (Sinclair and Ludlow, 1985). Matin *et al*,. 1989, proposed that relative water content is an important criterion for drought tolerance in barley. Slatyer (1955), observed that a reduction by 5% in RWC led to reduction in photosynthesis by 40 to 50%. Generally, plants growth and development is retarded under stressed conditions such as that of different watering regimes as a result of the impairment of vital physiological and metabolic functions. Microscopic investigations of dehydrated cells reveal damages, including cleavage in the membrane and sedimentation of cytoplasm content (Blackman *et al*. 1995).

Table 8 Means of Relative water content of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato variety (Pectomech) cultivars at the vegetative stage (4 weeks after transplanting) at different watering regimes.

	Relative water content (%)	
Watering regime (ml)	CLN2001A	Pectomech
250	89.77	86.42
500	92.99	92.38
750	92.98	92.55
1,000	94.30	92.83
1,250	95.29	94.55
LSD (5%)	***2.50***	

Table 9 Means of Relative water content of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato variety (Pectomech) cultivars at the reproductive stage (9 weeks after transplanting) at different watering regimes.

Watering regime (ml)	Relative water content (%)	
	CLN2001A	Pectomech
250	73.92	71.55
500	81.76	84.17
750	87.08	92.23
1,000	94.14	94.46
1,250	95.22	95.71
LSD (5%)	***6.54***	

4.1.4 Comparisons of means of plant height at 4 and 9 weeks after transplanting in heat tolerant and non-heat tolerant tomato cultivars at different watering regimes.

Table 10 Means of Plant heights of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato variety (Pectomech) cultivars at the vegetative stage (4 weeks after transplanting) at different watering regimes.

Watering regime (ml)	Plant height (cm)	
	CLN2001A	Pectomech
250	16.00	21.38
500	23.70	28.10
750	24.38	28.06
1,000	25.30	31.30
1,250	17.70	33.40
LSD (5%)	***4.70***	

Table 11 Means of Plant heights of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato variety (Pectomech) cultivars at the reproductive stage (9 weeks after transplanting) at different watering regimes.

Watering regime (ml)	Plant height (cm)	
	CLN2001A	Pectomech
250	64.22	72.56
500	69.12	83.36
750	71.08	80.65
1,000	83.25	81.43
1,250	68.90	89.26
LSD (5%)	***3.06***	

4.1.5 Comparisons of means of shoot: root ratio of heat tolerant and non-heat tolerant tomato cultivars 4 and 9weeks after transplanting

The result in Tables 12 and 13 indicate that different watering regimes did not significantly affect shoot: root ratio of both the CLN2001A and the Pectomech 4 weeks after transplanting. At the reproductive phase, however, the CLN2001A (heat tolerant) cultivar was significantly affected unlike the Pectomech cultivar that did not show any significant response to different watering regimes. Numerically, plants that received the least amount of water of 250 ml produced the lowest shoot: root ratio whilst the plants that were supplied with more water recorded a higher shoot:root ratio. This phenomenon is consistent with work done by McMichael and Quisenberry, (1991) in an experiment that indicated a decrease in shoot:root ratio when cotton was subjected to drought. Plant exhibit increased root length during decreased watering regimes conditions in order to get deeper water from the ground. The partition of assimilates between roots and shoot is well regulated and coordinated in the healthy growing plant. The partitioning of assimilates between roots and shoots is very important in plant growth and development as it determines the overall rate of dry matter production since it affects the leaf weight ratio and hence the relative growth rate. The importance of shoot:root ratio in the study of plants cannot be over emphasized as a result of the interdependence between them in influencing growth. Stikic *et al.,* 2003 observed that when tomato plant was subjected to partial root drying, there was reduction in the growth of both the stem and leaves, whilst root development was increased.

Table 12 Shoot: root ratio of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato (Pectomech) cultivars at the vegetative stage (4 weeks after transplanting) at different watering regimes.

Watering regime (ml)	Shoot: root ratio	
	CLN2001A	Pectomech
250	7.83	8.12
500	7.71	7.87
750	8.13	9.49
1,000	10.50	8.12
1,250	8.61	9.95
LSD (5%)	***4.47***	

Table 13 Shoot: root ratio of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato (Pectomech) cultivars at the reproductive stage (9 weeks after transplanting) at different watering regimes.

Watering regimes (ml)	Shoot: root ratio	
	CLN2001A	Pectomech
250	10.16	12.46
500	15.51	12.96
750	16.12	14.37
1,000	15.10	13.49
1,250	15.22	14.01
LSD (5%)	***2.48***	

4.1.6 Comparisons of means of vegetative and reproductive leaf number of heat tolerant tomato and non-heat tolerant tomato (Pectomech) at different watering regimes

Results in Tables 14 and 15 shows that both the heat tolerant and the control variety responded significantly to different watering regimes in terms of the number of leaves produced during the vegetative and reproductive phases of growth. At the vegetative stage, leaf number decreased as watering regimes increased up to 1,250 ml. Increasing water supply to the plant appears to rather impede the smooth growth and development of new leaves as a result of the anaerobic conditions introduced by the excessive water at that treatment leading to reduced number of leaves per plant. At the reproductive stage, on the other hand, the plants appear to produce more leaves as the volume of water supply was increased. This could be attributed to the fact that the plant has increased in size and therefore doing better under increased water supply. Work done by Hsiao *et al.*, (1985) indicates that leaf expansion in several species is observed when grown in conditions of optimum moisture. Krieg and Sung (1986) also determined that decreases the number of leaves on sympodial branches of cotton. Leaf expansion in several species has been shown to be sensitive to different watering regimes (Hsiao, 1973).

Table 14 means of number of leaves per plant of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato (Pectomech) cultivars at the vegetative stage (4 weeks after transplanting) at different watering regime.

watering regime (ml)	Number of leaves	
	CLN2001A	PECTOMECH
250	10.33	9.67
500	11.33	10.00
750	8.67	6.33
1,000	9.33	8.33
1,250	7.00	5.67
LSD (5%)	***3.3***	

Table 15 Means of number of leaves per plant of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato (Pectomech) cultivars at the reproductive stage (9 weeks after transplanting) at different watering regimes.

Watering regime (ml)	Number of leaves	
	CLN2001A	PECTOMECH
250	14.33	12.00
500	17.00	14.00
750	17.67	17.67
1,000	17.67	15.67
1,250	12.67	18.00
LSD (5%)	***3.93***	

4.1.7 Comparisons of means of stem diameter of heat tolerant and non-heat tolerant tomato cultivars as influenced by different watering regimes.

Stem diameter did no differ significantly between the two cultivars irrespective of the amount of water supplied (Tables 16 and 17). However, at the reproductive stage of growth (9weeks after transplanting) the different watering regimes significantly affected the stem diameter of both the heat tolerant (CLN2001A) and the control (Pectomech). The heat tolerant cultivar recorded a significant increase in stem diameter at 750 ml of water compared to the other treatments.

The control (Pectomech) on the other hand, recorded the highest stem diameter value of 0.55cm at a watering regime of 1,250 ml. This result indicates that provision of water beyond 750 ml to the heat tolerant (CLN2001A) cultivar will impart negatively to the plant in terms of stem diameter possibly leading to weaker stems that are prone to logging.

Table 16 Comparisons of means of stem diameters of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato (Pectomech) cultivars at the vegetative stage (4 weeks after transplanting) at different watering regimes.

Watering regime (ml)	Stem diameter (cm)	
	CLN2001A	PECTOMECH
250	0.444	0.491
500	0.432	0.484
750	0.428	0.493
1000	0.435	0.468
1250	0.437	0.464
LSD (5%)	***0.1072***	

Table 17 Comparisons of means of Stem diameters of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato (Pectomech) cultivars at the reproductive stage (9 weeks after transplanting) at different watering regimes.

Watering regime (ml)	Stem diameter (cm)	
	CLN2001A	PECTOMECH
250	0.48	0.47
500	0.48	0.52
750	0.51	0.55
1000	0.44	0.55
1250	0.44	0.56
LSD (5%)	***0.076***	

4.1.8 Comparisons of means of total chlorophyll content of heat tolerant and non heat tomato cultivars as influenced by different watering regimes

Table 7 shows that different watering regimes significantly affected the chlorophyll contents in the leaves of both the CLN2001A and the control (Pectomech) cultivars. Cultivar differences were observed. For the CLN2001A cultivar, increasing the water levels resulted in increase of chlorophyll content from 11.15 mg/g in the 250 ml treatment to 17.97 mg/g at 750 ml treated plants. The least chlorophyll content was recorded at the highest watering regime level. This decline could be attributed to the fact that different watering regimes, both in terms of its excess and deficit water level at that treatment was in excess of the plants requirement and therefore led to the breakdown of the chlorophyll. The Pectomech cultivar also responded in like manner with increasing chlorophyll level being recorded as water supply increased until it peaked at 22.74mg/g when 1,000 ml of water was supplied beyond which a decline began to manifest with a resultant 18.60 mg/g chlorophyll level being recorded. This result is in agreement with Montagu and Woo, (1999) and also Nilsen and Orcutt, (1996) who stated that water deficit can destroy the chlorophyll and prevent its making.

The adverse effect of different watering regimes on chlorophyll concentration has previously been shown for young peach trees by Steinberg *et al.* (1990). The reductions in chlorophyll concentrations (due to leaf senescence, according to Kirnak *et al*. (2001), Dhindsa *et al*. (1981), Chen *et al*,. (1991) is associated with the increased electrolyte leakage from plant leaves during stresses. The significant effect of water treatment on the chlorophyll content on the heat tolerant variety and the control has a far reaching impact on the plant growth and productivity as declining chlorophyll content as observed with increased water content beyond a certain threshold will mean reduced photosynthetic ability of the plant. Kirnak *et al*., (2001) reported that water deficit significantly decreases chlorophyll content just as stress resulting from excess water supply reduces total chlorophyll by 55%.

Table 18 Comparison of means of total chlorophyll content of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato (Pectomech) cultivars, 9 weeks after transplanting, at different watering regimes.

Watering regime (ml)	Chlorophyll content (mg/g)	
	CLN2001A	PECTOMECH
250	11.15	14.53
500	15.41	16.63
750	17.97	19.20
1,000	11.75	22.74
1,250	8.49	18.60
LSD (5%)	***4.212***	

4.2.1 Fruit qualities (pH and Brix) of Heat Tolerant and non-heat tolerant tomato cultivars as influenced by different watering regimes.

The results in Table 8 show that the effect of different watering regimes within the heat tolerant tomato cultivar were not significant but significant in Pectomech. The pH (4.36) in Pectomech was highest at the highest watering regime of 1,250 ml.

Soluble solids (Brix) differed significantly with different applications of watering regimes (Table 9). Treatment at 250 ml watering regime recorded the lowest Brix level whilst the 500 ml treatment yielded the highest Brix for the CLN2001A cultivar but Pectomech produced the highest brix value of 8.5 at when 750 ml of water was supplied. Of the two varieties, the Pectomech produced the highest brix value of 8.5% unlike the CLN2001A that produced the highest brix value of 5.07% and this indicates varietal differences between the two verities.

It was observed in both cultivars that soluble solids content decreased beyond a certain level (750 ml for Pectomech and 500 ml for CLN2001A) as the water treatments levels increased. This also shows that heat tolerant and non-heat tolerant tomato cultivars respond differently to different watering regimes. The taste quality of tomato is largely influenced by the contents of soluble sugar and organic acid and their ratio (Dorais *et al.*, 2001). Bucheli *et al.*, (1999) observed that higher contents of soluble sugar and organic acid in tomato is an attribute of better fruit taste and quality. Warner *et al*,. (2004) studied the effect of water stress on tomatoes and concluded that total soluble solids (%) was negatively affected by irrigation water quantity. This could be attributed to the fact that high fruit water content reduces the sugar concentration in the fruit thereby leading to a declining brix level. Generally, the Pectomech recorded higher brix figures than the CLN2001A at all stress levels.

Table 19 Comparisons of means of fruit pH of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato (Pectomech) cultivars at different watering regimes.

Watering regime(ml)	Ph	
	CLN2001A	PECTOMECH
250	4.31	3.62
500	4.08	4.32
750	4.20	4.29
1,000	4.12	4.29
1,250	4.18	4.36
Lsd (5%)	***0.71***	

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Table 20 Comparisons of means of Soluble Solids (Brix) of heat tolerant tomato and non-heat tolerant tomato cultivars at different watering regimes.

Watering regime (ml)	Brix %	
	CLN2001A	PECTOMECH
250	3.50	5.43
500	5.07	5.10
750	4.77	8.50
1,000	4.27	5.40
1,250	4.00	4.13
LSD (5%)	***0.66***	

4.3.0 Yield of Heat Tolerant Tomato as Influenced by different watering regimes

4.3.1 Comparisons of means of fruit numbers and weights of heat tolerant and non-heat tolerant tomato as influenced by different watering regimes.

Results in Tables 21 and 22 indicate that different watering regimes significantly affected fruit number and yield of both the heat tolerant tomato and the control cultivars. Birhanu and Tilahun (2010) observed similar responses to water stress when he reported decreases in number and sizes of tomato fruits from plants subjected to water stress. Cultivar differences were significant. The heat tolerant cultivar recorded the highest fruit number at 500 ml treatment whilst that of the control at was attained at 1,250 ml. This indicates that continuous supply of water to the heat tolerant variety beyond the 500 ml mark was detrimental to the plant in terms of the number of fruits production unlike the control whose maximum number of fruit production was attained at the watering regime of 1,000 ml and 1,250 ml. In terms of fruit weight, the heat tolerant cultivar recorded the highest fruit weight at 500 ml watering regime while the control or Pectomech recorded the highest fruit weight between 1,000 ml – 1,250 ml treated plants (Figure 13). The lower fruit numbers and fruit weight at the least watering regimes agrees with the findings of Singh *et al.*, (1988) who observed a significant reduction in yield of drought stressed plant.

Table 21 Means of number of fruits per plant of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato variety (Pectomech) cultivars at different watering regimes.

Watering regime (ml)	Number of fruits per plant	
	CLN2001A	Pectomech
250	4.79	2.02
500	13.79	2.89
750	12.79	4.02
1,000	7.87	5.20
1,250	4.41	5.33
LSD (5%)	***1.93***	

Table 22 Means of Fruit Weight of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato variety (Pectomech) cultivars at different watering regimes.

Watering regime (ml)	Fruit weight per plant (g)	
	CLN2001A	Pectomech
250	3.79	5.91
500	11.61	16.11
750	9.97	17.57
1,000	8.08	37.48
1,250	8.44	36.73
LSD (5%)	***1.47***	

4.4.1 Comparison of means number of seeds per fruit of heat tolerant and non-heat tolerant tomato cultivars as influenced by different watering regimes.

Table 23 shows that the number of seeds per fruit was significantly affected by the water treatments the plants were subjected to. Cultivar differences were significant. The heat tolerant variety recorded the highest seed number per fruit at 1,000 ml while that of Pectomech was highest at 1,250 ml treatment. Singh, 1995, in his study on effect of water stress on dry bean observed that when water stress is imposed during the flowering and pod filling periods reduced seed yield. Ethylene and ABA are senescence and hormones produced under stress conditions and can hamper fruit and seed development (Davies, 2010).

Water deficit after anthesis influences grain size, although grain number per ear is also reduced if the deficit occurs in the first two weeks after anthesis (Fischer 1973). In assessing the effect of different watering regimes on seed yield in soybean, Dornbos *et al.*, (1989) reported that seed yield were reduced significantly by drought imposed during the pod filling period.

Table 23 Comparison of means of number of seeds per fruit of heat tolerant tomato (CLN2001A) and non-heat tolerant tomato (Pectomech) cultivars at different watering regimes.

Watering regime (ml)	Number of seeds per fruits	
	CLN2001A	PECTOMECH
250	3.33	2.00
500	10.00	4.00
750	13.00	6.33
1,000	14.00	6.67
1,250	9.00	10.33
Lsd (5%)	***3.23***	

4.4.2 .Comparisons of means of percentage seed germination of heat tolerant (CLN2001A) and non-heat tolerant (Pectomech) tomato cultivars as influenced by different watering regimes.

Results in Table 24 indicate that different watering regimes significantly affected percentage seed germination in both the heat tolerant and control cultivars. Cultivar differences were also observed to be significant. The result indicates that as more water was supplied to the plant percentage seed germination increased from 36% to 81% for the heat tolerant variety and 26.7% to 84% for the control. Simiciklas *et al*.,.(1989) investigated the effect of different watering regimes on soybean and reported that when the stress occurs during the seed filling period, there was a reduction in seed quality as assessed by germination test.

Table 24 Mean percentage seed germination of Heat tolerant tomato (CLN2001A) and non-heat tolerant tomato (Pectomech) cultivars at different watering regimes.

	Percentage seed germination	
Watering regime (ml)	CLN2001A	PECTOMECH
250	36.70	26.70
500	73.70	60.30
750	81.00	72.70
1,000	82.00	80.70
1,250	81.70	84.00
Lsd (5%)	***14.11***	

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

In general it was observed that the heat tolerant cultivar or line had lower growth rates in terms of leaf area, relative growth rate, net assimilation rate and leaf weight ratio compared to the non-heat tolerant one. The non-heat tolerant tomato cultivar was found to be a better carbohydrate producer at the normal temperature regimes in which they were cultivated. Cultivar differences were observed when they were subjected to varying watering regimes in terms of growth, yield and fruit quality. The heat tolerant cultivar was found to have the highest relative growth rate at 500 ml treatments while that of the non-heat tolerant was highest at 1,000 ml indicating cultivar physiological differences. The study also reveals that tq1he heat tolerant cultivar did not thrive well under high watering regimes unlike the control Pectomech. Thus, the water requirements for heat tolerant tomatoes may be different from that of non-heat tolerant tomato cultivars.

In terms of yield (the number of fruits per plant) the heat tolerant tomato cultivar had the highest fruit number at a watering regime of 1,000 ml with an average of 14 fruits whilst the control gave the lowest number of fruits at the 5.3 fruits per plant at the maximum irrigation volume of 1,250 ml. At the highest water stress level of 250 ml, the heat tolerant cultivar produced higher fruits numbers of 4.41 whilst the control produced 2.02 fruits at that same watering level, indicating that the CLN2001A tolerates drought better than the control (Pectomech).

The study revealed that the quality of the fruits was significantly affected by different watering regime treatments. There was a general decrease in quality attributes of the fruits as the water regime increased. For example, the highest sugar content (Brix) value of 5.07% for the heat tolerant variety (CLN2001A) was attained at the relatively low watering regime of 500 ml and then begun to decrease as more water was supplied until a low brix value of 4.00 was attained at 1,250 ml watering level. The Pectomech, however, recorded the highest brix value of 8.50 at a watering regime of 750 ml after which it declined sharply to the lowest value of 4.13 at a watering regime of 1,250 ml.

The pH of the fruits of the heat tolerant tomato was highest at the lowest watering level of 250 ml unlike the control (Pectomech) which recorded the highest pH value of 4.36 at the watering regime of 1,250 ml. Different watering regimes imposed significant effects on the growth and yield of CLN2001 but on quality, only the fruit brix was significantly affected whilst the fruit pH was not significantly affected.

It can therefore be concluded that growth and physiological and yield attributes of the heat tolerant and non-heat tolerant tomato cultivars studied respond differently to different watering regimes under normal growing or temperature regimes of between 25 -31^{o}C as observed in this study.

5.2 RECOMMENDATIONS

It is recommended that the study be repeated to confirm the result obtained in the experiment.

Studies on nutrient requirements of several heat and non-heat tolerant tomato cultivars at different watering regimes should be initiated to determine the particular mineral elements that are better absorbed under different watering regime conditions. It is advised that tomato producers should use lower water volumes or irrigation levels when cultivating heat tolerant tomato cultivars.

REFERENCES

Abdelmageed, A.H., N. Gruda and Geyer, B. (2003). Effect of high temperature and heat shock on tomato (*Lycopericon esculentum* Mill) genotypes under controlled conditions. Conference for International Agricultural Research for Development, October 8-10, 2003, Deutsher Tropenteg, Gottingen, pp: 1-7.

Addicott, F. T., Lyon, J. L., Ohkuma, K., Thiessen, W. E., Carns, H. R., Smith, O. E., Cornforth, J. W., Milborrow, B. V., Ryback, G. and Wareing, P. F. (1968). "Abscisic acid: A new name for abscisin II (dormin)". *Science* **159**:1493.

Al-Harbi A.R., AI-Orman A.M and El-Adgham IF.I. (2008) Effect of Drip Irrigation Levels and Emitters Depth on Okra (*Abelmoschus esculentus*) Growth. *J Applied Sci* **8** (15): 2764-2769.

Altschuler, M., and Mascarenhas, J.P. (1982). Heat shock proteins and effects of heat shock in plants. *Plant Mol. Biol.* **1**: 103-115.

Aragüés, R. V., Urdanoz, M. Çetin, C. Kirda, H. Daghari, W. Ltifi, M. Lahlou, A. Douaik.(2011) Soil salinity related to physical soil characteristics and irrigation management in four Mediterranean irrigation districts. *Agricultural Water Management*, **98**, pp: 959-966.

Arteca R. N. (1996). Seed germination and seedling growth. *In:* Arteca R. N. (Ed.). Plant Growth Substances, Principles and Applications, Chapman and Hall, New York, 332 pp.

Assmann, S.M, Snyder, J.A. and Lee, Y.R.J. (2000) ABA-deficient (aba1) and ABA-insensitive (abi1-1, abi2-1) mutants of Arabidopsis have a wild-type stomatal response to humidity. *Plant Cell and Environment* **23**: 387-395.

Baber, S. A., Walker, J. M., and Vasey, E. H. (1963). Mechanisms for the movement of plant nutrients from the soil and fertilizer to the plant root. *J. Agr. Food Chem*. **11**, 204-207.

Bacon, M.A. (2004) *Water use efficiency in plant biology*. M.A. Bacon (Ed.), Water Use Efficiency in Plant Biology, Blackwell Publishing Ltd., Oxford, UK , pp. 1–26.

Bacon, M.A., Wilkinson, S. and Davies W.J (1998). pH-regulated leaf cell expansion in droughted plants is abscisic acid dependent. *Plant Physiology* **118**:1507–1515.

Bajji, M. Lutts, S. and Kinet, J.M. (2001). Water deficit effects on solute contribution to osmotic adjustment as a function of leaf ageing in three durum wheat (*Triticum durum* Desf.) cultivars performing differently in arid conditions. *Plant Sci*. **160**:669-681.

Bandurski, R. S., Cohen, J. D., Slovin, J., and Reinecke, D. M. (1995). "Auxin biosynthesis and metabolism". Plant Hormones: Physiology, Biochemistry and Molecular Biology. *Dordrecht: Kluwer*. pp. 39-65.

Barnabas, B. Jager, K. and Feher, A. (2008) The effect of drought and heat stress on reproductive processes in cereals. *Plant Cell Environ* **31**:11–38.

Barrow**, N. J. (**1987**),** The effects of phosphate on zinc sorption by a soil. *Journal of **Soil** Science*, **38**: 453–459.

Barnabas, B. Jager, K. Feher, A. (2008) The effect of drought and heat stress on reproductive processes in cereals. *Plant Cell Environ* **31:** 11–38.

Barrs, H.D. and Klepper, B. (1968) Cyclic variations in plant properties under constant environmental conditions. *Physiologia Plantarum*. ;**21**:711–730.

Bar-Tsur, A. Rudich, J. and Bravdo, B. (1985) High temperature effects on CO_2 gas exchange in heat-tolerant and -sensitive tomatoes. *Journal of the American Society for Horticultural Science.* **110**: 582–586.

Bates, L.S., Waldrew, R.R. and Teare, I.D. (1973), Rapid determination of free proline for water-stress studies. *Plant Soil*, **39**:205-207.

Baver, L. D. (1948) *Soil physics*: 2d ed., John Wiley and Son. pp. 126-135, 181-192.

Baver, L. D. (1940), *Soil Physics*, chap. V. Soil Structure, John Wiley & Sons, Inc., London. pp. 160-167.

Bearce, B. C., and Kohl, H. C., Jr. (1970) Measuring osmotic pressure of sap within live cells by means of a visual melting point apparatus. *Plant Physiol.* 46: 515–519.

Ben-Hassine, A., Ghanem, M.E., Bouzid, S. and Lutts, S. *(*2008) An inland and a coastal population of the Mediterranean xero-halophyte species Atriplex halimus L. differ in their ability to accumulate proline and glycinebetaine in response to salinity and water stress. *J Exp Bot* **59***:* 1315–1326.

Berlin, J.E. Quinsenberry, F. Bailey, M. Woodworth and McMicheal, B. L. (1982) Effect of water stress on cotton leaves: I. an electron microscopic stereological study of the palisade cells. *Plant Physiol*. **70**:238-243.

Berry J, and Bjorkman, O. (1980) Photosynthetic response and adaptation to temperature in higher plants. *Annu Rev Plant Physiol* **31**: 491-543.

Besset J., M. Genard T. Girard V. Serra and C. Bussi, C. (2001) Effects of water stress applied during the final stage of rapid growth on peach trees. *Scientia Horticulturae*, **91**: 289-303.

Birhanu, K. and Tilahun, K. (2010) Fruit yield and quality of drip-irrigated tomato under deficit irrigation. *African Journal of Food Agriculture Nutrition and Development*. **10**(2), 2139-2151.

Björkman, O. (1981). Responses to different quantum flux densities.In *Physiological Plant Ecology. I. Responses to the Physical Environment* (O. L. Lange, P. S. Nobel, C. B. Osmond, and H. Ziegler,eds.), pp. 57–107. Springer-Verlag, New York.

Bjorkman, O., Mooney, H.A. and Ehleringer, J. (1975) Photosynthetic responses of plants from habitats with contrasting thermal environments: Comparison of photosynthetic characteristics of intact plants. *Carnegie Inst Washington Yearb* **74**: 743–748.

Blackman, S. A. Obendorf, R.L and Leopold A.C. (1995) Desiccation tolerance in developing soybean seeds: The role of stress proteins. *Plant Physiol*., **93**: 630-638.

Blum, A. and Arkin, G.F. (1984) Sorghum root growth and water-use affected by water supply and growth duration. *Field Crops. Res*. **9**: 131–149.

Bondada, B.R. and Oosterhuis, D.M (2000) Ontogenic changes in epicuticular wax and chloroplast integrity in cotton (*Gossypium hirsutum* L.) leaf. *Photosynthethica*.

Boyer, J.S. (1982). Plant productivity and environment. *Science* **218**:443-448.

Boyer, J.S. (1995) *Measuring the Water Status of Plants and Soils.* Academic Press, New.York. pp:. 243-436.

Boyer, J. S., and Knipling, E. B. (1965) Isopiestic technique for measuring leaf water potentials with thermocouple sychrometer. *Proc. Natl. Acad. Sci. USA* 54: 1044–1051.

Brian, P. W., Elson, G. W., Hemming, H.G., and Radley, M. (1954). "The plant-growth promoting properties of gibberellic acid, a metabolic product of the fungus Gibberella fujikuroi". *J. Sci. Food. Agr*. **5**:602-612.

Brown, H. T., and Escombe, F (1900) Static diffusion of gases and liquids in relation to the assimilation of carbon and translocation in plants. *Phil. Trans. Roy. Soc. London B* **193**: 223-291.

Brown, R. W. and Van Haveren, B. P., eds. (1972) *Psychrometry in Water Relations Research*. Proceedings of the Symposium on Thermocouple Psychrometers. Utah Agricultural Experiment Station, Utah State University, Provo.

Bucheli, P., E. Voirol, R., De La Torre, J., Lopez, A., Rytz, S., Tanksley, V. and Petiard (1999) Definition of nonvolatile markers for flavor of tomato (*Lycopersicon esculentum* Mill.) as tools in selection and breeding *Journal of Agricultural and Food Chemistry*, **47** , pp. 659–664.

Carter, M.R. (2002). Soil quality for sustainable land management: organic matter and aggregation interactions that maintain soil functions. *Agron. J*. **94**: 38-47

Carruthers, I. and Clark, C**. (**1981) *The economics of irrigation*. Liverpool, University Press Chidley T R E and Keys K M. 1970.

Chavez, M.M. (1991) Effects of water deficits on cotton assimilation. *Journal of Experimental Botany* **42**: 1-16.

Chen, C., T, Li, C.C, and Kao CH (1991) Senescence of rice leaves XXXI. Changes of chlorophyll, protein and polyamine contents and ethelyn production during senescence of chlorophyll-deficient mutant. *J.Plant Growth Regul*., **10**:1-5.

Childs, E. C. and Collis-George, N. (1950) The permeability of porous materials. *Proceedings of the Royal Society, Series A* **201**, 392-405.

Clark, J. A. and Levitt, J. (1956) The Basis of Drought Resistance in the Soybean Plant. *Physiologia Plantarum*, **9**: 598–606.

Claussen, W. (2005) Proline as a measure of stress in tomato plants. *Plant Sci*. **168**: 241-248.

Clements, H.F. (1937) Studies in the drought resistance of the sunflower and the potato. *Research studies of the State College of Washington,* Vol. V:97-98.

Clifford, S. C., Arndt, S. K., Corlett, J. E., Joshi, S., Sankhla, N.,Popp, M., and Jones, H. G. (1998). The role of solute accumulation, osmotic adjustment and changes in cell wall elasticity in drought tolerance in *Ziziphus mauritiana* (Lamk.). *J. Exp. Bot.* **49**, 967–977.

Cornish, K. and Zeevart, J.A.D. (1985) Movement of abscisic acid into the apoplast in response to water stress in *Xanthium strumarium. Plant Physiology,* **78**, 623-626.

Chris, B. (1987) Water Resources and Agricultural Development in the tropics. Longman Scientific and Technical, Longman Group, UK Limited. 82-85.

Cutler, A.J., Krochko, J.E. (1999): Formation and breakdown of ABA. *Trends in Plant Science* **4(12**), 472-478.

Daeter W, Slovik S, Hartung W (1993) The pH gradients in the root system and the abscisic acid concentration in xylem and apoplastic saps. *Philosophical Transactions: Biological Sciences* **341,** 49-56.

Dainty, J. (1976) Water relations of plant cells. In *Transport in Plants II, Part A, Cells,* U. Lüttge and M. G. Pitman, eds. *Encyclopedia of Plant Physiology*, New Series, Vol. 2. Springer-Verlag, Berlin, pp. 12–35.

Davies,P.J. (1995) *Plant Hormones*: Physiology, Biochemistry and Molecular Biology. Kluwer Academic Publishers, Dordrecht, The Netherlands *Physiological Transactions of Royal Society of London B*. **341,** 49-56**.**

David, W. (2002) Limitation to photosynthesis in water stressed leaves: stomata vs. metabolism and the role of ATP. *Annals of botany*. **89**: 871-885.

Davies, P. J. (2010). The plant hormones: their nature, occurrence, and functions in Plant Hormones: Biosynthesis, Signal Transduction, Action! ed Davies P., editor. (Dord recht: Springer Press;), 1–15.

De-Koning, A.N.M, (1990) "Long-Term Temperature Integration of Tomato: Growth and Development under Alternating Temperature Regimes," *Scientia Horticulturae*, Vol. **45**, No. 1-2, pp. 117-127.

Dhindsa, R.S., Plump, D.P, and Thorpe, T.A. (1981) Proline Biosynthesis and correlated with increased levels of membrane permeability and Lipid peroxidation, and decreased levels of superoxide dismutase and catalase. *J. Expe. Bot*,. **32**:93-101.

Dorais, A., Papadopoulos, A. and Gosselin N. (2001) Greenhouse tomato fruit quality *Horticultural Reviews*, **26** , pp. 239–319.

Dornbos, D.L. Jr., Mullen, R.E. and Shibbles, R.M.(1989) Drought stress effects during seed fill on soybean seed germination and vigour. *Crop Sci*. **29**: 476-480.

Ercan, N. and Vural, H. (1994), The effects of low temperatures on fruit set of tomatoes. *Acta Horticulturae*, **366**, 65-72.

Evers, D., Lefèvre, I., Legay, S., Lamoureux, D., Hausman, J.F., Rosales, R.O., Marca, L.R., Hoffmann, L., Bonierbale, M. and Schafleitner, R. (2010) Identification of drought-responsive compounds in potato through a combined transcriptomic and targeted metabolite approach. *J Exp Bot* **61***:* 2327–2343.

FAO/UNESCO, (1990) FAO/UNESCO Soil map of the world, generalized from the FAO/UNESCO soil map of the world (FA), 1971-1981, 14th International Congress of Soil Science, Kyoto, Japan.

Fernandez, G. and Johnston, M. (1995). Seed vigour testing in lentil, bean and chickpea. *Seed Sci.Technol*. **23**: 617-627.

Fernandez, D. and Castrillo M (1999). Maize leaf rolling initiation. *Photosynthetica*, **37**:493-497.

Fischera, R.A. (1973) The effect of water stress at various stages of development on yield processes in wheat. In: Slatyer R.O (ed.): Plant response to climatic factors. UNECESCO, Paris, pp. 233–241.

Fischer, R.A. and Maurer, R. (1976) Crop temperature modification and yield potential in a dwarf spring wheat. *Crop Science* **16**: 855–859.

Gaff, D.F. (1966). The sulphydryl-disulphide hypothesis in relation to desiccation injury of cabbage leaves. *Australian Journal of Biological Sciences* **19***:* 291–299

Glinka, Z. (1980) Abscisic acid promotes both volume flow and ion release to the xylem in sunflower roots. *Plant Physiology,* ***65****, 537-540.*

Glinka, Z, Reinhold, L. (1971) Abscisic acid raises the permeability of plant cells to water. *Plant Physiol* **48**: 103–105.

Green, P. B., and Stanton, F. W. (1967) Turgor pressure: Direct manometric measurement in single cells of *Nitella*. *Science* 155: 1675–1676.

Green, P. B. (1968) Growth physics in *Nitella*: A method for continuous in vivo analysis of extensibility based on a micro-manometer technique for turgor pressure. *Plant Physiol.* **43**: 1169–1184.

Gregory, A. G., Thorsten, K,; Mark, A. M., Thomas, L. R., Kenneth, A. S., Andrew, W., Jiong, F., Andrew, J. M. (2013) Water Uptake along the Length of Grapevine Fine Roots: Developmental Anatomy, Tissue-Specific Aquaporin Expression, and Pathways of Water Transport. *Plant physiology* **163**(3):1254-65.

Guin, G. (1976). Water deficit and ethylene evolution by young cotton bolls. *Plant Physiol.* **57**:403-405.

Hammer, K. C., Stewart, U.S. and Matrone, G.(1943)Thiamine determination by the fungusgrowth method and its comparison with other methods. *Food Res*. **8**:444-451.

Hamner, K.C., Bernstein, L. and Maynard, L.A.(1945) Effects of light intensity, day length, temperature, and other environmental factors on the ascorbic acid content of tomatoes. *Journal of Nutrition* **29**: 85–97.

Hammel, H. T., and Scholander, P. F. (1976) *Osmosis and tensile solvent*. Springer, Berlin.

Hare, P.D. and Cress, W.A (1997) Metabolic implications of stress-induced proline accumulation in plants. *Plant Growth Regul* **21**: 79–102.

Hare, P.D., Cress, W.A, and Van Staden J(1998) Dissecting the roles of osmolyte accumulation during stress. *Plant Cell Environ* **21**: 535–553

Hartung, W., Kaiser, W. M. and Burschka, C. (1983) Release of ABA from leaf strips under osmotic stress. *Zeitschrift fur pflanzenphysiologie,* **112**, S131-S138.

Harung, W. (1983) The site of action of abscisic acid at the guard cell plasmalemma of *Valerianella locusta.. Plant, Cell and Environmen*t, **6**, 427-428.

Heuvelink E. (2005), Developmental processes, In: Heuvelink E. (2005), Tomatoes, CABI Publishing, London, UK, p. 53-83.

Heydt, H. and Steudle, E. (1991) Measurement of negative pressure in the xylem of excised roots. Effects on water and solute relations. *Planta* 184: 389–396.

Hoffmann B, Kosegarten H (1995) FITC-dextran for measuring apoplast pH and apoplastic pH gradients between various cell types in sunflower leaves. Physiol Plant **95:** 327–335.

Hoffman, B. and Kosegarten, H. (1995) FITC-dextran for measuring apoplast p^H and apoplast p^H gradients between various cell types in sunflower leaves. *Physiologica Plantarum*, **95**, 327-335.

Hong, Z.L., Lakkineni, K., Zhang, Z.M. and Verma, D.P.S. *(*2000) Removal of feedback inhibition of delta(1)-pyrroline-5-carboxylate synthetase results in increased proline accumulation and protection of plants from osmotic stress. *Plant Physiol* **122:** 1129–1136

Hsiao, T.C., W.K. Silk and J. Jing. (1955) Leaf growth and water deficits: Biophysical effects in control of leaf growth. N.R Baker, W.J. Davies and C.K. Ong (eds.) Cambridge Univ. Press Cambridge. Pp239-266.

Hsiao, T.C. (1973) Plant responses to water stress. Annu. Rev. *Plant Physiol.* **24**: 519-570.

Hsiao, T.C., Silk, W.K. and Jing, J. (1985) *Leaf growth and water deficits*: Biophysical effects in control of leaf growth. N.R Baker, W.J. Davies and C.K. Ong (eds.) Cambridge Univ. Press Cambridge. Pp 239-266.

Hunt LA, Pararajasingham S. (1995) CROPSIM-WHEAT: a model describing the growth and development of wheat. *Canadian Journal of Plant Science*.;**75**:619–632.

Hüsken, D., Steudle, E., and Zimmermann, U. (1978) Pressure probe technique for measuring water relations of cells in higher plants. *Plant Physiol.* 61: 158–163.

Hylmo, B. (1953) Transpiration and ion absorption. *Physiol. Plant.***6**: ... Plasmodesmata in xylem vessels. *Bot. Gaz.***110**: 492–495.

Idso, S.B., Reginato, R.J. and Radin, J.W., (1982b) Leaf diffusion resistance and photosynthesis in cotton as related to a foliage temperature based plant water stress index. *Agric. Meteorol.*, **27**: 27--34.

IFPRI (2010) The Case of Tomato in Ghana: Productivity**.** Ghana Strategy Support Program (GSSP) GSSP Working Paper No. 19

Imber, D. and Tal, M**.** (1970) Phenotypic reversion of *flacca*, a wilty mutant of tomato, by abscisic acid. *Science* **169:** 592–593

Ishitani M, Nakamura T, Han S Y, and Takabe T (1995). Expression of the betaine aldehyde dehydrogenase gene in barley in response to osmotic stress and abscisic acid. *Plant Mol. Biol*., **27**: 307-315.

Ismael, S.M. (2010) Water Use Efficiency and Bird Pepper Production as Affected by Deficit Irrigation Practice. *International Journal of Agriculture and Forestry*.**2**, 2(5): 262-267

Jackson, R.D., Reginato, R.J. and Idso, S.B.,(1977). Wheat canopy temperature: A practical tool for evaluating water requirements. *Water Resource. Res.*, **13**: 651-656.

Jackson, R.D. (1982) Canopy temperature and crop water stress. In: Daniel Hillel (Editor), Advances in Irrigation Vol. I. Academic Press, New York, NY, pp. 43-85.

Jaleel, C.A, Manivannan, P. Wahid, A. Farooq, M., Al-Juburi, H.J., Somasundaram, R. Panneerselvam, R. (2009a) Drought Stress in Plants: A Review on Morphological Characteristics and Pigment Composition. *International Journal of Agriculture and Biology* **11**:100-105.

James, L.G. (1988) Principles of Farm Irrigation System and Design. John Wiley and Sons, New York, pp.40-43.

Jamison, V.C. (1946) Resistance to wetting in the surface of sandy soils under citrus trees in central Florida and its effect upon penetration and the efficiency of irrigation. Proceedings of the *Soil Science Society of America* **11**:103-109.

Jia, W. S. and Zhang, J.H. (1997) Comparison of exportation and metabolism of xylem-delivered ABA in maize leaves at different water status and xylem sap pH. *Plant Growth Regulation*. **21**, 103-113.

Johnstone, P.R., T.K. Hartz, M. LeStrange, J.J. Nunez, and Miyao, E.M. (2005) Managing fruit soluble solids with late-season deficit irrigation in drip-irrigated processing tomato production. *HortScience* 40(6): 1857-1861.

Kadioglu A, Terzi R (2007). A dehydration Avoidance Mechanism : Leaf rolling. *Bot. Rev*., **73** (4): 290-302.

Kaiser,W.M., Hartung,W. (1981) Uptake and release of abscisic acid by photoautotrophic mesophyll cells, depending on pH gradients. *Plant Physiology* **68**:202–206.

Kamoshita, A., Wade, L.J. and A. Yamauchi, (2000). Genotypic variation in response of rainfed lowland rice to drought and rewatering: III. Water extraction during the drought period. *Plant Prod. Sci.*, **3**: 189-196.

Kaplan, F., Kopka, J., Sung, D.Y., Zhao, W., Popp, M, Porat, R. and Guy, C.L. (2007) Transcript and metabolite profiling during cold acclimation of Arabidopsis reveals an intricate relationship of cold-regulated gene expression with modifications in metabolite content. *Plant J* **50***: 967–981*.

Kermode, A.R. *(2005)* Role of abscisic acid in seed dormancy. *J Plant Growth Regul.* **24***: 319–344.*

Kevekordes, K.G., McCully, M.E.M., Canny, J. (1988) Late maturation of large metaxylem Vessels in soybean roots: significance for water and nutrient supply to the shoot. *Ann. Bot. 62*: 105-117.

Khor, M. (2006) The impact of globalisation and liberalisation on Agriculture and small farmers in developing countries: The experience of Ghana, pp. 32-38 .

Kirnak H, Kaya C, Tas I, Higgs D (2001). The influence of water deficit on vegetative growth, physiology, fruit yield and quality in eggplants. Bulgarian J. *Plant Physiol*., **27** (3-4): 34-46.

Kishor, P., Hong, Z., Miao, G.H., Hu. C.A.A.and Verma, D.P.S. (1995) Over expression of 1-pyrroline-5-carboxylate synthase increases proline production and confers osmotolerance in transgenic plants. *Plant Physiol* **108**: 1387–1394.

Konings, H. (1989) Physiological and morphological differences between plants with a high NAR or a high LAR as related to environmental conditions. In: Lambers H, Cambridge ML, Konings H, Pons TL (eds) Causes and Consequences of Variation in Growth Rate and Productivity of Higher Plants, SPB Academic Publishing, The Hague, pp 101–123

Kramer, P. J. (1932) The absorption of water by root systems of plants. *Am. Jour. Bot.***19**: 148–164.

Kramer, P. J., (1955a). Water content and water turnover in plant cells. "*Encyclopedia of Plant Physiology",* **1**, pp. 194-222.

Kramer, P. J. (1969) *Plant and soil water relationships: a moderate synthesis* 1969. McDraw-Hill, Inc. New York: pp 352-361.

Kramer, P. J. (1988). Opinion: Changing concepts regarding plant water relations. *Plant, Cell Environ.* **11**, 565–569.

Kramer, M., R. Sanders, H. Bolkan, C. Waters, R. E. Sheehey, and Hiatt, W.R (1992). Post–harvest evaluation of transgenic tomatoes with reduced levels of polygalacturonase: processing, firmness and disease resistance. *Postharvest Biol. Technol.* **1**: 241–255.

Krieg,D.R. and Sung, J.F.M. (1986) Source-sink relations as affected by water stress during boll development. In 'Cotton Physiology Number 1'. (Eds JR Mauney, JM Stewart) pp. 73-77.

Krishnamurthy, L. Saxena, N.P. and Johansen C**. (**1993) Registration of a drought-resistant chickpea germplasm.*Crop Science* **33**:1424.

Krishnamurthy, L. Kashiwagi, J. Upadhyaya, H.D**.** and Serraj, R**.** **(**2003) Genetic diversity of drought avoidance root traits in the mini-core germplasm collection of chickpea. *International Chickpea and Pigeon pea Newsletter* **10**:21–24.

Leeper, G.W. and Uren, N.C. (1993) Acidity and alkalinity. In 'Soil science: an introduction'. (Eds GW Leeper, NC Uren) pp. 191 201. (Melbourne University Press: Carlton, Vic.)

Leopold, A. C. (1964) *Plant Growth and Development*. McGraw-Hill Book Co.,New York.pp.405-407.

Liang, J. Zhang, J. Wong, M. H. (1997) How do roots control xylem sap ABA concentration in response to soil drying*? Plant Cell Physiology* **38***:* 10–16.

Loomis, R.S. and Williams, W.A. (1963) Maximum crop productivity -an estimate. *Crop Sd.* **3**: 67-72.

Losch, R. (1977) Response of stomata to environmental factors- experiments with isolated epidermal strips of Polypodium vulgare. I. Temperature and Humidity. *Oecologia* **29**:85–97.

Liu, F.L., Jensen. C.R. and Andersen, M.N. (2003) Hydraulic and chemical signals in the control of leaf expansion and stomatal conductance in soybean exposed to drought stress. Functional Plant Biology, 30, 65-73.

Luan, S. (2002) Signaling drought in guard cells. *Plant Cell and Environment* **25**: 229-237

Maggio A, Miyazaki S, Veronese P et al (2002) Does proline accumulation play an active role in stress induced growth reduction? Plant J 31:699–712.

Matin, M.A., Brown, J.H and Ferguson, H. (1989). Leaf water potential, relative water content, and diffusive resistance as screening techniques for drought resistance in barley. *Agronomy Journal*. **81**: 100-105.

Martin, J.J. and Juniper, D.E. (1974). *The Cuticles of Plants.* Edward Arnold, London.pp 453-459

Maximov, N.A. (1929). *The plant in relation to water.* The Macmilan Company, New York. 451pp.

McCully, M. E. Roots in Soil (1999) Unearthing the complexities of roots and their rhizospheres. *Annual Review of Plant Physiology and Plant Molecular Biology* **50,** 695-718.

McIlrath, W.J., Abrol, Y.P. and Heiligman, F.(1963) Dehydration of seeds in intact tomato fruits. *Science* **142**:1681–1682.

McMichael, B.L., and Quisenberry, J.E. (1991). Genetic variation for root-shoot relationships among cotton germplasm. *Environ. Exp. Bot*. **31**:461–470.

McMichael, B.L., and J.D. Hesketh. (1982) Field investigations of the response of cotton to water deficits. Field Crops Res. 5: 319- 333.

Millar, B. D. (1966) Relative turgidity of leaves: temperature effects in measurement. *Science* **154**:512-513.

Miller, C. (1916) Comparative study of the root systems and leaf areas of the corn and sorghums. *J. Agric. Res*. **6**: 311-333.

Mitchell, J.H., Siamhan, D., Wamala, M.H., Risimeri, J.B, Chinyamakobvu, E., Henderson, S.A. and Fukai, S. (91998) The use of seedling leaf death score for evaluation of drought resistance in rice. *Field Crops Research* **55**, 129-139.

Monk, L.S., Fagernstedt, and Crawford, R.M.M. (1987) Superoxide dismutase as an anaerobic polypeptide. A key factor in the recovery from oxygen deprivation in *Iris pseudacorus.* Plant Physiol. **95**:72-82.

Montheith, J.L. 1972. Solar radiation and productivity in tropical ecosystems, *J. appl. Ecol*. **9**: 747.

Munns, R. and Sharp R.E. *(*1993*)* Involvement of abscisic acid in controlling plant growth in soils of low water potential. *Australian Journal of Plant Physiology* **20**, 425–437.

Munns, R and Sharp, R.E (1993) Involvement of ABA in controlling plant growth in soils at low water potential. Australian Journal of Plant Physiology, 20, 425-437.

Nanjo, T., Kobayashi M, Yoshiba Y, Kakubari Y, Yamaguchi-Shinozaki K, Shinozaki K (1999a) Antisense suppression of proline degradation improves tolerance to freezing and salinity in Arabidopsis thaliana. *FEBS Lett* **461***:* 205–210.

Murahama, M., Yoshida, T., Hayashi, F., Ichino, T., Sanada, Y. and Wada, K. *(*2001) Purification and characterization of Δ^1-pyrroline-5-carboxylate reductase isoenzymes, indicating differential distribution in spinach (Spinacia oleracea L.) *leaves. Plant Cell Physiol* **42***:* 742–750.

Nash, D., Miyao, M., Murata, N. (1985) Heat inactivation of oxygen evolution in photosystem II particles and its acceleration by chloride depletion and exogenous manganese. *Biochim Biophys Acta* **807**:127–133.

Nelson, W. R., and L. D. Baver**. (**1940). Movement of water through soils in relation to the nature of the pores. *Soil Sci. Soc. Amer. Proc*. 5: 69-76.

Nichols, K.A., Wright, S.F., Liebig, M.A. and Pikul J.L Jr.(2004) Functional significance of glomalin to soil fertility. Proceedings from the Great Plains Soil Fertility Conference Proceedings. Denver, CO, 2-4.

Nilson, E.T and Orcutt, D.M.(1979) Physiology of plants under stress, Abiotic Factors. *2nd Ed., John Wiley and Sons Inc.,* New York, p.689.

Nkansah, G. O. and Ito, T. (1994) Relationship between some physiological characters and yield of heat-tolerant and non-tolerant and tropical tomato cultivars at high temperatures. *Japanese Society for Horticultural Science,* Vol. 62 (4): 781-788.

Nkansah, G. O., K. O. Bonsu., A. Nukaya., A. Kiriiwa and K. G. Ofosu-Budu.(2006) Breeding for heat tolerance in tomatoes in Ghana: Physiological mechanisms and yield attributes of some heat tolerant and non-heat tolerant tomatoes. *Ghana Journal of Horticulture.* **Vol. 5**: 11-16.

Nkansah G.O., Okyere, P., Coffie, R. and Voisard, J.M. (2007). Evaluation of four exportable hybrid okra varieties in three different ecological zones of Ghana. *Ghana J. of Horticulture* . **6**:25-31.

Nobel, P. S. (1999) *Physicochemical and Environmental Plant Physiology*. Academic Press, San Diego.

Oertli, J. J., Lips, S. H., and Agami, M. (1990) The strength of sclerophyllous cells to resist collapse due to negative turgor pressure. *Acta Oecol.* 11: 281–289.
Ofosu-Budu, K.G. (2003) Performance of citrus rootstocks in the forest zone of Ghana. *Ghana Journal of Hort*. **3:** 1-9.

Opeña, R.T. and Lo. S.H. (1979) Genetics of heat tolerance in heading Chinese cabbage. *Hort-Science* **14**:33–34.

Outlaw, W.H. (2003) Integration of cellular and physiological functions of guard cells. *Critical Reviews in Plant Sciences* **22**: 503-529.

Outlaw, W.H. and De-Vlieghere-He X. *(*2001) Transpiration rate:An important factor controlling the sucrose content of the guard cell apoplast of broad bean. *Plant Physiology* ***126****:* 1716–1724

Pak. J. (2009). Generation Mean Analysis of Water Stress Tolerance in Okra. *Bot*., 41(1): 195-205.

Parvanova, D., Ivanov, S., Konstantinova, T., Karanov, E., Atanassov, A., Tsvetkov, T, Alexieva V, Djilianov, D. *(*2004) Transgenic tobacco plants accumulating osmolytes show reduced oxidative damage under freezing stress. *Plant Physiol Biochem* **42***:* 57–63.

Parida, A.K., Dagaonkar, V.S., Phalak, M.S. and Aurangabadkar, L.P. (2008) Differential responses of the enzymes involved in proline biosynthesis and degradation in drought tolerant and sensitive cotton genotypes during drought stress and recovery. *Acta Physiol Plant* **30**: 619–627

Passioura, J. B. (1980) The meaning of matric potential. *J. Exp. Bot.* 31: 1161–1169.

Pavlychenko TK (1937). Quantitative study of the entire root systems of weed and crop plants under field conditions. *Ecology* **18,** 62-79.

Pickard, W. F. (1983) The ascent of sap in plants. *Prog. Biophys. Mol. Biol.* **37**: 181–229.

Prager, D. J., and Bowman, R. L. (1963) Freezing-point depression: New method for measuring ultramicro quantities of fluids. *Science* 142: 237–239.

Radcliffe, D.E, Rasmussen, T.C.(2002) Physical properties of primary particles, in: Warrick A.W. (Ed.), Soil Physics Companion. *CRC Press*, New York, pp. 85–126.

Raven, P. H., Evert, R. F., and Eichhorn, S. E. (1992). Biology of Plants. New York: Worth. pp. 545-572.

Rawson, H.N. (1986). High temperature-tolerant wheat: A description of variation and a search for some limitations to productivity. *Wild Crops Res*. **14**:197-212.

Renner, O. (1912). *Versuche zur Mechanik der Wasserversorgung. 2. Über Wurzeltätigkeit*. *Ber. Deutsch. Bot. Ges*. **30**, 576–580; 642–648.

Reynolds, M.P., M. Balota, M.I.B. Delgado, I. Amani, and R.A.Fischer. (1994) Physiological and morphological traits associated with spring wheat yield under hot, irrigated conditions. *Aust. J. Plant Physiol*. **21**:717–730.

Richards, L. A. (1931) Capillary conduction of liquids through porous mediums. *Physics* **1**, 318-333.

Richards, L. A. and Wadleigh, C. H. (1952) Soil water and plant growth. *In* Soil Physical Conditions and Plant Growth. Ed. B T Shaw. American Society of Agronomy Series Monographs Volume II.pp. 74–251. Academic Press, New York.

Richards, R. A., G. J. Rebetzke, A. G. Condon and Van Herwaarden, A.F.(2002) Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. *Crop Sci*. **42**: 111-121.

Rick, C.M (1978) The tomato. *Sci. Amer*. **23**: 76–87.

Rodriguez, G.R., (2007) Effect of rice bran mulching on growth and yield of cherry tomato. *Cienciae Investigacion Agraria*, **34:** 181-186.

Routley, D.G. (1966) Proline accumulation in wilted ladino clover leaves. *Crop Sci*. **6:** 358-361.

Saglam, A.A., Kadioglu, R. Terzi, R. and Saruhan N (2008). Leaf rolling and biochemical changes in them in post-stress emerging *Ctenanthe setosa* plant under drought conditions. *Russ. J. Pl. Physiol*., **55**: 48- 53.

Sairam, R.K., Veerabhadra-Rao, K. and Srivastava, G.C. (2002) Differential response of wheat genotypes to long term salinity stress in relation to oxidative stress, antioxidant activity and osmolyte concentration, *Plant Sci.* **163**: 1037–1046.

Salisbury, F. B., and Ross, C. W. (1992). *Plant Physiology.* Belmont, CA: Wadsworth. pp. 357-407, 531-548.

Sandeep, S., Joji, G. V. and Paul, E. V. (2011) Essential Role of Tissue-Specific Proline Synthesis and Catabolism in Growth and Redox Balance at Low Water. *Plant Physiology* **157***:*1 292-304.

Sauter, A. Hartung, W. (2002)The contribution of internode and mesocotyl tissues to root to shoot signalling of abscisic acid. *Journal of Experimental Botany* **53**:297–302.

Sawahel, W.A. and Hassan, A.H. (2002) Generation of transgenic wheat plants producing high levels of the osmoprotectant proline. *Biotechnol Lett* **24***:* 721–725.

Sayre, J. D.(19260 Physiology of the stomata of Rumex patientia. *Ohio Jour*. *Sci*. **26**: 233-267.

Schenk, H. J. and Jackson, R. B. (2002) Rooting depths, lateral root spreads, and belowground/aboveground allometries of plants in water-limited environments. *Journal of Ecology* **90,** 480-494.

Scholander, P. F., Hammel, H. T., Bradstreer, E. D., and Hemmingsen, E. A. (1965) Sap pressure in vascular plants. *Science* 148: 339–346.

Sharkey, T. D. (1990) Water stress effect on photosynthesis. *Photosynthetica* **24**:651.

Seyed, H. A, Finn P., Mathias N. Andersen, Ali, R. S., Christian R. J, Søren H. (2011). Effects of irrigation strategies and soils on field grown potatoes: Root distribution. *Agricultural Water Management*, Volume **98**, Issue 8, 2011, Pp. 1280-1290.

Sharma, S. and Verslues, P.E. *(*2010) Mechanisms independent of abscisic acid (ABA) or proline feedback have a predominant role in transcriptional regulation of proline metabolism during low water potential and stress recovery. *Plant Cell Environ* **33***:* 1838–1851.

Shpiler, L. and Blum, A. (1986) Differential reactions of wheat cultivars to hot environments. *Euphytica* **35**: 483–492.

Simiciklas, K.D., Mullen, R.E. Carlson and A.D. Knapp, A.D. (1989) Drought induced stress effects on soybean seed calcium and seed quality. *Crop Sci*. **29**: 1519-1523.

Singh, S.P., (1995). Selection for water-stress tolerance in interracial populations of common bean. Crop Sci., 35, 118–124.

Sinclair, T.R. and Ludlow, M.M. (1985). Who taught plants thermodynamics? The unfulfilled potential of plant water potential. *Australian Journal of Plant Physiology* **12**: 213-217.

Singh, V.P, Harand, A.C. and khard, R.P.S. (1988) Production and utilization of mungbean in India. Pp. 488-498. In Shanmugasandaram, S., and Mclean, B.T. (Eds.). Mung bean. Proc of the 2nd inter. symps. AVRDC,Bangkok, Taiwan.

Slatyer R.O., (1955) Australian Journal of Agriculture Research, **61**: 365-377.

Slatyer, R. O. (1957). The significance of the permanent wilting percentage in studies of plant and soil water relations. *Bot*. *Rev*. **23**,585–636.

Slatyer**,** R.O**. (**1967) *Plant water relationships.* Academic Press, London, p. 366

Slatyer, R.O. (1977) Altitudinal variation in the photosynthetic characteristics of snow gum, *Eucalyptus pauciflora* Sieb. ex Spreng. IV. Temperature response of four population Slatyer, R. O. (1955) Studies of the water relations of crop plants grown under natural rainfall in northern Australia. *Aust. J. Agr. Res*. **6**:356-377.

Slovik, S. Daeter, W. and Hartung, W. *(*1995). Compartmental redistribution and long distance transport of abscisic acid (ABA) in plants as influenced by environmental changes in the rhizosphere. A biomathematical model. *Journal of Experimental Botany* **46***:* 881–894

Slavfk, B. (1974) *Methods of studying plant water relations*. Academic Publishing House of the Czech Academy of Sciences, Prague, and Springer, Berlin. 449 pp.

Stockton, J. R., Doneen, D.L. and Walhood, V.T. (1961) Boll shedding and growth of the cotton plant in relation to irrigation frequency. *Agron. J*. **53:**272-275.

Stockton, J. R., L.D. Doneen, and V.T. Walhood. (1961) Boll shedding and growth of the cotton plant in relation to irrigation frequency. *Agron*. J. **53**:272-275.

Sozzi, G. O., Cascone, O., and Fraschina, A. A. (1996) Effect of a high temperature stress on endobmannanase and a- and b-galactosidase activities during tomato fruit ripening. Postharvest Biology and Technology, 9, 49–53.

Sozzi, G.O. and Fraschina, A.A. (1997) Evaluation of sensory attributes and biochemical parameters in transgenic tomato fruit with reduced polygalacturonase activity. *Food Sci. Technol. Int*. **3**:93-102.

Steinberg, S.L, Miller, J.C, and McFarland MJ (1990). Dry matter partitioning and vegetative growth of young peach tress under water stress. Aust. J. Plant Physiol., **17**:6-32.

Stern, J., and E. Bresler, 1983. Nonuniform sprinkler irrigation and crop yield. *Irrig. Sci. 4*, 17-29.

Steudle, E. (1993) Pressure probe techniques: Basic principles and application to studies of water and solute relations at the cell, tissue and organ level. In *Water Deficits: Plant Responses from Cell to Community*, J. A. C. Smith and H. Griffiths, eds., BIOS Scientific, Oxford, pp. 5–36.

Stikic, R., Popovic, S., Srdic, S., Savic, M., Jovanovic, D. and Lj.Prokic, Z. (2003). Partial root drying (PRD): a new technique for growing plants that saves water and improves the quality of fruit. *Bulgarian Journal Plant Physiology*, special issue: 164-171.

Subbarao, G.V, Johansen, C. Slinkard, A.E, Rao, R.C.N. Saxena, N.P**.** and Chauhan, Y.S**.** **(**1995) Strategies for improving drought resistance in grain legumes. *Critical Reviews in Plant Sciences* **14**:469–523.

Szabados L, Savoure A (2010) Proline: a multifunctional amino acid.Trends. *Plant Sci* **15**:89-97.

Taiz, L. and Zeiger, E. (1991) *Plant physiology*. Redwood City: The Benjamim/Cummings Publishing Company, 1991. p565.

Takahashi, H. (1994) Hydrotropism and its interaction with gravitropism in roots. *Plant Soil* **165,** 301-308 (1994).

Tan, C.S. (1980) Estimating crop evapotranspiration for irrigation scheduling. *Agriculture Canada* Vol. **25**(4):26-29.

Taylor, C. A., H. F. Blaney, and W. W. McLaughlin, (1934) The wilting-range in certain soils and the ultimate wilting-point. *Amer. Geophys. Union Trans*. **15**:436-444.

Thomson, L.K., Blaylock, R., Sturtevant, J.M. and Brudvig, G.W. (1989) Molecular basis of heat denaturation of photosystem 11. *Biochemistry* **28:** 6,686-6,696.

Tindall, H.D. (1988) *Vegetables in the Tropics*. Mcmillan publisher, Hong Kong pp 351-359.

Tollenaar, M. and T. W. Bruulsema. (1988a). Efficiency of maize dry matter production during periods of complete leaf area expansion. *Agron. J.*, **80**: 580-585.
Tollenaar, M. and Bruulsema, T.W. (1988b) Effects of temperature and duration of kernel dry matter accumulation of maize. *Can J Plant Sci* **68**: 935–940.

Tukey, H.B. (1964) Dwarfing rootstocks for the pear. In: *Dwarfed Fruit Trees*, The MacMillan Co., New York. pp. 182–199.

Tyree, M. T. (1976) Negative turgor pressure in plant cells: Fact or fallacy? *Can. J. Botany* 54: 2738–2746.

Tyree, M. T., and Hammel, H. T. (1972) The measurement of the turgor pressure and the water relations of plants by the pressure-bomb technique. *J. Exp. Bot.* 23: 266–282.
Van der Vossen, H.A.M., Nono-Womdim, R. and Messiaen, C.M. (2004). *Lycopersicon esculentum* Mill. In: Grubben, G.J.H. and Denton, O.A. (Editors). PROTA 2: Vegetables/Légumes. . PROTA, Wageningen, Netherlands

Vendruscolo, E.C.G., Schuster, I., Pileggi, M., Scapim, C.A., Molinari, H.B., Marur, C.J. and Vieira, L.G. (2007) Stress-induced synthesis of proline confers tolerance to water deficit in transgenic wheat. *J Plant Physiol* **164**: 1367–1376
Villareal, R.L. an Lai, A.H. (1978) Development of heat-tolerant tomato varieties in the tropics. First Intl. Sym. Trop. Tomato. Asian Veg. Res. of Development Ctr., Shanhua, Taiwan, Republic of China. p. 188-200, 870.

Voetberg, G. S. Sharp, R. E. *(*1991) Growth of the maize primary root at low water potentials. III. Role of increased proline deposition in osmotic adjustment. *Plant Physiol* **96**: 1125–1130.
Vogel, H. J. (2000) A numerical experiment on pore size, pore connectivity, water retention, permeability, and solute transport using network models. *European Journal of Soil Science* **51**, 99-100.
Wang, W.X., Vinocur, B., Shoseyov, O. and Altman, A. (2001) Biotechnology of plant osmotic stress tolerance. Physiological and molecular considerations. *Acta Hort* **560**: 285–292.

Wang, W. and Vinocur, B., Altman, A. (2003) Plant responses to drought, salinity and extreme temperatures: towards genetic engineering for stress tolerance. *Planta* **218**, 1-14.

Wardlaw, I.F., Sofield, I. and Cartwright, P.M**. (**1980) Factors limiting the rate of dry matter accumulation in the grain of wheat grown at high temperature. *Austr. J. Plant Physiol.*, 7: 87-100.
Warner, J., Tan, C.S. and Zhang, Q. (2004). Effect of regulated deficit drip irrigation on processing tomato fruit solids and yield. Am. Soc. Of Agric. Biol. Eng., ASAE Annual Meeting, paper no: 042094.

Wiesner, C.J. (1970) Climate, Irrigation and Agriculture: A guide to the practice of irrigation. Angus and Robertson, Sydney. Pp 200-201.

Wilkinson, S. and Davies, W.J. (2002) ABA-based chemical signalling: the co-ordination of responses to stress in plants. *Plant, Cell and Environment* **25**:195–210.

Wilson, C. L., and Loomis W.E. (1962). *Botany*. Holt, Reinhart and Winston, New York, 573pp.

Wilson, P.B., Estavillo, G.M., Field, K.J.,Pornsiriwong, W., Carroll, A.J., Howell, K.A., Woo, N.S., Lake, J.A., Smith, S.M., Harvey, A. and Millar, A. (2009) The nucleotidase/phosphatase SAL1 is a negative regulator of drought tolerance in Arabidopsis. *Plant J* **58***:* 299–31.
Wilson, C. L., and W.E. Loomis (1962). *Botany*. Holt, Rinehart and Winston, New York, p:573
Yamashita, T. and Butler, W. L. (1968). Inhibition of chloroplasts by UV-irradiation and heat-treatment. *Plant Physiol*. **43**, 2037–2040.

Zacarias, L. and Reid, M.S. (1990) Role of zeaxanthin in blue light photoreception and modulation of light CO2 interactions in guard cells. *Journal of experimental Botany*, **49**, 433-443.

Zhang, C.S., Lu, Q, and Verma, D.P.S. (1995) Removal of feedback inhibition of delta 1-pyrroline-5-carboxylate synthetase, a bifunctional enzyme catalyzing the first two steps of proline biosynthesis in plants. *J Biol Chem* **270:** 20491–20496.

Zhu, B.C., Su, J., Chan ,M.C., Verma, D.P.S., Fan, Y.L. and Wu, R.*(*1998) Over expression of a Δ^1-pyrroline-5-carboxylate synthetase gene and analysis of tolerance to water- and salt-stress in transgenic rice. *Plant Sci* **139**: 41–48.

Zhang S.Q. *and* Outlaw W.H. Jr *(*2001a*)* The guard-cell apoplast as a site of abscisic acid redistribution in *Vicia faba* L. *Plant, Cell and Environment.* **24**, 347–355.