RESPONSE OF GREENHOUSE GROWN TOMATO (*Lycopersicum esculentum Mill*) TO SOILLESS MEDIA AND VARYING IRRIGATION SYSTEMS

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CERTIFICATION

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This report is dedicated to my Wife, Mrs. Alagha, Christianah Kehinde

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ABSTRACT

Soilless farming of vegetables in greenhouse has become a profitable venture in some parts of the world. A high degree of competence in engineering skills, irrigation techniques and cost reduction is required for its successful operation. In Nigeria, the potential of soilless farming in greenhouses has not received adequate attention. The use of soilless media and appropriate irrigation system to produce marketable tomato in a greenhouse were investigated.

Roma VF variety of tomato was planted in a greenhouse in Owo, Ondo state in six soilless media: sand, sawdust, Coconut Fiber (CF), Sand/Sawdust (1:1) (SS), Sawdust/CF (1:1) (SCF) and CF/Sand (1:1) (CFS). The control was tomato grown directly on a clayey loam soil adjacent to the greenhouse. Drip and micro sprinkler irrigation units were designed, constructed and calibrated. These were used to fertigate the crop with a pre-mix NPK 20:20:20 liquid fertilizer. The experiment was a 2 x 6 factorial combination with three replicates using completely radomised design. Water Use Efficiencies (WUE) of tomato were calculated while crop coefficients (K_c) and Potential Evapotranspiration (ET_p) of tomato were estimated using combination of data obtained from the greenhouse and that of a nearby weather station. Yield and percentage of marketable fruits of tomato were determined at maturation. The experiment was repeated for two growing cycles. Data were analysed using ANOVA at $p = 0.05$. Cost benefit analyses of using drip versus micro sprinkler irrigation system and the use of soilless media versus soil were evaluated.

Mean temperature and relative humidity inside and outside the greenhouse were 31±2 ^{o}C and 79±3 % and 27±2 ^{o}C and 74±3 %, respectively. The uniformity coefficient obtained for the sprinkler unit was 91 %, while the emission uniformity of the drip was 95 %. Total amount of water used by sprinkler was three times the amount used by the drip irrigation. The WUE of tomato varied from 5.4 to 6.8 g/l under sprinkler and 16.7 to 24.4 g/l under drip irrigation. The mean of K_c values varied between 0.44 and 0.92 and the ET_p values ranged between 93.3 and 158.9 mm. The CFS and CF produced the highest number of fruit yield of 5.9 and 5.6 kg/plant, respectively, while the control produced least value of fruit yield (2.1 kg/plant). There was a significant difference between yield of tomato under sprinkler and drip irrigation systems. The percentage of marketable fruits was 92, 85, 82, 80, 79, 78 and 60 for CFS, sand, CF, SCF, SS, sawdust and control, respectively. The benefit-cost ratio of drip irrigation versus micro sprinkler irrigation was 2:1, while that of soilless media versus soil was 6: 1.

Soilless planting produced tomato of higher yield and there was marked increase in production for the two growing cycles. Mixture of coconut fiber and sand (1:1) and drip irrigation system is recommended for the practice of greenhouse-grown tomato in the study area.

Keywords: Soilless media, Fertigation, Tomato, Greenhouse.

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CHAPTER ONE

1.1 INTRODUCTION

Soilless planting is an advanced agricultural mechanization method recently practiced in many advanced countries like Israel, Thailand and USA with poor agricultural soils or where there are limited lands for planting or in other countries where alternative to arable planting is desirable. It can be practiced in the house, in an apartment block or by those who do not have a garden. One may not have to spend enormous amount of money to start an hydroponic garden. Commercial vegetable production is very expensive involving costly inputs like suitable land, expensive fumigants, pesticides and herbicides. For some vegetables especially those produced on relatively small areas or having few pesticide label, continued soil-based production may be suitable. Soilless culture such as used in greenhouse provides alternative to soil-based culture especially for situations where suitable chemical treatments do not exist (George and Robert, 1999). Soilless culture in greenhouse for vegetable is relied on heavily in Europe, United States, the Middle East, Japan and Canada among others (George and Robert, 1999). Jensen (1991) observed that a high degree of competence in plant science and engineering skills are required for successful operation of soilless planting.

Different types of soilless media have been used in different parts of the world. Common materials used for soilless media preparations in New Zealand include peat, bark of some trees, sawdust, pumice and sand. Potential materials also include ponga, sphagnum, rockwool, cocofibre and expanded clay. BetterGrow Hydro Industrial Corporation (2007) which is based in United States listed bud blanket, canna coco, coco coir, rockwool, organic potting soil, perlite, coconut fiber and expanded clay as potential materials for soilless planting. Each of the listed materials can be used on its own or as mix. The requirements of the medium are adequate porosity, cleaniness, and allowance for good drainage and air circulation. In addition to all of this, there is the need for fertigation.

The term fertigation refers to the application of fertilizers with the irrigation water. Most greenhouse vegetable production systems use this approach for fertilizing the crop. It is most appropriate for those production systems which rely on either hydroponics or on an inert substrate for crop culture. Adding nutrients to the crop with the irrigation water in these systems is a straightforward technique that is easily automated. When done properly, correct levels of nutrients can be supplied to the plants with a minimum of waste.

Hydroponics is a technology for growing plants in nutrient solutions (water and fertilizers), with or without the use of an artificial medium (e.g. sand, gravel, vermiculite, rockwool, peat moss, sawdust) to provide mechanical support. Liquid hydroponic systems have no other supporting medium for the plant roots; aggregate systems have a solid medium of support which is referred to as soilless medium. Hydroponic systems are further categorized as open in which once the nutrient solution is delivered to the plant roots, it is not reused again or closed where surplus solution is recovered, replenished, and recycled (BetterGrow Hydro Industrial Corporation, 2007).

Some regional growers, agencies, and schools of thought persist in confining the definition of 'hydroponic' to refer to liquid systems only. This exclusion of aggregate hydroponics serves to blur statistical data, and may lead to an underestimation of the extent of the technology and its economic implications (Sorenson and Relf, 1996). According to A-A turbogarden (a publication in Turkey), there are five basic hydroponic systems which are; aeroponics, drip method**,** ebb and flow, NFT (Nutrient Film Technique) and the aeration method. Sorenson and Relf (1996) divided hydroponic systems into two broad divisions, namely the water culture systems and the aggregate systems. The water systems include the nutrient film technique, aeroponics and aeration methods while the aggregate systems are the flood and drain method, trickle feed method and the tube culture which is a modification of the trickle method. Advantages derived from soilless planting include among others:

(i) bypassing weeding for cost reduction and cultivation effectiveness;
(ii) eliminating of diseases associated with soil;
(iii) elimination of volatilization of fertilizers due to high temperature in the tropics which normally leads to acid rain;
(iv) optimal reduction in machinery cost;
(v) conservation of water (with recycling systems, hydroponic systems use one tenth the amount of water used in irrigated agriculture), EPA(2006)
(vi) eliminating of water pollution as a result of leaching of micro and macro nutrients to water table in soil farming.

According to Jensen et al. (1997), virtually, all hydroponic systems in temperate regions of the world are enclosed in greenhouse-type structures in order to provide temperature control, reduce evaporative water loss, give better control of diseases and pests, and protect hydroponic crops against weather parameters such as wind and rain. Hydroponic systems are also gaining importance in greenhouses especially in tropical regions where wind and rain may do considerable damage to crops. In the tropics, the sides of a greenhouse structure are often left open for natural ventilation but if pest infestations threaten, the sides can be covered with screens.

Planning is important before a home greenhouse project is started. Building a careful greenhouse does not need to be expensive or time-consuming. The final choice of the type of greenhouse will depend on the growing space desired, home architecture, available sites and costs. The greenhouse must, however, provide the proper environment for the growing plant. The greenhouse should be located where it gets maximum sunlight. Good drainage is another requirement for the site. When necessary, the greenhouse is to be built above the surrounding ground for rainwater and irrigation water to drain away. Other site considerations include the light requirements of the plants to be grown; locations of sources of heat, water, electricity and shelter from winter wind. Access to the greenhouse should be convenient for both people and utilities. A workplace for potting plants and a storage area for supplies should be nearby. Home greenhouse can be attached to a house or garage, or it can be a freestanding structure. The site and personal preference most often dictate the choices to be considered. An attached greenhouse can be a half greenhouse, a full-size structure, or an extended window structure. There are advantages and disadvantages for each type. A good selection of commercial greenhouse frames and framing materials is available. The frames could be made of wood, galvanized steel, or aluminium. Build-it-yourself greenhouses are usually for structures with wood or metal pipe frames. Plastic pipe materials generally are inadequate to meet snow and wind load requirements. Frames can be covered with glass, rigid fiberglass, rigid double-wall plastics, or plastic film. All the materials have merits, demerits and limitations which should be considered before a suitable choice is made.

The most common type of covering is polyethylene sheet film. This is considered fairly standard except that some films recently introduced into the market retard the loss of infrared heat. Such films are reported to reduce the heat loss from a greenhouse by 20%, and will probably be widely used for polyethylene covered structures in the future

(Jensen, 1991). Other glazing materials such as fiberglass, polyvinylchloride, Mylar, and Tedlar have proven either inappropriate, inconvenient, or in most cases, much more expensive than polyethylene, even though polyethylene may need replacement more frequently.

There has been little change in the design of the basic greenhouse structure over the last decade. Greenhouses are expensive, and controlling their environment requires considerable energy. This is not so in the tropics. Jensen (1991) observed that greenhouse in the tropics is often only a rain shelter with a cover of polyethylene over a crop to prevent rainfall from entering the growing area, i.e. the hydroponic beds. The shelter can also lessen the problem of foliage diseases. In such cases, the sides of the structures are left open for natural ventilation. To prevent insects from entering, especially those which are vectors for virus diseases, the sides are covered with screens. Wood framing absorbs heat during the day and expels it at night. Wood is aesthetically pleasing and available in a variety of type and grain. Wood structures easily support heavy glass and promote a more traditional design. Wood framing are regularly treated to prevent wood rot. Wood framing is best for warm to hot climates and is a popular choice for those building their own greenhouse (greenhouse.com.2007). Most home greenhouses require a poured concrete foundation similar to those in residential houses. Quonset greenhouses with pipe frames and a plastic cover use posts driven into the ground. Permanent flooring is not recommended because it may stay wet and slippery from soil mix media (Ross, 2006). Tomato (*lycopersicon esculentum*) is a very popular crop for production in greenhouses. Tomatoes are relatively easy to grow compared to cucumbers and lettuce, and yields can be very high.

Demand for tomatoes is usually high due to the vine-ripe nature and high level of eating quality. Tomatoes are now eaten freely throughout the world and their consumption is believed to benefit the heart among other things. Lycopene, one of nature's most powerful antioxidants, is present in tomatoes. When tomatoes are cooked, lycopene has been found beneficial in preventing prostate cancer (Smith, 2007). Tomato extract branded as Lycomato is now also being promoted for treatment of high blood pressure. About 50 to 125mm of annual rainfall is required to grow tomato while the temperature should be between 20 and 25^0 C with high sunshine (Ogieva, 1998). Ogieva (1998) also recommended a spacing for tomato of 60cm within row and 75cm between rows when staked, and 60cm within row and 90cm between rows when not staked. Recommended fertilizer is either N.P.K. (15:15:15) at 50g/ha or sulphate of ammonia at 28 g/ha. Transplanting is done when seedling is about 15 to 20cm tall.

Most greenhouse tomato crops are grown today with very little pesticide sprays applied to the crop. This is especially true in northern states of USA and also in Canada. Environmental controls are important in managing diseases and biological pest control has become a standard practice. Insect and disease management in Florida greenhouses is much more challenging due to the climate conditions and high pest populations (Hochmuth et al., 2003).

Greenhouse tomato crops are started from transplants to ensure uniform crop establishment. One of the keys to successful tomato crops is high quality transplants. Each grower must be careful and ensure that everything possible is done to ensure that the highest quality plants are set in the production house. Disease transmission is the biggest concern. The use of rooted suckers from one's own crop or from someone else's house is a very dangerous practice. The suckers may contain insects such as white flies or thrips or the suckers might be infected with a disease such as a virus. For the bag-culture system, bags are placed on the cleaned floor of the house in twin-rows and the irrigation lateral laid out along each row. Dilute nutrient solution is applied to thoroughly wet the mix in the bags. It is helpful to apply the solution to bags before drainage slits are cut. The irrigation emitters are inserted and water is applied for several hours to soak the mix. Drainage slits are cut to remove excess water before the bags are planted.

Tomatoes are self-pollinated; pollen from a flower pollinates the same flower. To accomplish pollination, pollen must be loosened from the anthers and dusted onto the stigma. Outdoor wind assists in pollen dehiscence, but in the greenhouse, the flowers must be vibrated. Without vibration, poor fruit set, shape, and size could result. Recently, certain species of bumble bees have been used in greenhouses for pollination. These bees are commercially cultured and supplied to the grower. Bees are economical pollinators for growers with more than one-sixteeth hectare of tomatoes. Hives are usually active for 6 to 10 weeks, and then must be replaced. Tomatoes require close attention to fertilizer programs so that high yields and high quality fruit can be obtained. Growers should learn to fertilize the crop by the parts per million (ppm) method rather than by the soluble salt method. Fertilizer management is a part of the production practices that can be easily managed when the basics are understood. On the other hand, poor fertilizer management can lead to serious quality problems that take long periods to correct. For the trough system, all plant material should be removed and the irrigation system flushed and cleaned. Chlorination and/or acidification might be needed to clean out bacteria and/or calcium carbonate scale.

1.2 Statement of the problem

In Nigeria, agricultural soil is becoming degraded due to intensive use, while competition from other uses and urbanization are on the increase. In many regions of the world, it is difficult for soilless planting of vegetables in greenhouses to compete well with field crops. In many parts of the world, soilless farming of vegetables in greenhouses has become a profitable venture. Different countries practice soilless farming for various reasons. Some for lack of good soils, land or space for farming as a result of urbanization and competition from other uses like in highly industrialized countries. Some are involved just to serve as an alternative to soil culture due to the many advantages of soilless farming which are inexhaustible as it can bypass weeds and pests. Soilless farming can even be practiced in the house, an apartment or even in the garage apart from the resultant high and quality yield in terms of firmness, taste and marketability. A high degree of competence in engineering skills, irrigation techniques and costs reduction are required for successful operation of soilless farming. In Nigeria, the potentials and profitability of soilless planting in greenhouses have not received adequate attention. It is therefore necessary to determine the potential of producing marketable vegetables in Southern Nigeria, using locally available soilless media and appropriate irrigation methods.

1.3 Specific Objective

The aim of this study is to produce tomato in Nigeria using soilless media and appropriate irrigation systems.

1.4 Other objectives of the study

Other objectives are to;

(i) determine the potential of producing tomato in Nigeria using sand, sawdust, coconut fiber and mixtures of the soilless media with one another.

(ii) examine the influence of sprinkler and drip irrigation methods on tomatoes grown in the various soilless media

(iii) determine the most appropriate soilless medium and irrigation method for tomato production based on yield and yield quality

(iv) develop models capable of reflecting the performance of tomato in the fertigated soilless media

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Hydroponic System

The use of hydroponic technology can be a viable alternative to methyl bromide soil fumigation for greenhouse grown tomatoes, strawberries, cucumbers, peppers, eggplants, and some flowers. Hydroponics allows crop culturing without soil fumigation by providing a system where majority of a plant's nutrient needs are met by mixing water soluble nutrients with water, and eliminating requirements for soil. Hydroponic systems that use only a nutrient solution, are categorized as water culture or solution culture, however, if the nutrient solution is used in combination with solid inert matter (i.e., Rockwool, turf stone, clay granules, sawdust, flexible polyurethane foaming blocks, composed hardwood bark, or peat) to physically support root systems and hold the hydroponic solution, it is categorized as a substrate culture or aggregate culture (EPA, 2006). If the nutrient solution is recycled, then the system is considered to be a closed hydroponic system. If the solution is discharged after use, it is considered to be an open hydroponic system. In addition to the advantages of absence of competing weeds, soil borne pests and toxic residues; water conservation; conditions that can be altered quickly to suit specific crops, various growth stages, and environmental/climate conditions; hydroponic or soilless cultures on artificial substrates also brings fresh oxygen to the root zone and takes away "off-gases," the waste by-product of the root zone, making it a highly efficient and cost-effective technology (Anon, 1992a). Because nutrients are readily available in hydroponic systems, plants have smaller, more efficient root systems and can spend more energy growing the more valuable above ground stems, foliage, and fruit. Furthermore, growers can space plants closer together, thus producing more agricultural products for a given area, while avoiding competition for scarce nutrients in the root zone (Resh, 1993). Hydroponic systems will not compensate for poor growing conditions such as improper temperature, inadequate light, or pest problems. Hydroponically grown plants have the same general requirements for good growth as field-grown plants. The major difference is the method by which the plants are supported and the inorganic elements necessary for growth and development are supplied.

The principal advantages of hydroponics as listed by Jensen(1991) include high-density planting, maximum crop yield, crop production where no suitable soil exists, freedom from the constraints of ambient temperatures and seasonality, more efficient use of water and fertilizers, minimal use of land area, and suitability for mechanized production and disease control. A major advantage of hydroponics, as compared with culture of plants in soil, is the isolation of the crop from the underlying soil which may have problems associated with disease, salinity, or poor structure and drainage. The costly and time-consuming tasks of soil sterilization and cultivation are unnecessary in hydroponic systems, and a rapid turnover of crops is readily achieved. The principal disadvantage of hydroponics, relative to conventional open-field agriculture, is the high cost of capital and energy inputs, especially if the structure is artificially heated and evaporatively cooled by fan and pad systems. Such systems of environmental control are not always needed in the tropics. A high degree of competence in plant science and engineering skills are required for successful operation. Because of its significantly higher costs, successful applications of hydroponic technology are limited to crops of high economic value in specific regions and often at specific times of the year, when comparable open-field crops are not readily available (Jensen, 1991).

Both strawberries and cucurbits are successfully grown in greenhouses in the Netherlands using artificial substrates of peat and rockwool, respectively on hanging shelves or on raised shelves outdoors (Sneh et al., 1983, Braun and Supkoff, 1994). Substrates are sterilized for reuse using steam (Liebman, 1994, USDA, 1996). Growers sterilize the recycled nutrient water by heating it to about 90°C.

2.2 Soilless Media

Up till the 1970s, container plants were grown in potting mix which was based on soil and amended with coarse sand and peat (John Innes mixes). Today many container plants, whether in nursery, glasshouse or home situations, are grown in what is called “soilless media” where the soil is replaced by other materials (Spiers, 1999). The materials used in a soilless mix can be manipulated or processed to produce a growing medium with superior physical properties to soil. Unlike soil, media mixes are usually free of contamination from disease, pests and weeds. Some materials, such as bark, are thought to actually suppress disease. Some materials used for soilless media are the by-products of other industries such as bark, or are recycled forms of waste matter such as compost.

Thus, using soilless media can be relatively inexpensive and environmentally friendly. Ferguson (1998) experimented soilless planting with elephant ears. He discovered that the ears on the elephants were 3 times as big as those from the same sized corn planted in the ground only a few meters away and were healthier and more colorful than their sisters in the flower beds.

The primary purpose of a soilless medium is to provide a lightweight substrate that holds water and nutrients, permits gas exchange to and from the roots, as well as mechanical support. Many different components can be used to formulate soilless mixes. There are five major components used by professional mix companies for greenhouses in the U.S. and Canada. These are peat, bark (aged or composted), coir, perlite, and vermiculite. Other components are also used but mainly in more regional mixes (Ferry, 2006). Lime, a wetting agent, and a nutrient charge is commonly added to professional greenhouse mixes. Greenhouse pepper crops in Florida are grown in soilless culture. The plants are grown in containers filled with soilless media, such as perlite, pine bark, or peat mixes (Cantliffe et al., 2004). The media can be reused for two or three crops if disease contamination does not occur. The containers used are nursery pots (12- 16 liters) with one plant per pot. Another planting scheme uses flat polyethylene bags that are 90cm long (20 liters) with 3 to 4 plants per bag. The plant containers are aligned in double rows, one next to the other leading to plant population densities of 3 to 4 plants/m^2. Also, similar marketable fruit yields were harvested from plants grown in various substrates, such as perlite, pine bark, or peat-perlite mixes. “Pine bark, milled, and sieved to particle sizes smaller than 2.5cm^2, has shown to be a promising medium in Florida because of its low cost, availability, lack of phytotoxicity, and excellence as a plant production media (Cantliffe et al., 2004). Dirk (2005) conducted a research to determine the conduciveness of different soilless growing media to Pythium root and crown rot of cucumber under near- perlite commercial conditions. Substrates made from rockwool, coir dust and pumice were compared. It was concluded that Rockwool slabs of 7 cm height were more conducive to the Pythium disease than coir dust slabs, pumice or perlite. Greenhouse growers have had many years to adopt soilless culture for vegetable production and many soilless systems have been developed. Early systems relied on naturally available sand, gravel, volcanic rock, or various mixtures of these materials. Nutrient-film systems, involving producing crops in recirculating nutrient solutions, have been used for many years. Modern systems employ manufactured media such as rockwool, perlite, expanded clay, and other materials in plastic containers or plastic wrapping. Certain organic products, such as pine bark, coconut coir, rice hulls, composted plant materials, etc., have been used successfully for greenhouse culture of vegetables (Hochmuth et al., 2003). Hochmuth and Davis (1999) compared 6 soilless media and media combinations in a vertical production system for Basil, leafy vegetable. The media and their combinations together with yield data are detailed in Table 2.1 which shows that all the soilless media and combinations performed well for the production of basil with only minor differences in crop yield from one media to another. The tower with perlite and coconut coir (25:75) had somewhat poorer color on plants in the bottom pots only. This perhaps was due to wetter conditions in those lower pots. However, yields were very similar across each media treatment with about 0.2kg/plant produced over a period of about 15 weeks of harvest. Hochmuth (1999) then concluded that any of the media or media combinations used in that study would be excellent for production of basil in the Verti-Gro production systems.

2.3 Greenhouse Vegetable Production

Profitable greenhouse vegetable production depends on a complex system of chemical processes that make up plant growth. With optimum greenhouse and cultural management systems, growers hope to maximize the efficiency of plant growth so that high yields of high quality vegetables result (Hochmuth, 2001). The leading States in greenhouse vegetable production in US are California, Florida, Colorado, Arizona, Ohio, Texas, and Pennsylvania—all with over 90,000m^2 of production each (U.S Census of Agriculture, 1997). Bell pepper growers in Florida, and perhaps other areas of the country, have a viable alternative to growing them in the field. During the 2002-2003 growing season, 7,120 hecters of bell peppers were planted and mostly green bell pepper fruits (mature but unripe stage of fruit development) were harvested from these field crops. Coloured bell pepper fruits (ripe) attract market values that are 3-5 times higher than green fruits, but high fruit quality and yield of coloured fruits are difficult to obtain in open field environments. In the United States, the consumption of high-quality red, orange, and yellow bell peppers (*Capsicum annuum*) has increased dramatically in the past decade. To satisfy consumer demand, Mexico, The Netherlands, Canada, Israel, and Spain export high-quality greenhouse-grown peppers to the United States. In Florida, high market prices, consumer demand, and a suitable environment for growing coloured peppers

Table 2.1: Yield of Basil in Soilless

Media	Volume Ratio	Yield (oz/plant)
Perlite	100	6.8
Perlite & Vermiculite	85:15	7.4
Perlite & Coconut Coir	75:25	7.3
Perlite & Coconut Coir	50:50	7.4
Perlite & Coconut Coir	25:75	7.8
Scotts Metro Mix^{TM} (366-P)	100	7.4

Source: Hochmuth (1999)

under protected agriculture have encouraged greenhouse growers to consider the economic viability of the crop (FOIA, 2005).

Cultivation of sweet pepper (*Capsicum annuum* L.) in the greenhouse allows the production of high quality coloured fruits year round (Jovicich and Cantliffe, 2000). The tomato is a very popular crop for production in greenhouses. Tomatoes are relatively easy to grow compared to cucumbers and lettuce, and yields can be very high. The demand for tomatoes is usually strong due to the vine-ripe nature and general overall high level of eating quality. Greenhouse tomatoes require large amounts of water, using 1 to 2 litres of water per plant per day during peak growing periods (Hochmuth, 1991). Cucumber varieties grown in greenhouses are known as European types. These special cucumbers are parthenocarpic; that is, they produce fruit without the need for pollination. In fact, care should be taken to avoid pollination by non-parthenocarpic cucumbers because this will result in bitter, misshapen fruit. Typically, cucumbers could be germinated in flats of rockwool or foam blocks, usually with a single seed per well to ensure planting with minimal root damage. Plants should be transplanted to final spacing in the greenhouse when they are large enough to handle without damage. They will usually be ready for transplanting in two to three weeks under optimal conditions (Boyhan, 2000). Hochmuth (1991) reported that vegetables produced in greenhouses require ample amounts of water for optimum growth, yield, and fruit quality. Water is the “universal solvent” in plant cells and is involved in many biochemical processes. Growth processes will slow, and lower yield and quality will result if the plant is without water even for a very short period. Greenhouse growers apply irrigation water daily in frequent, short applications. Fertilizers are generally applied through the irrigation water. Recirculation systems should be used when practicable to collect excess irrigation water and prevent leachates from entering groundwater. The most important leafy vegetable grown under greenhouse conditions is lettuce. Many different types and varieties of lettuce can be grown under greenhouse conditions (Boyhan, 2000).

The advantages and disadvantages of greenhouse vegetable production in Florida, USA as stated by Cantliffe et al. (2005) are as highlighted below.

Advantages

(i) Soil fumigation in not required.

(ii) Yields per ha can be up to 10 times the field grown

(iii) Quality of fruit is increased.

(iv) Incidence of most fungal and bacterial diseases is reduced.

(v) Insect vectored viruses are not a problem in screened greenhouses.

(vi) Fruit can be produced and marketed as pesticide-free.

(vii) Harvest efficiency can be improved.

(viii) In Florida, energy costs for heating are reduced or absent compared to colder climates

(ix) Increased efficiency of water use.

Disadvantages

(i) Start-up costs for greenhouse production can be high.

(ii) Growers require high skill especially for highly intensive field production.

2.4 Soil System

Greenhouse production is based on either soil or soilless culture. In soil culture, vegetables are produced in the native soil or in a loamy soil brought inside the greenhouse. In 1974, 70% U.S. production was based on soil culture and the remaining on soilless culture. By 1988, a significant shift to soilless systems had occurred, with soil systems making up only 40% of the acreage (Greer and Diver, 2000). Commercial vegetable production is very expensive involving many costly inputs. One of these inputs is suitable land, which is becoming scarce, particularly in urbanizing areas around the country. Intensive vegetable production in many areas is being practiced on the same land without regular rotation. Soil fumigants, such as methyl bromide, have provided for continuous vegetable culture in the same fields because these fumigants rid the soil of a broad spectrum of crop pests, including nematodes, insects, weeds, and disease organisms.

The combination of polyethylene mulch, drip irrigation, and soil fumigation has provided very efficient, profitable, and safe production of high-quality vegetables around the world. Recently, certain pesticides have been removed from the market and the popular methyl bromide soil fumigant was to be phased out by 2005 (Hochmuth et al., 2003). According to White (2007), with the loss of methyl bromide, vegetable growers will find it more difficult to eradicate certain soil-borne pests and weeds for successful vegetable production. Vegetable production in the native greenhouse floor soil in Florida is not recommended due to potential for disease organism and nematode build-up. More than 95% New Zealand's greenhouse vegetable growers have changed to soilless cultures in preference to growing in the soil during the last 15 to 20 years (White, 2007). Production in the native soil requires sterilization of the soil between crops. This is a large undertaking since an extremely large volume of soil must be sterilized in-place (Hochmuth, 2001). In soil culture, also known as ground culture, vegetables are raised on level ground as well as in mounded beds. Soil culture is more popular with organic growers than hydroponic methods. One of the reasons organic growers prefer soil culture to hydroponics is that soil-building practices are an already familiar concept based on decades of research and experience (Greer and Diver, 2000).

Planting directly into the soil requires the least amount of initial labour. The big disadvantage is possible disease, insect and weeds problems that can be present in the soil. This problem can increase over time with successive cropping, particularly if the same crop is grown repeatedly. Soil fertility should be determined and managed with soil testing. As with any field soil, the soil pH should be adjusted to between 6.0 and 6.5. Soluble salts build-up can be particularly severe with the soil system. According to Simonne and Huchmuth (2012) to minimize this problem, the house can be uncovered when not in production to allow rainfall to leach the soil. Optimum pH for most crops is about 6.0, but field tomatoes are considered to be moderately tolerant of soil acidity (pH 5.5-6.8). Tomatoes in soilless culture appear to be able to tolerate even lower pH values. Maximal yields were obtained at pH of between 4.5 and 5.0 but an increase of pH to 7.0 decreased the yield of tomatoes by 25% (Simonne and Huchmuth, 2012). In addition, fertilizers that do not contribute excess soluble salts should be used. This would include calcium nitrate, potassium nitrate, triple superphosphate, diammonium phosphate, potassium sulfate and sulphate of potash-magnesias (Boyhan, 2000).

2.5 Irrigation Systems

Drip irrigation, also known as trickle irrigation or micro-irrigation is an irrigation method which minimizes the use of water and fertilizer by allowing water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters. Modern drip irrigation has arguably become the most important innovation in agriculture since the invention of the impact sprinkler in the 1930s, which replaced wasteful flood irrigation. Drip irrigation may also use devices called micro-spray heads, which spray water in a small area, instead of dripping emitters. These are generally used on tree and vine crops with wider root zones. Subsurface drip irrigation (SDI) uses permanently or temporarily buried dripper line or drip tape located at or below the plant roots. It is becoming popular for row crop irrigation, especially in areas where water supplies are limited or recycled water is used for irrigation. Careful study of all the relevant factors like land topography, soil, water, crop and agro-climatic conditions are needed to determine the most suitable drip irrigation system and components to be used in a specific installation.

With the advent of modern plastics, major improvements in drip irrigation became possible. Plastic micro tubing and various types of emitters began to be used in the greenhouses of Europe and the United States. The modern technology of drip irrigation was invented in Israel by Simcha Blass and his son Yeshayahu. Instead of releasing water through tiny holes, blocked easily by tiny particles, water was released through larger and longer passageways by using friction to slow water inside a plastic emitter. The first experimental system of this type was established in 1959 when Blass partnered with Kibbutz Hatzerim to create an irrigation company called Netafim. Together they developed and patented the first practical surface drip irrigation emitter. This method was very successful and subsequently spread to Australia, North America, and South America by the late 1960s.

The components of the drip irrigation system listed in order from the water source are as follows:

(i) Pump or pressurized water source
(ii) Water Filter(s) - Filtration Systems: Sand Separator, Cyclone, Screen Filter, Media Filters
(iii) Fertigation Systems (venturi injector) and Chemigation Equipment (optional)
(iv) Backwash Controller
(v) Main Line (larger diameter pipe and pipe fittings)
(vi) Hand-operated, electronic, or hydraulic control valves and safety valves
(vii) Smaller diameter poly tube (often referred to as “laterals”)
(viii) Poly fittings and Accessories (to make connections)
(ix) Emitting Devices at plants (Emitters or Drippers, micro spray heads, inline drippers, trickle rings)

Drip (subsurface drip irrigation) is used almost exclusively when using recycled municipal waste water. Regulations typically do not permit spraying water through the air unless it has

fully treated to potable water standards. Because of the way the water is applied in a drip system, traditional surface applications of timed-release fertilizer are sometimes ineffective, so drip systems often mix liquid fertilizer with the irrigation water (fertigation). Fertigation and chemigation (application of pesticides and other chemicals to periodically clean out the system, such as chlorine or sulfuric acid) use chemical injector such as diaphragm pumps, piston pumps, or venturi pumps. The chemicals may be added constantly whenever the system is irrigating or at intervals. Fertilizer savings of up to 95% are being reported from recent field tests using drip fertigation and slow water delivery as compared to timed-release and irrigation by micro spray heads (Wikipedia, 2007). If properly designed, installed, and managed, drip irrigation may help achieve water conservation by reducing evaporation and deep drainage when compared to other types of irrigation such as flood or overhead sprinklers since water can be more precisely applied to the plant roots. In addition, drip can eliminate many diseases that are spread through water contact with the foliage.

However, drip irrigation has some disadvantages or shortcomings which make sprinkler irrigation an acceptable alternative especially where water is sufficient. These disadvantages include the following:

(i) Cost: Initial cost can be more than overhead systems.

(ii) Waste: The sun can affect the tubes used for drip irrigation, making them last shorter than they would otherwise. Longevity is variable.

(iii) Clogging: If the water is not properly filtered and the equipment not properly maintained, it can result in clogging.

(iv) Drip irrigation might be unsatisfactory if herbicides or top dressed fertilizers need sprinkler irrigation for activation.

(v) Drip tape causes extra cleanup costs after harvest. The user needs to plan for drip tape winding, disposal, recycling or reuse.

(vi) Waste of water, time and harvest, if not installed properly.

These systems require the study of all the relevant factors like land topography, soil, water, crop and agro-climatic conditions, and suitability of drip irrigation system and its components. According to Haman and Yeager (2005), there are some good reasons why overhead sprinkler irrigation systems are commonly used in the container nursery industry. Apart from being used for several years they are reliable, relatively low in maintenance and they can be used for chemical injection. The biggest drawback is that they are inefficient in water application, unless water can be recycled. In sprinkler or overhead irrigation, water is piped to one or more central locations within the field and distributed by overhead high-pressure sprinklers or guns. A system utilizing sprinklers, sprays, or guns mounted overhead on permanently installed risers is often referred to as a solid-set irrigation system. Higher pressure sprinklers that rotate are called rotors and are driven by a ball drive, gear drive, or impact mechanism. Rotors can be designed to rotate in a full or partial circle. Guns are similar to rotors except that they generally operate at very high pressures of 275 - 900 kPa and flows of 3 - 76 l/s with nozzle diameters in the range of 10 - 50 mm. Sprinklers may also be mounted on moving platforms connected to the water source by a hose. Automatically, moving wheeled systems known as travelling sprinklers may irrigate areas such as small farms, sports fields, parks, pastures, and cemeteries unattended. Most of these utilize a length of polyethylene tubing wound on a steel drum. As the tubing is wound on the drum powered by the irrigation water or a small gas engine, the sprinkler is pulled across the field. When the sprinkler arrives back at the reel, the system shuts off. Leboeuf (2012) concluded that choosing the right irrigation system requires more than grower experience. To be most effective, he suggested irrigation system should be designed by experts. In addition, Leboeuf, (2012) also reported that two primary methods are used for the in-field distribution of irrigation water in Ontario which are the drip irrigation (also known as trickle or micro-irrigation) and the sprinkler or overhead irrigation (includes boom, centre pivot, lateral move, travelling gun systems). The appropriate frequency of irrigation and amount of water applied are quite different between these two irrigation methods and these differences must be considered in irrigation scheduling. Each irrigation system also has inherent advantages and disadvantages

Vegetables produced in greenhouses require ample amounts of water for optimum growth, yield, and fruit quality. Water is the “universal solvent” in plant cells and is involved in many biochemical processes. Growth processes will slow, and lower yield and quality will result if the plant is without water even for a very short period. Hochmuth (2001) maintained that some type of water-status measuring system is needed to monitor water level in the growing medium. Based on research with various cultural systems, devices and rules-of-thumb have been developed. Given these numerous advantages and disadvantages of both the sprinkler and drip irrigation systems as applied to greenhouse vegetable production, it is desirable to determine which of these is better for vegetable production in some selected soilless media.

2.6 Irrigation Scheduling

Irrigation scheduling is the decision of when and how much water to apply to a field (Broner, 2005). Its purpose is to maximize irrigation efficiencies by applying the exact amount of water needed to replenish the soil moisture to the desired level. Irrigation scheduling saves water and energy. All irrigation scheduling procedures consist of monitoring indicators that determine the need for irrigation. Uniform water distribution across the field is important to derive maximum benefits from irrigation scheduling and management. Azah (2009) defined irrigation scheduling as the use of water management strategies to prevent over application of water while minimizing yield loss due to water shortage or drought stress. Accurate water application prevents over- or under-irrigation. Over-irrigation wastes water, energy and labour, leaches expensive nutrients below the root zone and out of reach of plants, reduces soil aeration and thus crop yields. Under irrigation stresses the plant and causes yield reduction. Without this, there is no means of determining when irrigation is required. Deciding when to irrigate is based on knowing to what level soil moisture can be allowed to deplete without causing undue water stress to the plant. This soil moisture level varies with soil type and water demand of the crop (Burt et al., 2008).

When sprinkler and drip irrigation methods are used, it may be possible and practical to vary both the irrigation depth and interval during the growing season. With these methods, it is just a matter of turning on the tap longer/shorter or less/more frequently. The methods used to determine the irrigation schedule are: plant observation, estimation and simple calculation. The plant observation method is normally used by farmers in the field to estimate when to irrigate. The method is based on observing changes in plant characteristics, such as colour, curling of the leaves and ultimately, plant wilting. For the estimation method, a table is provided with irrigation schedules for the major field crops grown under various climatic conditions. The simple calculation method is based on the estimated depth (mm) of the irrigation application, and the calculated irrigation water need of the crop during the growing season. Table 2.2 shows information on how to estimate irrigation schedule for major field crops during the period of peak water demand. The schedules are given for three different soil types and three different climates. The information adapted from FAO (1988) is based on calculated crop water needs and estimated root depth for each of the crops under consideration. The calculation assumes that with the irrigation method used, the maximum possible net application depth is 70 mm.

With respect to soil types, a distinction is made between sand, loam, and clay, which have, respectively, low, medium and high available water content. An overview indicating the climatic zones where ETo values can be found is given in Table 2.3. Irrigation schedules based on the crop water needs in peak period are given in Table 2.4. The irrigation schedule, which is obtained using Table 2.4, is valid for the peak period that is the mid-season stage of the crop. In order to save water, it may be feasible to irrigate, during the early stages of the crop development, with smaller irrigation applications than during the peak period. During the late season stage it may be feasible to irrigate less frequently, in particular, if the crop is harvested dry.

Table 2.2: Procedure for estimating Irrigation Schedule for major crops for different soils and climates

Soil Type/ Climate	Comments
Shallow and/or sandy soil	In a sandy soil or a shallow soil (with a hard pan or impermeable layer close to the soil surface), little water can be stored; irrigation will thus have to take place frequently but little water is given per application.
Loamy soil	In a loamy soil more water can be stored than in a sandy or shallow soil. Irrigation water is applied less frequently and more water is given per application.
Clayey soil	In a clayey soil even more water can be stored than in a medium soil. Irrigation water is applied even less frequently and again more water is given per application.
Climate 1	Represents a situation where the reference crop evapotranspiration ETo = 4 - 5 mm/day.
Climate 2	Represents an ETo = 6 – 7 mm/day.
Climate 3	Represents an ETo = 8 – 9 mm/day.

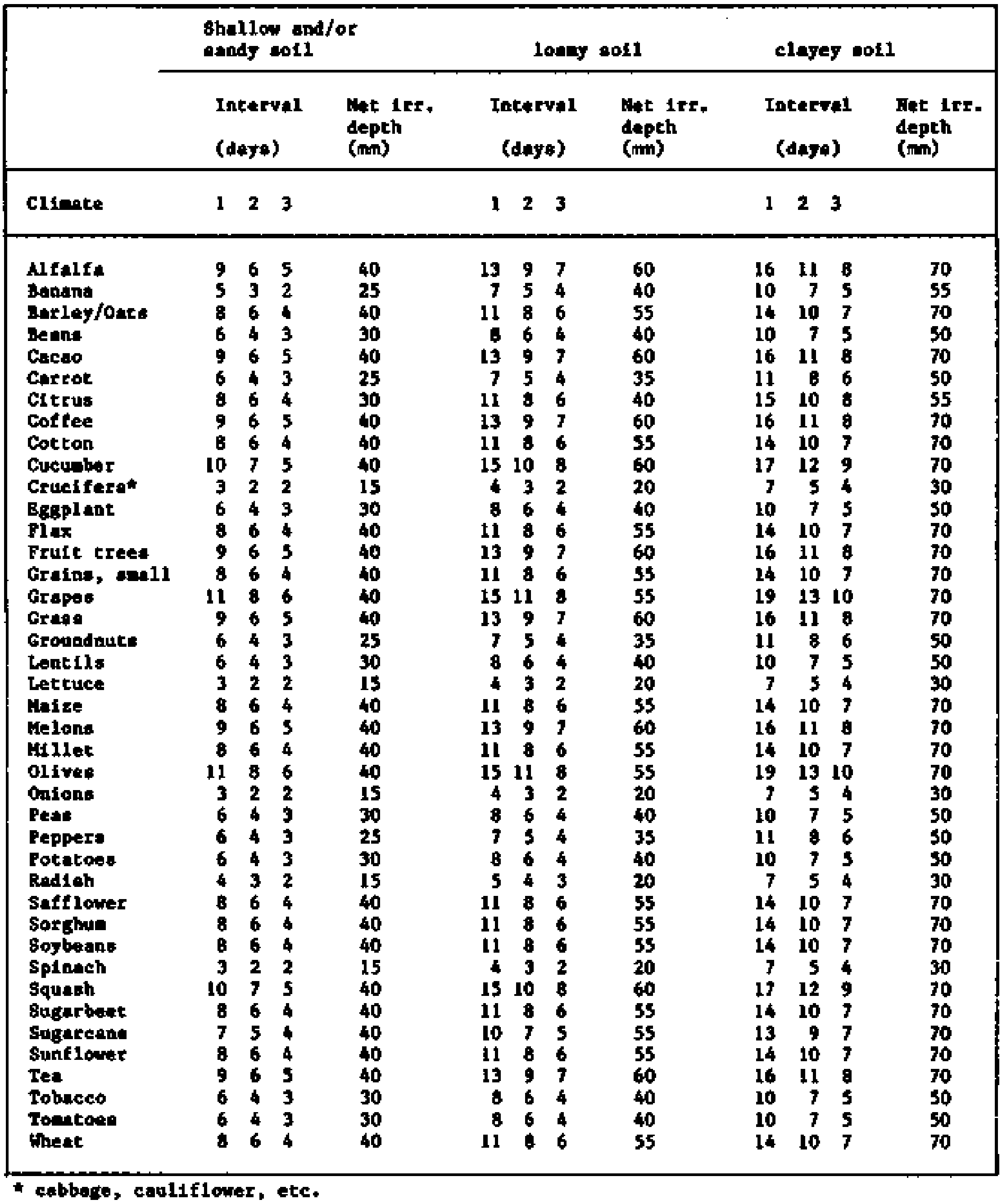
Source: FAO (1998)

Table 2.3: Reference crop evapotranspiration (mm/day)

Climatic zone	**Mean daily temperature**		
	Low (<15°C)	**Medium (15-25ºC)**	**High (>25ºC)**
Desert/arid	4 – 6	7 – 8	9 – 10
Semi-arid	4 – 5	6 – 7	8 – 9
Sub-humid	3 – 4	5 – 6	7 – 8
Humid	1 – 2	3 – 4	5 – 6

Source: FAO (1998)

Table 2.4: Estimated irrigation schedules for major crops based on the crop water needs in the peak period



	Shallow and/or sandy soil				loamy soil				clayey soil			
	Interval (days)			Net irr. depth (mm)	Interval (days)			Net irr. depth (mm)	Interval (days)			Net irr. depth (mm)
Climate	1	2	3		1	2	3		1	2	3	
Alfalfa	9	6	5	40	13	9	7	60	16	11	8	70
Banana	5	3	2	25	7	5	4	40	10	7	5	55
Barley/Oats	8	6	4	40	11	8	6	55	14	10	7	70
Beans	6	4	3	30	8	6	4	40	10	7	5	50
Cacao	9	6	5	40	13	9	7	60	16	11	8	70
Carrot	6	4	3	25	7	5	4	35	11	8	6	50
Citrus	8	6	4	30	11	8	6	40	15	10	8	55
Coffee	9	6	5	40	13	9	7	60	16	11	8	70
Cotton	8	6	4	40	11	8	6	55	14	10	7	70
Cucumber	10	7	5	40	15	10	8	60	17	12	9	70
Crucifers*	3	2	2	15	4	3	2	20	7	5	4	30
Eggplant	6	4	3	30	8	6	4	40	10	7	5	50
Flax	8	6	4	40	11	8	6	55	14	10	7	70
Fruit trees	9	6	5	40	13	9	7	60	16	11	8	70
Grains, small	8	6	4	40	11	8	6	55	14	10	7	70
Grapes	11	8	6	40	15	11	8	55	19	13	10	70
Grass	9	6	5	40	13	9	7	60	16	11	8	70
Groundnuts	6	4	3	25	7	5	4	35	11	8	6	50
Lentils	6	4	3	30	8	6	4	40	10	7	5	50
Lettuce	3	2	2	15	4	3	2	20	7	5	4	30
Maize	8	6	4	40	11	8	6	55	14	10	7	70
Melons	9	6	5	40	13	9	7	60	16	11	8	70
Millet	8	6	4	40	11	8	6	55	14	10	7	70
Olives	11	8	6	40	15	11	8	55	19	13	10	70
Onions	3	2	2	15	4	3	2	20	7	5	4	30
Peas	6	4	3	30	8	6	4	40	10	7	5	50
Peppers	6	4	3	25	7	5	4	35	11	8	6	50
Potatoes	6	4	3	30	8	6	4	40	10	7	5	50
Radish	4	3	2	15	5	4	3	20	7	5	4	30
Safflower	8	6	4	40	11	8	6	55	14	10	7	70
Sorghum	8	6	4	40	11	8	6	55	14	10	7	70
Soybeans	8	6	4	40	11	8	6	55	14	10	7	70
Spinach	3	2	2	15	4	3	2	20	7	5	4	30
Squash	10	7	5	40	15	10	8	60	17	12	9	70
Sugarbeet	8	6	4	40	11	8	6	55	14	10	7	70
Sugarcane	7	5	4	40	10	7	5	55	13	9	7	70
Sunflower	8	6	4	40	11	8	6	55	14	10	7	70
Tea	9	6	5	40	13	9	7	60	16	11	8	70
Tobacco	6	4	3	30	8	6	4	40	10	7	5	50
Tomatoes	6	4	3	30	8	6	4	40	10	7	5	50
Wheat	8	6	4	40	11	8	6	55	14	10	7	70

* cabbage, cauliflower, etc.

Source: FAO (1998)

2.7 Innovative Techniques in Soilless Planting

Soilless culture is a modern practice, although growing plants in containers has been used in the past to produce aesthetic plants, rare fruits and expensive vegetables. However, it played no role in commercial food supply. In the early 70s, researchers developed complete nutrient solutions, coupled their use to appropriate rooting media, and studied how to optimise the levels of nutrients, water and oxygen to demonstrate the superiority of soilless media in terms of yield. This technique was further developed for food production in soilless media, first in the Netherlands and later in a few other countries (Raviv, 2010).

Raviv (2010) carried out a research in Israel to investigate the level of development of soilless farming on commercial food production. He averred that commercial application of soilless media has evolved at a fast pace, gaining popularity among growers throughout the world. He adduced reasons for this to be the various advantages derivable from soilless media. These advantages according to Raviv (2010) include the following:

1. Ability to maintain simultaneous optimal levels of water and oxygen availabilities to plant root.
2. Ease of controlling optimal nutritional status in the root zone.
3. Most growing media are initially pathogen-free, and can be relatively easily maintained this way during the course of the crop and between crop cycles.
4. Water and fertilisers can be recirculated, thus preventing environmental pollution and loss of resources and improving water and nutrient use efficiencies.
5. Many substrate types are based on recycled materials. Most of them can be further recycled, after the end of the growing cycle.

All these, Raviv (2010) opined, resulted into fast increase in terms of the area of land used for soilless production of food, yields per unit area and capital investment. He compared the productivity of soilless culture with soil-based food production and concluded that soilless farming was better for producing high quantity of crop with good quality. He maintained that the technique has a great potential in providing food security even on commercial bases and thus called for all knowledge gaps to be bridged for required future researches.

Naasz and Bussieres (2010) conducted a research in Canada on wetting properties of growing media which are important factors to consider in order to optimize irrigation management (water and fertilizer inputs) thereby minimizing environmental concerns (pollution of ground and surface waters). The objective of his study was to evaluate the effect of two commercial wetting agents (with different doses) on physical and chemical properties of peat-based substrates and their influence on growth of three ornamental plants at various irrigation volumes. The study concluded that natural infestation with mites and aphids became epidemic in the conventionally grown plants (approx. 15 and 18 times gas diffusion and hydraulic conductivity in growing media containing one of these wetting agents (regardless of the dose applied).It was also observed that a strong correlation between gas diffusion and plant performances existed, even if crops were planted under different irrigation managements (standard or reduced volumes). Naasz and Bussieres (2010) concluded that regardless of the wetting agent used, plants cultivated on growing media containing reduced doses of wetting agent indicated good crop performances than those containing the recommended concentration.

Tomatoes are mainly grown on rockwool but alternative substrates that could reduce the rockwool waste are desirable. Composts have been suggested as an alternative growing medium for the non-sustainable peat-or cocoa fiber-based media and could partly replace those substrates in a mixture. Compost originating from green waste is generally low in salt content and can be considered an appropriate substitute for many peat or cocoa fiber based growing media. In addition, compost-induced suppression of soil-borne plant diseases was reported. In Belgium, Vergote et al. (2010) studied the effect of composted green waste amendments in the growing medium on the yield and quality of tomato. The suitability of green waste compost as a growing medium for tomato crop production was compared with coconut coir. Vergote et al (2010) found that the mineral content of tomato leaves was unaffected by the growing medium. Amending composted green waste to the coconut coir substrate resulted in a lower yield of marketable fruits than the 100% coconut coir substrate. This effect was more pronounced as more compost was added to the substrate. There were no significant differences observed in quality parameters of tomato such as taste (sensory panel), firmness, soluble solids and titratable acidity.

In the Netherlands, reuse of drainage water is obligatory for all soilless growing systems to reduce environmental pollution. However, this system has its own limitations. Apart from technical and phytopathogenic aspects, accumulation of Na, Cl or other residual ions could be a problem. Accumulation will occur if the uptake rate is lower than the concentrations in the irrigated water. Netherlands in recent time generated a database to determine the maximum acceptable concentrations of ions in the root environment and water sources, for some crops. In all cases Na was shown to be the problematic element. Voogt and Van-Os (2010) investigated problems of managing chemical water quality in closed hydroponic systems. They found out that a high tolerance for Na did not necessarily mean a high uptake rate for the ion as was found out for sweet pepper. It was also discovered that water sources differ highly in Na concentrations. In general, for completely closed growing systems only rainwater or desalinated water is suitable. For some crops such as rose, chrysanthemum and sweet pepper, the natural background concentrations of Na in rainwater is sometimes even higher than the average uptake rate. Accumulation above the maximum acceptable concentrations should be monitored and a fraction of the nutrient solution should be discharged to prevent yield reduction or decline in fruit or yield quality. However, losses in yield depend highly on the water management strategies used by the grower. They advised that good strategies should be developed for discharge of drainage water as low as possible for N and P. These should be based on the uptake dynamics of Na and Cl and minimal required N and P levels observed with different crops. Such strategies have been tested for rose which resulted in significant reduction in the nutrient losses.

The management of closed soilless systems is quite difficult when only saline irrigation water is available to the growers, generally due to NaCl. Under these conditions, the accumulation of sodium and chloride induces an increase in the electrical conductivity (EC) of the recirculating nutrient solution, which therefore is discharged more or less frequently, thus resulting in a waste of water and environmental pollution occasioned by leaching of the nutrient. In Italy, Incrocci et al (2011) examined the interactive effects of boron and salinity on greenhouse tomato grown in closed soilless system. They found out that the elevated boron (B) concentrations are often found in association with high salinity in irrigation water, especcially in municipal wastewater effluents, which are increasingly used in agriculture. Very little attention has been paid to investigate the influence of boron and NaCl concentration in irrigation water on greenhouse plants grown in closed soilless systems. Incrocci et al (2011) investigated the water use, mineral uptake, crop yield and fruit quality of tomato (*Solanum lycopersicum* L.) plants grown in perlite with recycling nutrient solution (RNS) prepared with two different B concentrations (46 or 185 μmol/l) and NaCl (0.5 or 10.0 mmol/l). RNS was discharged and replaced by newly-prepared nutrient solution whenever EC exceeded 6.0 dSm/l. It was concluded that the protective effect of salinity against B resulted from the increased frequency of flushing which reduced the accumulation of B in the root zone. Notwithstanding the differences in the incidence of leaf burn, it was discovered that there was no important effects of B and NaCl concentrations in RNS were found in terms of leaf area development, dry weight accumulation, crop yield and fruit quality.

Similarly, Gent and Short (2012) conducted a research on a simple system to recycle nutrient solution to greenhouse tomato grown in rockwool in USA. Since, using recycled nutrient solution to water plants is the preferred legislative solution to prevent groundwater pollution from intensive agricultural production in United States, several potential problems may arise from using recycled nutrient solutions to produce vegetable crops. Accumulation or deficiency of elements in nutrient solutions could slow plant growth, lower product quality, and reduce the dietary value of vegetables. Gent and Short (2012) examined the composition of a nutrient solution as it was periodically recycled to a greenhouse tomato crop in comparison to solutions that were used to water the plant only once. They reported that the transition in the plant from vegetative to fruit growth, which coincides with warmer weather, resulted in a decreased demand for nitrate and other nutrients, and an increase in electrical conductivity of water drained from the root zone. It was also discovered that it took longer time to restore the solution in the root zone to an optimal composition in the recycle compared to the discharge treatment. It was further reported that there were no consistent effects on yield, and little difference in composition of fruit or vegetative tissue, despite the large but temporary variation in composition of the nutrient solution due to recycling. Also, in USA, Bissey et al. (2010) developed a sensor to measure water content and pore water electrical conductivity of soilless substrates. Knowledge of pore water electrical conductivity (EC) is becoming a priority as researchers and growers always advocate efficient irrigation and fertilization for their plant grown on soilless media. According to Bissey et al. (2010), three independent measurements are necessary to calculate pore water EC using the well-known Hillhorst model which are bulk dielectric permittivity, bulk EC, and temperature. While all three of these measurements are commercially available, issues with accuracy, precision, repeatability and price have kept growers from adopting this technology.

Bissey et al (2010) developed a sensor that could accurately and precisely measure bulk dielectric permittivity, bulk EC, and temperature that could be used by a grower to calculate both substrate water content and pore water EC.

Sabooroo et al. (2008) conducted an experiment in Iran to evaluate the effect of some soilless media and several fertilizers on growth parameters of citrumelo (*Citrus pardisi* × *Poncirus trifoliate*) seedlings planted in a greenhouse. Soilless media used include Vermiculate/Perlite (1:1), Coco peat, Peatmoss and Peatmoss/Perlite/Coco peat (2:2:1) by volume. The fertilizers used are Biofol, Phosamco, Master, Kristalon and Floral while the growth parameters monitored were seedling height, number of leaves, and the level (amount) of Magnesium, Manganese, Iron, Zinc and Potassium in the leaves. They found out that the number of leaves per seedling were higher in Peat moss and Kristalon and Peat moss and Floral, respectively. It was concluded then that the best treatments appeared to be Peat moss and Peat moss/Perlite/Coco peat in combination with Phosamco and Floral.

In China, Ning et al (2010) studied the effects of biogas slurry as topdressing fertilizer on growth, yield and quality of tomato in greenhouse. Biogas slurry is the liquid residue of organic waste by anaerobic fermentation. It contains nitrogen, phosphorus, potassium, trace elements, amino acids and other nutrient material, which are necessary for plant growth. They compared the biogas slurry with a mixed solid inorganic-organic fertilizer which serves as a control. They concluded that biogas reduced pH and EC in growing media. It was also discovered that, though biogas slurry as topdressing promoted the growth and development of tomato plants, there is no significant difference between the biogas and mixed solid-inorganic fertilizer in total yield, fruit enlargement rate, content of nitrate and soluble sugar. The plant stem width with biogas slurry was thicker and nitrate content of fruits with slurry was higher than when mixed solid-inorganic fertilizer was used. It was further discovered that biogas decreased the acidity of tomato fruits which improved the quality of the fruits.

In a similar manner, Factor et al. (2012) also looked at the problems of diseases and pests affecting tomato plant. In tropical conditions, depending on the local altitude, it is possible to cultivate potatoes throughout the whole year. In Brazil particularly, the climatic conditions allow planting and harvesting of potatoes in all months of the year but most harvests fall within the periods that favour incidence of pests and diseases. Good productivity therefore depends majorly on the ability to control pests and diseases in the crop, so as to procure potato seeds of good quality. Factor et al (2012) found out that one of the main strategies of producing potato seeds of high health is the use of hydroponic or soilless systems. They observed that in the tropics, the choice of hydroponic or soilless system for potato seed production will depend on the technological level of the producer or company and availability of fund and local infra-structure.

CHAPTER THREE

3.1 MATERIALS AND METHODS

3.1 Experimental Site

The experiment was carried out in Owo, Ondo State, South West Nigeria. According to Olugbenga et al. (2008), Owo lies between Latitudes 5^o 45' and 7^{o}52'N; and Longitude 4^o 20' and 6^o 05'E. The natural vegetation of this area is the lowland tropical forest, composed of a variety of hard wood timbers. The vegetation also consist of woody savannah, featuring species like blighia sapida and parkia biglobosa. The climate also consists of distinct wet and dry season with mean annual temperature of about 20 to 30 ^{0}C and annual relative humidity of about 75 to 80 %. The maximum annual precipitation hovers around 2,000 mm

3.2 Preconstruction Consideration

The major engineering design considerations were divided into four categories namely: site selection, choice of structure, environmental controls and materials handling. The greenhouse was constructed on a land which is about 1km away from Rufus Giwa Research Farm in Owo, Ondo State, South West, Nigeria. The site was selected due to the existing 15.6m deep well operated by a $1^{1/}{}_{2}$ horse power DP-151 DAF water pump. The motor is housed in the well as shown in Plate 1. The greenhouse was located such that it takes the advantage of wind direction for natural ventilation and wind pollination of the vegetable. A small, single-unit, structurally simple building was erected. The slope of the land is about 15 % and this favours good drainage of the greenhouse. Thermometers were installed to monitor the temperature in the house. Enough space was provided for various materials handling inside the greenhouse.

3.2.1 Construction of a Home Type Greenhouse

A 3.14m x 3.10m x 1.83m (length x breath x height) wooden frame home type greenhouse was constructed. Materials were selected from locally available, less expensive and moderately durable ones such that the whole house was structurally strong. Plates 2 and 3 show the front and end views of the green house respectively.

Plate 1: A 15.6m deep well operated by a 11/2 horse power DP-151 DAF water pump

Plate 2: Front View of the greenhouse

Plate 3: End view of the greenhouse

3.2.2 Frame

Wooden frames of hardwood (masonia) were used to improve the durability of the greenhouse. The woods were pressure treated with chromated copper arsenate (CCA) preservatives to resist decay.

3.2.3 Glazing Materials

The roof was glazed with polyethylene film. This was chosen due to its low cost, light weight, availability and high light transmittance (Plate 4). To prevent insects from entering, especially those which are vectors for virus diseases, the sides were covered with screens. This was based on the recommendation of Jensen (1991) for tropical climate.

3.2.4 Foundations and Floors

Fine gravels were spread on the floor to provide a weed barrier and separation from the native soil. The corners of the greenhouse were properly anchored to the ground.

3.2.5 Roof System

The gable roof is 0.67m above the height of the house with a vent of 0.80m x 0 82m on the ridge line to provide natural ventilation (Plate 5). This high-roof is less expensive and more suited for use in regions with subtropical and tropical climates (Jovicich and Cantliffe, 2000).

3.2.6 Air Circulation

The roof vent allows air to escape from the hottest point on the roof ridge. Cooler air enters the base vent, creating a chimney effect and circulating cool fresh air throughout the greenhouse.

3.2.7 Platform

A platform of six rows of redwood benches were separated into three rows each by a space of 0.44m along its length to separate the sprinkler unit from the drip system. The space also provided a walkway between the two irrigation systems. Each bench row carried a drainage hole along its length as depicted by Plate 6. The platform is 2.16m x 2.14m with a height of 0.50m. Assess space of 0.60m was provided at the front and at one

Plate 4: Roof of greenhouse being glazed with polyethylene film

Plate 5: The gable roof with vent

end of the platform away from the greenhouse foundation, while 0.45m was provided at the other end.

3.3 Irrigation Design

The two methods of irrigation system used for the experiment were the sprinkler and the drip. Water was stored in big transparent rubber tank of 1000 l capacity at very high elevation of 4.5m to provide the high pressure needed by both systems to deliver the water (Plate 7). Liquid fertilizer (Boost Extra – N:P:K:20:20:20) was applied through the irrigation water (fertigation) at the rate of 60ml to 15l as recommended by the manufacturer. The nutrient content in the fertigated water was monitored by measuring the pH and electrical conductivity (EC) values of the water before application. The pH and the EC of the water varied between 7.3 to 7.7 and 2.7 dS/m to 3.0 dS/m, respectively.

3.3.1 The Sprinkler System

Component parts

1. Overhead tank to store water and fertilizer and to provide the needed operating pressure.
2. Main supply pipeline consisting of 25mm diameter and 9.8m long PVC pipe.
3. One gauge valve installed at 1.5m height on the main supply pipeline below the overhead tank
4. Three 20 mm diameter risers each of 100 cm height.
5. Three gauge valves (installed at the middle of each riser) for controlling the application rate of the sprinklers in each lateral.
6. Three 12.5mm diameter perforated pipe sprinkler that sprayed water in a non-overlap pattern at fairly uniform rate which serve as the laterals.
7. Eighteen graduated plastic cans of the same size (volume) for uniformity coefficient determination.

Plate 7: Rubber tank placed on the scaffold

Sprinkler distribution pattern

Materials used include the following:

1. 9″ block Scaffold (4.5m high)
2. Storage tank (1000 l)
3. Perforated pipe sprinklers
4. Measuring cylinder
5. Stopwatch
6. Rubber cans (area, a = $2.83 \times 10^{-3} m^2$) r = 0.03m

Eighteen rubber cans were placed at an equidistance of 35cm along each of the three parallel perforated pipe laterals containing six nozzles each. The laterals were spaced at 35cm to one another, all corresponding to within and between row spacings, respectively. The whole arrangement was on a common platform with the drip irrigation unit. The volume of water caught by each can after 3 min was recorded (Plate 8) from which sprinkler discharge, Q was determined. Application rate for each discharge was computed using the relationship given by Robert and James (2001) as follows.

$$A = KQ/a \qquad 3.1$$

where, A = application rate in mm/hr

Q = Sprinkler discharge in l/min

a = wetted area of sprinkler (surface area of can) in m^2

K = correction factor = 60, when A is expressed in mm/hr

The uniformity coefficient of the sprinkler system was determined. This coefficient represents the potential efficiency of operation of the sprinkler. The Christiansen's formula as used by (Michael and Ojha, 2003) for uniformity coefficient, Cu is given as follows:

$$\mathrm{Cu} = 100\left(1.0 - \frac{\Sigma x}{mn}\right) \qquad 3.2$$

Where m = average application rate (mm/hr)

n = total number of observation points

X = deviation of individual observations from the average application rate, mm/hr and

mn = sum of application rates for all the observation points.

Tables 3.1 and 3.2 show the application rate and the coefficient of uniformity for all the observation points.

Plate 8: Experiment to determine the discharge of the sprinkler

Table 3.1: Determination of application rate from the flow rate

Catch cans	Flow rate (FR) (Q x 10^{-4} m^3/s)	Application rate (FRxK*) (mm/hr)
1	5.00	10.60
2	6.52	13.82
3	5.87	12.45
4	5.80	12.30
5	5.40	11..45
6	5.06	10.73
7	6.68	14.42
8	5.70	12.08
9	6.51	13.80
10	5.72	12.13
11	6.38	13.53
12	6.26	13.27
13	4.70	9.96
14	6.31	13.38
15	6.41	13.59
16	5.38	11.41
17	5.11	10.83
18	6.22	13.19

K* = Equivalent conversion factor = 2.12 and FR is converted from l/min to m^3/s

Table 3.2: Determination of uniformity coefficient (frequency = 1/ observation point)

Application rates (AR) (mm/hr)	Frequency	Numerical deviation ±(m – AR)
10.60	1	1.78
13.82	1	1.44
12.45	1	0.07
12.30	1	0.08
11..45	1	0.93
10.73	1	1.65
14.42	1	2.04
12.08	1	0.30
13.80	1	1.42
12.13	1	0.25
13.53	1	1.15
13.27	1	0.89
9.96	1	2.42
13.38	1	1.00
13.59	1	1.21
11.41	1	0.97
10.83	1	1.55
13.19	1	0.81
mn = 222.81		$\sum X = 19.96$

m = 222.81/12 = 12.38 mm/hr

for, n= 18 and mn = 222.81, m = 222.81/18 = 12.38mm/hr

C_u = 100 (1.0 - 19.96/222.81)

= 100 (0.9104)

= 91.04 %

Other Design criteria

1. Topographic features: The only important factor that was considered is the slope of the greenhouse floor which is about 15 %.
2. Water supply: This was from a 15.6m deep well capable of supplying three flats throughout the year. The pH of the water was between 7.3 and 7.7, while the EC was between 2.7 and 3.0 dS/m.
3. Climatic conditions: The consumptive use of a crop depends upon the climatic parameters such as temperature, radiation intensity, humidity and wind velocity. The sprinkler was designed for the daily peak rate of consumptive use of the crop. To achieve uniform sprinkling of water, the perforations on lateral lines were made of the same number of uniform openings of about 1mm diameter and were not overlapping.
4. Soilless media properties: The application rate of the irrigation system was determined to be m = 12.38mm/hr as shown in Eqn. 2.2. The application rate however can be adjusted by a control valve which was installed in each of the riser supplying each of the laterals.
5. Depth of irrigation: This was determined from the table provided by FAO (1998) for tomato in sandy soil similar to soilless media (30mm) on the basis of available moisture holding capacity of the chosen soilless media.
6. Irrigation Interval: This was determined to be 5 days (section 3.3.4)
7. Sprinkler spacing: Spacing of the sprinkler heads (within rows) and spacing of pipes (between rows) are both 35cm as against 60cm within rows and 75cm between rows when staked or 60cm within rows, 90cm between rows when not staked when planting on the soil. This results into a very much higher planting density when compared with soil culture.

3.3.2 The Drip System

Component parts and dimensions

1. The overhead unit consists of 1000 l overhead tank (which creates the required pressure), a filter and a pressure valve.
2. 2.5 cm diameter PVC pipe (main).
3. Three 2.0 cm diameter PVC risers, each 0.3m above the platform (0.8m above the ground)
4. Three 1.25 cm diameter drip lines, each 2.34m long
5. 18 short path orifice type, point source drip emitters (6 on each of the 3 drip lines) with each at 0.12m below the drip line.

Emission uniformity of the drip irrigation unit

The emission uniformity of drip was estimated using the relationship as reported in Fasinmirin (2007) and is given as:

$E_n = 100(1.0 - 1.27\, C_v/\sqrt{N_e})\, Q_{min}/ Q_{ave}$ 3.3

where E_n = The design emission uniformity (%)

N_e = number of point source emitters per emission point

C_v = manufacturer's coefficient of variation which is 0.03 for point source emitters

Q_{min} = the minimum emitter discharge rate in the system (l/h)

Q_{ave} = the average or design emitter discharge rate (l/h)

If $C_v = 0.03$, Q_{ave} = 1.84 l/hr, Q_{min} = 1.81 l/hr, = 1 are substituted in equation 3, then

$E_n = 95\%$

Volume of water required per plant per day was estimated from the following relationship:

Volume of water required/plant/day = (ET_p * area/crop)/E_n 3.4

Similarly, $ET_p = ET_0 * P/85$ 3.5

where ET_p = Peak evapotranspiration rate for the month under consideration (February)

ET_o = Reference evapotranspiration rate for the month = 8 mm/day (estimated from Table 2.3)

P = Percentage of total area shaded by crop which is close to 80% as recommended by Ewemoje et al. (2004).

Inputting these values into equation 3.5,

ET_p = 7.53 mm/day.

Area/crop = surface area of bag = 0. 0283m^2

Volume of water/ plant/day = 7.53 x 0.0283/0.95 = 0. 22l/plant/day.

Because the media do not communicate with soil mass and water soon drain out of the drainage holes at the bottom of each bag, this value was increased by a factor of safety which was chosen to be 2 based on the average daily values of evapotranspiration.

Therefore, volume of water/plant/day was 0.44L.

Other design considerations

1. Total head required for easy flow of fertigated water in the system was put at 0.96m based on Fasinmirin (2007) for similar point source emitter
2. Plant spacing: This was the same as for the sprinkler system.
3. Slope of the land (15 %) was used to determine the location of the main and the laterals

3.3.3 Layout of the Combined Sprinkler and Drip Irrigation Systems

The spacing between laterals and between emitters in the drip system are the same as that of the sprinkler system. The drip laterals and the emitters were laid horizontally on the surface of the bags containing the soilless media.

Generally, all the bags were perforated at the base to provide for drainage. The leachate from each bag was collected through a system of network of pipes that delivered the leachate to a common trough, where it was collected and recirculated. Figures 3.1 and 3.2 show the line diagram of the combined irrigation units before the erection of the greenhouse while Figure 3.3 shows the combined assemblage of the two irrigation systems inside the greenhouse.

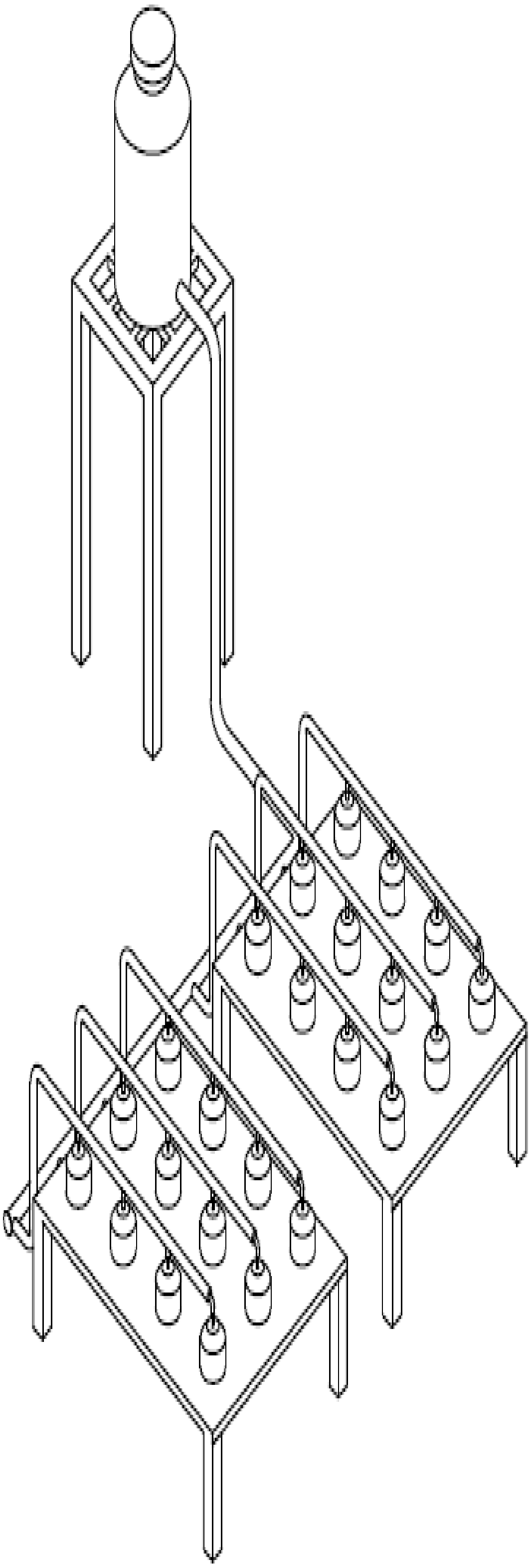


Fig. 3.1: Pictorial view of the combined irrigation units

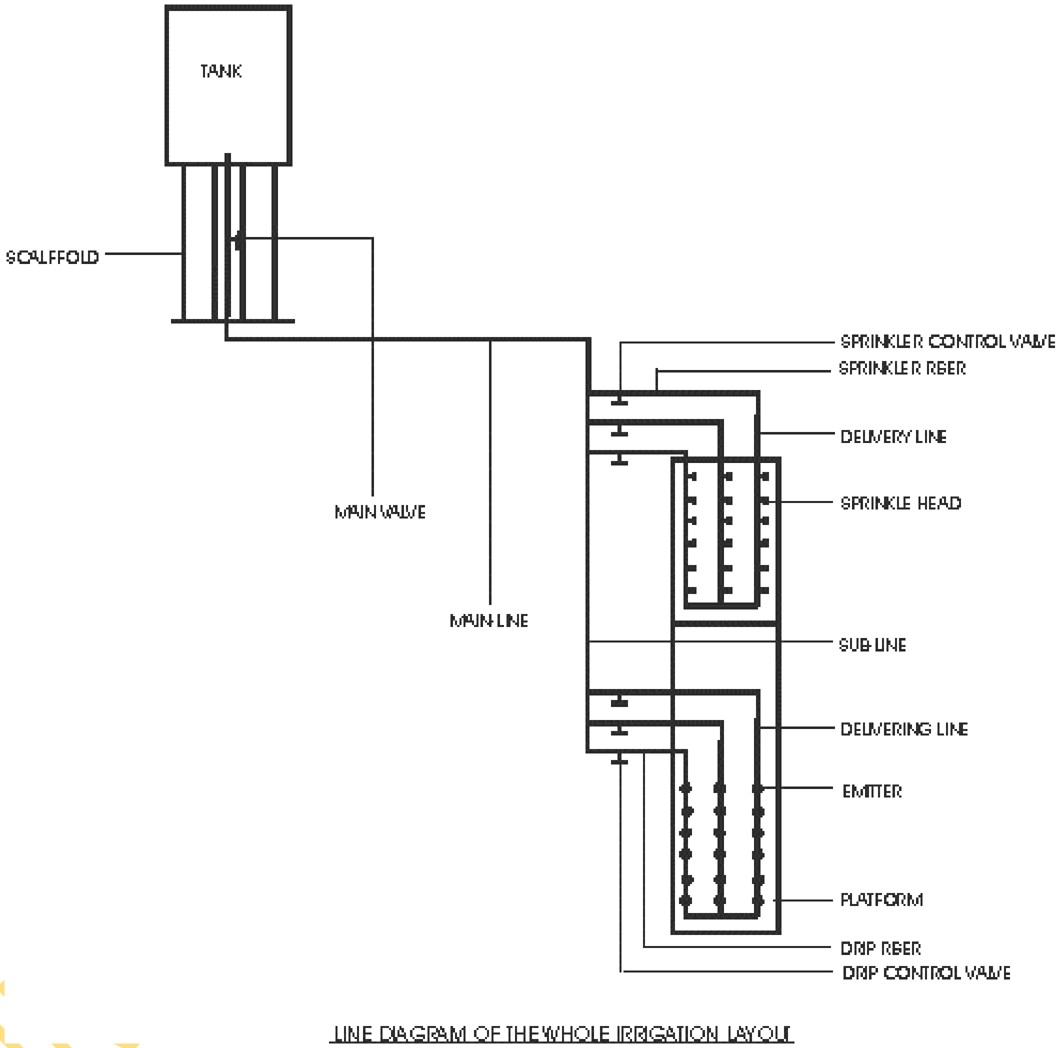


Fig. 3.2: The line diagram of the combined irrigation units

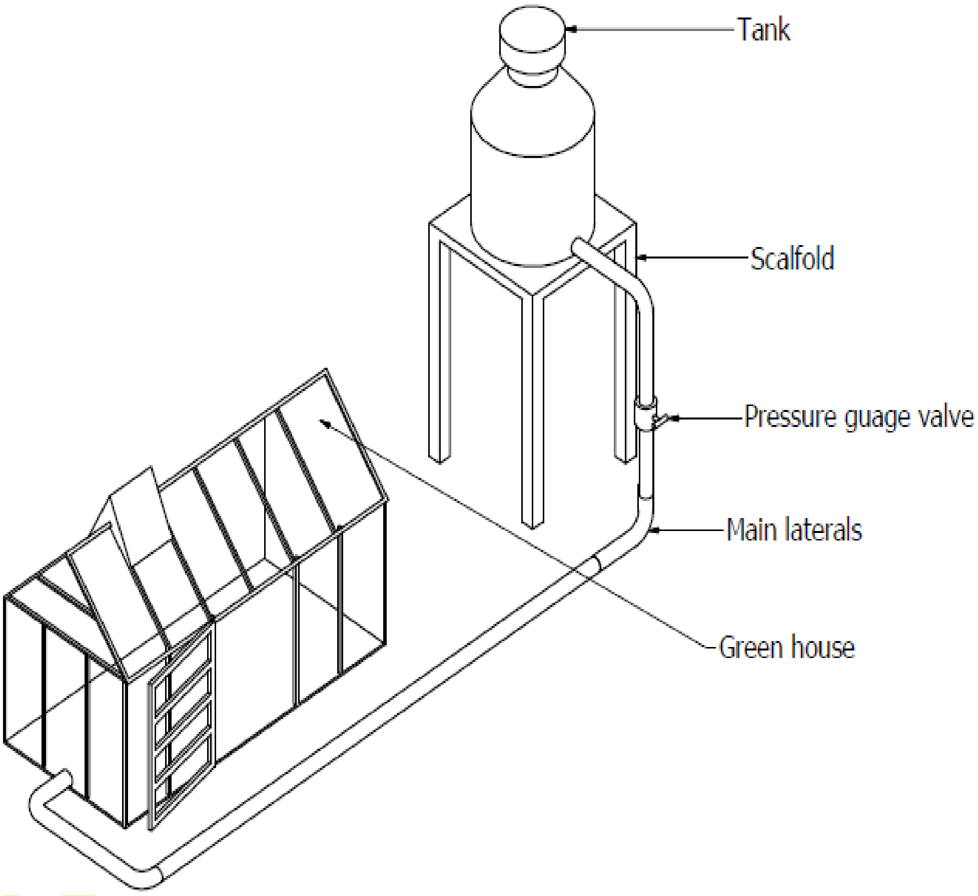


Fig. 3.3: Combined assemblage of the two irrigation systems inside the greenhouse

3.3.4 Irrigation Scheduling

Irrigation schedule was determined by the simple calculation method based on the total growing period as provided by FAO (1998). This was done by taking the steps highlighted below:

Step1: Estimate the net and gross irrigation depth (d) in mm.

Step2: Calculate the irrigation water need (IN) in mm, over the total growing season.

Step3: Calculate the number of irrigation applications over the total growing season.

Step4: Calculate the irrigation interval in days.

From Table 3.3, the root depth or the gross irrigation depth of tomato (dnet) was chosen to be 50cm and the approximate net irrigation depth from Table 3.4 is 30mm. The irrigation water need (in mm/month) for tomatoes, planted 20th February and harvested 30th June, as estimated from a similar example for a similar climate with shallow and/ or sandy soil (FAO, 1998), is as presented in Table 3.5, which sums up to 715mm/month.

The number of irrigation application over the growing season was calculated as:

No. of application = Irrigation water needed over growing season/ 30(dnet) = 715/30

= 24

Irrigation Interval = Total growing season (days)/ No. of Application = 120/24 = 5 days

Since the media were not soil mass but rather isolated from the ground water, the applied water soon drain away because of the drainage holes at the bottom of the bags containing the media. The number of application was therefore increased for different growth periods with the same amount of irrigation water to have different numbers of fertigations per day under both irrigation systems with respect to the different growth stages and efficiencies of the two systems.

Table 3.3: Approximate root depth of the major field crops

Shallow rooting crops (30-60 cm):	Crucifers (cabbage, cauliflower, etc.), celery, lettuce, onions, pineapple, potatoes, spinach, other vegetables except beets, carrots, cucumber.
Medium rooting crops (50-100 cm):	Bananas, beans, beets, carrots, clover, cacao, cucumber, groundnuts, palm trees, peas, pepper, sisal, soybeans, sugarbeet, sunflower, tobacco, tomatoes.
Deep rooting crops (90-150 cm):	Alfalfa, barley, citrus, cotton, dates, deciduous orchards, flax, grapes, maize, melons, oats, olives, safflower, sorghum, sugarcane, sweet potatoes, wheat.

Source: FAO (1998)

Table 3.4: Approximate net irrigation depths (mm)

Soil Type	Shallow Rooting Crops	Medium Rooting Crops	Deep Rooting Crops
Shallow and/or sandy soil	15	30	40
Loamy soil	20	40	60
Clayey soil	30	50	70

Source: FAO (1998)

Table 3.5: Monthly irrigation water need by tomato

Month	Water need (mm)
February	40
March	120
April	170
May	200
June	185

3.4 Experimentation

Roma VF variety of tomato was seeded on 8th February, 2009 and seedlings were transplanted at an average height of about 12cm on 20th February, 2009 inside a self-constructed home type greenhouse in six different soilless media inside polythene bags. The media were sterilized sawdust, washed sand, grinded coconut fibers and combinations of the three media in 1:1 ratio by volume. The volume of the medium in each bag was approximately 13 litres. The water holding capacity and air porosity of the growing media are detailed in Table 3.6. These parameters were determined volumetrically in the laboratory.

Sprinkler and drip irrigation systems were used to fertigate the crop with a pre-mix NPK 20:20:20 liquid fertilizer. The irrigation water was recycled in the course of irrigation. The same variety of tomato plant was planted directly on heaps in a clayey loam soil adjacent to the greenhouse as a control experiment for comparison with traditional tomato cultivation on soil in the study area. The physical and chemical properties of the soil are presented in Table 3.7. The experiment was repeated in June, 2009 when sowing was done on 12th June and transplanting was carried out on 25th June, following the same method. Plates 9 and 10 show the native soil during land preparation and the third week after transplanting, respectively.

The daily temperature, relative humidity and moisture content of the soilless media in the greenhouse were monitored with respect to the requirements of tomato plant. Agro-climatological data were obtained from the meteorological station of the Department of Agricultural Engineering, Rufus Giwa Polytechnic with additional automatic weather station which is situated at about 1 km away from the site (Plate 11). Fertilization was by fertigation; that is, fertilizer was applied through the irrigation water according to specific recommendations. For the effective irrigation water application, the horizontal production system was used for the experiment. The system uses bags filled with the soilless mix and arranged in rows on raised platform. The bags have drainage holes which deliver the leachate to a drainage trough below the raised platform. The medium was checked daily to ensure that flooding did not occur. Irrigation pipes, nozzles, emitters, drainage troughs and other equipment in the greenhouse were disinfested periodically. The 3 soilless media and 3 media combinations amount to 6 media treatments in the trial. Two irrigation systems were used to supply the needed water and nutrients. The resulting 12 treatments

Table 3.6: Physical properties of the growing media.

Growing media	**Water holding capacity %**	**Air porosity %**
Sand	20	45
Sawdust	76	20
Coconut fiber	87	23
Sand/ Sawdust	52	30
Sawdust/Coconut fiber	80	18
Coconut fiber/Sand	55	34

Table 3.7. Physical and chemical properties of soil of the experimental site.

	Soil depth	
Soil parameter	**0-15 cm layer**	**15-30 cm layer**
Physical properties		
Soil texture		
% loam	35:66	31:44
% silt	10:00	10:00
% clay	54:34	58:56
Textural class	clay	clay
Bulk density (Mgm^{-3})	1.528	1.653
Saturated hydraulic Conductivity ($cmhr^{-1}$)	0.522	0.453
Available water capacity ($mm\ m^{-1}$)	301.02	288.05
Chemical properties		
Organic carbon (%)	0.540	0.510
Free $CaCO_3$ (%)	9.17	9.40
Available N (kg/ha)	146.83	134.98
Available P_2O_5 (kg/ha)	56.20	38.70
Available K_2O (kg/ha)	398.82	342.11
Physico-chemical properties		
pH (1:2)	7.4	7.5
EC (1:2) (dSm^{-1})	0.30	0.28
CEC [Coml.(p+) kg^{-1}]	49.8	49.2

Plate 9: Land preparation of soil for planting of tomato

Plate 10: Tomato planted directly on the soil 23 days after transplanting

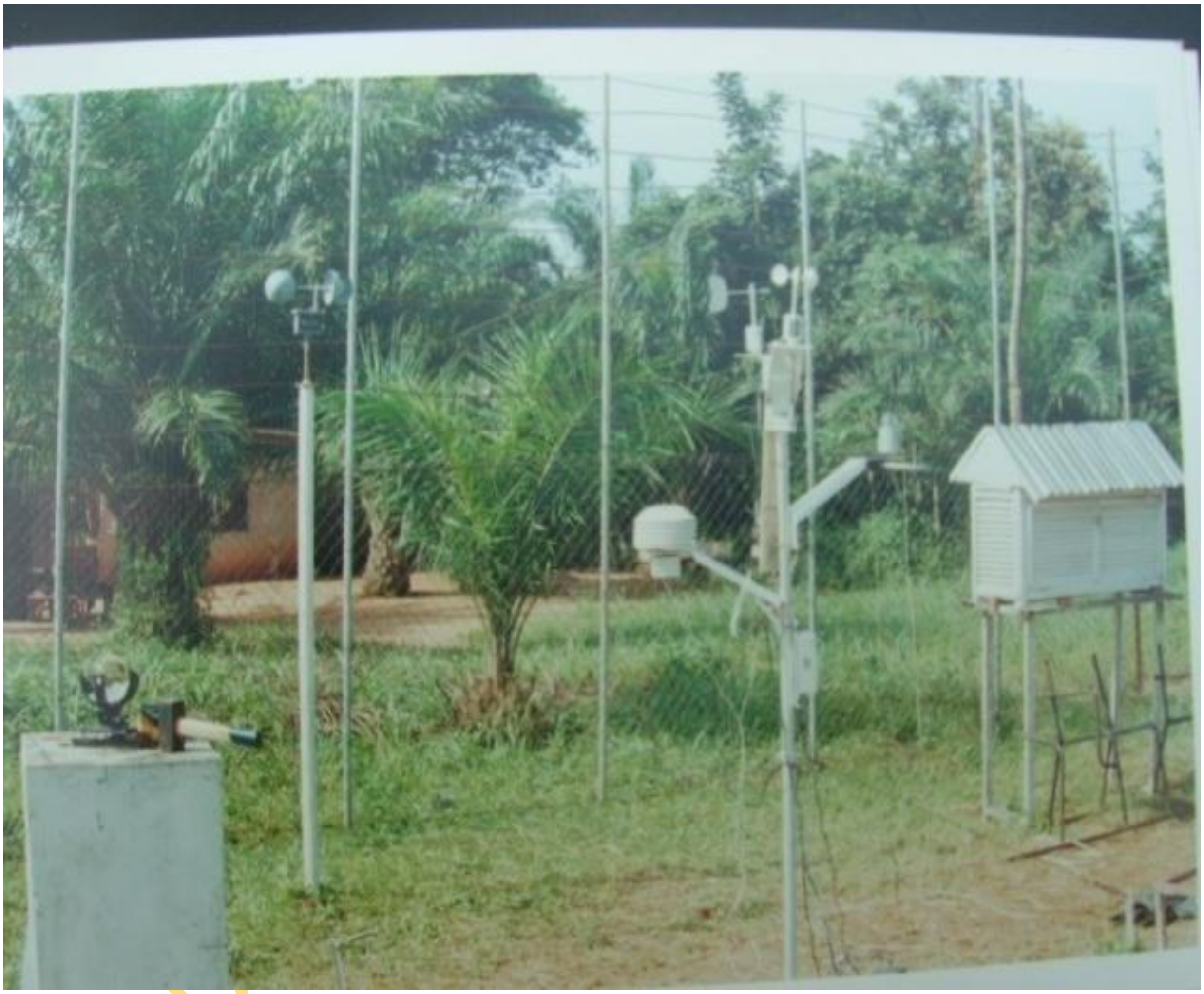


Plate 11: Agro-meteorological station of Agric Engineering Dept. Rufus Giwa Polytechnic boosted with an Automatic Weather station

included all possible combinations of type of media and irrigation systems. Each of the 12 treatments was replicated 3 times to have a total of 36 plants stands. The experimental design was a 2 x 6 factorial design with three replicates and randomized complete block design with a control.

One seedling of tomato was planted in each bag. All the plants were fertigated on the same schedule with several fertigations per day during daylight (6am - 8:00pm), depending on crop demand in each given medium. Each treatment had a different irrigation volume calculated as a function of the evapotranspiration (difference between the applied and drained volume of water) of the previous day. Fertigated water saved from drainage from both systems was recycled manually from the leachate after the electrical conductivity (EC) was determined. The volume of water to be applied was estimated by dividing the evapotranspiration of the previous day by 0.85 between the transplanting and the beginning of flowering and by 0.80, from flowering to harvest to elevate the soil moisture to field capacity and provide desirable leaching fraction of 0.15 and 0.20 as suggested by Campos et al. (2006). Water-status measuring system consists of a calibrated soil moisture tester to monitor water level in the growing medium. Flow rates and "pump on/off" cycles were therefore adjusted during the growing season and growing stages to account for different water demand in each media to arrive at the experimental design shown in Table 3.8. The arrangement of treatments is as shown in Table 3.9. The growth stages are: Stage I (period between transplanting to the beginning of flowering), Stage II (period between the start of flowering and fruiting) and Stage III (period between fruiting to maturation and harvest). In order to establish all the plants in the bags, irrigation treatments started 15 days after transplanting. Plates 12 and 13 show tomato plants after 23 days under sprinkler and drip irrigations respectively while Plates 14, 15 and 16 depict tomato at 85 days after planting under sprinkler, drip and on native soil, respectively. Plates 17 and 18 show the performance of tomato under sprinkler and drip irrigation respectively during the second planting in the month of June.

Table 3.8: Treatment design for tomato

Treatment	Sprinkler	Irrigation		Drip Irrigation		
	StageI SM I	StageII SM II	StageIII SM III	StageI DM I	StageII DM II	StageIII DM III
T1	Xx	Xx	Xx	Xx	Xx	Xx
T2	Xx	Xx	Xx	Xx	Xx	Xx
T3	Xx	Xx	Xx	Xx	Xx	Xx
T4	Xx	Xx	Xx	Xx	Xx	Xx
T5	Xx	Xx	Xx	Xx	Xx	Xx
T6	Xx	Xx	Xx	Xx	Xx	Xx
T1	Xx	Xx	Xx	Xx	Xx	Xx
T2	Xx	Xx	Xx	Xx	Xx	Xx
T3	Xx	Xx	Xx	Xx	Xx	Xx
T4	Xx	Xx	Xx	Xx	Xx	Xx
T5	Xx	Xx	Xx	Xx	Xx	Xx
T6	Xx	Xx	Xx	Xx	Xx	Xx
T1	Xx	Xx	Xx	Xx	Xx	Xx
T2	Xx	Xx	Xx	Xx	Xx	Xx
T3	Xx	Xx	Xx	Xx	Xx	Xx
T4	Xx	Xx	Xx	Xx	Xx	Xx
T5	Xx	Xx	Xx	Xx	Xx	Xx
T6	Xx	Xx	Xx	Xx	Xx	Xx

Table 3.9: Field Layout of Plots

Sprinkler			Drip		
Ts1	Ts6	Ts2	Td1	Td6	Td2
Ts2	Ts5	Ts1	Td2	Td5	Td1
Ts3	Ts4	Ts5	Td3	Td4	Td5
Ts4	Ts3	Ts6	Td4	Td3	Td6
Ts5	Ts2	Ts4	Td5	Td2	Td4
Ts6	T51	Ts3	Td6	Td1	Td3

T1 = Sand
T2 = Sawdust
T3 = Coconut fiber
T4 = Sand/sawdust
T5 = Sawdust/coconut fiber
T6 = Coconut fiber/sand
s = Sprinkler, d = Drip

Plates 12: Tomato plant under sprinkler 23 days after transplanting

Plates 13: Tomato plant under drip irrigation 23 days after transplanting

Plate 14: Tomato under sprinkler irrigation 85 days after transplant

Plate 15: Tomato under drip irrigation 85 days after transplant

Plate 16: Tomato planted directly on the soil 85 days after transplant

Plate 17: Tomato under sprinkler irrigation during the second planting

Plate 18: Tomato under drip irrigation during the second planting

Fertilizer recommendations for tomato were based on Hochmuth (1990). Supplementary application of fertilizers were made based on daily observations of symptoms for extra demands. Total irrigation water and fertilizer applied from seedling to maturity for each treatment was estimated.

Fruits from all treatments were harvested at full maturity and evaluated for weight, width, length, number of fruits per stand, and percentage of marketable fruits per plant. Analysis of variance was used to determine differences among treatments. Analysis of cost, management and labour requirements which are important factors for intending growers was equally carried out. Analysis was also carried out for maximum yield of the crop grown in the clayey loam soil and that grown in the soilless media to determine the degree of disparity between the two. The experiment was carried out for two cropping periods of 4 months each which are February to June and June to October, 2009, respectively. The results were compared with results of similar studies from other countries.

3.5 Determination of Crop Coefficient, Evapotranspiration and other Hydrological Parameters

The crop coefficient (k_c) was obtained by relating the actual crop evapotranspiration (ET_{crop}) to
reference crop evapotranspiration (ET_o) as given in the equation below.

$$K_c = ET_{crop} / ET_0 \qquad 3.6$$

where K_c = crop coefficient
ET_{crop} = crop evapotranspiration
ET_o = reference crop evapotranspiration

i) Pan evaporation method (FAO, 1986)

$$ETo = K_p E_{pan} \qquad 3.7$$

where

ET_o is the reference crop evapotranspiration,

k_p is pan coefficient

E_{pan} is pan evaporation

ii) Adjusted Blaney – Criddle (ABC) model for the tropics (Fapohunda and Ude, 1992)

$$ET_p = (37.846 - 0.254R_H)K_c K_t TP/100 \qquad 3.8$$

where

ET_p = Potential evapotranspiration (mm/day)

K_t = (0.0173T - 314) or monthly temperature factor

T = mean monthly temperature (^{o}F)

P = monthly percent of daylight hours of the year

R_H = relative humidity.

3.5 Laboratory Procedures

Nutrient solution formulation and mixing was done manually according to the crop nutrient requirement (CNR), during the season. Plant growth rate was used as a guide to further determine the amount of nutrients needed in the nutrient solution during the growth cycle. Moderate amount of nutrients was used early in the season as base application as recommended by Jones and Benton (1999). Small amounts of a pre-mix liquid fertilizer (N:P:K: 20:20:20 -Boost Extra foliage fertilizer complex) were supplied on a continual basis as suggested by Hochmuth (1990). Fertilizer materials of high quality were purchased from a reputable source in Ibadan. The recommended application rate for the Boost Extra for tomato is 60 ml to 15 l. Laboratory analyses include nutrient formulation, determination of the pH and EC of the irrigation water and the physical characteristics of the soilless media. These were carried out in the soil laboratory of the Department of Soil Science, Faculty of Agriculture, Federal University of Technology, Akure and in the Soil and Water Laboratory of the Department of Agricultural Engineering, Rufus Giwa Polytechnic, Owo.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Conditions Inside and Outside the Greenhouse

The daily values of mean temperature and relative humidity averaged at every 15 days interval is as presented in Table 4.1. These parameters were slightly higher than those outside the greenhouse. The differences were not too high because of good aeration of the greenhouse, exposure of its sides (except of course for the screen), thin polythene roofing materials and a location that takes advantage of wind direction. Mean temperature and relative humidity inside and outside the greenhouse were 31±2 ^{o}C and 79 ±3% and 27 ±2 ^{o}C and 74 ±3%, respectively. The very small variation in mean monthly temperatures favours good performance of tomato as supported by Jensen et al. (1997). Also the mean monthly values of temperature of 20-36 ^{0}C were suggested as acceptable for tomato production in the tropical region by Ogieva (1998). Adams et al. (2001) also observed that high temperature above 30^{0}C will result in low fruit yield. The mean monthly variation in relative humidity was as low as ±3 both inside and outside the greenhouse which is also an indication of a conducive environment for good performance of tomato (Adams et al., 2001). Other climatic data obtained from the weather station such as daily maximum and minimum temperatures, rainfall, relative humidity, number of sunshine hours and radiation are presented in the Appendices 1 to 6.

Table 4.1: Air Temperature and Relative Humidity inside and outside the greenhouse

Period	Air Temp (^oC)		Rel. humidity (%)	
	Inside	Outside	Inside	Outside
February 1-15	34	30	81	72
February 16-28	38	35	69	64
March 1-15	35	31	81	80
March 16–31	36	34	78	76
April 1-15	29	27	82	80
April 16-31	32	29	84	76
May 1-15	30	27	78	73
May 16-31	28	25	86	82
June 1-15	30	25	90	84
June 16-31	26	23	89	80
July 1-15	28	24	88	84
July 16-30	26	21	82	80
August 1-15	27	22	74	70
August 16–31	29	25	70	68
September 1-15	27	24	80	78
September 16-30	31	22	90	81
October 1-15	29	25	75	84
October 16-31	30	27	75	79
Average	**31**	**27**	**79**	**74**

4.2 Water Used at Various Vegetative Growth Stages

A summary of the volume of water used by each soilless medium under each irrigation system at various growth stages for the two growing periods is presented in Table 4.2. Water used in stage II which is the period between the start of flowering and fruiting is significantly higher (at 0.05 LS) than the one used in stages I & III under both sprinkler and drip irrigation systems. Under the sprinkler irrigation, water used in stage III is higher than that of stage I whereas under drip irrigation this trend is reserved. This could be attributed to wastage of water in stage III under sprinkler due to interception by leaves and shoots of tomato before getting to the soilless medium. This trend could also be due to lower Coefficient of Uniformity of the sprinkler. These arguments are probably responsible for the general increase in total water applied under sprinkler as compared to the drip for all the growth stages. The daily usage of water at various growth stages were added together every 10 days over the growing period to yield a curve of cumulative water use versus days after sowing (DAS) for the sprinkler and drip systems as depicted by Figures. 4.1 and 4.2, respectively. Both curves are sigmoidal and bear close resemblance to the one reported by FAO (2010); here, there were sharp lines instead of smooth curves probably as result of minimal wastage in water application between the various growth stages, since water application was closely monitored under the soilless media. Tables 4.3 and 4.4 present the summary of volume of water and liquid fertilizer used respectively for both growing periods. It could be deduced that the sprinkler irrigation used 3 times the amount of water used by the drip irrigation. The growth of tomato was critically affected in stage II under sprinkler due to additional water requirement as a result of interception by leaves, shoots and flowers. The quality of fruit also reduced under the sprinkler system but the total yield was not affected. Drip system saved liquid fertilizer as compared to the sprinkler. The control used solid fertilizer as recommended. It should be noted that about 20% of of the total fertigated water from both systems was recycled manually from the leachate after the electrical conductivity (EC) was determined. In addition to affecting overall growth and yield, water management affects fruit quality. Fruit size is reduced in situations where water is inadequate. This is supported by Hochmuth (2003).

Table 4.5 presents the data on water use efficiencies (WUE) of tomato under the various soilless media and irrigation treatments. The WUE is the yield (g) per liter of water used to produce the crop. On the average the WUE for drip is about three times higher than that for sprinkler which indicates efficient use of water in converting to fruit yield by the

Table 4.2: Volume of water used by each soilless treatment at various vegetative stages (liters)

	Sprinkler Irrigation			Drip Irrigation		
Treatment	Stage I SV	Stage II SV	Stage III SV	Stage I DV	Stage II DV	Stage III DV
T1	12	48	25	7.9	14.4	6.4
T2	11	35	22	6.2	12.5	5.6
T3	13	41	20	6.8	12.2	6.2
T4	15	38	27	7.1	12.6	6.9
T5	12	36	18	5.6	12.2	6.0
T6	12	32	26	7.1	13.5	6.6
T1	12	46	24	6.9	15.1	7.2
T2	11	36	20	6.3	13.3	5.8
T3	14	37	25	7.0	13.3	5.9
T4	15	38	22	7.2	12.7	7.0
T5	11	36	21	5.8	12.5	6.3
T6	13	36	23	7.3	13.2	6.4
T1	12	46	20	7.2	13.9	6.8
T2	12	33	22	6.9	12.0	6.7
T3	11	35	27	6.7	13.4	6.1
T4	12	35	28	7.3	13.3	7.5
T5	11	29	26	6.5	12.6	6.1
T6	13	38	27	7.1	13.2	6.4
Average					13.1	

Stage 1 – Planting to the beginning of flowering

Stage 2 – Flowering to fruiting

Stage 3 – Fruiting to maturation and harvest

SV – Volume of water used by sprinkler

DV – Volume of water used by Drip

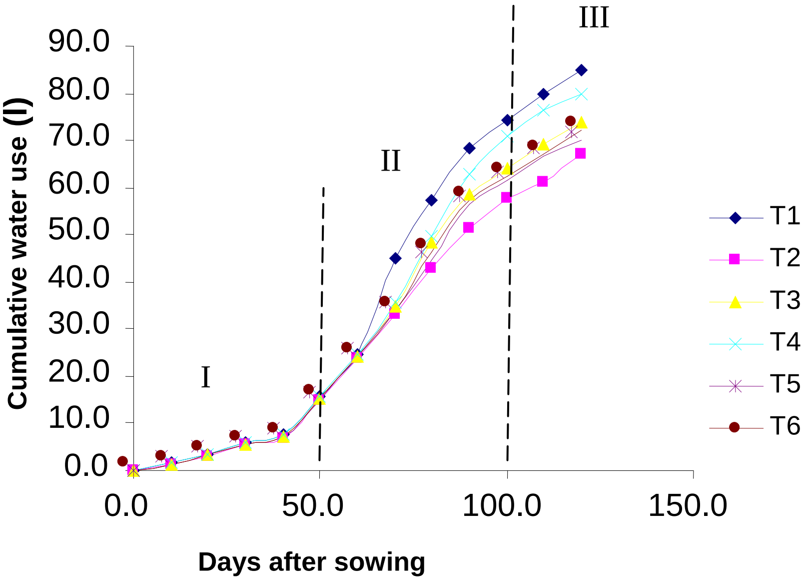


Fig. 4.1: The 10-day cumulative water use by tomato under sprinkler irrigation.

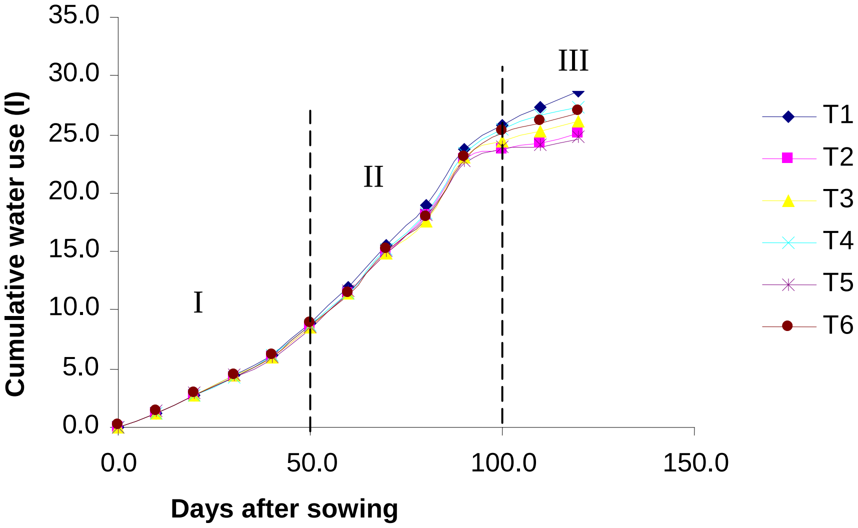


Fig. 4.2: The 10-day cumulative water use by tomato under drip irrigation.

Table 4.3: Summary of water used for the two growing cycles (liters)

Period of planting	Sprinkler	Drip	Control
Feb – June, 2009	1,331	474.5	3,780
June – Oct, 2009	1,287	461.2	3,240

Table 4.4: Summary of liquid fertilizer used for the two growing cycles (liters)

Period of planting	Sprinkler	Drip	Control
Feb – June, 2009	5.32	1.90	15.12
June – Oct, 2009	5.15	1.84	12.96

Table 4.5: Average water use, yield and water use efficiencies (WUE) of tomato for all soilless and irrigation treatments

Treatment	WATER USE (l)						YIELD (Kg)		WUE (g/l)	
	SPK	DRIP	SPK	DRIP	SPK	DRIP	SPK	DRIP	SPK	DRIP
Month/yr	02/09		06/09		(Average)					
T1	82	28.6	78	22.7	80	28.2	4.6	5.5	5.8	19.5
T2	68	25.1	72	24.6	70	24.9	4.4	4.8	6.3	19.3
T3	72	25.9	71	25.6	72	25.8	4.8	6.3	6.7	24.4
T4	78	27.7	73	25.5	76	26.6	4.1	4.3	5.4	16.2
T5	67	24.5	66	24.2	76	24.4	3.8	4.2	5.0	16.8
T6	72	27.4	77	26.6	75	27.0	5.1	6.6	6.8	24.4
CNT	1260		1080		1170		2.1		0.02	

SPK – sprinkler, CNT – control, WUE – Water Use Efficiency drip system. The highest values of 24.44 and 24.42 g/l were obtained for T_6 and T_3 respectively under drip while the highest value of 6.80 and 6.67g/l were also obtained for T_6 and T_3 respectively under sprinkler irrigation.

4.3 Crop Coefficient, Evapotranspiration and other Hydrological Parameters

The daily values of crop coefficients (K_c) for tomato under various soilless media were averaged over 10 days and 30 days to reveal decade and monthly trends. Fig 4.3 shows decade values of K_c for the combined season of 12 decades corresponding to the growth period of tomato under the various soilless media. Crop coefficient increased steadily from between 0.42 and 0.47 in the first decade to about 0.5 and 0.6 in the 6th decade depending on the type of soilless medium. This showed that daily evapotranspiration and hence water use by tomato increased uniformly in all treatments at low rate from few days after planting up to the beginning of flowering. Up to the 6th decade, there was no marked difference in K_c for all treatments. Between the 6th and 8th decade K_c progressively increased in all treatments and there was a marked difference for all treatments. This coincided with the period of flowering and fruiting. The highest value of K_c was recorded in T1 followed closely by T2 and the least was in T5. This peak value of about1.0 at the 8th decade coincided with the period of flowering and fruiting which showed that T1 demanded highest amount of irrigation water at this stage while T5 required the least. Beyond the 8th decade, a sharp decline in K_c is evident to a value corresponding to value of about 0.64 for T1 and T4 while for the remaining soilless media the value fell to between 0.48 and 0.52. This showed water demand at the 8th to the 10th decade which corresponded to maturation and harvest stage is lesser than that needed at the beginning of flowering to fruiting but slightly higher than for emergence to the beginning of flowering. At this period of fruiting and harvest all treatments generally required less water. Piccini et al. (2007) and Suleiman et al. (2007) presented K_c curves for cotton and peanut, respectively which are similar to the present study except that the curve obtained by Piccini et al (2007) rises and declines twice before the later decades indicating that cotton showed some erratic water demands just before the maturation and harvest stage. This could be as a result of difference in root depth of cotton which is deeper than tomato and peanut which belong to the same root zone.

Tables 4.6 and 4.7 contain data on monthly values of Crop Coefficient (K_c) and Potential Evapotranspiration (ET_p) for the first planting in February and second planting in June, values of K_c and ET_p for the second planting period are generally higher than for first

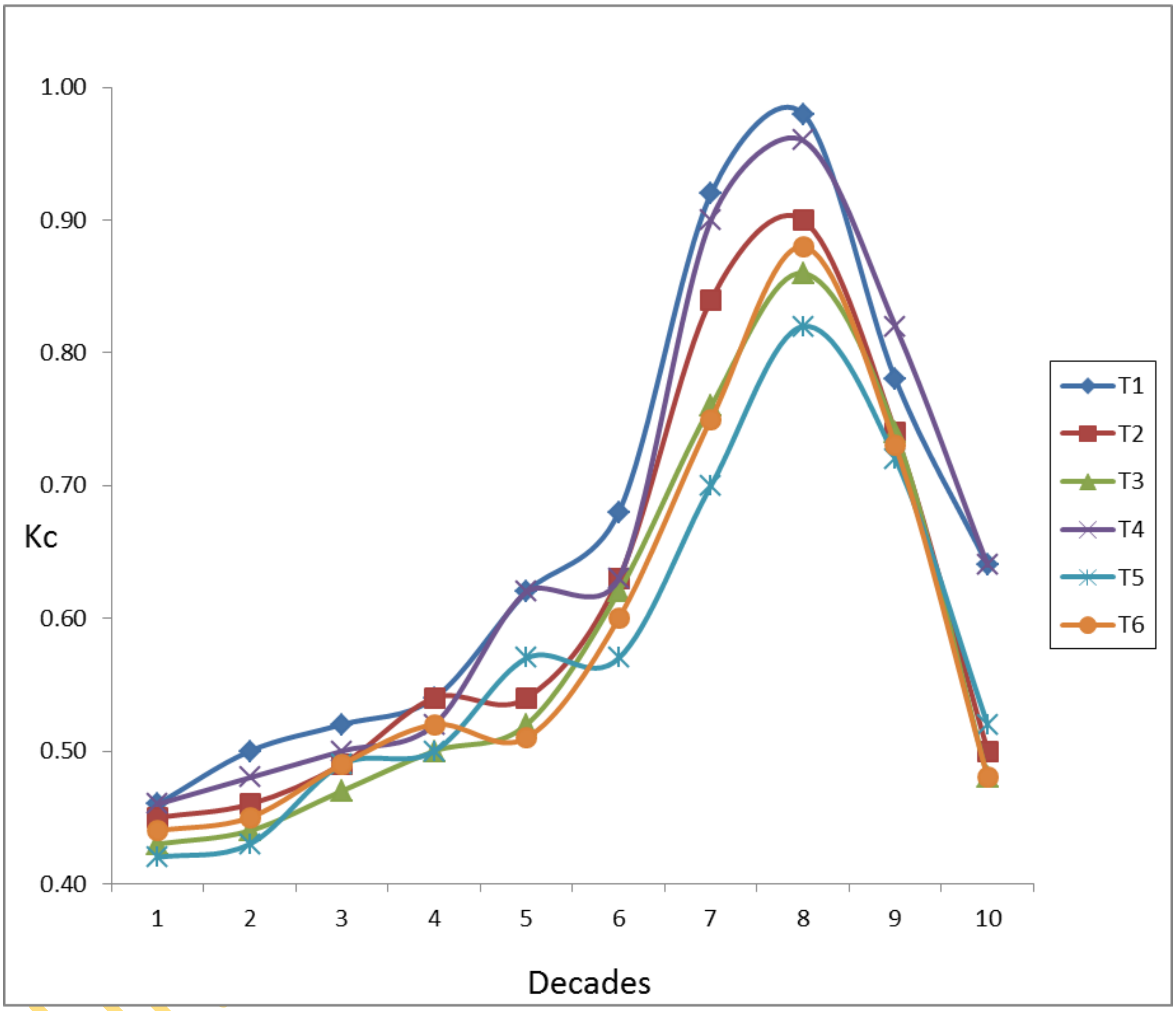


Fig. 4.3: Decade values of Crop coefficients of tomato grown in various soilless media

Table 4.6: Monthly Values of K_c and ET_p for February planting

Month	RH(%)	T(^oF)	P (hr)	K_t	K_c	ET_p(mm)
Feb.	72	98	6.51	1.38	0.45	149.1
March	76	86	5.80	1.17	0.52	114.2
April	81	85	4.49	1.16	0.86	143.3
May	85	81	4.85	1.09	0.55	88.6
June	87	78	4.92	1.04	0.42	63.1

Table 4.7: Monthly Values of K_c and ET_p for June planting

Month	RH(%)	T(^oF)	P (hr)	K_t	K_c	ET_p(mm)
June	87	78	4.92	1.04	0.46	138.6
July	87	79	4.88	1.23	0.75	133.8
August	71	81	5.23	1.09	0.97	168.7
Sept.	87	83	5.54	1.12	0.82	158.9
Oct.	84	84	6.12	1.14	0.56	123.5

respectively. The potential evapotranspiration (ET_p) was calculated based on Eqn. 7. The planting. This is an indication that much water was required for growth during the second planting. The second planting which is June to October coincided with a period of relatively higher temperature and subsequently higher values of evapotranspiration. Relative humidity increased steadily from 72% in February to 87% in June. During the first planting period, the value remained fairly the same for the remaining months up to October, corresponding to the second planting period. It could be inferred that continuous increase in relative humidity lowered the yield of tomato since higher yield was recorded during the second planting period which coincided with the period of little variation in relative humidity (Table 4.5). On the other hand, temperature decreased in reversed order to relative humidity from 98 ^{o}F in February to 78 ^{o}F in June during the first planting period and increased from June up to 84 ^{o}F in October coinciding with the second planting period. It could be suggested that high values of temperature have a negative effect on the yield of tomato during the first planting cycle compared with the second planting cycle when temperature values were lower. Temperature was recorded in ^{o}F for ease of computation of potential evapotranspiration as given in Equation 7. Although total yield increased during the second planting cycle but much water was required for the higher values of K_c and ET_p recorded for this period. On the average, the two planting cycles received the same number of hours of sunshine per day but variation in monthly temperature accounts for the difference in the values of K_c for the whole months of February to October.

4.4 Relationship between Plant Height, Number of Leaves and Number of Days after Sowing of Tomato

The height and number of leaves of tomato planted in the various soilless media under the sprinkler and drip irrigation system can be estimated from the number of days after sowing. Figs. 4.4, 4.5 and 4.6 showed the correlation between height of tomato planted in soilless media T1/T2, T3/T4 and T5/T6, respectively, under sprinkler irrigation versus days after planting. All the curves follow the power trend and show high coefficient of determination except for treatment T6 in which logarithmic relationship appears as the best fit which shows that height of tomato is less predictable when planted in T6 under sprinkler. With these curves, the height of tomato planted in any of the soilless media and irrigated with the sprinkler system, can be predicted from the number of days after sowing with much accuracy. On the other hand, the height of the crop can be used to estimate the age of the tomato. Fig. 4.4 showed a power curve with a very high correlation coefficient of 0.983 and 0.987 for T1 and T2 respectively. This means that height of tomato is highly predictable for T1 and T2 from the numbers of days after planting but prediction will be more accurate if tomato is planted in T2. Fig. 4.5 showed that T3 and T4 followed the same curve with R^2 of 0.992 and 0.985 respectively suggesting that tomato planted in T3 is highly predictable, followed by that planted on T4. The trend followed by T5 and T6 in Table 4.6 is power and logarithmic curve, with R^2 of 0.988 and 0.987, respectively. This suggests that it is easier to estimate tomato height from number of days after planting when planting in T5 than in T6. The same curves and the same arguments hold for height of tomato planted in T1/T2, T3/T4 and T5/T6 under drip irrigation as presented in Figs 4.7 - 4.9. The R^2 are 0.994, 0.989, 0.998, 0.997, 0.991 and 0.995, respectively for T1, T2, T3, T4, T5 andT6. The estimation of the height of tomato from the number of days after planting can be made in all the treatments under both irrigation system but the best estimate is achievable in T3 (R^2 = 0.998) while the least accurate estimate is expected when planting in T2 (0.989).

Figures 10 - 12 and Figures 13 - 15 were used for predicting the number of leaves of tomato in all the soilless media and the control under sprinkler and drip irrigation systems, respectively with all the relationships following similar power curves. This showed that number of leaves are also predictable with respect to number of days after planting for all treatments and under both irrigation systems. The highest R^2 of 0.982 was achievable with T4 under the sprinkler irrigation while the least R^2 of 0.975 was obtained for T1. The R^2 values obtainable under the drip were high enough for good prediction of number of leaves with respect to number of days after planting but were generally lower than those obtained under the sprinkler irrigation system. This implied that it is easier to estimate numbers of leaves of tomato planted under sprinkler system than that planted under the drip system.

In general it was observed that estimation of height of tomato from numbers of days after planting is easier than that of numbers of leaves of tomato under both irrigation systems. Data on other yield parameters such as number of fruits, stem girth, stem dry matter and leave area index did not show good correlation with number of days after planting.

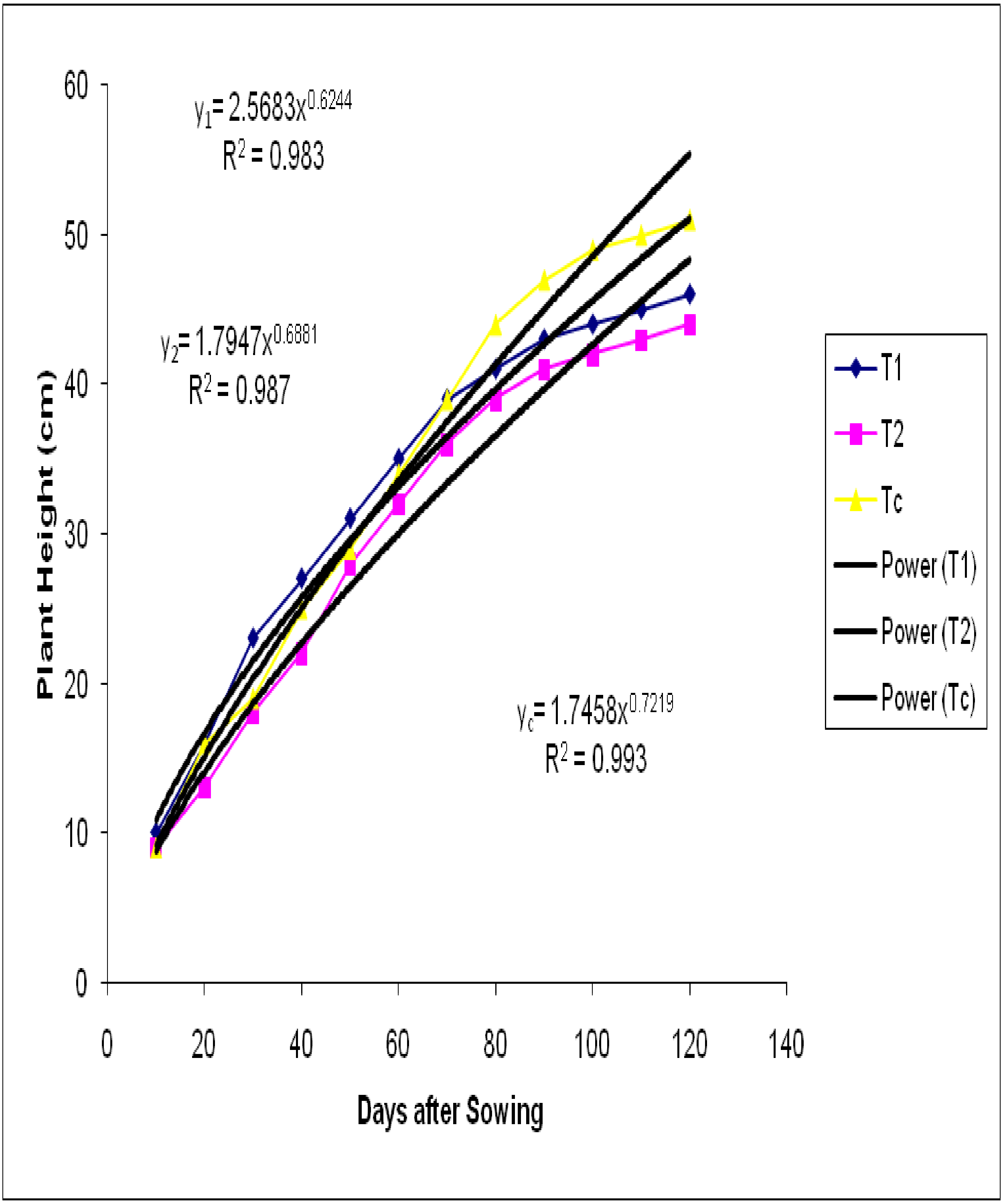


Fig. 4.4: Relationship between height of tomato and days after sowing for T1,T2 and Tc under sprinkler system

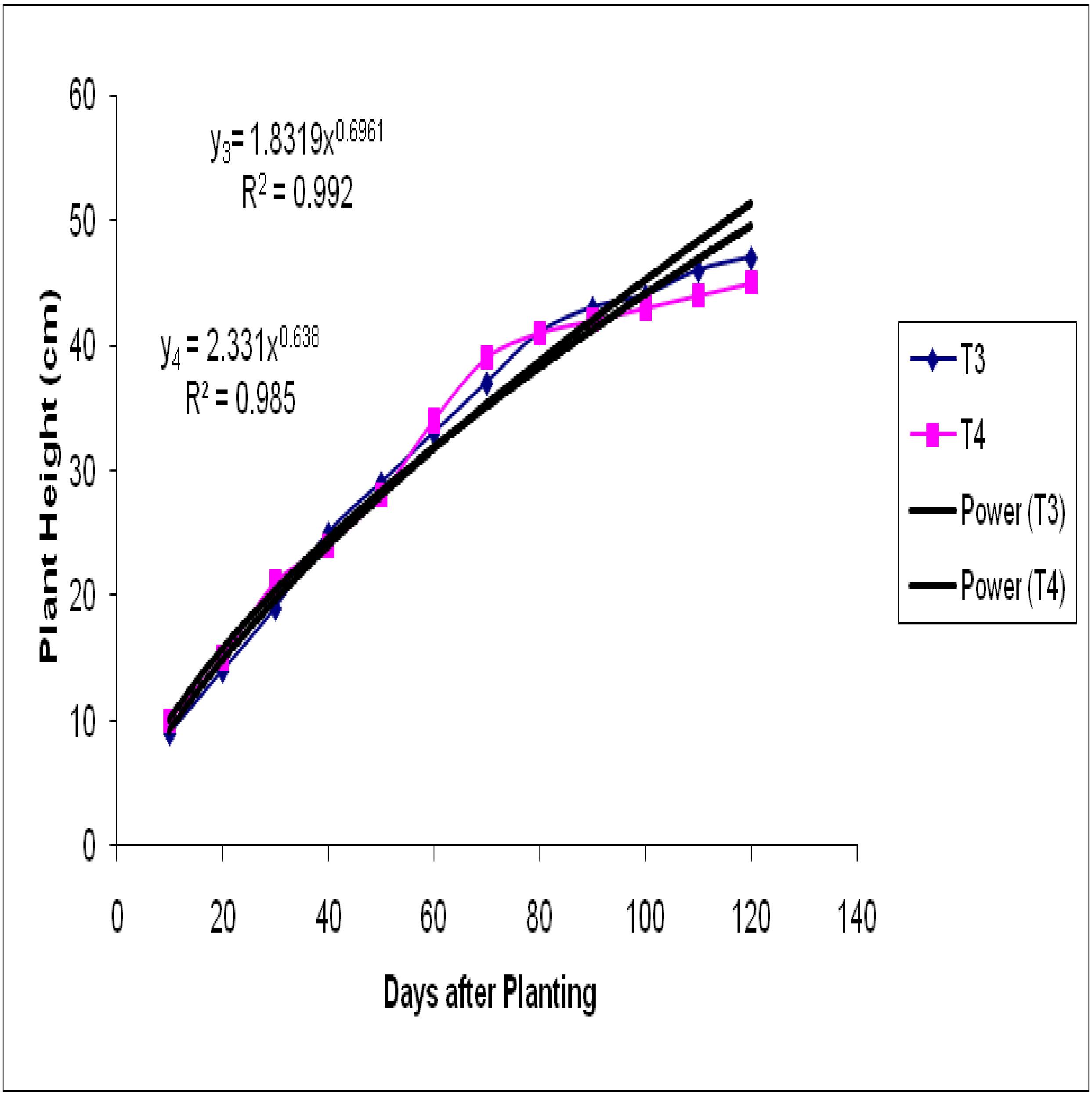


Fig. 4.5: Relationship between height of tomato and days after sowing for T3 and T4 under sprinkler system

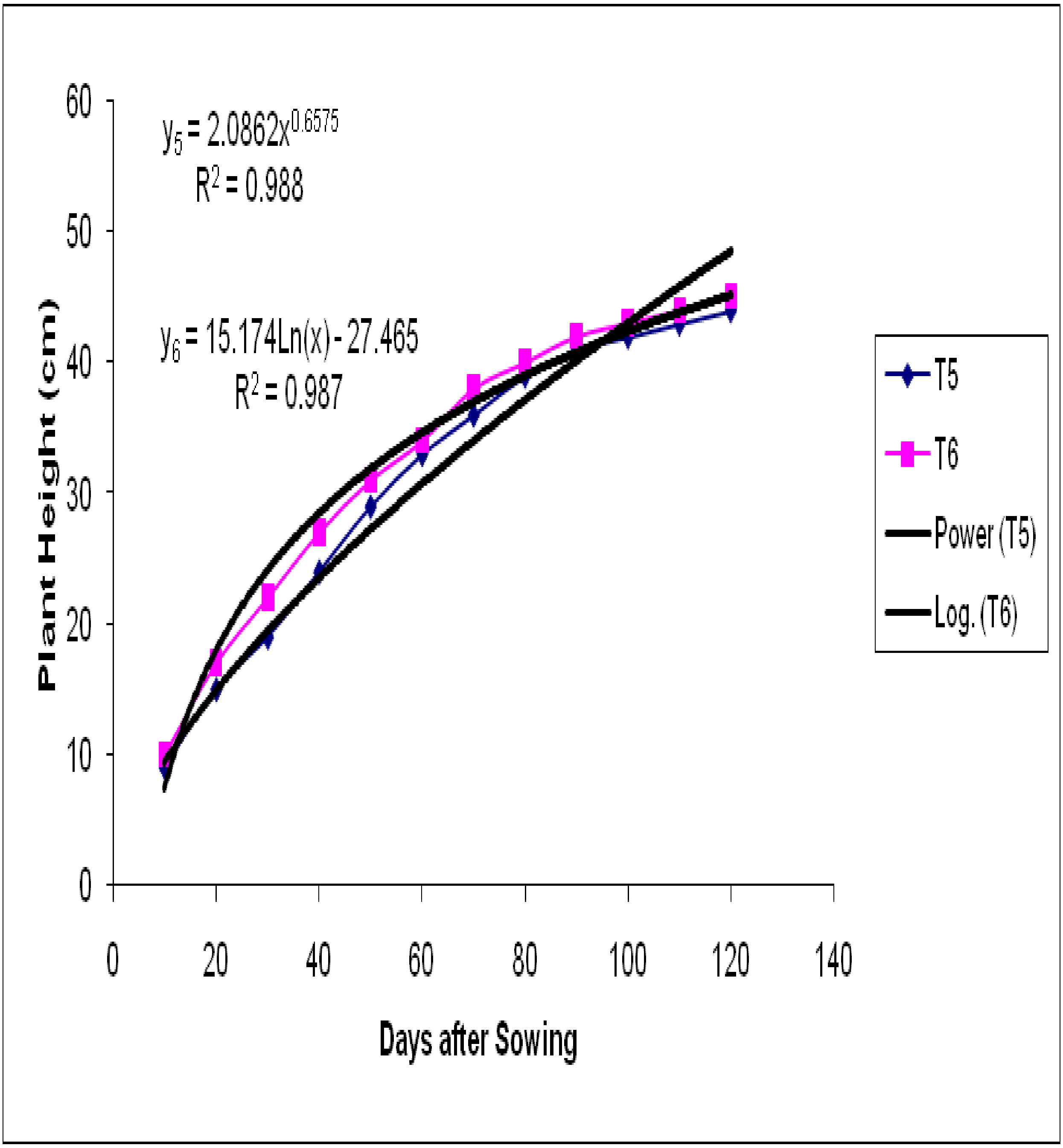


Fig. 4.6: Relationship between height of tomato and days after sowing for T5 andT6 under sprinkler system

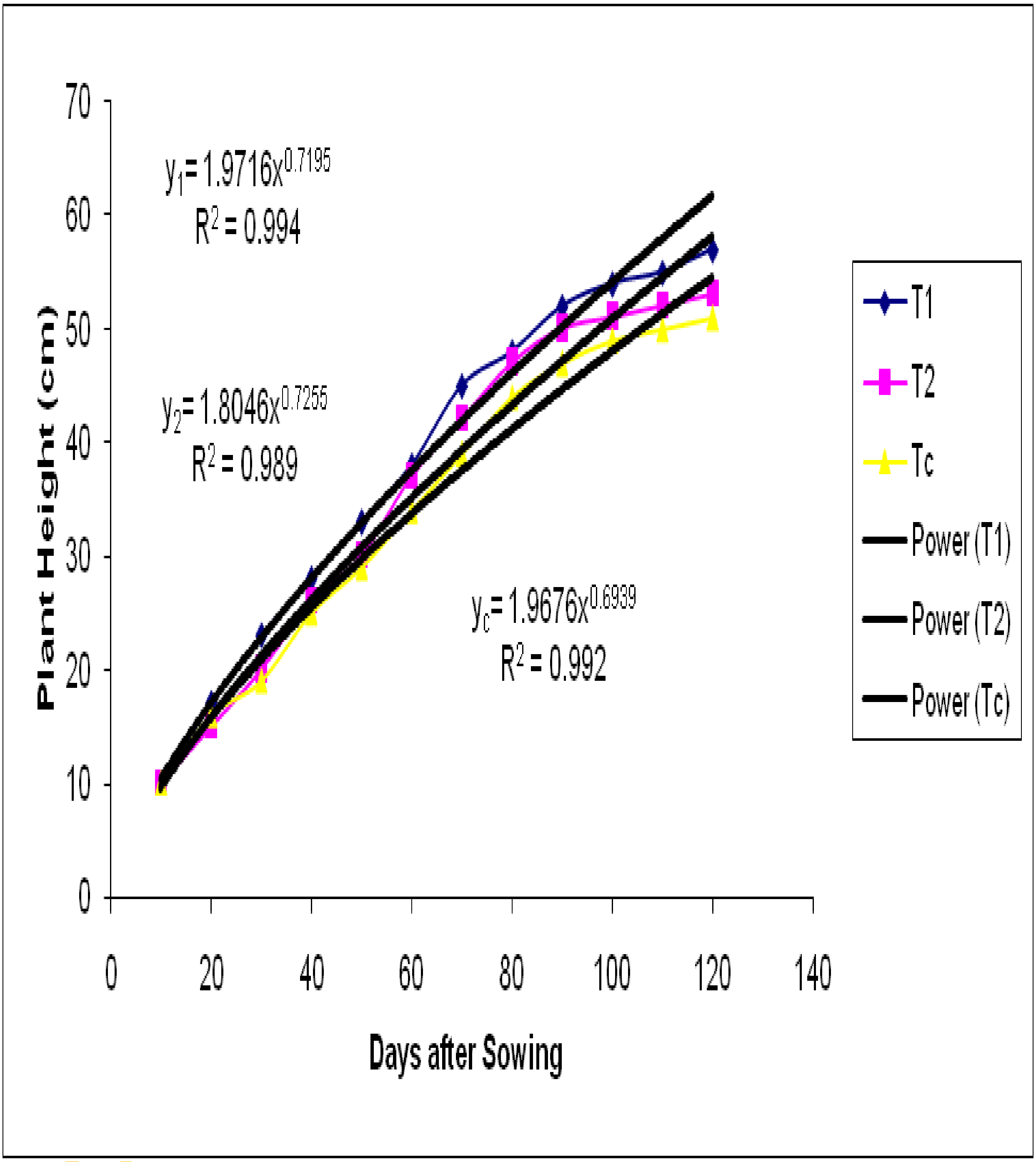


Fig. 4.7: Relationship between height of tomato and days after sowing for T1, T2 and Tc under drip system

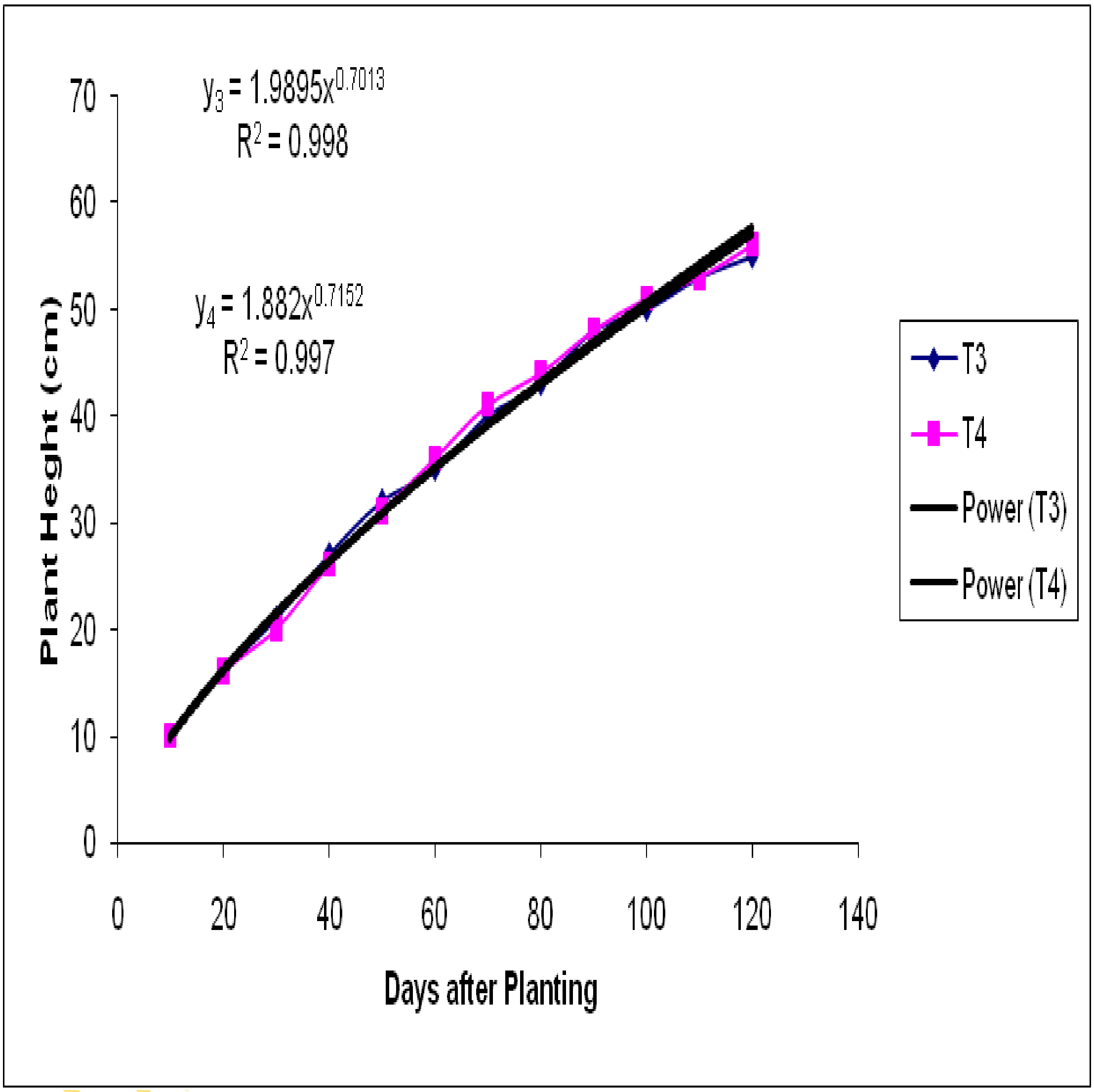


Fig. 4.8: Relationship between height of tomato and days after sowing for T3 and T4 under drip system

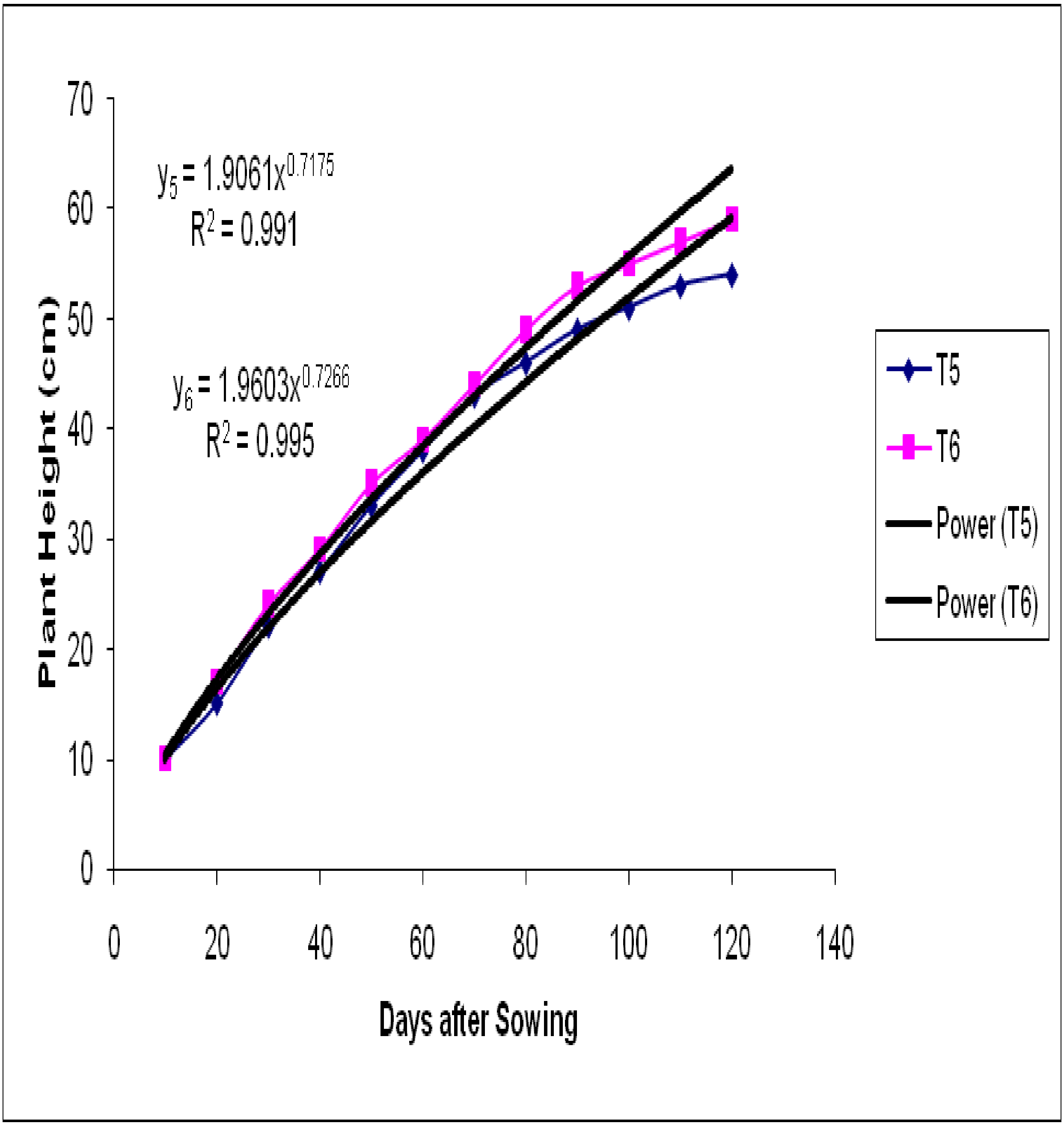


Fig. 4.9: Relationship between height of tomato and days after sowing for T5 andT6 under drip system

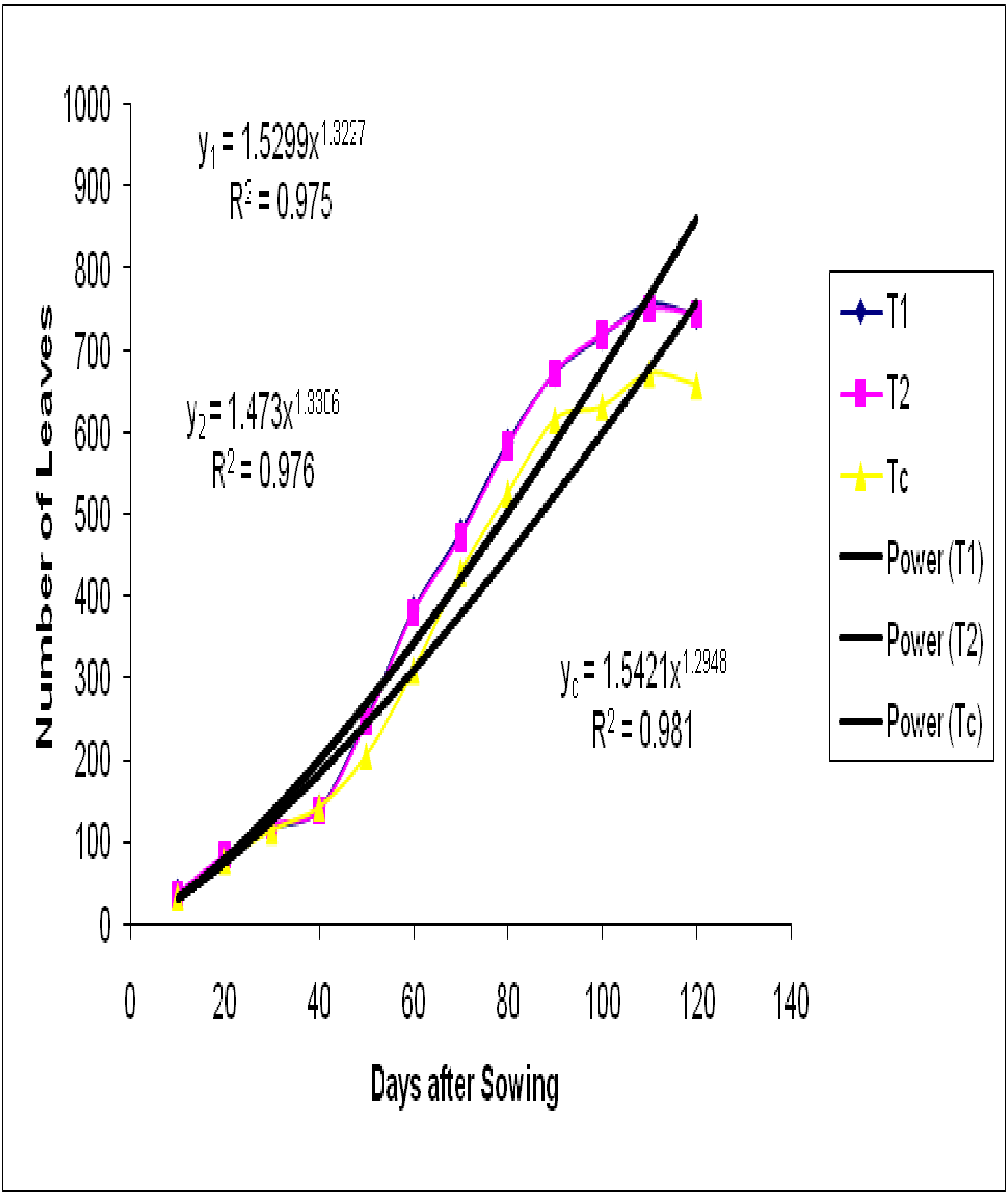


Fig. 4.10: Relationship between number of leaves of tomato and days after sowing for T1, T2 and Tc under sprinkler system

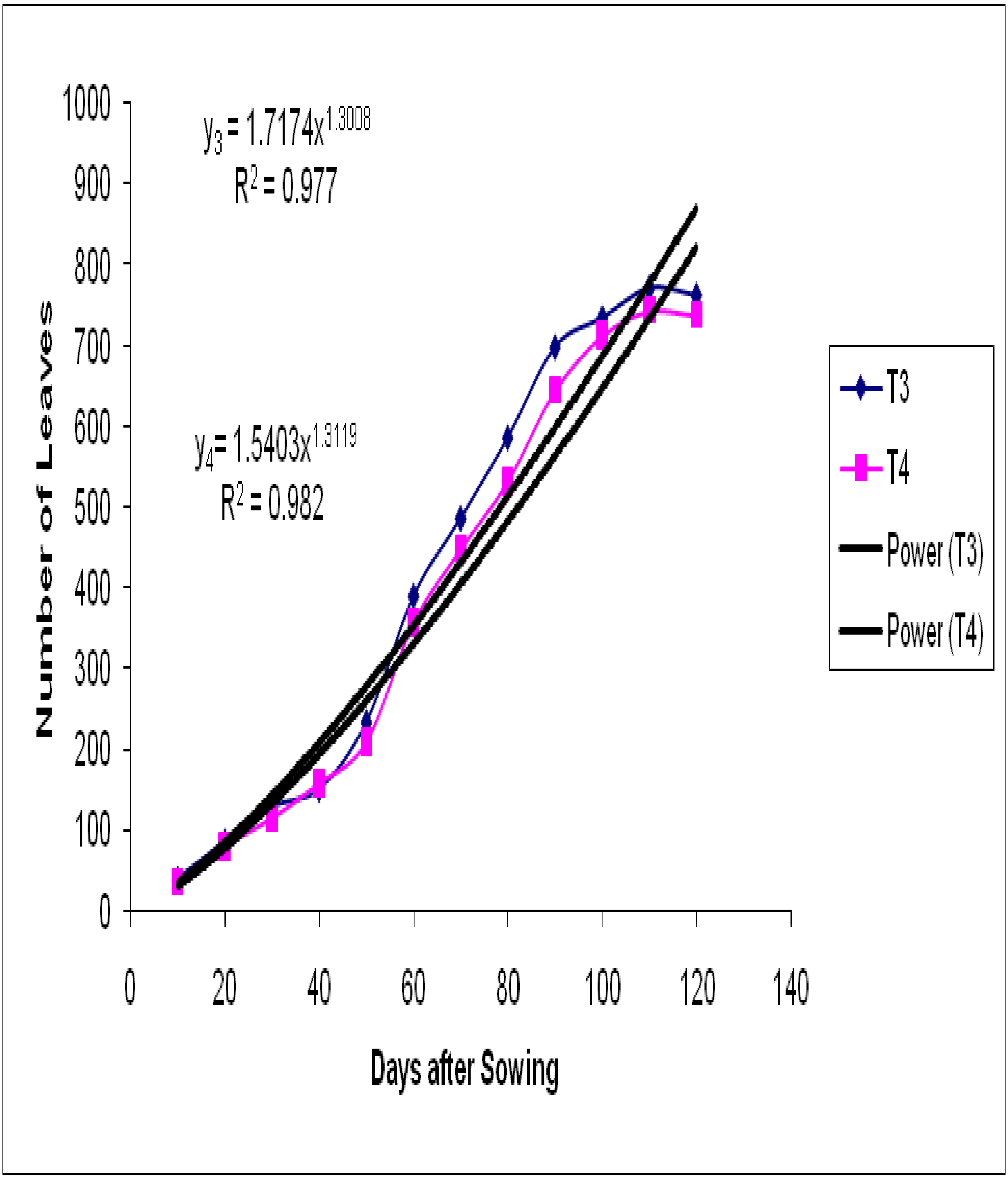


Fig. 4.11: Relationship between number of leaves of tomato and days after sowing for T3 and T4 under sprinkler system

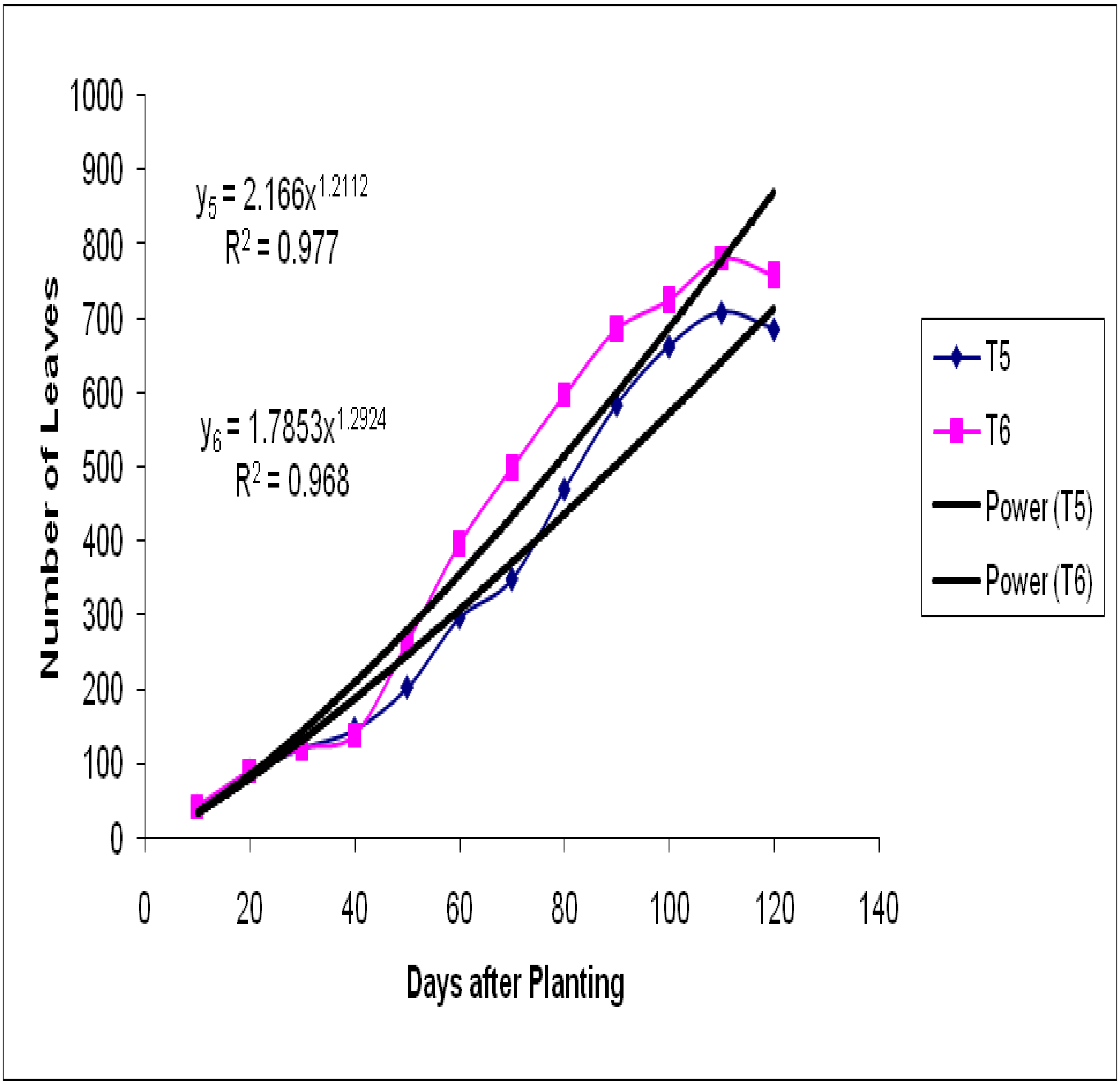


Fig. 4.12: Relationship between number of leaves of tomato and days after sowing for T5 and T6 under sprinkler system

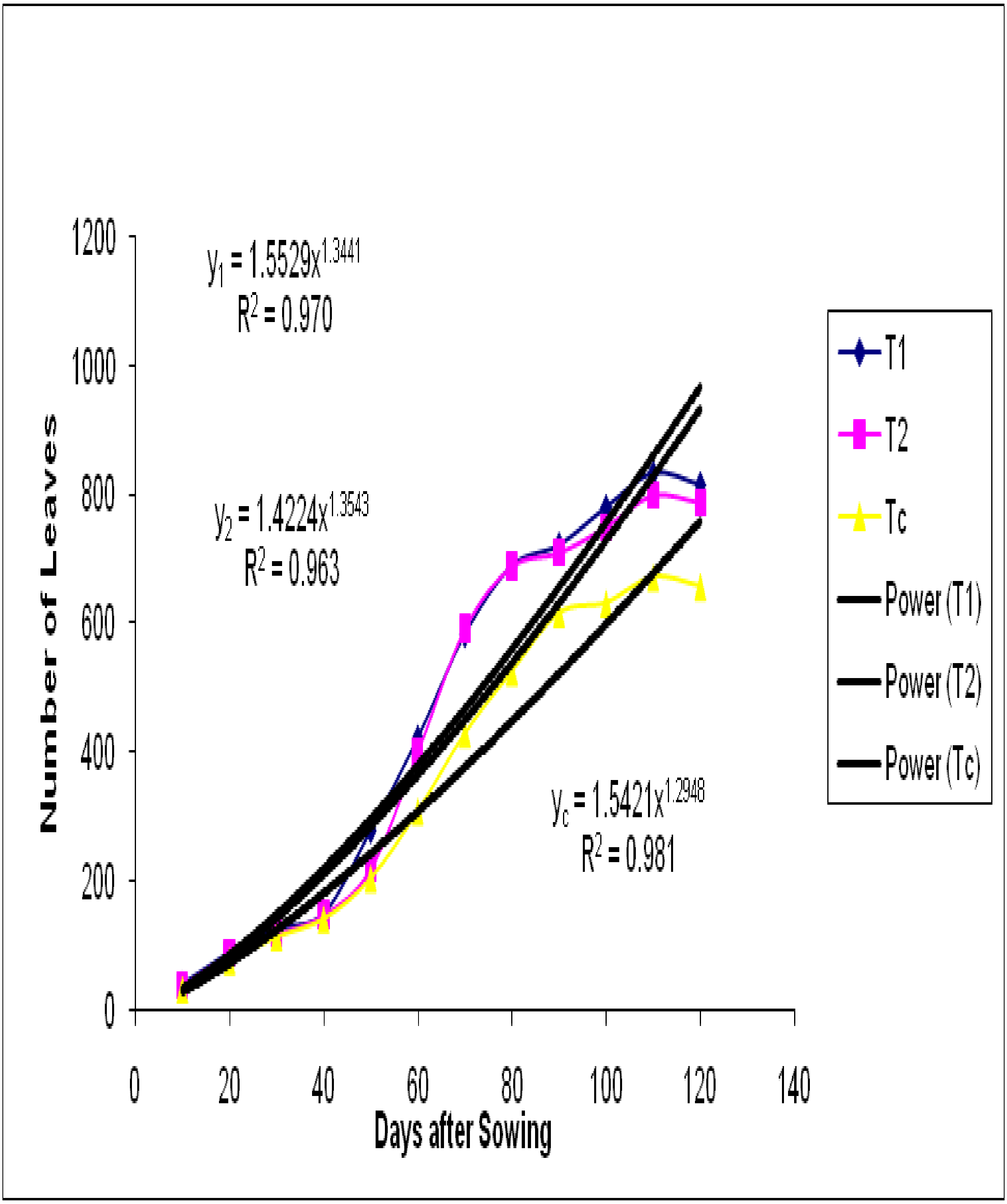


Fig. 4.13: Relationship between number of leaves of tomato and days after sowing for T1, T2 and Tc under drip system

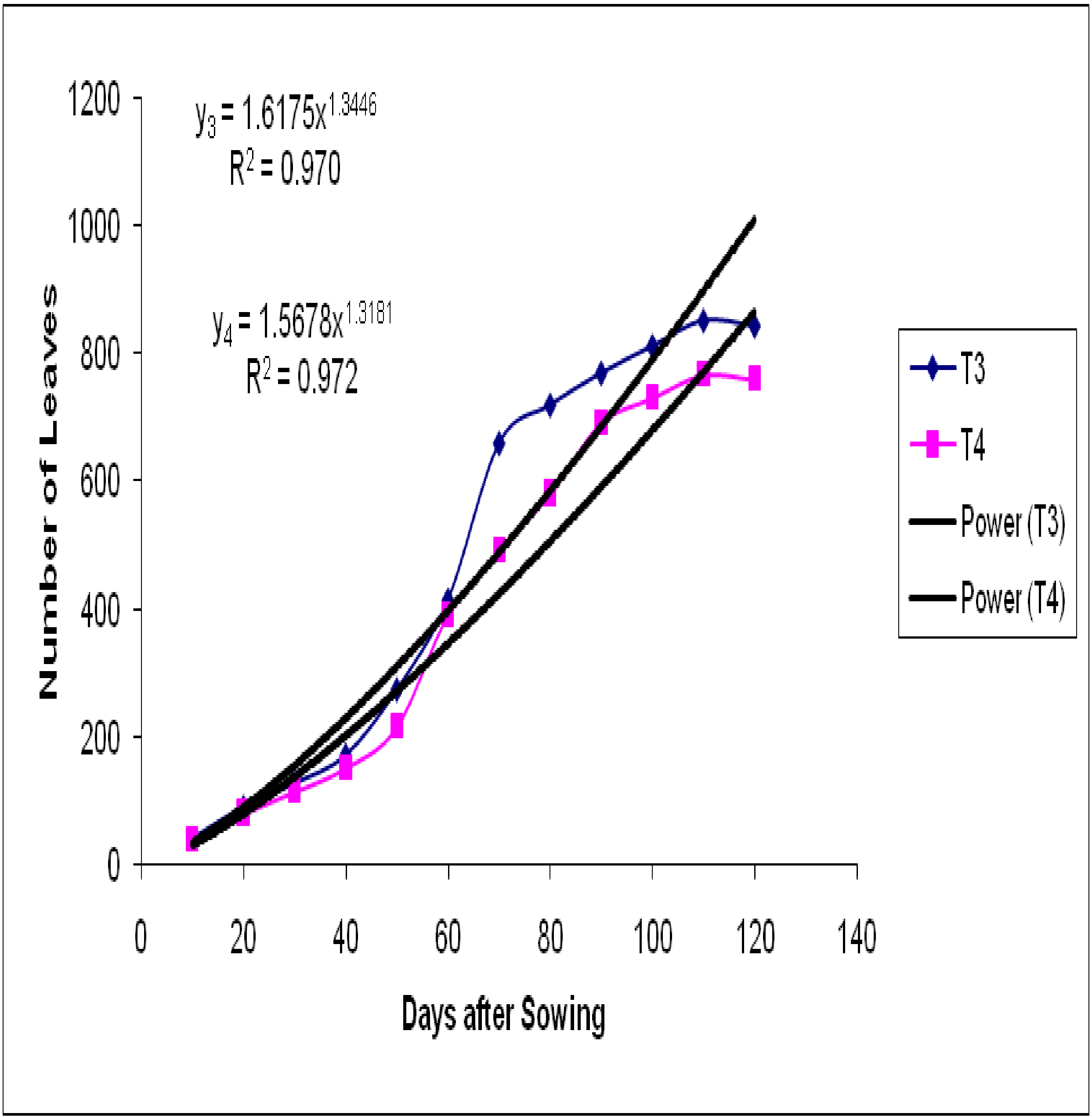


Fig. 4.14: Relationship between number of leaves of tomato and days after sowing for T3 and T4 under drip system

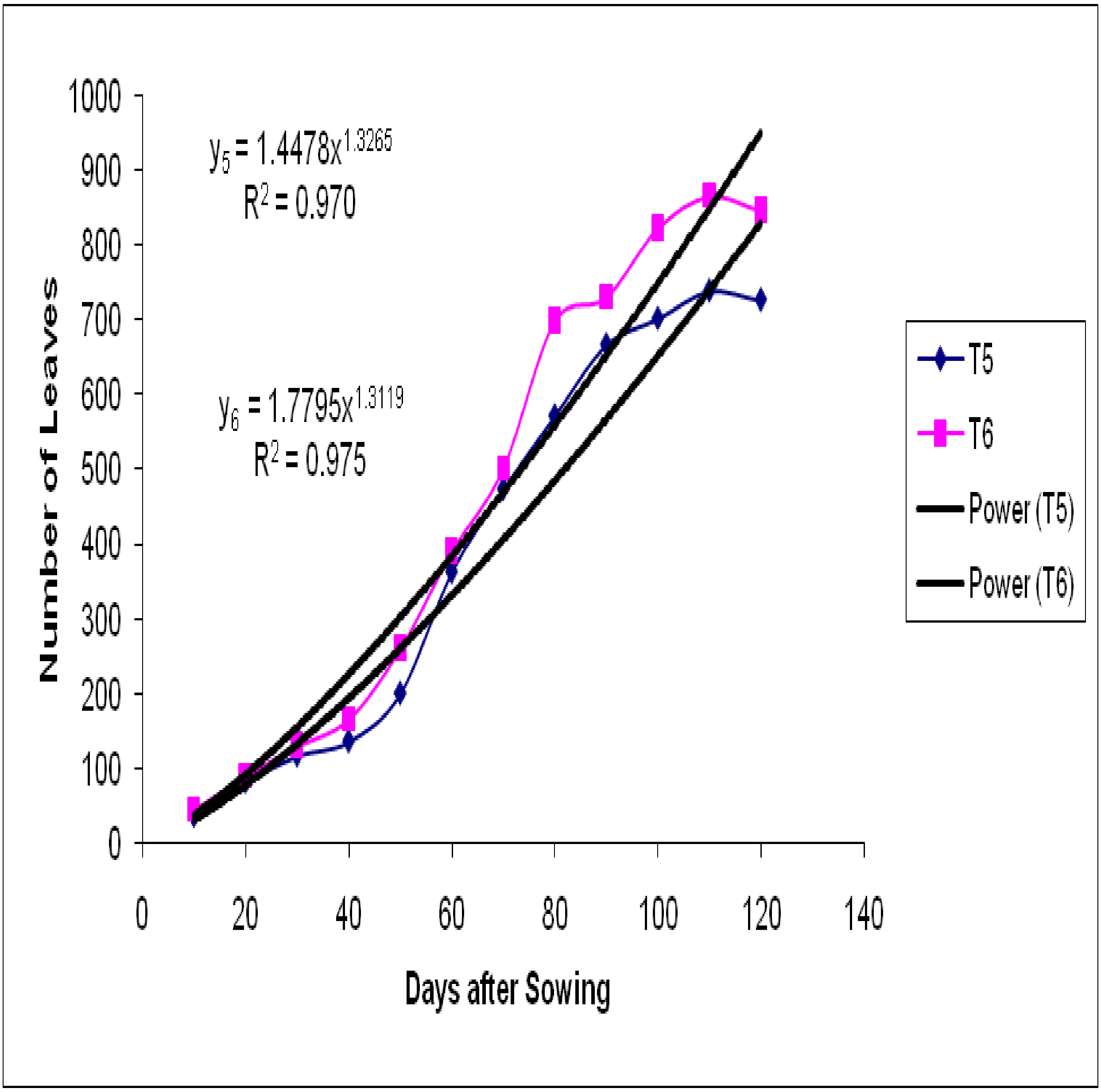


Fig. 4.15: Relationship between number of leaves of tomato and days after sowing for T5 and T6 under drip system

4.5 Yield and Yield Components of Tomato

The total fruit yield, size and quality of tomato planted in the various soilless media and Irrigation treatments for February and June planting are presented in Tables 4.8 and 4.9, respectively. Tables 4.8 and 4.9 show very clearly the superiority of tomato fertigated with drip irrigation system as compared to sprinkler system in terms of total yield, fruit size and quality. Tomato planted in treatment medium T_6 is best under both sprinkler and drip irrigation, followed closely by treatment T_3 for both February and June planting. The same results as for first planting in February were observed for second planting in June except that there is slight improvement in the general performance of tomato planted in June in terms of total yield and yield quality, probably as a result of improvement in operational and management skills during the second planting. Table 4.8 showed that yield of tomato under the drip irrigation during the first planting period was generally higher than that of the sprinkler irrigation system. The yield from all the soilless media treatments was in the other of T6> T3> T1 > T2 > T4 > T5 under both irrigation systems. It was observed that this order does not apply to fruit size of tomato which followed different orders for the two different irrigating systems. For instance, the size of tomato in the soilless media followed the order T6> T2> T3 > T1 > T4 > T5 under the sprinkler irrigation while under the drip irrigation the order was T6> T3> T1 > T2 > T4 > T5. This showed that fruit yield is not exclusively a function of fruit size alone but rather depends on both fruit size and number of fruits. It could be observed from Tables 4.8 and 4.9 that fruit yield, fruit size and percentage of marketable fruits are generally higher under drip irrigation system than under the sprinkler system and that T6 produced the best tomato in terms of fruit yield, fruit size and percentage of marketable fruits. This was followed very closely by T3 and the control produced tomato with the least yield and quality. The means, coefficient of determination, coefficient of variation and the root mean square values of fruit weight (FW) and some yield variables such as number of leaves (NL), plant height (PH), number of fruits (NF), stem girth (SG) and stem dry matter (SDM) of tomato under sprinkler and drip irrigation were compared as presented in Appendix 13. The means of the yield and all the yield variables are higher for tomato planted under the drip system than under the sprinkler system. Appendix 14 presents a clearer picture of the mean values of all the variables for all the soilless media and irrigation systems. The T6 and T3 produce tomato with highest fruit yield, number of leaves and stem girth under both irrigation systems while number of fruits, plant height, and stem dry matter varies under different irrigation systems and soilless media. The Duncan's Multiple Range Test for separation of means of yield and yield variables of tomato is presented in Table 4.10. The means with the same letter are not significantly different at (0.5 level of significance) and means are decreasing alphabetically. Means with letter ‘a’ is higher than means with letter ‘b’ in value etc. From Table 4.10 it is observed that T6 and T3 are not significantly different and both have the highest means for all yields and yield variables under both sprinkler and drip irrigation except for numbers of fruits of tomato. This means that irrespective of the irrigation method used, T6 and T3 will always produce tomato of highest yield, height, number of leaves, stem girth and dry matter except that number fruits will reduce but fruit size and weight will increase. Number of fruits is highest for T4 followed by the control under both irrigation systems. This means that T4 and the control will produce tomato with higher number of fruits but relatively small in size and weight. Mean of T5 is least, compared to other soilless media for the overall yield and yield variables for both of the irrigation systems. It was therefore deduced from the Duncan’s multiple range test that the best soilless medium for tomato plant under both sprinkler and drip systems was T6, followed by T3. Figures. 4.16 - 4.21 are used to compare the growth of tomato under sprinkler and drip irrigation systems for all the media treatments. For all the treatments, values obtained for fruit weight, number of leaves, plant height, stem girth and stem dry matter are generally higher under drip than sprinkler, except for number of fruits as explained earlier. Figure 4.22 compares the value of the leave area index (LAI) of tomato under the two irrigation systems. The LAI values are higher under sprinkler than under drip for all the soilless media except for T2 which has the lowest value.

Table 4.8: Yield and quality of tomato planted in various soilless media (Feb 2009 planting)

	Yield (kg/plant)		Size (cm^3)		% of marketable fruits	
Treatment	Sprinkler	Drip	Sprinkler	Drip	Sprinkler	Drip
T1	4.5	5.4	117	129	55	68
T2	4.3	4.6	110	125	50	63
T3	4.7	6.2	111	131	56	67
T4	4.1	4.2	109	111	57	64
T5	3.8	4.1	105	113	52	64
T6	5.1	6.5	126	134	68	77
Tc	2.1	2.1	105	105	65	65

Table 4.9: Yield and quality of tomato planted in various soilless media (June 2009 planting)

	Yield (Kg/plant)		Size (cm3)		% of marketable fruits	
Treatment	Sprinkler	Drip	Sprinkler	Drip	Sprinkler	Drip
T1	4.7	5.6	119	131	56	67
T2	4.5	5.0	112	126	52	65
T3	4.9	6.4	100	133	57	69
T4	4.2	4.4	111	114	57	66
T5	3.8	4.2	107	115	53	63
T6	5.2	6.7	127	135	68	79
Tc	2.2	2.2	103	103	62	62

Table 4.10: Duncan's Multiple Range Test for means of yield and yield variables of tomato at (0.5 level of significance)

T	FWS	FWD	NLS	NLD	PHS	PHD	NFS	NFD	SGS	SGD	SDMS	SDMD
CNT	e 3.80	f 3.80	c 672.00	f 672.00	a 51.00	C 51.00	ab 86.33	ab 86.33	cd 3.80	d 3.80	c 42.00	f 42.00
T1	bc 4.60	c 5.50	b 738.00	bc 817.00	bc 43.67	ab 54.67	bcd 82.00	c 80.33	ab 4.43	a 4.93	b 48.33	c 52.00
T2	cd 4.40	d 4.77	b 735.00	c 790.33	bc 43.67	bc 52.33	ab 85.33	cd 78.00	bc 4.13	b 4.47	b 46.00	d 49.33
T3	ab 4.77	b 6.27	b 741.67	ab 836.67	b 45.67	abc 54.00	cd 80.33	de 74.00	a 4.63	a 5.03	b 48.00	b 54.33
T4	de 4.10	e 4.30	b 728.67	d 744.33	bc 44.00	abc 54,00	a 86.67	a 88.00	cd 3.87	bc 4.23	c 43.33	e 45.67
T5	e 3.83	ef 4.10	c 695.00	e 714.00	c 42.00	bc 52.00	abc 84.33	bc 82.00	d 3.63	cd 3.93	c 41.00	e 44.33
T6	a 5.07	a 6.60	a 781.67	a 852.67	b 44.67	a 57.00	d 79.33	e 69.67	a 4.77	a 5.33	a 51.33	a 58.67

NOTE: Means with the same letter are not significantly different.

S = under sprinkler, D = under drip, FW = Fruit weight (kg), NL = No. of leaves, PH = Plant height (cm), NF = No. of fruits, SG = Stem girth (cm) and SDM = Stem dry matter (kg)

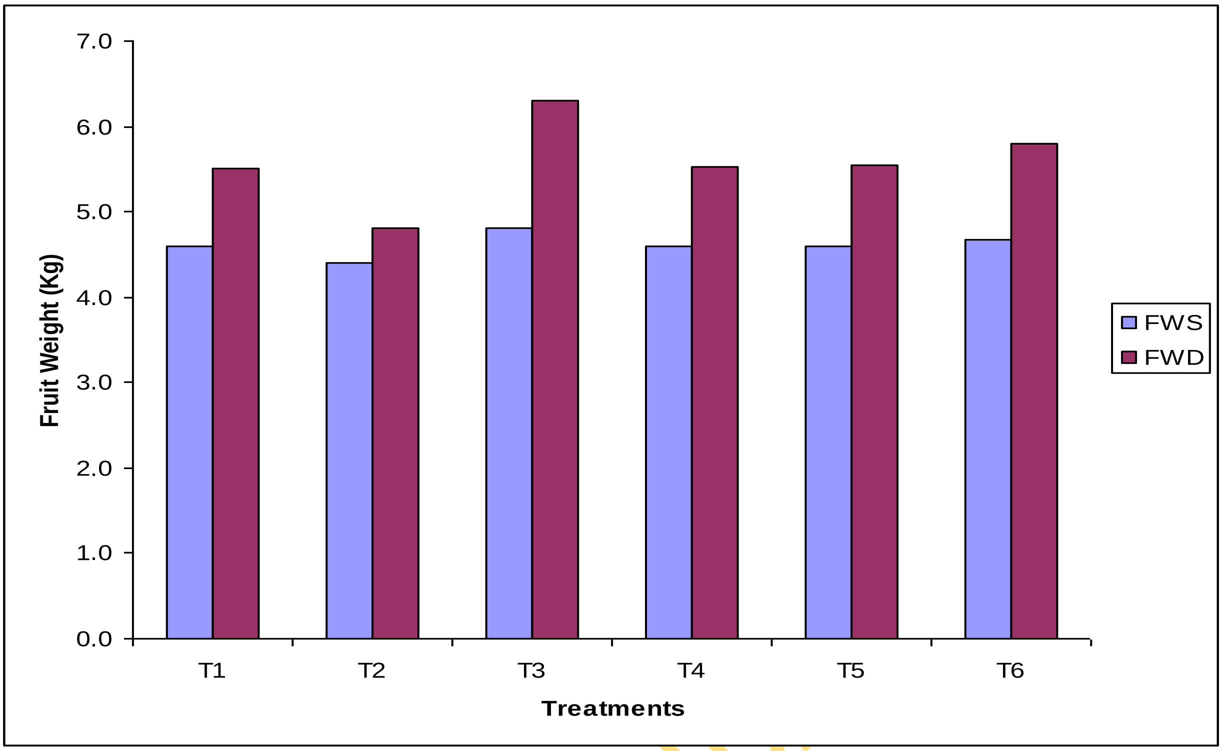


Fig. 4.16: Comparison of fruit weight of tomato under soilless media and irrigation treatments

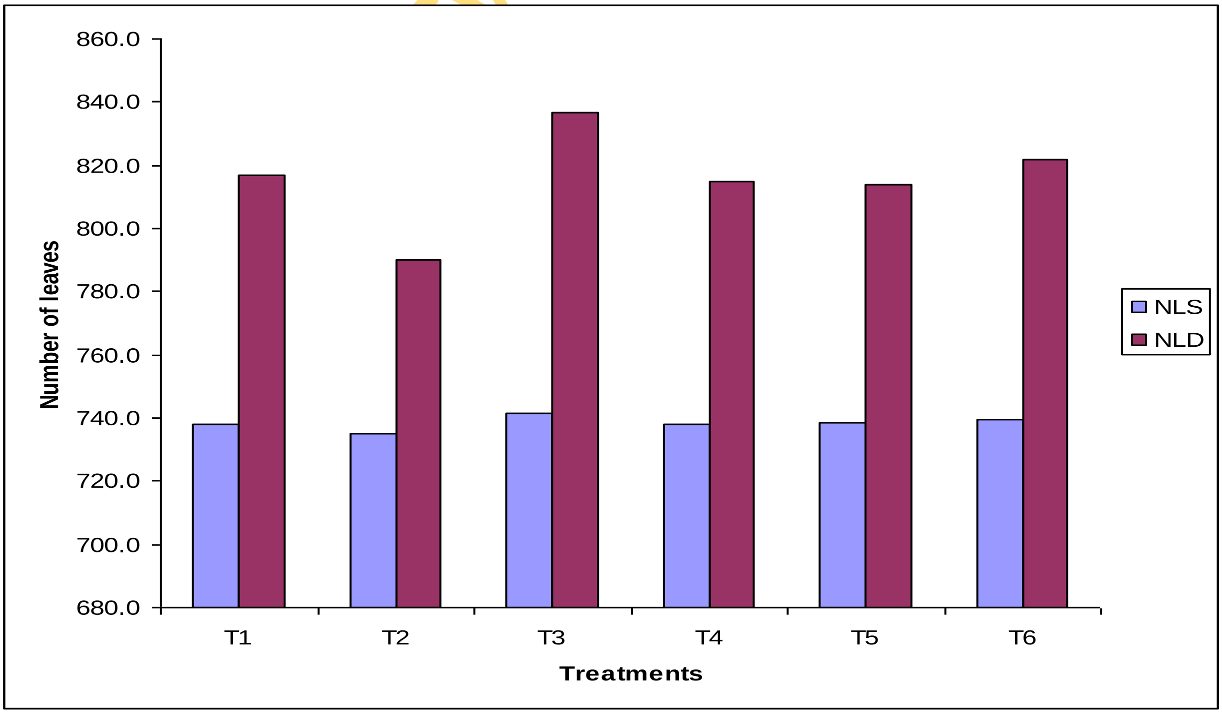


Fig. 4.17: Comparison of number of leaves of tomato under soilless media and irrigation treatments

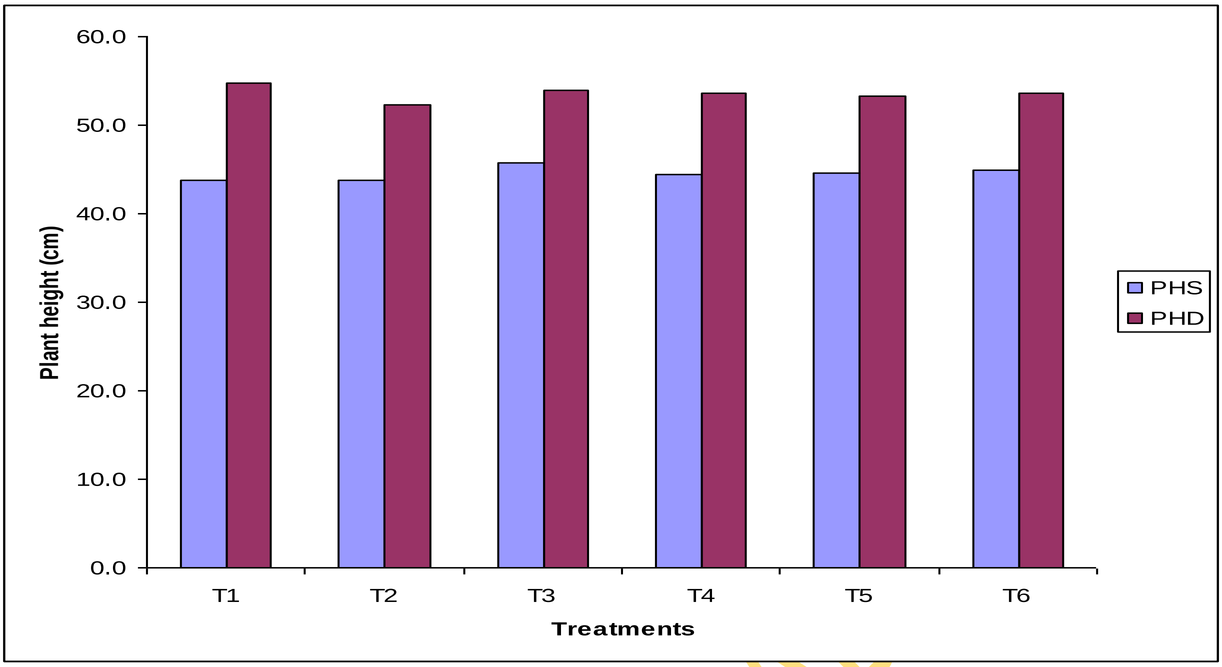


Fig. 4.18: Comparison of height of tomato under soilless media and irrigation treatments

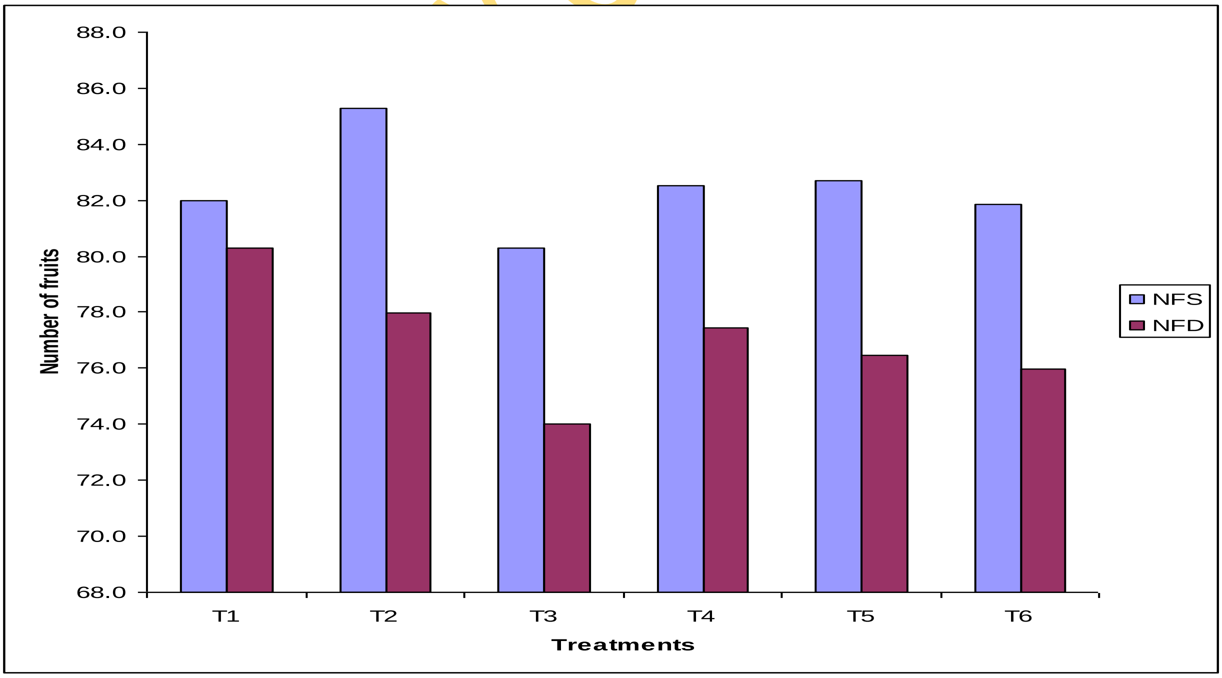


Fig. 4.19: Comparison of number of fruits tomato under soilless media and irrigation treatments

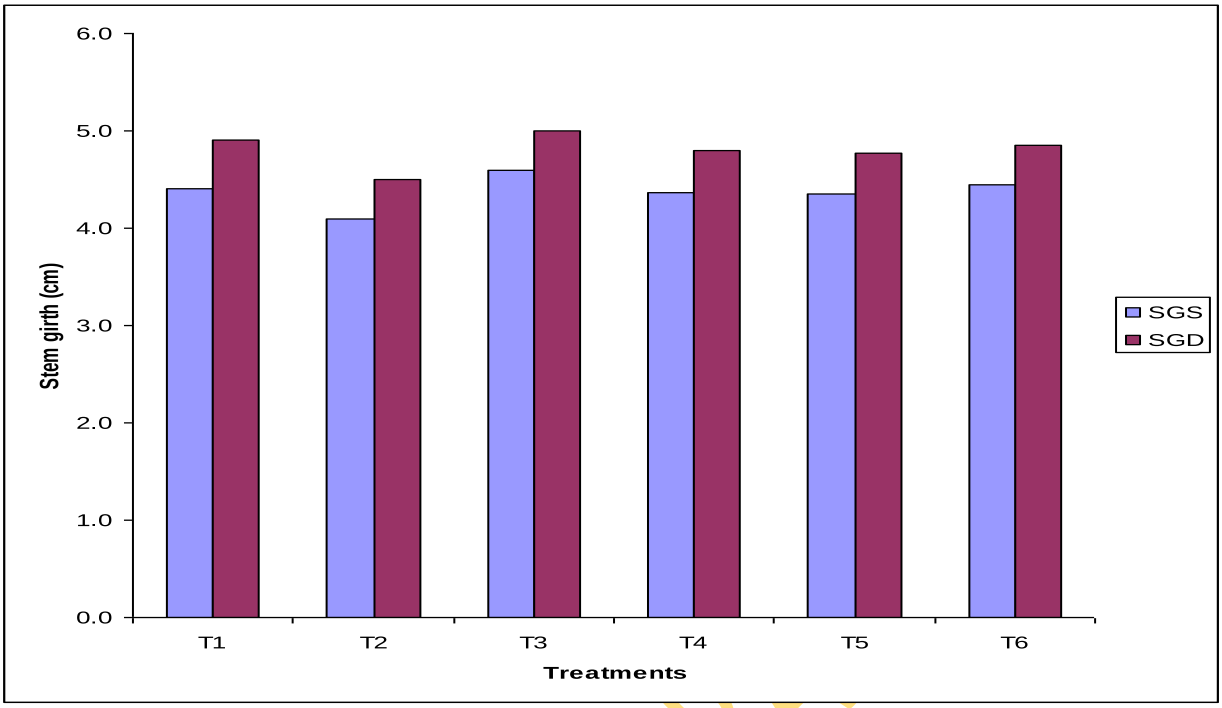


Fig. 4.20: Comparison of stem girth of tomato under Soilless media and irrigation treatments

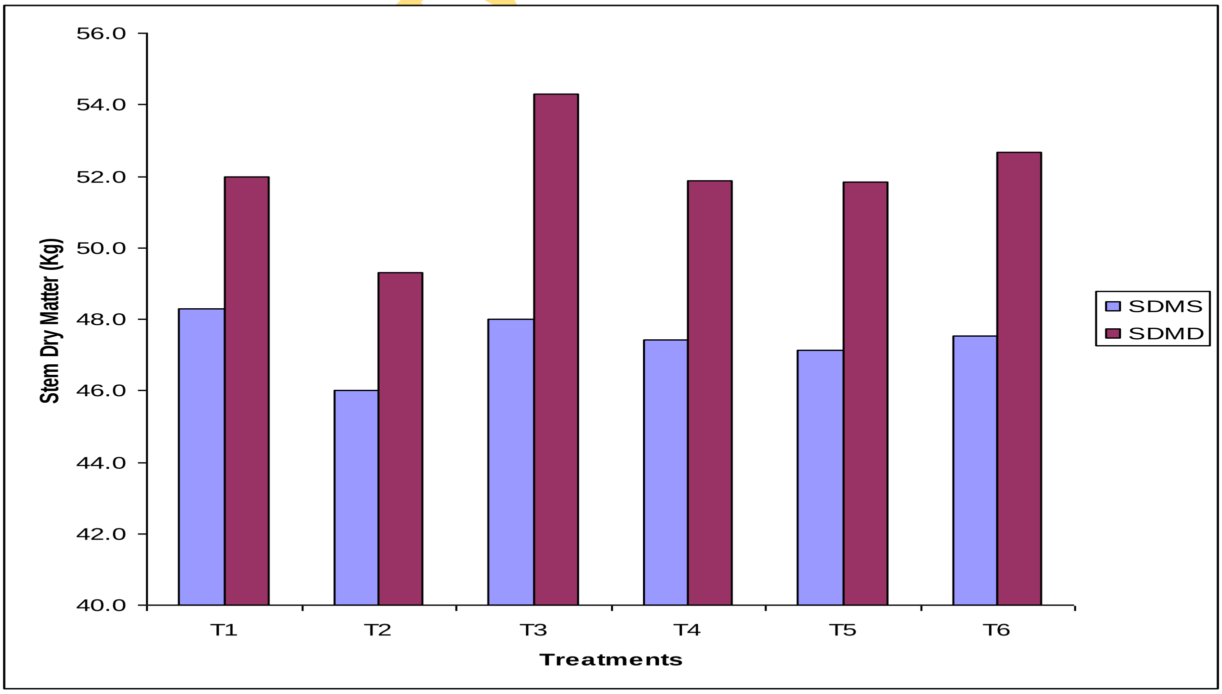


Fig. 4.21: Comparison of stem dry matter of tomato under soilless media and irrigation treatments

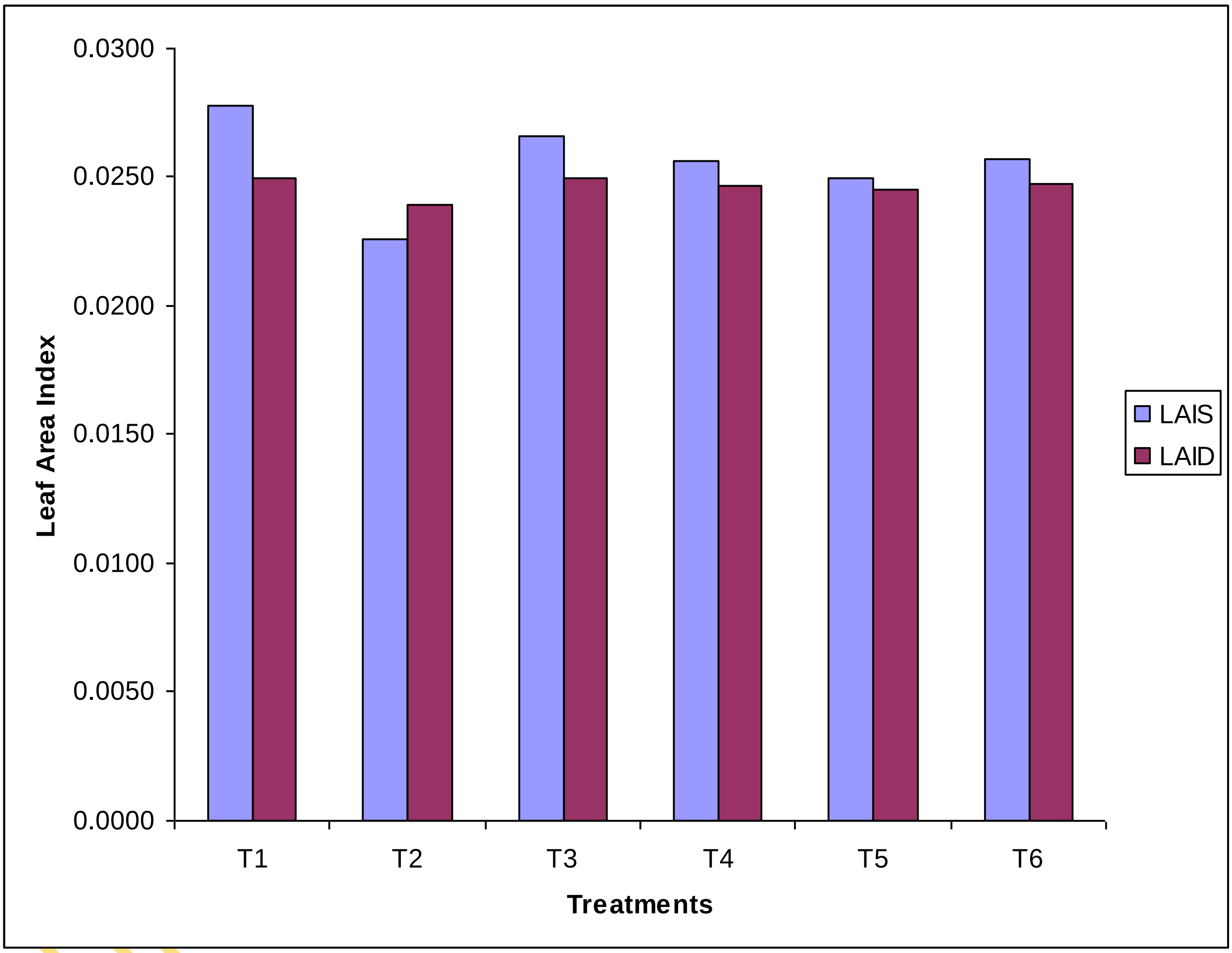


Fig. 4.22: Leaf surface area (LAI) of tomato under drip and sprinkler Irrigation systems

4.6 Model Equations

The results from the statistical analysis showed that yield does not have correlation with the amount of water used by tomato in each soilless medium but rather with the type of irrigation. Regression model was therefore developed for the 6 soilless media treatments under the 2 irrigation types and for 5 yield variables.

Regression Models for the 6 soilless media under Sprinkler (S) irrigation are given as:

$FWS1 = -3.7 + 720NLS + 46PHS + 83NFS + 4.4SGS + 42SDMS \quad (r^2 = 0.985)$

$FWS2 = -10.1 + 750NLS + 44PHS + 87NFS + 3.9SGS + 46SDMS \quad (r^2 = 0.983)$

$FWS3 = 4.7 + 742NLS + 47PHS + 79NFS + 4.6SGS + 50SDMS \quad (r^2 = 0.988)$

$FWS4 = -9.2 + 722NLS + 44PHS + 88NFS + 3.8SGS + 42SDMS \quad (r^2 = 0.981)$

$FWS5 = 3.9 + 689NLS + 42PHS + 86NFS + 3.5SGS + 40SDMS \quad (r^2 = 0.984)$

$FWS6 = 1.4 + 780NLS + 45PHS + 76NFS + 5.2SGS + 52SDMS \quad (r^2 = 0.987)$

Regression Models for the 6 soilless media under Drip (D) irrigation are given as:

$FWD1 = -0.04 + 834NLD + 55PHD + 79NFD + 5.0SGD + 52SDMD \quad (r^2 = 0.986)$

$FWD2 = -6.5 + 780NLD + 52PHD + 81NFD + 4.5SGD + 48SDMD \quad (r^2 = 0.983)$

$FWD3 = 6.2 + 852NLD + 55PHD + 70NFD + 5.1SGD + 55SDMD \quad (r^2 = 0.985)$

$FWD4 = 0.02 + 736NLD + 52PHD + 88NFD + 4.0SGD + 46SDMD \quad (r^2 = 0.985)$

$FWD5 = 0.69 + 708NLD + 50PHD + 81NFD + 3.8SGD + 46SDMD \quad (r^2 = 0.984)$

$FWD6 = 11.3 + 863NLD + 55PHD + 69NFD + 5.4SGD + 60SDM \quad (r^2 = 0.988).$

Where,

FW, NL, PH, NF, SG and DM are fruit weight, number of leaves, plant height, number of fruits, stem girth and dry matter respectively. The coefficient of determination (r^2) is equal or greater than 0.98 for all the treatments, under the two irrigation systems. This implies that if the total fruit weight from a soilless medium is known under any of the two irrigation methods, the number of leaves, plant height, number of fruits, stem girth and stem dry matter of tomato planted in the medium can be estimated.

The procedure for the Two-Way ANOVA relating fruit weight with number of fruits, number of leaves, stem girth, height and stem dry matter of tomato are presented in Appendix 15-20. Each of the ANOVA includes the effect of irrigation and soilless media types on each of the 6 yield parameters mentioned above. The randomized complete block design (RCBD) shows that for all the yield variables F- critical is less than F- tabulated under both irrigation type and soilless media type except for plant height where F- critical (2.772853) is greater than F- tabulated (0.572555) under soilless media type. These results show that there is a significant relationship between both the irrigation type and the soilless media type for all the yield variables except for plant height where there exist no significant relationship between height of tomato and the type of soilless media. In all, there exist no significant relationship between the interactions of the irrigation method and soilless media type on the yield variables.

4.7 Cost Benefit Analyses

Total variable and fixed cost of constructing, installing and using sprinkler irrigation for the first and second year are summarized in Tables 4.11 and 4.12, respectively while that of the drip are in Tables 4.13 and 4.14. For both systems, cost continues to decrease after the first year because it does not include the fixed cost of construction and installation of the systems. Table 4.15 summarizes the cost of using the control experiment for the first year which is constant for the second and subsequent years when the cost of using the same piece of land will increase due to the need to prevent associated attack of diseases, pest and nematodes and cost of amending the soil. The general assumption used in the computation is that tomato was planted three times in a year. Table 4.16 describes the procedure for estimating benefit from tomato per year while using sprinkler, drip or the control. Yield (Kg/m^2) was estimated from total yield and area used for production of tomato under sprinkler, drip and the control. The area under each of sprinkler and drip irrigation was 4.6224 m^2 which approximately is about 5 m^2 while that under the control is 9.72 m^2. These values were then used as basis for computing the benefits from the three methods of producing the tomato. Also the market price of tomato during the period under investigation varied between N500 and N800/kg, depending on the quality of tomato and the time of the year. For this analysis, N600 was assumed as reasonable for computing total benefits per year for the three systems. Tables 4.17 and 4.18 were used to compute the benefit cost ratio of using the two irrigation systems and the control for the first and the second year, respectively. Drip was rated as 1st, sprinkler 2nd and the control as 3rd. The benefit cost ratio continues to increase for both sprinkler and drip with drip having higher rate of increase while for the control, the benefit- cost ratio is constant and is likely to decrease as year of production increases as cost of production is likely to increase. The analysis is best presented in Figure 4.23 which shows clearly the rate of increase after the first year. The benefit-cost ratio of drip irrigation versus micro sprinkler irrigation was 2:1 while that of soilless media versus soil was 6: 1.

Table 4.11: Summary of total cost of using sprinkler irrigation for first year (3 cycles)

S/No	Materials	Unit Used	Unit Price (N)	Total Cost (N)
1	1” & ¾” Pipe	2&2 = 4	300	1200
2	½” pipe	2	200	400
3	1”Control valves	1	300	300
4	¾” Control valves	3	250	750
5	1” by ¾” Elbow joint	1	50	50
6	¾” by ½” Elbow joint	3	50	150
7	½” Plugs	3	40	120
8	1” Socket	2	50	100
9	1” by ¾” Tee-Joint	2	40	80
10	½” Tee-Joint	18	40	720
11	PVC Gum	1	250	250
12	Plumber Malt	½	70	35
13	Liquid Fertilizer (Boost Extra)	3	800	2400
14	Rubber Tank	1	4000	4000
15	Cost of Installation		1200	1200
16	Labour/management cost	3croppings	1200/cropping	3600
17	Cost of local purchase of water	3croppings	1500	4500
Total Cost				23675

Table 4.12: Summary of total cost of using sprinkler irrigation for second year (3 cycles)

S/No	Materials	Unit per cropping	Unit Price (N)	Total Cost (N)
1	Liquid Fertilizer (Boost Extra)	3	800	2400
2	Labour/management cost	3	1200	3600
3	Cost of local purchase of water	3	3000	9000
	Total Cost			15000

Table 4.13: Summary of total cost of using drip irrigation for first year (three croppings)

S/No	Materials	Unit Used	Unit Price (N)	Total Cost (N)
1	1” & ¾” Pipe	2x2 = 4	300	1200
2	½” pipe	2	200	400
3	Control valves	1	300	300
4	¾” Control valves	3	250	750
5	1” by ¾” Elbow joint	1	50	50
6	¾” by ½” Elbow joint	3	50	150
7	½” Plugs	21	40	840
8	1” Socket	2	50	100
9	1” by ¾” Tee-Joint	2	40	80
10	½” Tee-Joint	18	40	720
11	PVC Gum	1	250	250
12	Plumber Malt	½	70	35
13	Liquid Fertilizer (Boost Extra)	1	800	800
14	Rubber Tank	1	4000	4000
15	Cost of Installation		1400	1400
16	Labour/management cost	3coppings	1600/cropping	4800
17	Cost of local purchase of water	3croppings	500	1500
	Total Cost			18875

Table 4.14: Summary of total cost of using drip irrigation for second year (3 cycles)

S/No	Materials	Unit per cropping	Unit Price (N)	Total Cost
(N)				
1	Liquid Fertilizer (Boost Extra)	1	800	800
2	Labour/management cost	3	1600	4800
3	Cost local purchase of water	3	500	1500
Total Cost				8600

Table 4.15: Summary of total cost of using control for first year (3 cycles)

S/No	Materials	No. of cropping	Unit Price (N)	Total Cost
(N)				
1	Land preparation	3	500	1500
2	Labour/management cost	3	1650	4950
3	Solid Fertilizer	3	350	1050
4	Cost of local purchase of water	3	2500	7500
Total				15000

Table 4.16: Procedure for estimating Benefit from tomato per year while using sprinkler, drip or the control

Description	Sprinkler	Drip	Control
Total yield (Kg)	80.4	94.8	68.4
Total area used (m^2)	4.6224	4.6224	9.72
Yield (Kg/ m^2)	17.394	20.509	7.037
Yield at approx. 5 m^2 (Kg)	86.968	102.544	35.185
Estimated market value (#/Kg)	600:00	600:00	600.00
Revenue per planting (RPP) (#)	52,181	61,526	21,110
Revenue per year (RPPx3) (#)	156,543	184,578	63,330

Note

Area under Sprinkler = 2.16 m x 2.14 m = 4.6224 m^2

Area under Drip = 2.16 m x 2.14 m = 4.6224 m^2

Area under Control = 0.6m x 0.9m x 6 treatments x 3 replicates = 9.72 m^2

Table 4.17: Cost Benefit analysis of using sprinkler, drip and control for the first year (3 cycles)

Type of irrigation	Cost (C) (N)	Benefit (B) (N)	B/C	‘B – C’/C	Ranking
Sprinkler	23,675	156,543	6.61	5.61	2nd
Drip	18,875	184,578	9.78	8.78	1st
Control	15,000	63,330	4.22	3.22	3rd

Table 4.18: Cost Benefit Analysis of using sprinkler, drip and control for the second year (3 cycles)

Type of irrigation	Cost (C) (N)	Benefit (B) (N)	B/C	‘B – C’/C	Ranking
Sprinkler	15,000	156,543	10.44	9.44	2nd
Drip	8,000	184,578	21.46	20.46	1st
Control	15,000	63,333	4.22	3.22	3rd

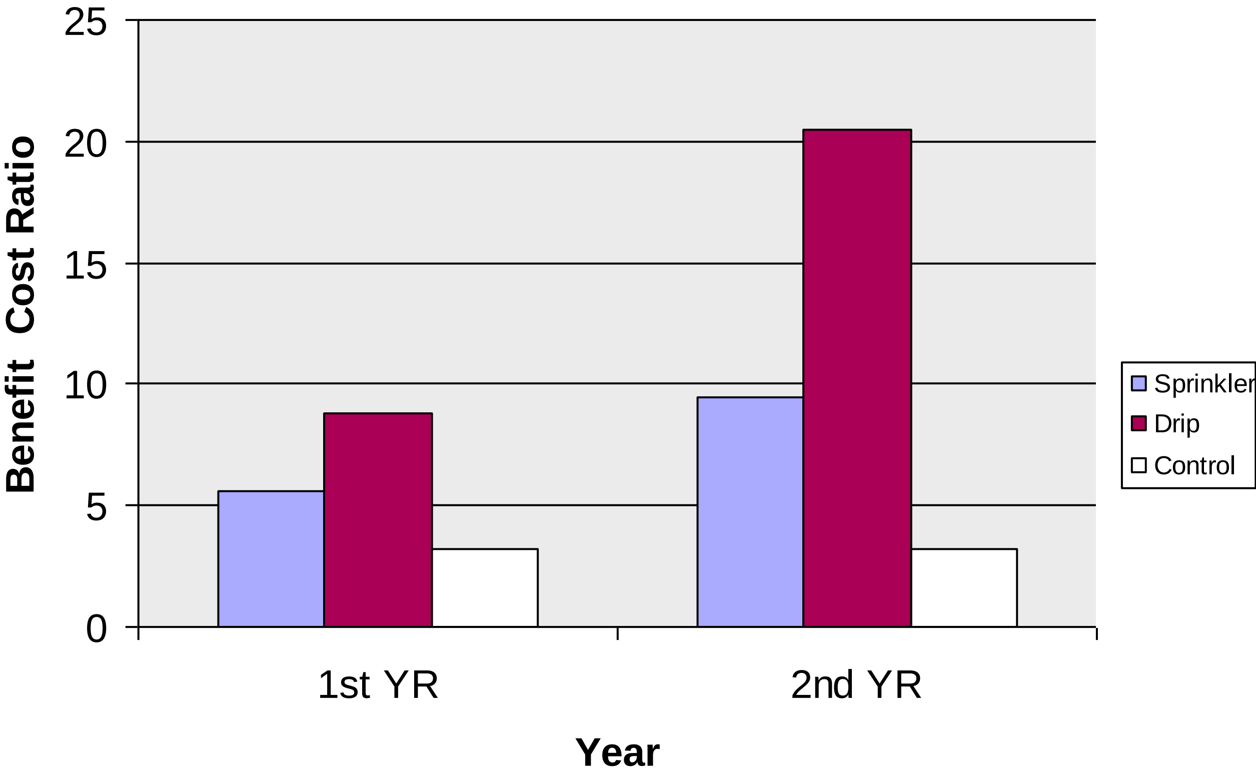


Fig. 4.23: Bar chart for cost benefit analysis of using sprinkler, drip and the control

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. Soilless planting produce tomato of higher yield and better quality than soil culture.
2. There was marked increase in production of tomato for the two growing cycles.
3. Mixture of coconut fiber and sand (1:1) is recommended for greenhouse-grown tomato in the study area.
4. Drip irrigation produced tomato of greater yield and better quality than sprinkler irrigation.
5. Tomato planted directly on bare soil produced least fruit yield and quality.
6. The amount of water used by sprinkler irrigation is three times that used by drip irrigation system under the conditions considered.
7. Benefit-cost ratio for drip irrigation was higher than sprinkler while this parameter is higher for soilless media as compared to use of soil.
8. Residents of urban areas may find the data and information in this study useful to contemplate soilless farming of vegetables in the house, an apartment or garage.
9. The result of the benefit/cost ratio can be used to advise intending soilless growers in Nigeria.
10. It is expected that this research will complement the work of the few researchers on this subject in Nigeria.

5.2 Recommendations

1. Other materials like rice husk, cocoa coir and peat, should be tested as soilless media and other vegetable crops can similarly be used for the research so as to further support this study.
2. The study may be carried out for five years cropping to further show the extent of the superiority of soilless media and drip irrigation over the traditional method of planting directly on the soil.

3. Soilless planting is generally recommended for urban areas and cities with scarce agricultural soil.
4. Soilless planting can be encouraged as method of land recovery practice for agricultural purpose in the desert and land degraded area of Nigeria.

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APPENDICES

Appendix 1: Rainfall data for the growing periods of year 2009

AGRO-CLIMATIC DATA FROM THE METEOROLOGICAL STATION OF THE DEPT OF AGRIC ENGR., OWO.

	STATION	Owo	LGA	Owo	YEAR	2009	DATA	Rainfall(mm)				
DATE	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	6.0	0	0	17.5	30.5	0	10.5
3	0	0	0	0	0	10.0	0	0	6.0	0	3.0	0
4	0	0	0	0	0	0	0	26.0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	30.0	5.1	21.0
6	0	0	0	0	0	0	0	17.0	0	0	0	0
7	0	0	15.0	0	0	0	0	0	10.9	0	0	0
8	0	0	0	0	0	0	0	30.0	5.5	0	0	0
9	0	0	0	0	0	0	30.6	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	10.5	0	0	0	0	0	0	0
12	0	0	0	0	0	35.0	0	18.0	6.0	13.0	0	0
13	0	0	0	0	0	20.7	0	19.1	10.8	0	0	0
14	0	0	0	0	0	0	23.0	0	7.5	0	0	0
15	0	0	0	0	43.4	0	0	0	6.0	8.0	0	0
16	0	0	4.70	0	0	30.6	0	20.6	4.0	0	0	0
17	0	0	0	0	0	0	36.3	10.2	5.2	14.2	0	0
18	0	0	4.40	0	0	0.5	42.0	0	0	0	0	0
19	0	0	30.0	0	30.0	0	6.5	0	0	0	0	0
20	0	0	0	0	0	0	0	0	16.0	0	0	0
21	0	0	0	0	40.5	0	36.5	0	0	0	0	0
22	0	0	0	42	0	30.5	0	0	8.5	25.0	0	0
23	0	0	0	0	22.5	46.4	1.6	0	0	0	0	0
24	0	0	28.8	12.2	0	6.8	21.6	0	8.0	12.0	0	0
25	0	0	0	0	0	9.0	0	0	0	0	0	0
26	0	0	20.5	16	0.1	23.5	5.2	0	5.6	0	0	0
27	0	0	0	22	0	0	30.5	4.0	0	0	0	0
28	0	0	0	0	0	15.0	0	0	0	0	0	0
29	0	--	0	0	0	0	20.6	0	4.0	0	0	0
30	0	--	0	23.5	20.6	40.5	30.5	0	0	0	0	0
31	0	--	11.6	--	0	--	0	0	--	0	--	0
Total	0	0	115	115.7	167.6	274.5	284.9	144.9	219.6	132.7	8.1	31.5
Average	0	0	7.19	7.47	10.48	17.71	17.81	9.06	14.17	8.29	0.52	1.97

Appendix 2: Maximum temperature data for the growing periods of year 2009

AGRO-CLIMATIC DATA FROM THE METEOROLOGICAL STATION OF THE DEPT OF AGRIC ENGR., OWO.

	STATION	Owo	LGA	Owo	YEAR	2009	DATA	Max. Temp(0C)				
DATE	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
1	34	33	39	33	37	30	30	30	30	28	35	30
2	34	34	36	34	34	30	31	28	29	31	34	29
3	34	36	30	35	32	32	29	30	29	31	35	30
4	36	37	33	33	33	30	26	29	30	29	33	30
5	35	38	36	34	30	30	28	28	32	30	34	34
6	35	34	35	32	31	30	27	29	30	32	34	34
7	34	33	33	34	31	31	27	29	29	33	34	29
8	36	36	34	35	32	28	28	28	30	34	35	30
9	36	36	34	35	32	30	29	27	30	32	35	35
10	35	38	32	32	33	28	28	29	31	33	36	32
11	36	39	34	33	31	29	27	28	30	34	37	30
12	34	37	33	33	33	29	26	32	30	30	36	30
13	36	40	35	33	33	26	27	30	32	31	35	33
14	39	37	36	32	34	27	26	29	31	34	36	36
15	35	34	38	33	30	28	28	28	32	34	36	40
16	36	33	35	32	31	29	26	33	30	34	35	39
17	35	32	37	34	29	28	27	33	29	34	35	40
18	34	36	40	33	29	29	28	29	29	35	36	36
19	36	33	40	36	28	30	27	29	31	33	30	32
20	34	37	37	35	30	29	26	34	30	34	30	30
21	36	37	38	34	29	29	27	34	29	33	34	29
22	35	39	35	33	29	29	28	30	27	34	34	27
23	38	39	33	37	30	30	26	31	30	34	35	30
24	40	35	35	36	30	28	26	33	31	33	34	28
25	39	39	33	35	30	30	27	34	28	33	33	30
26	40	41	37	35	29	30	27	30	29	32	33	32
27	40	40	36	36	30	28	26	29	30	31	32	35
28	41	39	34	35	30	29	27	30	33	31	33	36
29	39	--	36	33	30	27	26	29	28	29	34	38
30	38	--	35	36	29	27	26	29	27	32	34	37
31	37	--	36	--	30	--	26	30	--	31	--	39
Total	1127	1022	1095	1021	959	870	843	931	896	999	1027	1020
Average	70.44	70.48	68.44	65.87	59.94	56.13	52.69	58.19	57.81	62.44	66.258	63.75

Appendix 3: Minimum temperature data for the growing periods of year 2009

AGRO-CLIMATIC DATA FROM THE METEOROLOGICAL STATION OF THE DEPT OF AGRIC ENGR., OWO.

	STATION	Owo	LGA	Owo	YEAR	2009	DATA	Min. Temp(0C)				
DATE	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
1	24	26	20	24	23	22	20	20	26	25	24	25
2	24	25	22	23	22	22	20	23	24	25	26	23
3	23	25	22	21	23	22	18	24	22	24	24	24
4	23	26	20	24	24	22	19	24	22	23	22	25
5	24	25	19	23	24	23	20	20	23	23	23	25
6	22	25	19	24	24	24	21	20	23	23	22	24
7	23	26	20	24	21	23	18	23	23	24	22	24
8	25	26	20	24	24	21	20	23	23	25	21	25
9	26	24	21	23	22	21	20	24	23	25	22	22
10	24	24	22	27	20	22	18	23	24	25	23	26
11	23	23	20	25	22	21	18	23	22	24	23	25
12	23	24	19	24	22	21	18	22	24	23	22	23
13	24	26	18	23	23	22	18	22	24	24	22	23
14	23	24	20	24	21	22	18	24	23	24	24	27
15	22	23	20	23	20	21	17	23	23	23	23	25
16	22	24	23	24	20	21	17	25	22	22	25	24
17	24	24	22	23	22	24	18	24	22	22	24	26
18	20	23	20	23	21	24	17	23	22	22	22	24
19	23	24	20	24	22	25	18	24	22	24	22	27
20	23	24	20	22	24	22	18	25	24	23	23	23
21	24	25	21	24	22	18	18	25	22	23	23	20
22	26	24	22	24	24	17	18	26	22	23	23	20
23	25	23	20	22	22	16	18	25	24	23	22	21
24	26	24	21	25	24	16	20	26	23	23	22	19
25	24	24	20	23	23	17	19	26	23	24	21	20
26	23	23	22	22	25	17	17	25	23	22	24	18
27	24	23	26	24	23	18	17	25	22	22	25	18
28	24	23	25	24	22	18	17	24	24	25	25	22
29	23	--	24	23	23	17	16	24	23	25	24	22
30	25	--	24	23	24	16	16	25	25	24	25	24
31	24	--	23	--	23	--	16	26	--	24	--	22
Total	733	680	655	706	699	615	563	736	692	731	693	716
Average	45.81	46.90	40.94	45.55	43.69	39.68	35.19	46.00	44.65	45.69	44.71	44.75

Appendix 4: Relative humidity data for the growing periods of year 2009

AGRO-CLIMATIC DATA FROM THE METEOROLOGICAL STATION OF THE DEPT OF AGRIC ENGR., OWO.

	STATION	Owo	LGA	Owo	YEAR	2009	DATA	Relative humidity (%)				
DATE	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	70	67	82	85	84	85	88	74	91	75	78	68
2	73	77	76	81	83	87	85	64	92	79	77	76
3	56	82	76	83	87	89	91	60	90	80	88	77
4	63	80	86	80	96	88	92	56	89	82	73	57
5	64	76	82	81	85	87	91	71	89	88	70	58
6	48	77	77	82	83	88	87	58	91	86	78	77
7	53	69	73	83	85	87	88	84	88	84	66	86
8	58	65	82	81	82	87	90	80	88	80	67	88
9	70	70	80	81	85	85	89	58	88	82	56	86
10	56	78	78	80	96	85	91	74	86	86	63	66
11	66	88	78	81	86	87	92	54	90	84	68	65
12	68	85	80	83	87	86	92	80	91	91	57	65
13	59	74	86	85	82	85	91	72	89	88	55	70
14	54	76	82	80	82	85	89	70	88	85	78	73
15	47	80	76	81	82	85	88	74	90	75	74	71
16	44	81	76	83	80	84	90	60	89	90	63	65
17	58	78	66	81	87	89	89	65	89	88	53	68
18	56	77	73	82	82	89	91	56	91	88	56	56
19	77	56	77	81	87	88	87	71	88	91	66	64
20	78	67	80	85	84	87	88	58	88	86	79	77
21	66	64	78	83	84	87	90	84	80	85	84	78
22	76	54	76	81	86	85	91	80	90	84	85	80
23	68	48	76	81	83	86	92	57	91	82	90	56
24	72	56	73	82	85	86	90	74	85	79	76	67
25	64	70	81	81	82	88	88	62	83	90	65	78
26	62	73	77	80	83	87	90	71	90	88	78	90
27	65	71	73	86	86	88	92	80	85	88	79	83
28	48	66	74	83	85	88	91	81	80	84	89	87
29	45	--	60	82	83	85	87	74	76	82	94	76
30	51	--	58	80	82	87	88	64	80	81	78	79
31	60	--	72	--	81	--	90	71	--	76	--	80
Total	1895	2005	2364	2458	2625	2600	2778	2137	2625	2607	2183	2267
Average	118.4	138.3	147.8	158.6	164.1	167.7	173.6	133.6	169.4	162.9	140.8	141.7

Appendix 5: Solar radiation data for the growing periods of year 2009

AGRO-CLIMATIC DATA FROM THE METEOROLOGICAL STATION OF THE DEPT OF AGRIC ENGR., OWO.

	STATION	Owo	LGA	Owo	YEAR	2009	DATA	Radiation(ml+)				
DATE	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
1	8.7	11.4	14.7	17.4	11.0	10.2	9.6	12.5	12.1	17.2	18.5	19.5
2	12.6	13.3	12.6	14.5	20.9	15.2	11.1	12.3	10.8	6.6	17.8	17.2
3	9.8	13.6	19.0	5.3	17.6	18.4	13.2	14.3	11.0	14.1	16.4	15.3
4	14.4	13.3	14.5	17.8	11.5	12.2	15.0	7.8	11.3	10.2	19.3	19.0
5	17.4	11.2	14.1	19.4	17.6	9.4	14.2	7.6	8.9	15.4	9.0	12.8
6	13.4	12.8	22.6	17.5	15.6	5.3	14.3	9.5	11.3	16.2	18.2	11.9
7	15.3	12.8	18.1	19.4	14.3	16.4	12.5	9.4	11.2	11.2	17.4	15.9
8	10.4	14.6	18.5	15.3	16.4	15.3	10.5	9.6	13.0	17.2	22.9	14.7
9	12.4	14.3	14.0	20.3	17.4	12.8	8.3	4.5	6.8	14.6	17.8	14.3
10	10.1	15.3	10.3	17.6	10.2	14.3	13.5	6.6	13.3	15.8	15.7	16.8
11	10.1	14.5	19.1	15.1	14.6	18.7	0.3	10.0	13.6	11.6	19.3	15.6
12	10.1	14.3	14.6	14.9	10.5	11.6	10.3	4.4	10.3	10.5	19.2	16.6
13	12.8	14.9	14.7	6.6	14.4	16.5	16.3	9.3	13.8	17.6	17.6	19.8
14	15.2	14.4	16.4	3.5	12.5	16.3	8.3	7.0	14.6	16.9	18.2	16.5
15	11.2	19.4	17.4	20.2	15.3	12.5	3.5	9.3	9.6	10.3	15.0	15.4
16	10.1	17.2	16.5	17.6	17.1	16.8	8.8	9.6	8.8	18.4	15.5	19.4
17	10.5	14.4	15.4	14.5	20.3	7.5	9.2	14.3	9.4	18.6	19.4	19.2
18	14.0	10.8	14.5	18.9	10.3	12.8	8.2	8.8	13.5	16.5	13.5	21.2
19	10.8	11.3	12.8	12.5	14.6	9.7	7.5	9.3	11.7	17.4	17.3	10.4
20	6.3	16.2	17.0	16.5	18.2	16.2	8.5	14.0	15.3	6.4	19.5	16.7
21	14.3	16.7	17.5	145.0	14.3	15.2	7.8	10.9	10.4	17.0	19.6	15.0
22	19.4	13.3	14.8	18.1	12.1	10.2	11.4	13.4	10.9	16.2	20.3	19.4
23	10.5	14.2	22.6	8.8	10.4	12.7	4.8	14.5	13.4	14.8	19.4	15.8
24	10.6	14.1	14.7	13.3	15.9	13.7	9.1	18.0	14.5	18.1	20.2	15.5
25	9.7	17.2	15.3	14.4	19.4	17.3	10.4	10.4	17.6	16.2	19.2	20.2
26	10.8	16.2	13.4	8.7	9.1	15.7	7.5	10.3	10.5	17.3	16.7	20.8
27	10.7	14.0	19.0	18.7	11.4	13.4	6.8	13.4	10.5	4.9	18.2	14.8
28	13.6	17.3	20.1	9.6	15.8	15.1	11.1	13.5	13.7	13.7	19.2	16.9
29	12.4	--	16.1	19.4	14.6	18.8	9.3	16.2	13.6	16.5	17.6	16.8
30	11.2	--	16.5	18.6	18.6	16.4	5.4	6.1	16.3	17.3	21.5	16.2
31	12.6	--	12.7	--	16.3	--	9.4	6.2	--	23.2	--	12.5
Total	371.4	403.0	499.5	579.4	458.8	416.6	296.1	323.0	361.7	457.9	539.4	512.1
Average	23.2	27.8	31.2	37.4	28.7	26.9	18.5	20.2	23.3	28.6	34.8	32.0

Appendix 6: Sunshine data for the growing periods of year 2009

AGRO-CLIMATIC DATA FROM THE METEOROLOGICAL STATION OF THE DEPT OF AGRIC ENGR., OWO.

	STATION	Owo	LGA	Owo	YEAR	2009	DATA	sunshine(hours+)				
DATE	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
1	4.2	2.2	6.8	5.7	2.9	1.6	1.6	4.0	1.6	3.7	9.6	8.3
2	4.9	2.4	4.5	6.1	9.5	8.3	3.7	3.3	0.5	0.0	7.5	8.7
3	4.0	1.4	9.2	0.8	5.3	8.4	6.2	5.9	6.2	3.7	9.3	4.7
4	4.0	2.3	7.5	6.7	3.0	4.8	4.3	0.0	0.7	1.5	6.6	8.9
5	4.5	2.1	5.1	7.8	9.3	5.8	6.4	0.9	0.9	3.1	2.8	4.5
6	4.2	2.1	8.0	8.9	7.4	0.8	3.6	1.8	3.6	6.2	9.6	1.4
7	2.2	2.1	7.9	6.6	7.9	8.7	5.1	23.0	2.2	9.1	8.1	6.6
8	3.2	3.9	6.9	1.0	7.6	5.6	1.9	2.5	4.3	8.9	8.8	7.7
9	1.4	3.1	6.0	8.1	6.9	3.2	0.6	3.1	0.3	3.1	9.4	7.8
10	2.9	3.5	1.5	4.1	3.2	3.8	5.8	0.6	6.0	6.2	7.8	6.3
11	0.2	5.8	8.4	4.9	7.3	5.4	0.8	0.0	4.2	2.6	9.8	6.6
12	3.2	8.2	7.1	3.4	3.3	2.1	4.3	7.8	3.8	4.4	7.4	7.2
13	5.0	6.8	6.8	0.5	2.8	10.3	7.2	0.7	2.6	7.4	7.6	7.4
14	7.1	2.6	5.8	1.3	3.9	7.0	1.9	2.5	3.7	5.6	8.8	7.2
15	5.4	8.0	6.9	8.4	6.5	5.2	1.5	2.0	2.0	0.0	7.6	8.2
16	4.7	9.4	8.0	5.6	4.5	7.8	1.6	1.8	1.9	5.4	7.7	5.9
17	5.2	8.3	5.7	7.1	10.0	2.2	2.4	3.6	2.1	9.7	7.3	5.4
18	6.1	5.4	5.5	4.1	2.8	1.8	2.5	4.4	5.7	4.9	4.6	5.9
19	5.9	8.4	5.3	4.7	4.7	0.8	0.6	0.8	1.9	7.9	8.1	3.1
20	1.4	6.4	6.0	6.2	7.3	6.5	1.9	1.9	5.0	3.7	9.8	5.2
21	8.5	8.8	7.9	3.5	1.6	6.3	2.3	4.1	1.9	6.5	8.4	5.0
22	5.8	8.5	5.4	5.8	4.2	0.9	1.4	8.9	2.6	8.3	10.3	5.3
23	3.7	6.9	9.4	0.8	5.1	2.8	0.4	1.8	4.5	7.9	9.6	3.5
24	4.7	6.1	5.8	5.4	8.1	4.4	2.1	3.1	5.4	8.1	9.2	2.1
25	3.6	5.4	6.8	6.6	5.8	5.0	0.0	6.9	7.1	7.3	9.1	4.5
26	4.6	4.8	4.0	0.6	2.9	6.1	2.8	2.0	3.4	0.6	7.9	4.8
27	5.6	6.7	9.1	9.7	5.7	2.4	2.4	2.1	3.7	8.6	7.1	7.2
28	7.6	6.4	9.2	6.8	9.1	8.9	2.3	6.1	4.1	4.9	9.0	4.9
29	6.7	--	7.3	4.3	5.9	9.5	3.9	7.2	6.0	5.4	9.3	4.6
30	5.8	--	7.1	9.2	6.4	6.0	0.3	1.8	0.0	9.0	9.5	1.1
31	2.3	--	3.9	--	5.6	--	2.0	2.4	--	10.4	--	4.0
Total	138.6	148.0	204.8	154.7	176.5	152.4	83.8	117.0	97.9	174.1	247.6	1.0
Average	8.7	10.2	12.8	10.0	11.0	9.8	5.2	7.3	6.3	10.9	16.0	10.9

Appendix 7: The means procedure for soilless treatments and yield variables of tomato

```
Variable Coeff      Mean       Std Error N         Maximum     Minimum
of Variation   Std Dev
treat                3.50           0.41   18           6.00           1.00
50.21          1.76
FWS                   4.46           0.11  18           5.40           3.70
10.06          0.45
FWD                   5.26           0.23  18           6.80           4.00
18.73          0.98
NLS                  736.67           7.23  18         805.00         688.00
4.16         30.66
NLD               792.50          12.40    18         863.00          696.00
6.64         52.60
PHS                43.94          0.38    18          47.00          40.00
3.70          1.63
PHD                54.00          0.55    18          59.00          50.00
4.31          2.33
The SAS System
```

Appendix 8: The regression procedure for yield variables FWS, FWD, NLS, NLD, PHS and PHD

```
Model: MODEL1
Dependent Variable: treat
Number of Observations Read          18
Number of Observations Used          18
Analysis of Variance
Sum of            Mean
Source                   DF        Squares          Square    F Value     Pr > F
Model                     6       27.21727         4.53621       1.97     0.1556
Error                    11       25.28273         2.29843
Corrected Total          17       52.50000
Root MSE               1.51606    R-Square     0.9184
Dependent Mean         3.50000    Adj R-Sq     0.2557
Coeff Var             43.31592
Parameter Estimates
Parameter        Standard
Variable     DF        Estimate           Error    t Value     Pr > |t|
Intercept     1        35.15331        23.04292       1.53       0.1553
FWS           1         2.29614         3.07643       0.75       0.4711
FWD           1         2.98403         1.21950       2.45       0.0324
NLS           1         0.00169         0.02102       0.08       0.9372
NLD           1        -0.07785         0.02698      -2.89       0.0148
PHS           1        -0.17402         0.29039      -0.60       0.5611
PHD           1         0.19481         0.19333       1.01       0.3353

Treat=35.1533+2.2961FWS+2.9840FWD-0.0017NLS-0.0779NLD-0.1740PHS+0.19481PHD
R-Square=9.184
The SAS System
```

Appendix 9: The correlation procedure for FWS, FWD, NLS, NLD, PHS and PHD

```
7 Variables: treat     FWS       FWD       NLS       NLD       PHS       PHD
Simple Statistics
Variable               N         Mean        Std Dev         Sum         Minimum
Maximum
treat                    18          3.50000          1.75734        63.00000
1.00000       6.00000
FWS                      18          4.46111          0.44871        80.30000
3.70000       5.40000
FWD                      18          5.25556          0.98412        94.60000
4.00000       6.80000
```

```
NLS                       18       736.66667        30.66134            13260
688.00000      805.00000
NLD                       18       792.50000        52.60088            14265
696.00000      863.00000
PHS                        18        43.94444          1.62597        791.00000
40.00000       47.00000
PHD                        18        54.00000          2.32632        972.00000
50.00000       59.00000
```

Continuation of Appendix 9: Pearson Correlation Coefficients

```
N = 18 Prob > |r| under H0: Rho=0
                 Treat          FWS           FWD          NLS            NLD     PHS          PHD
Treat          1.00000       -0.00373       0.07823       0.13974      -0.13650      -0.05147
0.23022
0.9883         0.7577         0.5802        0.5891        0.8393        0.3581
FWS           -0.00373        1.00000       0.91634       0.79298       0.93746       0.60962
0.53535
0.9883                        <.0001        <.0001        <.0001        0.0072        0.0220
FWD            0.07823        0.91634       1.00000       0.70810       0.94396       0.59022
0.55756
0.7577         <.0001                       0.0010        <.0001        0.0099        0.0162
NLS            0.13974        0.79298       0.70810       1.00000       0.67854       0.48455
0.47007
0.5802         <.0001         0.0010                      0.0020        0.0416        0.0490
NLD           -0.13650        0.93746       0.94396       0.67854       1.00000       0.56500
0.53408
0.5891         <.0001         <.0001        0.0020                      0.0146        0.0224
PHS           -0.05147        0.60962       0.59022       0.48455       0.56500       1.00000
0.26437
0.8393         0.0072         0.0099        0.0416        0.0146                      0.2891
PHD            0.23022        0.53535       0.55756       0.47007       0.53408       0.26437
1.00000
0.3581         0.0220         0.0162        0.0490        0.0224        0.2891
The SAS System
```

Appendix 10: The regression procedure for yield variables NFS, NFD, SGS, SGD, SDMS and SDMD

```
Model: MODEL1
Dependent Variable: treat
Number of Observations Read          18
Number of Observations Used          18
Analysis of Variance
Sum of           Mean
Source                       DF        Squares         Square     F Value     Pr > F
```

```
Model                    6       16.57817        2.76303       0.85    0.5606
Error                   11       35.92183        3.26562
Corrected Total         17       52.50000
Root MSE             1.80710    R-Square     0.9158
Dependent Mean       3.50000    Adj R-Sq    -0.0574
Coeff Var           51.63151
Parameter Estimates
Parameter        Standard
Variable     DF        Estimate          Error    t Value     Pr > |t|

Intercept     1       44.93760       26.23834       1.71       0.1148
NFS           1       -0.28458        0.26522      -1.07       0.3062
NFD           1       -0.06514        0.15263      -0.43       0.6778
SGS           1       -2.91801        2.58949      -1.13       0.2838
SGD           1       -0.77678        2.29188      -0.34       0.7410
SDMS          1       -0.27666        0.37744      -0.73       0.4789
SDMD          1        0.31794        0.28233       1.13       0.2841

Treat=44.9376-0.2846NFS-0.0651NFD-2.918SGS-0.7768SGD-0.2767SDMS+0.3179SDMD
R-Square=9158
```

Appendix 11: The correlation procedure for NFS, NFD, SGS, SGD, SDMS and SDMD

```
7 Variables:    treat     NFS     NFD     SGS     SGD     SDMS     SDMD
Simple Statistics
Variable              N         Mean          Std Dev             Sum
Minimum       Maximum
treat                 18       3.50000        1.75734        63.00000
1.00000       6.00000
NFS                   18      83.00000        3.32548            1494
76.00000      89.00000
NFD                   18      78.66667        6.35240            1416
67.00000      90.00000
SGS                    18       4.24444        0.47307        76.40000
3.50000       5.20000
SGD                    18       4.65556        0.54039        83.80000
3.70000       5.40000
SDMS                   18      46.33333        3.69419       834.00000
40.00000      52.00000
SDMD                   18      50.72222        5.18828       913.00000
43.00000      60.00000
```

Continuation Appendix 11: of Pearson Correlation Coefficients

```
N = 18 Prob > |r| under H0: Rho=0
treat           NFS          NFD          SGS          SGD          SDMS         SDMD
treat         1.00000       -0.15098       -0.21604       -0.06368       -0.03717       -0.06343
0.09355
0.5498        0.3892       0.8018       0.8836       0.8026       0.7120
NFS         -0.15098       1.00000       0.76297       -0.81140       -0.75286       -0.74218      -
0.72619
0.5498                     0.0002       <.0001       0.0003       0.0004       0.0006
NFD         -0.21604       0.76297       1.00000       -0.76015       -0.73455       -0.78458      -
0.85075
0.3892        0.0002                    0.0003       0.0005       0.0001       <.0001
SGS           -0.06368       -0.81140       -0.76015       1.00000       0.85956       0.89310
0.88490
0.8018        <.0001       0.0003                    <.0001       <.0001       <.0001
SGD           -0.03717       -0.75286       -0.73455       0.85956       1.00000       0.91836
0.88701
0.8836        0.0003       0.0005       <.0001                    <.0001       <.0001
SDMS          -0.06343       -0.74218       -0.78458       0.89310       0.91836       1.00000
0.91049
0.8026        0.0004       0.0001       <.0001       <.0001                    <.0001
SDMD           0.09355       -0.72619       -0.85075       0.88490       0.88701       0.91049
1.00000
0.7120        0.0006       <.0001       <.0001       <.0001       <.0001
```

Appendix 12: Factorial ANOVA models for yield variables

Anova: Two-Factor With Replication   FW

SUMMARY	Treat1	treat2	treat3	treat4	Treat5	treat6	Total
trial1							
Count	2	2	2	2	2	2	12
Sum	9.3	8.9	9.6	8	7.6	10.4	53.8
Average	4.65	4.45	4.8	4	3.8	5.2	4.4833333
Variance	0.005	0.045	0.02	0.02	0.02	0.08	0.2615152
Count	2	2	2	2	2	2	12
Sum	10.3	8.9	11.1	8.6	8	11.4	58.3
Average	5.15	4.45	5.55	4.3	4	5.7	4.8583333
Variance	0.845	0.045	1.445	0	0.02	1.62	0.8135606

Count	2	2	2	2	2	2	12
Sum	10.7	9.7	12.4	8.6	8.2	13.2	62.8
Average	5.35	4.85	6.2	4.3	4.1	6.6	5.2333333
Variance	0.005	0.005	0	0.02	0.02	0.08	0.9424242

Total

A

Count	6	6	6	6	6	6
Sum	30.3	27.5	33.1	25.2	23.8	35
Average	5.05	4.583333	5.51667	4.2	3.966667	5.83333333
Variance	0.275	0.061667	0.68567	0.032	0.030667	0.75866667

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Irrigation	3.375	2	1.6875	7.0722	0.005414	3.55455715
soilless media	16.34916667	5	3.26983	13.704	1.32E-05	2.77285315
Interaction	1.548333333	10	0.15483	0.6489	0.754847	2.41170204
Within	4.295	18	0.23861			
Total	25.5675	35				

Continuation of Appendix 12: Two-Factor ANOVA With Replication

SUMMARY	treat1	treat2	treat3	treat4	treat5	treat6	Total
trial1							
Count	2	2	2	2	2	2	12
Sum	164	167	158	177	171	156	993
Average	82	83.5	79	88.5	85.5	78	82.75
Variance	2	0.5	0	0.5	0.5	8	15.295
Count	2	2	2	2	2	2	12
Sum	161	167	152	171	163	151	965
Average	80.5	83.5	76	85.5	81.5	75.5	80.417
Variance	4.5	12.5	50	12.5	0.5	84.5	29.538
Count	2	2	2	2	2	2	12
Sum	162	153	152	176	165	140	948
Average	81	76.5	76	88	82.5	70	79
Variance	2	0.5	2	8	0.5	18	38
Total							
Count	6	6	6	6	6	6	
Sum	487	487	462	524	499	447	
Average	81.16667	81.1667	77	87.33333	83.16667	74.5	
Variance	2.166667	15.7667	12.8	6.266667	3.766667	35.5	

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Irrigation	86.05556	2	43.0278	3.741546	0.043771	3.554557
Soilless Media	615.8889	5	123.178	10.71111	6.77E-05	2.772853
Interaction	88.27778	10	8.82778	0.767633	0.65742	2.411702
Within	207	18	11.5			

Total	997.2222	35

Continuation of Appendix 12: Two-Factor ANOVA With Replication

SUMMARY	treat1	treat2	treat3	treat4	Treat5	treat6	Total
trial1							
Count	2	2	2	2	2	2	12
Sum	1476	1485	1454	1443	1397	1585	8840
Average	738	742.5	727	721.5	698.5	792.5	736.667
Variance	648	112.5	450	0.5	180.5	312.5	1051.88
Count	2	2	2	2	2	2	12
Sum	1572	1500	1623	1479	1396	1623	9193
Average	786	750	811.5	739.5	698	811.5	766.083
Variance	4608	1800	3280.5	24.5	200	5304.5	3223.9
Count	2	2	2	2	2	2	12
Sum	1617	1591	1658	1497	1434	1695	9492
Average	808.5	795.5	829	748.5	717	847.5	791
Variance	112.5	24.5	162	612.5	882	4.5	2389.82
Total							
Count	6	6	6	6	6	6	
Sum	4665	4576	4735	4419	4227	4903	
Average	777.5	762.67	789.1667	736.5	704.5	817.167	
Variance	2111.1	1045.5	3158.567	278.7	346.3	1748.57	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Soilless media	17753.17	2	8876.583	8.5354	0.00247	3.55456
Interaction	47631.25	5	9526.25	9.1601	0.00018	2.77285
Interaction	6970.833	10	697.0833	0.67029	0.73742	2.4117
Within	18719.5	18	1039.972			

Total	91074.75	35

Continuation of Appendix 12: Two-Factor ANOVA With Replication SG

SUMMARY	treat1	treat2	treat3	treat4	treat5	Treat6	Total
trial1							
Count	2	2	2	2	2	2	12
Sum	9	8	9	7.5	7.1	10	50.6
Average	4.5	4	4.5	3.75	3.55	5	4.2167
Variance	0.02	0.02	0.02	0.005	0.005	0.08	0.2833
Count	2	2	2	2	2	2	12
Sum	9.3	8.9	10	8.1	7.6	9.8	53.7
Average	4.65	4.45	5	4.05	3.8	4.9	4.475
Variance	0.245	0.005	0.02	0.005	0	0.5	0.2748
Count	2	2	2	2	2	2	12
Sum	9.8	8.9	10	8.7	8	10.6	56
Average	4.9	4.45	5	4.35	4	5.3	4.6667
Variance	0.18	0.005	0.08	0.125	0.18	0.02	0.2642
Total							
Count	6	6	6	6	6	6	
Sum	28.1	25.8	29	24.3	22.7	30.4	
Average	4.683333	4.3	4.833333	4.05	3.783333	5.066667	
Variance	0.121667	0.06	0.090667	0.099	0.077667	0.154667	

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Irrigation	1.223889	2	0.611944	7.270627	0.004848	3.554557
Soilless media	7.251389	5	1.450278	17.23102	2.63E-06	2.772853
Interaction	0.279444	10	0.027944	0.332013	0.960497	2.411702
Within	1.515	18	0.084167			

Total	10.26972	35

Continuation of Appendix 12: Two-Factor ANOVA With Replication PH

SUMMARY	group1	group2	group3	group4	group5	group6	Total
trial1							
Count	2	2	2	2	2	2	12
Sum	89	88	92	87	86	90	532
Average	44.5	44	46	43.5	43	45	44.333
Variance	4.5	0	2	0.5	2	0	1.8788
Count	2	2	2	2	2	2	12
Sum	97	95	100	97	90	99	578
Average	48.5	47.5	50	48.5	45	49.5	48.167
Variance	84.5	40.5	50	24.5	50	60.5	31.061
Count	2	2	2	2	2	2	12
Sum	109	105	107	110	106	116	653
Average	54.5	52.5	53.5	55	53	58	54.417
Variance	12.5	0.5	4.5	2	2	2	5.7197
Total							
Count	6	6	6	6	6	6	
Sum	295	288	299	294	282	305	
Average	49.16667	48	49.83333	49	47	50.83333	
Variance	40.56667	22.8	22.56667	32	33.2	47.36667	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Irrigation	621.7222	2	310.8611	16.33723	9E-05	3.554557
Soilless media	54.47222	5	10.89444	0.572555	0.720214	2.772853
Interaction	28.27778	10	2.827778	0.148613	0.998029	2.411702
Within	342.5	18	19.02778			

Total	1046.972	35

Continuation of Appendix 12:

Two-Factor ANOVA With Replication SDM

SUMMARY	treat1	treat2	treat3	Treat4	treat5	Treat6	Total
Trial1							
Count	2	2	2	2	2	2	12
Sum	97	92	96	84	82	104	555
Average	48.5	46	48	42	41	52	46.25
Variance	0.5	0	8	0	2	0	16.75
Count	2	2	2	2	2	2	12
Sum	100	94	103	92	87	110	586
Average	50	47	51.5	46	43.5	55	48.8333
Variance	8	2	24.5	0	12.5	50	24.5152
Count	2	2	2	2	2	2	12
Sum	104	100	108	91	87	116	606
Average	52	50	54	45.5	43.5	58	50.5
Variance	0	0	8	0.5	0.5	0	27.1818
Total							
Count	6	6	6	6	6	6	
Sum	301	286	307	267	256	330	
Average	50.16667	47.67	51.1667	44.5	42.66667	55	
Variance	4.166667	3.867	15.3667	3.9	4.666667	17.2	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Irrigation	110.0556	2	55.0278	8.502146	0.002514	3.55456
Soilless media	617.1389	5	123.428	19.07039	1.26E-06	2.77285
Interaction	19.27778	10	1.92778	0.297854	0.972471	2.4117
Within	116.5	18				

Appendix 13: Means, Coefficient of determination, Coefficient of variation and the Root mean square of yield and yield components of tomato

Yield/ yield component	Mean	R-Square	Coeff Var	Root MSE
FWS	4.366667	0.896254	4.240397	0.185164
FWD	5.047619	0.981206	3.404079	0.171825
NLS	727.4286	0.827875	2.502676	18.20518
NLD	775.2857	0.961172	1.975695	15.31728
PHS	44.95238	0.859009	2.952830	1.327368
PHD	53.57143	0.613008	3.359012	1.327368
NFS	83.42619	0.654356	2.899214	2.420153
NFD	79.76190	0.890419	3.248661	2.591194
SGS	4.180952	0.801495	5.928024	0.247848
SGD	4.533333	0.892233	5.071474	0.229907
SDMS	45.71429	0.907895	2.981060	1.362770
SDMD	49.47619	0.967442	2.494992	1.234427

Appendix 14: Least Squares Means of yield and yield components of tomato

T	FWS	FWD	NLS	NLD	PHS	PHD	NFS	NFD	SGS	SGD	SDMS	SDMD
CNT	3.80	3.80	672.00	672.00	51.00	51.00	86.33	86.33	3.80	3.80	42.00	42.00
T1	4.60	5.50	738.00	817.00	43.67	54.67	82.00	80.33	4.43	4.93	48.33	52.00
T2	4.40	4.77	735.00	790.33	43.67	52.33	85.00	78.00	4.13	4.47	46.00	49.00
T3	4.77	6.27	741.62	836.67	45.67	54.00	80.33	74.00	4.63	5.03	48.00	54.33
T4	4.10	4.30	728.67	744.33	44.00	54.00	86.67	88.00	3.87	4.23	43.33	45.67
T5	3.83	4.10	695.00	714.00	42.00	52.00	84.33	82.00	3.63	3.93	41.00	44.33
T6	5.07	6.60	781.67	852.67	44.67	57.00	79.33	69.67	4.77	5.33	51.33	58.67

Appendix 15: Two factor ANOVA for tomato fruit weight with three replicates and six groups

ANOVA – FW

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Irrigation	3.375	2	1.6875	7.0722	0.005414	3.55455715
soilless media	16.34916667	5	3.26983	13.704	1.32E-05	2.77285315
Interaction	1.548333333	10	0.15483	0.6489	0.754847	2.41170204
Within	4.295	18	0.23861			
Total	25.5675	35				

Appendix 16: Two factor ANOVA for number of fruits of tomato with three replicates and six groups

ANOVA – NF

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Irrigation	86.05556	2	43.0278	3.741546	0.043771	3.554557
Soilless Media	615.8889	5	123.178	10.71111	6.77E-05	2.772853
Interaction	88.27778	10	8.82778	0.767633	0.65742	2.411702
Within	207	18	11.5			

Appendix 17: Two factor ANOVA for number of leaves of tomato with three replicates and six groups

ANOVA – NL

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Soilless media	17753.17	2	8876.583	8.5354	0.00247	3.55456
Interaction	47631.25	5	9526.25	9.1601	0.00018	2.77285
Interaction	6970.833	10	697.0833	0.67029	0.73742	2.4117
Within	18719.5	18	1039.972			
Total	91074.75	35				

Appendix 18: Two factor ANOVA for tomato stem girth with three replicates and six groups

ANOVA – SG

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Irrigation	1.223889	2	0.611944	7.270627	0.004848	3.554557
Soilless media	7.251389	5	1.450278	17.23102	2.63E-06	2.772853
Interaction	0.279444	10	0.027944	0.332013	0.960497	2.411702
Within	1.515	18	0.084167			
Total	10.26972	35				

Appendix 19: Two factor ANOVA for plant height of tomato with three replicates and six groups

ANOVA – PH

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Irrigation	621.7222	2	310.8611	16.33723	9E-05	3.554557
Soilless media	54.47222	5	10.89444	0.572555	0.720214	2.772853
Interaction	28.27778	10	2.827778	0.148613	0.998029	2.411702
Within	342.5	18	19.02778			
Total	1046.972	35				

Appendix 20: Two factor ANOVA for stem dry matter of tomato with three replicates and six groups

ANOVA - SDM

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Irrigation	110.0556	2	55.0278	8.502146	0.002514	3.55456
Soilless media	617.1389	5	123.428	19.07039	1.26E-06	2.77285
Interaction	19.27778	10	1.92778	0.297854	0.972471	2.4117
Within	116.5	18	6.47222			
Total	862.9722	35				