THE PRODUCTION OF VEGETABLE CROPS UNDER PROTECTION FOR SMALL-SCALE FARMING SITUATIONS

BY

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M INST AGRAR: PLANT PRODUCTION (AGRONOMY)

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Department: Plant Production and Soil Science
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Abstract

Experiments were conducted with tomato under shade netting and with lettuce in a vertical hydroponic system at the Hatfield Experimental Farm, University of Pretoria.

The objectives of the study were:

1. To evaluate the effect of different types of shade netting on tomato production
2. To develop a vertical hydroponic system for lettuce production which would be suitable for use by small-scale farmers.

In the tomato trial the highest number of fruit per plant (47) was produced under 12% white shade and 40% black shade nets, and the lowest fruit number (35) was produced under 30% black net. The highest yield of 6.2 kg per plant was obtained under the 18% white net while 30% black net produced the lowest yield of 3.9 kg per plant.

The best yield of lettuce grown in plastic tubes with eight vertically arranged plant positions were obtained with a continuous high flow rate of the nutrient solution. However, a simplified manual system where the nutrient solution was delivered by gravity from a small reservoir tank resulted in comparable yields.

Key words: Lettuce, nutrient solution, shade net, tomato, vertical hydroponic system.

CHAPTER 1

INTRODUCTION

A significant problem facing world agriculture is the variation in crop yields from year to year due to variation in environmental stresses like drought, flooding, high wind velocities and high or low temperatures. Damage caused by stresses can also result in physiological disorders in crop plants. Tipburn in lettuce is caused by high temperature (Sherf & Macnab, 1986) among other factors. Catface in tomatoes is caused by poor pollination resulting from low temperatures (Kalloo, 1986). Growing crops under protection can contribute to overcome these problems in order to get high yields of good quality. Protected cultivation involves more sophisticated growing techniques than unprotected cultivation in the field. It implies greater financial cost for the grower in the construction and management of the protective structures. Historically, this began by the production of seedlings in protective hotbeds for setting into the fields when the last threat of frost had passed. In recent decades this concept has been developed to the extent of supplying the optimum aerial and root environment to optimize plant growth. Factors which can be controlled include temperature, radiation, composition of the atmosphere (CO_2 concentration), water supply and plant nutrition.

Protective coverings vary from shade netting and simple film plastics (passive protected cultivation) to structures with glass or rigid sheet plastic and equipped with sophisticated environmental controls (active protected cultivation) (Kozai, 1988). Passive protected cultivation refers to structures where environmental control equipment is absent or simple in order to minimize the initial cost and running costs. The environment is naturally controlled in a passive way by the physical properties of the structural covering materials. Structures are typically designed to make maximum use of climatic resources like solar energy and temperature, and minimizing the use of artificial energy like electricity.

Active protected cultivation refers to systems where the environment is more actively managed. A range of sophisticated systems of environmental control are available, utilizing measures like forced ventilation, evaporative or mechanical cooling, heating by means of warm water circulation or electric heating, carbon dioxide enrichment and artificial lightning. Automated computerized environmental control systems are available. Disadvantages are the cost of such systems, complicated management and the risk of losses when the system malfunctions (Kozai, 1988).

Two local companies, Alnet South Africa and Knittex produce a range of netting materials for agricultural applications. Available shade densities range from 10% to 85% in white, black and green colors. At present little is known about the suitability of the different types of netting for vegetable production.

Apart from controlling the aerial environment, the rooting environment can also be controlled to improve growth of vegetable crops. One way of controlling the root environment is with hydroponic systems, which is the technology of growing plants without soil. Plants are grown in nutrient solution, with or without the use of artificial growing media to provide mechanical support to the plants. In recent years vertical hydroponic systems, where the plants are grown in vertical layers, are receiving more attention. A potential advantage is that much higher yields per unit area of growing space are possible.

The possibility of obtaining high yields and good quality from various high value crops on a relatively small area offers opportunities to small-scale farmers. Adapting protected cultivation and hydroponic production system to suit the requirements of small-scale farmers is essential.

The objectives of the study were:

1. To evaluate the effect of different types of shade netting on tomato production.
2. To develop a vertical hydroponic system for lettuce production which would be suitable for use by small-scale farmers.

CHAPTER 2

LITERATURE REVIEW

2.1 HYDROPONIC VEGETABLE PRODUCTION

2.1.1 Definition

Hydroponics refers to the technology of growing plants in a nutrient solution with or without the use of a substrate (e.g. gravel, sand, vermiculite, rockwool, peatmoss or sawdust) to provide mechanical support to the plants (Jensen & Collins, 1985; Jensen, 1997). Liquid hydroponic systems have no supporting medium for the plant roots, while aggregate hydroponic systems have solid growing media to support the plants. In most cases hydroponic systems are enclosed inside greenhouses or shade nets in order to provide some temperature control, to reduce evaporative water loss, to better control diseases and pests and to protect the crops against the elements of weather such as wind and rain.

A major advantage of hydroponics as compared to growth of plants in soil is the isolation of crops from the soil, which often has problems associated with diseases, salinity or poor structure and drainage. Costly and time consuming soil preparation is unnecessary in hydroponic systems and a rapid turnover of crops is readily achieved as replanting can be done within a day or two after harvesting. The principal disadvantages of hydroponics are the cost of capital and energy inputs relative to conventional open-field production. A high degree of competence in plant science and engineering skills is also required for successful operation of the system. Because of its significantly higher costs, successful application of hydroponic technology is limited to crops of high economic value (Jensen & Collins, 1985).

2.1.2 Closed and open hydroponic systems

All hydroponic systems are categorized with respect to how the nutrient solution is used, as either "closed" where the nutrient solution is recirculated, or "open" where the nutrient solution is not recirculated. A common practice with a closed system is to use nutrient solution for one or two weeks before replacing it. Usually additional fertilizers are added during this period to ensure that sufficient nutrients are available to the plants. The recirculated nutrient solution is continuously changing in nutrient composition due to plant uptake and by the evapotranspiration of water from the solution (Graves, 1985). The successful commercial application of closed hydroponic systems is more dependent on good knowledge of plant needs for water and nutrients than open systems. Nutrients can built up to excessive levels which are toxic to plants or be depleted to extremely low levels if not supplied at concentrations analogous to plant needs.

In an open hydroponic system plants are supplied with fresh nutrient solution through the growing media at each irrigation. The fresh nutrient solution may be pumped from the reservoir tank or may be provided from nutrient concentrates which are diluted through a fertilizer proportioner. Nutrient management problems can be considerably reduced and the potential for nutrient deficiency may also be lessened with the use of an open system (Jensen & Collins, 1985).

2.1.3 Components of a hydroponics system

A typical layout of a hydroponic system is a series of troughs in which the crop is grown, a catchment tank containing the nutrient solution, circulation pumps; a flow pipe delivering the nutrient solution to the upper part of the growing trough and the return pipe collecting the solution for return to the catchment tank (Cooper, 1979).

The catchment tank being the lowest point in the system is typically sited below ground level and is covered to exclude light thus preventing algae growth. Care should be taken to exclude contamination from the adjacent soil which can introduce soil borne diseases into the circulating water. The size of the tank will depend on the size of the system. However, larger tanks are more advantageous particularly in the warmer climates (Cooper, 1979 and Burrage, 1992). The catchment tank is preferably of rigid material such as PVC (polyvinyl chloride), fiberglass or concrete sealed with non-phytotoxic resins.

The circulation system is usually electrically driven with stainless steel or non-phytotoxic plastic impellers capable of withstanding slightly corrosive nutrient solutions. Two pumps are normally provided, should one fail the other is switched on automatically or manually. The pumps may be mounted above the catchment tank or submerged in it (Jensen & Collins, 1985).

Various forms of troughs or gullies made from polyethylene and other rigid structures are available. Aluminium troughs have been used in more automated systems (Cooper, 1979). The size and the shape of the troughs are dictated by labour efficiency rather than biological and engineering constraints (Jensen & Collins, 1985). Vine crops such as tomatoes usually are grown in troughs wide enough for ease in pruning, training and harvesting. A close control should be kept on the materials used throughout the system to ensure they are non-phytotoxic. Polyethylene, rigid PVC and polypropylene appear to have little phytotoxicity, whereas problems have been experienced with flexible PVC and butyl rubber. Copper and galvanized zinc piping should not be used as both elements accumulate in solution, rapidly reaching toxic levels (Burrage, 1992).

2.1.4 Liquid hydroponic systems

Liquid hydroponic systems are by their nature closed systems (Jensen & Collins, 1985). Plant roots are exposed to the nutrient solution without any substrate and the nutrient solution is reused. Liquid hydroponic systems includes the nutrient film technique (NFT) and aeroponics (Root mist technique).

The nutrient film technique was developed during the late 1960s by Dr Allan Cooper at the Glasshouse Crop Research Institute, England (Cooper, 1979). The NFT system appear to be the most rapidly evolving type of hydroponic system today (Jensen & Collins, 1985). In a nutrient film technique system, a thin film of nutrient solution flows through parallel series of sloping gullies or channels which contains the plant roots (Cooper, 1979; Graves, 1983). The nutrient solution is pumped to the higher end of the trough and flow by gravity past the plant roots to the catchment pipes. The solution is monitored for replenishment of salts and water before it is recycled. A practical advantage of this system is that the nutrient solution can be easily heated during winter months to obtain optimum temperature for root growth or be cooled during hot summers in arid regions to avoid bolting and other undesirable plant responses (Cooper, 1979; Jensen & Collins, 1985). However, if the flow of the nutrient solution stops the roots will dry up and become stressed quickly. An additional problem is that the growing channels can get blocked by the roots of vigorous growing plants.

In aeroponics the plants are suspended with the roots enclosed in a spraying box (Scotter & Burger, 1989). The box is sealed so that the plant roots are in darkness to inhibit algae growth. Misting systems are used to spray the roots periodically. The misting system is normally turned on for only a few seconds every two to three minutes which is sufficient to keep the plant roots moist and the nutrient solution aerated (Jensen & Collins, 1985).

2.1.5 Aggregate hydroponic systems

In aggregate hydroponic systems a solid inert growing medium (sand, gravel, rockwool, peatmoss, sawdust, or pine bark) is used to provide support to the plants (Jensen & Collins, 1985; Olympios, 1992; Schwartz, 1995; Hardgrave & Harriman, 1995). As in liquid systems, the nutrient solution is delivered directly to the plant roots Aggregate systems may be closed or open depending on whether the surplus nutrient solution is recovered and re-used. Aggregate hydroponic systems include trough or trench culture and bag culture.

Trough culture systems involve relatively narrow growing beds, either as above grades troughs (supported by stands) or sub grade troughs (constructed on a greenhouse floor). Concrete is usually used as a construction material for permanent trough installation. Fiberglass and PVC-film can also be used (Jensen & Collins, 1985).

Container culture is similar to trough culture except that the growing media is placed in container-like plastic bags which are placed on the greenhouse floor, thus avoiding the cost of constructing troughs or trenches and complex drainage systems. Drip application of the nutrient mixture is recommended and the nutrient solution is not recycled, thus reducing nutrient solution management problems. Large plants growing in high light and high temperature conditions will require up to two liters of nutrient solution per day (Jensen & Collins, 1985). In Europe, where controlled environment agriculture is used more widely, container culture is replacing trough culture because of its ease in operation and in moving of material in and out of the greenhouse (Jensen & Collins, 1985). The containers can be used for at least two years and are much easier and less costly to steam sterilize than troughs.

2.1.6 Nutrient solution

All the nutrient elements required for plant growth have to be present in the circulating water of a hydroponic system. Some of the elements may be present in the water supply such as sodium and chlorine but not necessarily in the right proportions. The nutrient elements will have to be added to the circulating water, namely nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), boron (B), copper (Cu), molybdenum (Mo) and zinc (Zn). These elements must be maintained at appropriate concentrations since too little will result in deficiencies, while excess can lead to toxicity (see Table 2.1).

Table 2.1 Recommended concentration of elements in nutrient solution for NFT cropping (Cooper, 1979)

Element	Symbol	Concentration (ppm)
Nitrogen	N	200
Phosphorus	P	60
Potassium	K	300
Calcium	Ca	170
Magnesium	Mg	50
Iron	Fe	12
Manganese	Mn	2
Boron	B	0.3
Copper	Cu	0.1
Molybdenum	Mo	0.2
Zinc	Zn	0.1

Closed hydroponic systems such as the nutrient film technique are economical in the use of nutrients but require frequent monitoring and adjustment of the nutrient solution. Electrical conductivity is a convenient measure of the total salt concentration, but it provides no indication of the concentration of the major elements and is virtually unaffected by the quantity of trace elements present in the solution (Jensen & Collins, 1985). Thus, periodic chemical analyses are required, usually every 2-3 weeks for major elements and every 3-4 weeks for minor elements (Graves, 1983). It is essential that the relative concentration of nutrients in the nutrient solution approximate crop uptake ratio, otherwise some nutrients accumulate while others are depleted. Additions to the solution may be required to maintain a proper balance of nutrient elements. Nutrient solution pH should be maintained between 5.5 and 6.5 because it is within this range that plants can absorb most of the nutrient elements. This ensures that phosphates remain in the more soluble form and that the iron chelate, Fe EDTA remains associated and is therefore less liable to precipitation (Graves & Hurd, 1983)

As the nutrient solution is not recovered and recycled in open systems, it does not require monitoring and adjustments, once mixed, it is used until depleted. Though the nutrient solution *per se* does not require monitoring in open systems, the growing media may, particularly if the irrigation water is relatively saline or if the hydroponics facility is located in a warm, high sunlight region. To avoid salt accumulation in the growing media, enough irrigation water must be used to allow some drainage from the planting beds. This drainage should be collected and tested periodically for total dissolved salts.

2.1.7 Nutritional disorders

Nutritional disorders in hydroponics do not differ in cause and effect from such disorders in field agriculture. Nutritional disorders are more likely to occur in closed hydroponic systems than in open systems because nutrients may build up to toxic levels or be depleted if not monitored. The most common nutritional disorders in hydroponic systems are caused by too much ammonium and zinc and too little potassium and calcium. High levels of ammonium, which causes various physiological disorders in tomatoes, can be avoided by providing no more than 10% of the required nitrogen in the ammonium form. It is best to completely avoid ammonium in nutrient solutions. Low levels of potassium (less than 100 ppm in the nutrient solution) can affect tomato acidity and reduce the percentage of high quality fruits (Winsor & Masey, 1978). Low levels of calcium induces blossom end rot in tomatoes (Nakuya & Tayeko, 1990; Nukaya, Goto, Jang, Kano & Ohkawa, 1995; Paiva, Sampaio & Martinez 1998) and tipburn on lettuce (Sherf & Macnab, 1986). Zinc toxicity is caused by the dissolution of the elements from the galvanized pipes in the irrigation system and it can be avoided by using plastic or other materials suitable for agriculture. Nutrient related disorders of crop plants can be avoided by maintaining careful control of the composition of the nutrient solution, particularly in closed systems (Graves, 1983).

2.1.8 Disease and insect control in hydroponic systems

One advantage of hydroponic growing systems is the avoidance of soil borne pathogens, especially fungi that cause diseases. The introduction of pathogens and insects pests happens when people are moving in and out of the greenhouse or contamination may be through dust on the uncovered systems (Paulitz, 1997). Innoculum may also be introduced through infected seed or propagation material. Peat has been shown to contain pathogens (Runia, 1994 and Paulitz, 1997). Pest populations can increase at an alarming rate in controlled environment installations because of lack of natural environmental checks. Root diseases in closed hydroponic systems can spread quickly affecting all plants. The use of ultra violet radiation to control bacterial plant pathogens in the nutrient solution is used in the Netherlands (Runia, 1994) and in England (Jensen & Collins, 1985).

2.2 TOMATO PRODUCTION UNDER PROTECTION

Tomato *(Lycopersicon esculentum)* belongs to the Solanaceae family. Tomato is a short-lived perennial grown as an annual crop. Growth can either be determinate or indeterminate. Tomato is a warm season crop but it can be produced in cold climates under protection. The plant requires 3 to 4 months from time of seeding to produce the first ripe fruit (Kalloo, 1986).

2.2.1 Morphology and development

2.2.1.1 The seed

Seed of the genus *Lycopersicon* are oval in shape and flattened. Seed size may vary from 3 to 5 mm in length. The seed consists of the embryo, endosperm and testa. The embryo consists of the radicle, hypocotyl and two cotyledons. The endosperm provides nutrition for the initial growth of the embryo, while the testa or the seed coat encloses the embryo and the endosperm. The characteristics of the seed influence germination performance. More rapid germination has been observed with smaller seed, and this is thought to be due to a reduced endosperm thickness (Whittington, Childs, Hartridge & How, 1965; Mobayen, 1980; Pickens, Steward & Klapwijk, 1986). Age of tomato seed has been shown to be of little importance to germination as long as the seed are stored in an air-tight container. Calvert (1973) reported over 90 % germination with ten-year-old seed.

2.2.1.2 **The root system**

Tomatoes usually have a fairly well defined taproot but there is also abundance of lateral roots of a fibrous nature. The roots system may, however, be modified as a result of cultural operations; e.g. root damage during transplanting can give rise to a greater density of fibrous roots often without a taproot (Calvert, 1973; Maree, 1993). The plant forms adventitious roots on the stem if favourable conditions are provided. A layer of moist peat or compost at the stem base will encourage new roots to form at this point.

2.2.1.3 **The stem**

The young stem is soft, hairy and become hard, woody and copiously branched when mature. It is erect to semi-erect. The plant can be classified into determinate and indeterminate types. With the determinate types, vegetative growth stops with the commencement of the reproductive stage. The plants are erect and bushy with restricted flowering and fruiting periods. In indeterminate types the main stem grows indefinitely. Vegetative growth continues together with reproductive development, and such cultivars are ideal for long season cropping. The stem is typically about 4 cm in diameter at the base and is covered with hairs. At the tip of the main stem is the apical meristem, a region of active cell division where new leaves and flower parts are initiated (Calvert, 1973).

2.2.1.4 **The flower**

Flowers of the *Lycopersicon* species are bright yellow in color. The calyx consists of the sepal leaves and the corolla is made up of five segments. The style is shorter than the pollen tube and the stigma is thus situated below the anthers ensuring that self-pollination can take place easily. Under conditions of poor light (during winter) the style may lengthen and consequently be situated above the anthers. In this situation pollination take place with some difficulty and only about 12% of the flowers are fertilized while up to 60% fertilization may be expected in the case of flowers with the normal short styles (Calvert, 1973; Kalloo, 1986). Under greenhouse conditions pollination can be improved with the aid of bumblebee (Papadopoulos & Khosla, 1995) or by mechanically shaking of the flower trusses.

2.2.2 Environmental responses

2.2.2.1 **Temperature**

Germination, plant growth, flowering, fruit set, photosynthesis and yield are all influenced by temperature. The optimum temperature for germination ranges from 18 °C to 26 °C. Temperatures above 34 °C during the daytime, and above 40 °C for longer than four consecutive hours, causes flower abortion. At low temperatures there is slow or reduced germination. A difference of 5 °C to 8 °C between day and night temperature improves germination, growth and development, flowering and yield (Voican, Lacutus & Tanasescu, 1995). There is a marked influence of temperature on the initiation of flowers. The number of flowers per inflorescence and the total number of flowers per plant are the major determinants of the number of fruit, and thus of yield. Favourable temperature for flower initiation is between 20 °C and 25 °C. Two weeks after cotyledon expansion, when initiation of the first inflorescence takes place, is the most sensitive period. Exposure of seedlings to low temperatures (10 to12 °C) during this period accelerates the formation of flowers. Fruit set in tomato is very much influenced by temperature. The tomato plant has a long flowering and fruiting duration and during this period maintenance of favourable temperatures (21 to 24 °C) is important in order to obtain proper and abundant fruit set. At high temperatures fruit set is impaired. Various experiments have proved that temperatures above 32 °C lead to the reduction in fruit set. Pollen production and viability are reduced at high temperatures (Kalloo, 1986). Inability of the pollen to reach the stigma surface, poor pollen tube growth and blossom drop is associated with high temperatures. During hot dry weather abnormal projection or elongation of the style is a common feature.

2.2.2.2 Light and daylength

Light provides the energy essential for plant growth. The accumulation of plant matter is the result of the process of photosynthesis which takes place only when the electromagnetic radiation within the range of 400 to 700 nm is absorbed by chlorophyll in the leaves. The essential feature of the process is the chemical fixation of the energy by the conversion of CO_2 obtained from the air and water from the soil into carbohydrates such as sugar. Generally, the rate of photosynthesis is related to the intensity of the radiation. In very poor light there may be no accumulation of dry matter because only enough carbohydrates will be synthesized to allow respiration to continue and to keep the plant alive. This light level is known as the compensation point. At a higher level of light intensity plant matter will accumulate and the rate of photosynthesis will also increase until that intensity is reached where photosynthesis no longer increases because other factors, such as CO_2 concentration is limiting. This is known as the saturation point. Another factor is the duration of the light period, also referred to as the daylength or the photoperiod. For many plant species photoperiod affects the onset of flowering. However, tomato is daylength insensitive or photoperiodically day neutral in its flowering habit (Calvert, 1973).

2.2.2.3 **Carbon dioxide**

Carbon dioxide is often a limiting factor for greenhouse tomato production, particularly in winter due to its limited availability in unventilated greenhouses. Increase in tomato yield by CO_2 enrichment is due to a number of effects of elevated CO_2 which occur in both the vegetative and the reproductive stage of the plant growth. The beneficial effects of CO_2 enrichment on plant growth are mainly attributed to increased photosynthetic activity (Slack, 1986). The rate of photosynthesis is directly related to the amount of CO_2 available provided light intensity and water are not limiting. Young tomato plants are more responsive to CO_2 enrichment in the greenhouse than older plants (Wittwer & Honma, 1969), and it is, important that enrichment should be started at an early stage and continued throughout the growing period. According to Morgan (1971) CO_2 enrichment advances the dates of first anthesis and promotes early cropping. Growth rates can be increased by up to 50 %, and flowering and fruiting accelerated by a week or more. Smith (1966) reported a difference of nine days in earliness of anthesis on plants enriched with CO_2 as compared to non-enriched plants.

2.2.3 Cultivation practices

2.2.3.1 Production and treatment of seedlings

Treatment of the seed with fungicides before sowing is essential. Seed can be treated with thiram prior to sowing (Maree, 1993). The seedlings can be grown in seedling trays. For better germination, seedling trays should be provided with shade. Seedlings should be thinned out to reduce competition and to remove weak or diseased plants at the appearance of the first true leaves. Before transplanting, hardening of the seedlings is essential as it helps to establish the plants into the field (Calvert, 1973). Maree (1993) also found that hardening of the seedlings results in bigger seed leaves, thick stem and increased flowers in the first and second trusses. During transplanting care should be taken to avoid damaging the plants, as such damage will allow entry of pathogens into the plant.

2.2.3.2 Planting methods and training systems

According to Resh (1993) tomato seedlings should be transplanted into their permanent positions when they have 3 to 4 true leaves and their roots have penetrated the growing cubes in the seedling trays. Only strong healthy plants should be transplanted. The normal planting arrangement for greenhouse tomatoes is to use a double row system (Van de Voren, Welles & Hayman, 1986; Maree, 1993).

According to Maree (1993) double rows should be spaced 60 cm apart and with a spacing of 40 cm in the rows. The width of the path between the double rows could vary from 1.3 m to 1.6 m. Saglam & Yazgan (1995) found 0.75 m by 0,35 m spacing yielded more fruit per plant and heavier individual fruit mass than spacing at 0.75 m by 0.2 m or 0.75 m by 0.15 m.

Greenhouse tomatoes are trained vertically retaining a single main stem. A popular training system for tomatoes grown in protected structures is by using a string suspended from an overhead wire and tied to the base of the plants (Maree, 1993). All side shoots growing on the main stem should be removed at an early stage. Senesced leaves at the bottom of the plant should be removed for better air circulation around the plant and to limit infestation by fungal rot (*Botrytis*) (Resh, 1993).

2.2.3.3 **Water requirements**

Plant growth and development and quality of the fruit is very much influenced by the soil moisture content. The water requirements depend upon the rate of transpiration which is influenced by atmospheric demand. To maximize crop productivity and optimize water use it is important to irrigate efficiently to meet the evapotranspiration at all times. Unlimited supply of water is not always desirable; in the cultivation of tomatoes it is important to restrict water supply and hence limit excessive vegetative growth. Water restriction reduces the risk of abortion of the fruit trusses and improves quality of the fruit (Cooper & Hurd, 1968). According to Maree (1993) drip irrigation is suitable in the sense that it maximizes the efficiency of water use and the water is applied slowly and uniformly to the soil adjacent to the plant. It economizes watering by reducing water loss through runoff and evaporation.

2.2.3.4 **Nutrition**

When tomatoes are planted in soil, the soil should be tested for pH and electrical conductivity before planting starts. Should the pH be low, it can be improved by applying lime. Tomato requires a pH of 6.0. Should the conductivity be high, for instance 300 mS/cm the soil should be loosened and drenched to remove excess salts before planting. Water to be used for irrigation should be tested to ensure that it has a suitable pH and that there is no excess of unwanted salts. The next step according to Maree (1993) would be to pre- fertilize to ensure that the soil has a pH of 6.0 (KCℓ), a P content of 50 to 80 ppm and 100 to 120 ppm K.

Fertilizer program for greenhouse tomatoes according to Maree (1993):

Week 1-5 **Solution A**

31.1 kg potassium nitrate per ha per week

14.9 kg magnesium sulfate per ha per week

Solution B

16.8 kg calcium nitrate per ha per week

Week 6-9 **Solution A**

62.2 kg potassium nitrate per ha per week

29.8 kg magnesium sulfate per ha per week

Solution B

48.9 kg calcium nitrate per ha per week

Week 10-24 Solution A

93.3 kg potassium nitrate per ha per week

44.7 kg magnesium sulfate per ha per week

Solution B

73.2 kg calcium nitrate per ha per week

Supplementary to this fertilization program, it is recommended that a foliar spray containing macro and the microelements be applied regularly. Tomatoes under protection are mainly grown hydroponically and a wide range of substrates has been successfully used. This ranges from inert material like rockwool, perlite, coconut coir and sand to sawdust, compost and the mixtures of any of these. Various commercial fertilizers for hydroponic culture are available which are balanced with all the nutrient elements that plants require for normal growth. Many Solanaceae crops prefer nitrate (NO_3^-) rather than ammonium (NH_4^+) as a source of nitrogen and NO_3^- is a good source of nitrogen in hydroponic systems (Davis, Loescher, Hommond & Thornton, 1986; Zoronaza, Gonzalec, Carpena & Caselles, 1995)

2.2.3.5 **Pollination**

Under greenhouse conditions pollination problems can arise which will result in inadequate pollination. Low light and low temperatures result in poor pollination. Artificial pollination is often necessary in order to produce fruit of good shape, size and firmness. Poor pollination can result in disorders such as catface (Kalloo, 1986). Pollination is done by a hand held air-blower or an electric vibrator or by mechanically shaking of the flower trusses. Pollination can be improved with the aid of bumblebees (Papadopoulos & Khosla, 1995). Abak, Sani, Paksoy, Kaftanoglu & Yeninar (1995) and Asada & Ono (1997) also found an increase in yield on bumble-bee pollinated plants than where no bees were used. Number of fruit per unit area and the number of seeds per fruit were also increased.

2.2.3.6 **Hydroponic tomatoes**

Hydroponic tomatoes are raised as transplants. About 3 to 4 weeks after germination, when the seedlings have started to produce the second pair of leaves and when they are about 60 to 75 cm in height, they are transplanted on to the hydroponics beds. The spacing should be at least 45 cm in row and between the rows (Harris, 1987). They can be planted on liquid hydroponic systems like the nutrient film technique (Cooper, 1979) or on an aggregate system where solid growing media like gravel, rockwool and sand are used for plant support. Zekki, Gauthier & Gosselin (1996) found that aggregate hydroponic systems performs better than the nutrient film technique. Fresh and dry mass of the aerial plant parts cultivated in nutrient film technique systems were 23 and 35 % lower respectively compared to rockwool cultivated tomatoes. It was also found that prolonged recycling of the nutrient solution in a closed system reduced fresh mass and yield of tomatoes as compared to plants grown on nutrient film technique with regular renewal of the nutrient solution.

2.2.3.7 **Harvesting**

Picking should be done at the correct stage. The correct stage depends on the purpose for which the fruits are to be used. The fruit ripening stages according to Kalloo

(1986) are green, mature green, turning pink, red pink and over-ripe. For supermarkets the fruit should be picked when the bottom tip of the tomatoes have an orange-pink tint. The fruit will turn light red within two to three days. Greenhouse tomatoes are mainly harvested by hand. Soon after picking, the fruit should be cooled rapidly to 13 °C to increase the shelf life of the fruit by reducing the rate of respiration and other physiological processes which influence ripening.

2.2.4 Physiological disorders

In addition to diseases caused by micro-organisms, there are certain disorders which are caused by adverse weather conditions, nutrition disorders or other physiological factors. Control of the disorders is essential for profitable production of tomatoes.

2.2.4.1 Blossom-end rot

Blossom-end rot is the most serious physiological disorder of tomato. It is common in greenhouse and field grown tomatoes. Initially a brown discoloration starts at the blossom-end portion of the fruit. Gradually, a black spot develops which can encompass one half or more of the fruit. In the advanced stage the tissue shrinks and the skin becomes dark-grey to black (Fig.2.1). Secondary infection of soft rot or other microbial diseases may occur. The affected fruit are totally unsuitable for human consumption. This disorder is caused by a localized deficiency of calcium in the fruit (Paiva, Martinez, Casali & Padilha, 1998). It was also found that the incidence of blossom-end rot became higher with increasing NH_4^+-N concentration in the nutrient solution (Nakuya & Tayeko, 1990; Nukaya *et al.*, 1995). This is because NH_4^+ compete with calcium for absorption and calcium uptake decreases with an increase of NH_4^+ in the nutrient solution (Mengel & Kirkby, 1979). Any cultural practice that conserves soil moisture and maintains a fairly uniform moisture supply aid in the control of blossom-end rot. Spraying calcium salts solutions on the fruit and on the leaves is effective in controlling blossom-end rot.

2.2.4.2 **Fruit cracking**

Symptoms of this disorder are cracks on the maturing fruit at any time from a few days before pink color begins to the red ripe stage (Fig 2.1). Fruit of most varieties will crack when there is excessively high temperature and sudden changes in soil moisture supply to plants. When low soil moisture is followed by irrigation, the sudden increase in water content of the cells may create internal pressure enough to crack the fruit. Cracking is also common during the rainy season when rain follows a dry spell. A higher incidence of cracking was found in fruit grown under high relative humidity (Maroto, Bardizi, Lopez, Pascual & Alagarda, 1995). Prevention lies in varietal selection for maximum resistance, avoidance of high fruit temperature and maintenance of uniform soil moisture conditions.

2.2.4.3 **Catface**

This disorder is characterized by a large scar at the blossom-end portion of the fruit. Affected fruit have ridges and blotches and at the blossom-end the fruit is malformed. This disorder is caused by low temperature, which causes faulty pollination and poor fertilization (Kalloo, 1986). According to Naude, Ferreira, Van Den Berg & Bosch, (1992) this disorder is common on the first fruit produced on the plant and also on tomatoes which start to flower under low temperature conditions.

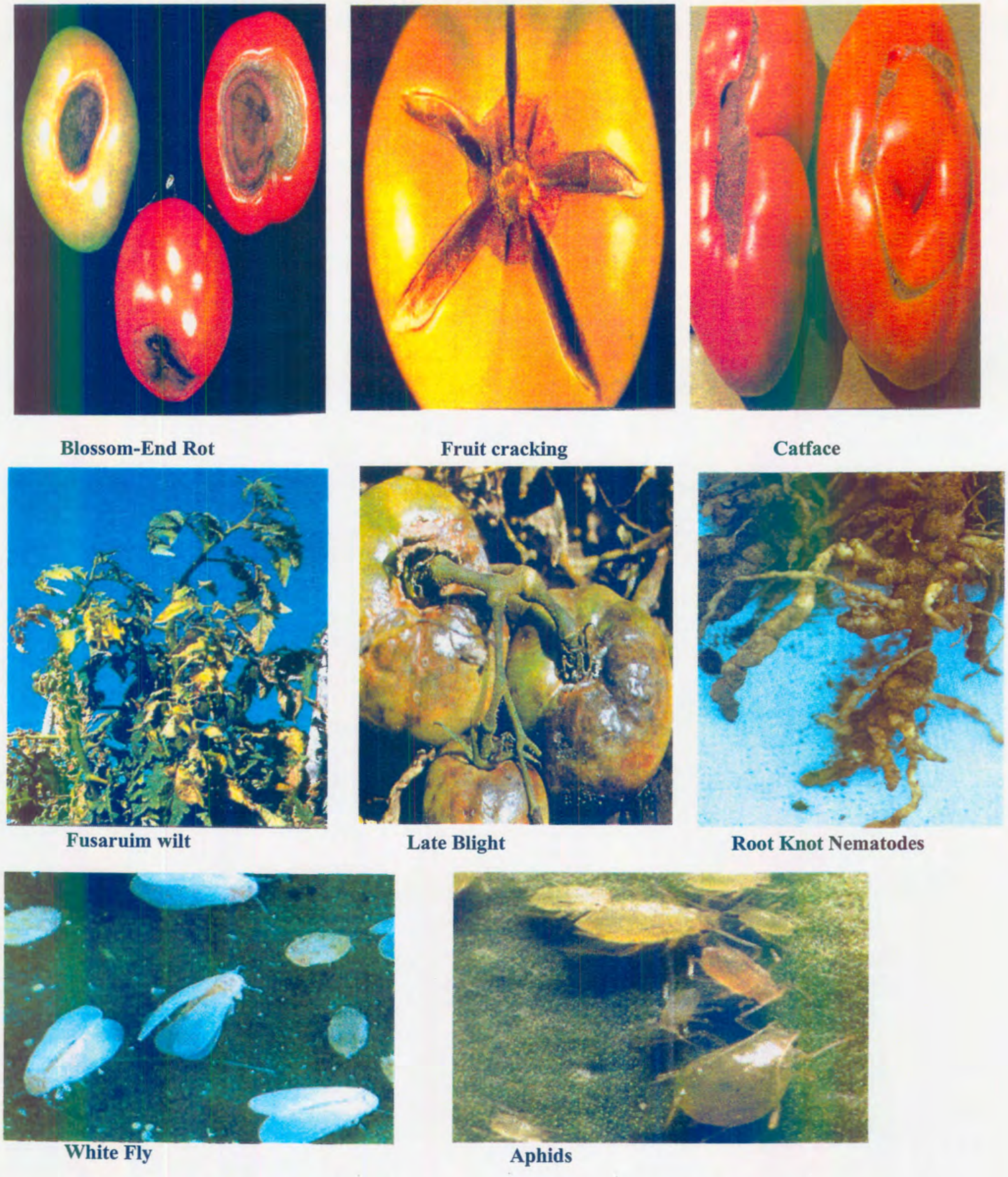


Figure 2.1 Photographs illustrating some important disorders, diseases and pests in tomato production

2.2.5. Diseases

Tomato is attacked by various fungal, bacterial and viral diseases. Almost all parts of the plant are affected by diseases, and on the basis of the part affected the diseases are classified as leaf, stem, fruit, root and post-harvest or storage diseases.

2.2.5.1 Fusarium wilt

This is the most important disease of tomato where intensive cropping is followed. The disease is common in warm humid climates and is a soil borne disease. A fungus, *Fusarium oxysporum F. lycopersici* causes this disease. Fusarium wilt fungus survives in tomato debris or in the soil as tough chlamydospores. It spreads from infected plant material, through irrigation water and also by infected seeds. Symptoms include bright yellowing of older leaflets on the base of the plant and wilting. Wilted leaves turn brown and dry but do not fall off. Control of Fusarium wilt is mainly by using resistant cultivars. Almost all tomato cultivars in South Africa are resistant to Fusarium wilt (Naude, *et al.,* 1992). Crop rotation also helps in controlling this disease.

2.2.5.2 Bacterial wilt

This disease is caused by a bacterium, *Ralstonia solanacearum.* It attacks tomatoes and other related crops such as potatoes, tobacco, peppers and weeds like *Datura*. It also attacks plants that are not related to tomato like groundnuts and bananas. Bacterial wilt can spread from one field to another if contaminated soil is transported by means of implements, vehicles or even on shoes. It can also move across a field through runoff water. The bacteria can survive for many years in the soil. They infect plants through the roots or stem, mainly through small wounds, like those caused by nematodes or transplanting. After infection, the bacteria move to the vascular system of the plant and the pith collapses. According to Naude *et al.*, (1992) two strains of bacterial wilt occur in South Africa, namely Biovar2 and Biovar3. Both strains can attack tomato. Bacterial wilt resistance in South African tomato cultivars is effective only against Biovar3. Symptoms include rapid wilting and death of the plants. There is no chemical registered for control of bacterial wilt.

2.2.5.3 **Late Blight**

Late blight disease is caused by the fungus *Phytophthora infestans*. This is probably the most destructive disease of tomato and potato in the world. It spreads very quickly and can completely defoliate a tomato crop in less than a week after the first symptoms have been seen. The fungus spreads over long distances by means of air borne spores. The disease is favoured by cool nights and misty weather, and spores germinate rapidly at temperatures of 5 °C to 21 °C. Late blight attacks all above ground parts. Affected plants look as if they have been damaged by frost. Irregular, greenish black or brown leaf spots develop, sometimes with a purple margin on the upper surface of the leaf. Lesions enlarge under cool, moist conditions destroying the plant. Fruit symptoms include grey brown lesions which look like bruises which covers the whole fruit (Fig 2.1). Lesions become copper brown with a rough surface. Late blight can be controlled effectively with fungicides like Mancozeb or Methalaxyl if applied correctly (Krause, Nel & Van Zyl, 1996).

2.2.5.4 **Grey mould**

Grey mould is caused by the fungus *Botrytis cinerea.* It is a problem in greenhouse tomatoes and occur where the plant population and humidity are high. Under greenhouse conditions, where light intensities are low and relative humidity reach 95 to 100% during the night, *Botrytis* often affects all parts of the plant (Sherf & Macnab, 1986) The fungus produces spores on dead leaves and stalks which will infect healthy plants Affected plants have light brown or grey lesions on stalks which turn black. The fruit shows irregular grey or pale green spots with pale margins, and grey moulds develop on the margins. Soft rotting may follow. Regulation of greenhouse temperature and relative humidity is the most important and practical control measures. Good control can be achieved by applying benomyl, chlorothalonil or other products listed by Krause *et al.*, (1996).

2.2.6 Tomato pests

2.2.6.1 **Nematodes**

Nematodes are one of the most serious pests of tomato, causing severe yield loss particularly in sandy soil (Sherf & Macnab, 1986). The incidence largely depends on factors like host variety and initial nematode population in the soil and temperature conditions. In vegetable growing areas, *Meloidogyne javanica* and *M incognita* species are the predominant ones. Their host range is very wide, as they attack almost all the plants grown in the world. Infection may start at the seedling stage and can continue throughout the growing season. Stunting and yellowing of leaves take place due to the formation of galls on the roots. A suitable crop rotation and fallowing program can reduce the nematode population. Different chemicals for nematode control are listed by Krause *et al*., (1996). The use of resistant cultivars is the most economic way of controlling nematodes.

2.2.6.2 **Aphids**

Aphids attack the leaves and the stem. There are several species of aphids damaging tomato, among them *Myzus persicae* is the most prevalent one. The damage is caused by direct as well as indirect methods. The nymphs and the adults attack the growing shoots and leaves thereby reducing plant vigour. Aphids spread virus diseases and they also secrete a honeydew like substance which invites fungi to grow. In the case of severe infestation the plants wilt and die. Aphids can be controlled effectively with a number of insecticides (Krause *et al.*, 1996).

2.2.6.3 **White fly** ***(Bemisia tabaci Gennadius)***

White fly is a serious pest of tomatoes. It sucks the sap from the leaves and stem causing yellowing on the affected areas. Both nymphs and the adults are harmful and can transmit viral diseases. White fly is a problem particularly in autumn and mid-summer when temperatures are favourable. A strict spraying programme has to be followed in order to control this pest. Regular spraying with methomyl is recommended (Maree, 1993).

CHAPTER 3

EFFECT OF SHADING ON TOMATO PRODUCTION

3.1 Introduction

Tomatoes are produced throughout the year in South Africa but production is often affected by unfavourable climatic conditions. Tomato fruit produced under unfavourable conditions are small and of poor quality (Sakyma, 1968). Kalloo (1986) and Sakyma (1968) found that a higher incidence of physiological disorders were found in fruit produced under low temperatures and these disorders were reduced when plants were grown under shade. A significant reduction in the percentage of sun scald fruit were found in plants grown under shade net while the highest percentage of puffy and blotchy ripening of tomatoes were observed on plants grown under full sunlight and under high density of shade (63%) during late summer season in Egypt (El-Gizawy, Abdallah, Gomma & Mohammed, 1992). Shade net were also found to improve the total fruit yield of tomato plants, shoot dry mass (Russo, 1993) and characteristics like fruit mass, length and diameter (El-Gizawy *et al.*, 1992). Greenhouse production offers effective environmental control, but structures are expensive to build. An alternative to sophisticated greenhouses may be found in inexpensive shade net structures. Two local companies, Alnet South Africa and Knittex produce a range of netting materials for agricultural application. Available shade intensities range from 10% to 85% in white, black and green colors. Little information is available about the suitability of the different types of netting for vegetable production.

The objective of this investigation was to evaluate the effect of different types of shade netting on tomato production.

3.2 Materials and methods

Treatments and experimental design

The experiment was conducted at the Hatfield Experimental Farm, University of Pretoria from November 1998 to March 1999. Tomato plants cv."Shirley", an indeterminate type, were grown under six different shade nets, namely white 10%, 12%, 18 %, black 30%, 40 % and green 40% shade intensities and in full sunlight as a control treatment (Table 3.1).

The shade net structures had a width of 5m, a length of 10m and a height of 2m. Tomato seedlings were transplanted three weeks after sowing. Transplants were grown in 18L black plastic bags with composted pine mixture as a growing substrate.

Table 3.1 Mean photosynthetic active radiation (PAR) measurements in the six shade net structures (Magwaba, 1999)

Shade level	% PAR transmittance	shading % as measured	shading % according to manufactures
Full sun	100	0	-
10% white net	84.4	15.6	10
12% white net	82.7	17.3	12
18% white net	75.8	24.2	18
30% black net	67.7	32.3	30
40% black net	61.7	38.3	40
40% green net	58.7	41.3	40

Fertilization and irrigation

Nutrients were mixed with irrigation water and were supplied through an open dripper system delivering two liters per hour twice a day. Fertilizer mixtures used were:

- Hydro-gro (1000g per 1000L of water)
- Hortichem calcium nitrate (640g per 1000L of water)
- Hortichem potassium sulfate (150g per 1000 L of water)

The concentration and composition of the three fertilizer mixtures are given in Table 3.2

Tabl(3.2 Composition and chemical concentration of hydroponic fertilizer mixtures [According to the product labels as manufactured by Hortichem Division of Ocean Agriculture (PTY) Ltd *Tel* (011) 662 1947]

Composition	Concentration
Hydro-gro	
Nitrogen (N)	65g/ kg
Phosphorus (P)	45g/ kg
Potassium (K)	240g/ kg
Magnesium (Mg)	30g/ kg
Sulfur (S)	60g/ kg
Iron (Fe)	1680mg/ kg
Manganese (Mn)	400mg/ kg
Boron (B)	500mg/ kg
Zinc (Zn)	200mg/ kg
Copper (Cu)	30mg/ kg
Molybdenum (Mo)	50mg/ kg
Hortichem calcium nitrate	
Calcium (Ca)	15.5g/ kg
Nitrogen (N)	15.5g/ kg
Hortichem potassium sulfate	
Potassium (K)	42g /kg
Sulfur (S)	18g/ kg

Fertilizers were mixed as follows:

- 500L of water was added into a tank with 1000g of Hydro-gro and stirred until the chemical dissolved.
- 250L of water was added into the same tank and 640g of Hortchem calcium nitrate was added.
- 250L of water and 150g of Hortchem potassium sulfate was added in the solution and the solution was stirred until all the chemicals were dissolved.

Cultural practices

The plants were staked with strings tied around the base of the stems. The other end of the string was secured to a wire strung 2m above the growing containers. The plants were trained to single main stems. All developing shoots in the leaf axils were removed at a young stage. Senesced leaves were removed to allow better air circulation around the plants.

Measurements and statistical analysis

The following parameters were determined:

- Number of fruit produced per plant
- Individual fruit mass
- Total mass of fruit produced per plant

The fruit were harvested weekly over a period of nine weeks with the first harvest early in January. The experiment was analyzed as a completely randomized design. All data was analyzed with the aid of SAS (Statistical Analyses System), least significant differences (LSD) were calculated at the 5 % level of significance.

3.3 Results and discussion

The yield data summarized in Table 3.3 shows that the type of shade netting significantly affected tomato yield component. The highest number of fruit per plant (47) was produced under 12% white shade and 40% black shade nets, and the lowest fruit number (35) under the 30% black net. The highest yield of 6.2kg per plant obtained under the 18% white net was significantly better than the yield from the 10% white and 30% black nets. The mean fruit mass obtained from most of the shade net structures was approximately 110g per fruit. However, under the 18% white net the fruit was much larger at 148g per fruit. No explanation can be offered for the poor yield produced under the 30% black shade and 10% white shade nets. Russo (1993) in an experiment with 63% black polypropylene shade fabric and unshaded plants found that shading improved total fruit yield of tomato plants established in June but failed to improve yield of plants established in May and July. El-Gizawy *et al.*, (1992) recorded the highest fruit yield of tomato under 35% shading compared to 51% and 63% shading intensities and unshaded plants during the late summer season in Egypt.

Table 3.3 Effect of shade net on number of fruit per plant, mass of fruit per plant and individual fruit mass

Shade net	Number of fruit per plant	Marketable mass of fruit per plant (kg)	Individual fruit mass (g)
Full sunlight	39.6 ab	5.0 ab	132 ab
10% white net	38.4 ab	4.2 b	108 b
12% white net	47.5 a	5.3 ab	114 b
18% white net	42.3 ab	6.2 a	148 a
30% black net	35.2 b	3.9 b	108 b
40% black net	47.3 a	5.1 ab	112 b
40% green net	46.5 a	5.1 ab	109 b
Mean	42.4	4.9	118
CV (%)	24.4	31.7	25.2
LSD	11.1	1.7	32

Means followed by the same letter in each column do not differ significantly at P=0.05

For this summer grown tomato crop it is obvious that the intensity of shading did not affect yield in a consistent manner. The unprotected full sunlight treatment performed relatively poor, *inter alia* due to a less favorable microclimate resulting in water stress and blossom-end rot. Fruit damage caused by birds was also more severe for this treatment (data not presented). The yield of 5kg per plant does not include damaged and unmarketable fruit. The results indicate that shading could effectively reduce physiological disorders of tomato fruit. This is supported by the work of Cock-shull, Graves & Cave (1992) who noted improved quality on tomato fruit produced under shade as compared to those grown unshaded. Shading was found to reduce sun scald in tomato fruit, however, higher densities of shading (63%) increased the percentage of blotchy ripening in tomato fruits (El-Gizawy *et al.*, 1992).

In Figure 3.1 yield data for the production season is presented. From the third harvest onwards there was a consistent trend of higher yields from the 18% white and lower yields from the 30% black net structures. For the 18% white net, production peaked between harvest weeks 4 and 6, and declined after week 6. For many of the other treatments, notably the 10 and 12% white nets and 30% black net there were a trend of up and downward movement during all harvesting weeks and an increased yields towards the end of the experiment (weeks 7, 8 and 9). The pronounced peak in the yield of all the treatments except 18% white for harvest week 6 may be partly due to warmer temperatures during the preceding period. No explanation can be offered for the remarkable consistence in the weekly yields obtained in the 18% white structure, compared to larger but similar variation in the weekly yield obtained from the other shaded structures.

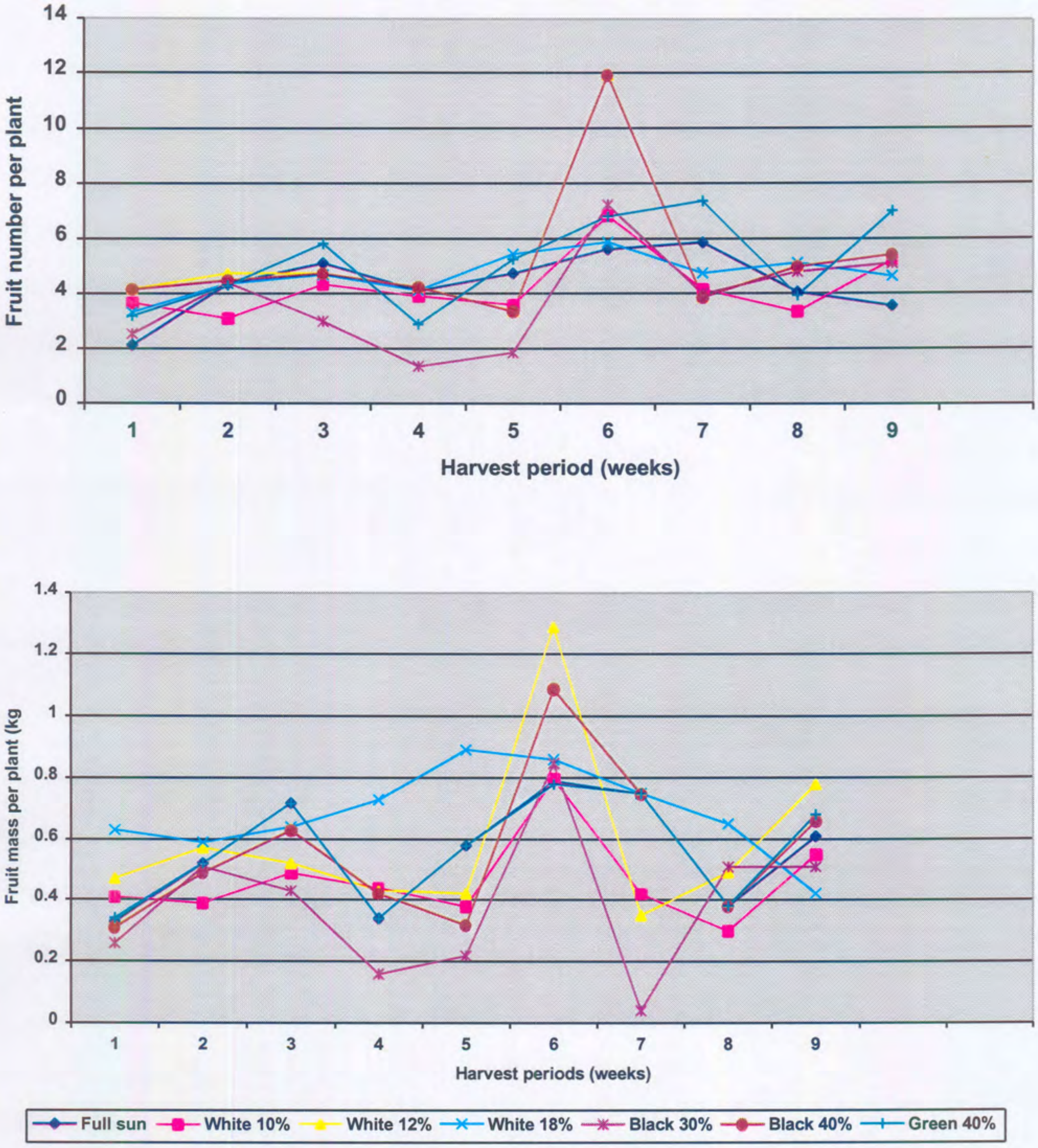


Figure 3.1 Effect of shade net on tomato yield over nine harvest periods

CHAPTER 4

ADAPTING A VERTICAL HYDROPONIC SYSTEM FOR LETTUCE PRODUCTION TO SMALL SCALE FARMING SITUATIONS

4.1 Introduction

4.1.1 Vertical hydroponic systems

Hydroponic culture is gaining importance for the production of protected vegetable crops and ornamental plants and few greenhouse crops are still grown in soil (Olympios, 1992). Due to the high capital cost per square meter of protective environment structures, vertical layer systems may be a viable option, especially for crops with relatively small plants like strawberry and lettuce. A small, inexpensive protective structure with a vertical hydroponic system may be a viable vegetable production enterprise for small-scale growers, provided the technical operation can be simplified. Various vertical systems are possible ranging from horizontal NFT troughs staked above each other to small containers arranged vertically. Relatively inexpensive containers made from PVC plastic tubes divided into a number of pockets are commercially available. Such tubes are typically suspended over a cable or beam, providing up to eight planting positions on both sides (L. Hutton- Personal communication, 1999)*.

* Mr L:s Hutton, Feed The People. www.FTP.org.za

4.1.2 Hydroponic lettuce production

Lettuce (*Lactuca sativa*) belongs to the *Compositae* family. It probably originated in Asia (Yamaguchi, 1983) and it was first used for its medicinal properties and as early as 4500 BC as food. Modern lettuce cultivars are grouped according to plant form and predominant use. Crisp-head lettuce is the most popular in southern Africa. Heads are firm, hard and the texture is brittle and crisp. Head size is usually large, about 150 mm in diameter, and often with a mass of more than 1 kg. Butter-head lettuce is small, soft, more fragile and perishable than the crisp head type. The leaves are thick, loosely folded and buttery in texture. Loose-leaf lettuce form clusters of partially open leaves, and do not form heads. Leaf color varies from light green to red. Cos lettuce has a more upright growth habit with a long head and narrow spatulate leaves. The heads are self-closing with leaves curling inwards at the tips. Leaves appear coarse but are tender and damage easily (Hemy, 1984).

Lettuce grows best at relatively cool temperatures and for this reason it is grown as a winter crop or a cool season crop. It is usually grown in areas in which the average temperatures are between 10°C and 20°C. However, it may be grown throughout the year. Temperatures higher than 21°C promotes seed stalk elongation, puffy heads, bitterness, and an increased tendency towards internal disorders (Yamaguchi, 1983; Kanaan, 1992; Thomson, Langhans, Both & Albright, 1998).

Transplants are raised from fresh, certified lettuce seed. Seed are sown in seedling trays. Typically the seedling trays are filled with growing media like peat. Irrigation is usually supplied three times a day in summer and once a day in winter. Water is applied until it starts to drain from the bottom of the seedling trays. Fertilizers should only be applied through the irrigation water. Hardening is usually done in the last week before transplanting by reducing water and fertilizer applications. Lettuce seedlings are ready for transplanting after four weeks in summer and five to six weeks in winter. Lettuce is planted at a spacing of 25 cm between plants (Harris, 1987). Nitrogen is the most important element in fertilization of lettuce. Nitrogen foliar fertilizer can be applied on the leaves to slow down the filling of the heads and to increase vegetative growth. The form in which nitrogen is applied to the plants is also important. Lettuce plants react better on nitrogen supplied in the form of nitrate (NO_3^-) nitrogen than ammonium (NH_4^+) nitrogen (Sandy, Rozek & Myczkowski, 1995).

Leaf lettuce is harvested as soon as the leaves are large enough for consumption while head lettuce is harvested when the heads become hard but before the seedstalk begin to develop. Harvesting is done in the morning. Lettuce is a highly perishable crop, and it should be cooled immediately after harvest to about 1°C and held at this temperature at high humidity of 95-97 % or it will loose its quality (Yamaguchi, 1983)

Lettuce is less prone to pest and diseases than most of the greenhouse, fungicides and pesticides registered for disease and insect control on lettuce in South Africa is listed by Naude, Van Der Berg & Thomson (1992) and Krause, Nel & Van Zyl, (1996).

The objectives of this study were:

1. To compare different substrates in a vertical hydroponic system.
2. To compare different nutrient solution application methods in order to develop a simplified system applicable to small-scale situations.
3. To monitor changes in pH and electrical conductivity of the nutrient solution as influenced by the different application methods.
4. To determine the effect of plant position on the vertical tube on the yield of lettuce.

4.2 Materials and methods

Trials with hydroponically grown lettuce in a vertical system were carried out in a glasshouse on the Hatfield Experimental Farm, University of Pretoria. In the first trial different substrates were compared while in the second trial different methods of supplying nutrient solution were evaluated. The vertical hydroponic system consisted of non-transparent white plastic tubes with a series of vertical plant holding pockets filled with appropriate substrate and supplied with nutrient solution. The plastic tubes were 1.7 m in length and 300 mm in diameter with sixteen pockets. Suspended over a cable eight pockets spaced 200 mm apart were available on each side. Small drainage openings were made at the bottom of each growing pocket. These openings allowed nutrient solution to drain from one pocket to the next. Excess nutrient solution was collected for recycling in the closed system or drained to waste in the open system. Nutrient solution was delivered into the top pocket by means of a micro drip tube.

Treatments and experimental design

Experiment 1: Effect of growing media

Lettuce seedlings, cv. Great Lakes were transplanted on 25th January 1999 in four different substrates namely, sawdust, sand, coconut coir and composted pine bark. Nutrient solution was delivered into the top pocket by means of a micro drip tube three times a day and the nutrient solution was applied until the bottom pocket started to drain. Excess nutrient solution was not recycled.

Fertilizer mixtures used were:

- Hydro-gro (1000g per 1000L of water)
- Hortichem calcium nitrate (640g per 1000L of water)
- Hortichem potassium sulfate (150g per 1000 L of water)

The concentration and composition of the three fertilizer mixtures are given in Table 4.1

Table 4.1. Composition and chemical concentration of hydroponic fertilizer mixtures [According to the product labels as manufactured by Hortichem Division of Ocean Agriculture (PTY) Ltd *Tel* (011) 662 1947]

Composition	**Concentration**
Hydro-gro	
Nitrogen (N)	65g/ kg
Phosphorus (P)	45g/ kg
Potassium (K)	240g/ kg
Magnesium (Mg)	30g/ kg
Sulfur (S)	60g/ kg
Iron (Fe)	1680mg/ kg
Manganese (Mn)	400mg/ kg
Boron (B)	500mg/ kg
Zinc (Zn)	200mg/ kg
Copper (Cu)	30mg/ kg
Molybdenum (Mo)	50mg/ kg
Hortichem calcium nitrate	
Calcium (Ca)	15.5g/ kg
Nitrogen (N)	15.5g/ kg
Hortichem potassium sulfate	
Potassium (K)	42g /kg
Sulfur (S)	18g/ kg

Fertilizers were mixed as follows:

- 500L of water was added into a tank with 1000g of Hydro-gro and stirred until the chemical dissolved.
- 250L of water was added into the same tank and 640g of Hortchem calcium nitrate was added.
- 250L of water and 150g of Hortchem potassium sulfate was added in the solution and the solution was stirred until all the chemicals were dissolved.

The experiment was terminated on 05th March 1999. Plants were harvested and dried in the oven for 48 hours at 65 °C and dry mass recorded. The Statistical Analysis System (SAS) program was used to analyze the data. Treatment means were compared using the Least Significant Difference (LSD) test at the 5% probability level of significance.

Experiment 2: Effect of nutrient solution application method

Three methods of supplying the nutrient solution were compared.

Treatment 1. Continuous flow by means of an electric pump (control)

The reservoir tank was placed at the bottom of the vertical columns and the surplus nutrient solution drained directly into the reservoir tank. Nutrient solution was continuously pumped from the reservoir tank to the drip tubes in the top pockets. The delivery rate into each top pocket was 4L per hour, obtained from two drippers each delivering 2L per hour.

Treatment 2. Continuous flow by means of a gravitational system

Nutrient solution was delivered by gravity from a tank 1 m above the plants. Nutrient solution draining from the vertical columns was collected and recirculated manually. The nutrient solution was always circulating. The delivery rate per dripper was 1L per hour with one dripper in each pocket.

Treatment 3. Pulse application operated manually

The plants were irrigated once daily for a short period at a high flow rate. The nutrient solution was delivered by gravity from the reservoir tank, which was placed one meter high above the plants. The plants were irrigated until the lowest pocket started to drain. The nutrient solution was also recirculated. The delivery rate was 6L per dripper per hour.

Fertilizer mixtures used were the same as in experiment 1, namely:

- Hydro-gro (1000g per 1000L of water)
- Hortichem calcium nitrate (640g per 1000L of water)
- Hortichem potassium sulfate (150g per 1000 L of water)

The concentration and composition of the three fertilizer mixtures are given in Table 4.1. For each of the three treatments 80L of nutrient solution was in circulation. A pH of 6.6 and an electrical conductivity of 2000mS/cm were recorded at the start of the experiment and the changes in pH and electrical conductivity were monitored every second day starting from the 7^{th} day after transplanting.

Lettuce seedlings cv. Great Lakes were transplanted on 13th July 1999 into the growing pockets of the vertical tubes. Coconut coir was used as growing medium. Each pocket contained 540 g of coconut coir.

Other treatments:

The pH and the electrical conductivity of the nutrient solution, as well as the lettuce yield were monitored separately for each of the growing pockets, resulting in the following treatments:

- Plant position on the tube (i.e. 1st, 2nd until the 8th growing pocket at the bottom).
- Side that the plastic tubes were facing (East and West).

Cultural practice

Foliar fertilizer Horti was applied to all plants every week at a concentration of 5ml per 2 L of water. Aphids were sprayed with methomex SL at a concentration of 11.25 ml per 5L whenever necessary. This production practice resulted in vigorous growth of the lettuce. See Figure 4.1 for photographs of the experimental setup and the good growth obtained.

Measurements and statistical analysis

The following parameters were determined:

1. Fresh and dry mass of lettuce as influenced by
   (a) different methods of nutrient solution application
   (b) Growing position on the tube
   (c) Sides which the tubes were facing
2. Changes in pH of the nutrient solution

(a) Every second day in the reservoir tank starting from the 7th day after transplanting

(b) Directly after harvesting in each growing pocket

3. Changes in electrical conductivity of the nutrient solution

(a) Every second day in the reservoir tank starting from the 7th day after transplanting

(b) Directly after harvesting in each growing pocket

The experiment was terminated on 16th August 1999. All the plants were harvested and dried in the oven for 72 hours at 65 °C . The Statistical Analysis System (SAS) program was used to analyze data. Treatment means were compared using the Least Significant Difference (LSD) test at the 5 %level of significance.

Figure 4.1. Photographs illustraiting the experimental setup and the good growth obtained with the vertical hydroponic system

4.3 Results and discussion

Experiment 1: Effect of growing media

The yield data summarized in Figure 4.2 shows that the different types of substrates significantly affected lettuce yield. The highest yield of about 8g dry mass per lettuce head was observed when coconut coir was used. Sand performed relatively poor with

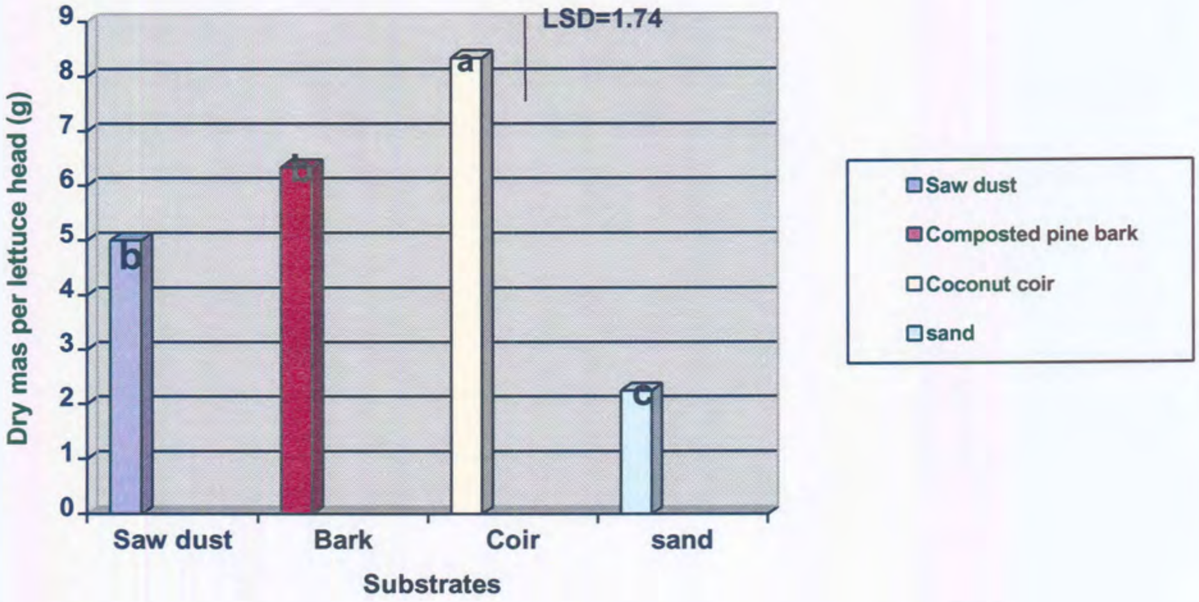


Figure 4.2 Effect of different substrates on yield of lettuce

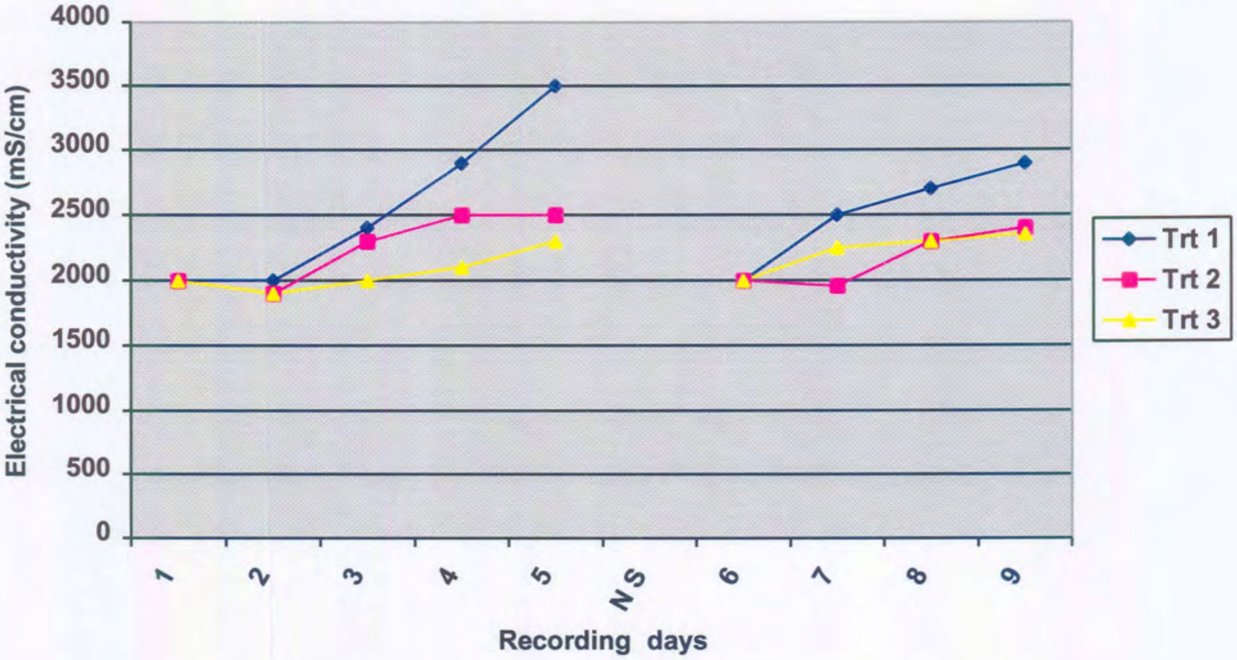
a dry mass of 2.2 g per lettuce head, while the composted pine bark mixture and saw dust treatments did not differ significantly with yields in the range of 5g to 6 g dry mass per lettuce head. No literature comparing the substrates used in this study could be found. However, Raja Harum & Muhammed (1992) obtained good results with coir in their experiment with coconut potting mix called "Cocomix" where it was found that 12 L and 8 L of cocomix per growing bag resulted in higher yields of tomatoes than 6 L and 4L cocomix per bag. Ansermino, Holcroft, Levin, Adams, Hiding, Kipp, Sonneveld & Kreij (1995) found that 100% of composted pine bark

(CPB) potting mixture gave better results in height of petunia transplants as compared to 75 CPB: 25 peat, 50 CPB: 50 peat, 25 CPB: 75 peat and 100% peat treatments. This was ascribed to better aeration of the pine bark substrate compared to the peat mixtures. The poor performance of sand in the present experiment may be due to poor water holding capacity and high bulk density. Based on the good results obtained with coconut coir this substrate was in the follow up experiment.

Experiment 2: Effect of nutrient solution application method

2.1 Electrical conductivity and pH of the nutrient solution

A graphical presentation of changes in electrical conductivity and pH of the nutrient solution as influenced by the different methods of nutrient solution application is given in Figure 4.3. The graph shows that the nutrient solution EC for all the treatments increased as the plants were growing. However, in treatment 1 the EC increased more than in treatment 2 and 3 where there were only a small increases. The pH of the nutrient solution of all the treatments decreased slightly during the first five recording days. The variation in pH values recorded from the second nutrient solution were small and was always in the range acceptable for crops grown in a soilless culture (Cooper, 1979; Siraj-Ali, Peterson & Tayama, 1987). The changes in pH and EC of the nutrient solution is in agreement with the observation of Mengel & Kirkby (1979) who found that pH decreases and EC of the solution increases if plants absorb more water than nutrient elements.



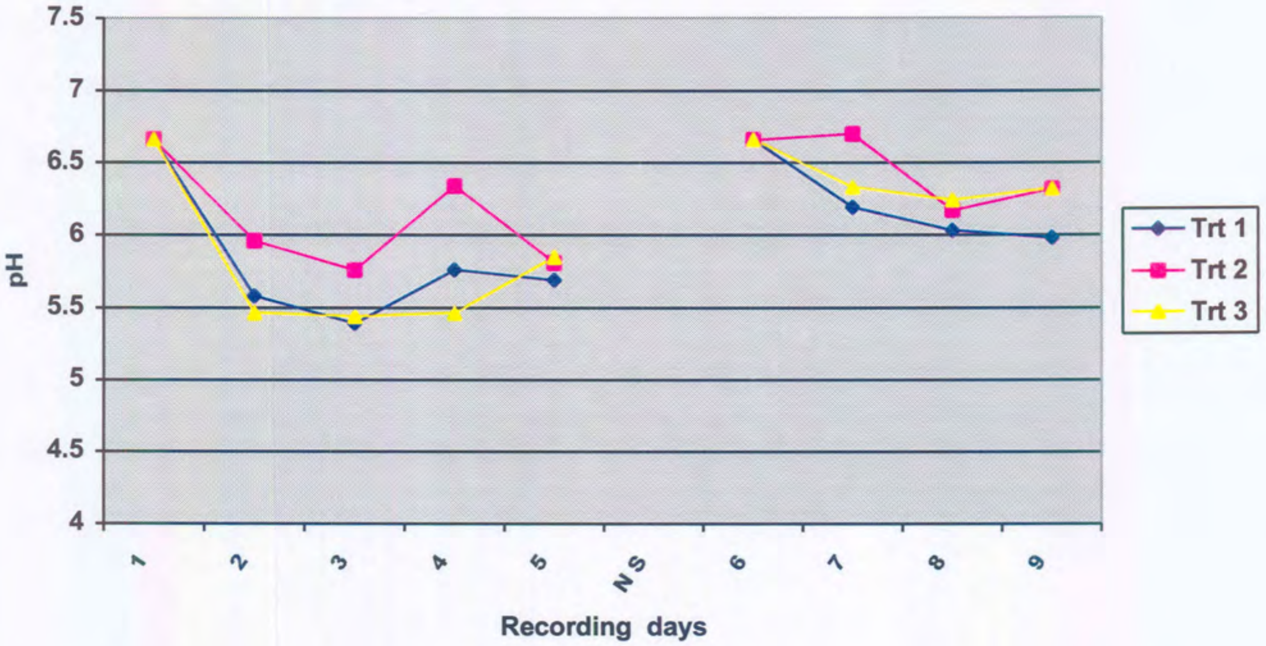


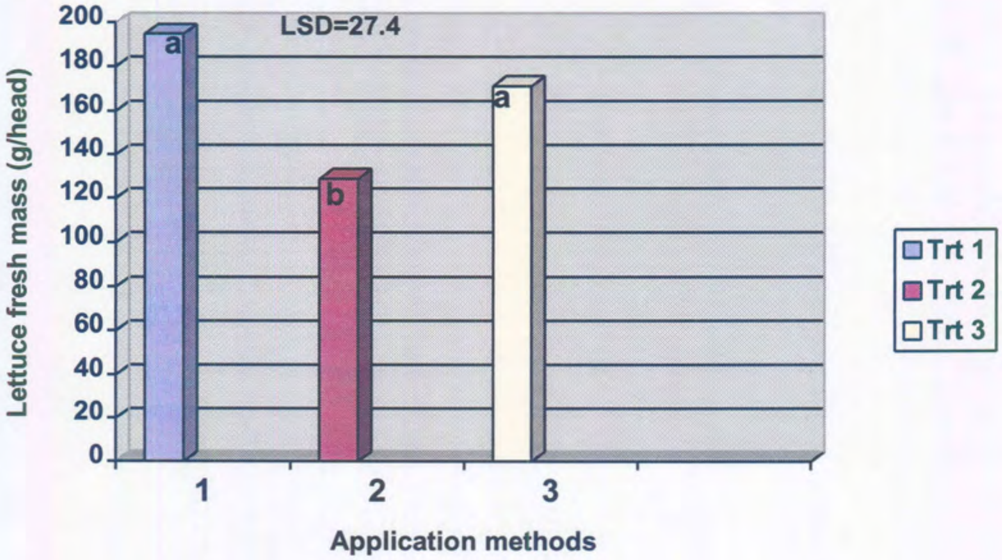
Figure 4.3 Effect of nutrient solution application methods on EC and pH of the nutrient solution

NS on the graph indicates the day on which the nutrient solutions were renewed.

Treatment 1 = Continuos flow - high flow rate
Treatment 2 = Continuos flow - low flow rate
Treatment 3 = Pulse application

2.2 Effect of nutrient solution application methods on yield of lettuce

The yield data summarized in Figure 4.4 shows that the method of nutrient solution application significantly affected lettuce yield. The highest yield of about 194.5g fresh mass per lettuce head was produced when the nutrient solution was applied continuously using a high flow rate (treatment 1), while applying the nutrient solution using a low flow rate (treatment 2) performed relatively poor resulting in a yield of about 129g per lettuce head. Treatment 1 did not differ significantly from treatment 3 (pulse application) but differed significantly from treatment 2. The reason for the poor performance of treatment 2 may be that plants were experiencing periodic moisture stress during the growing period due to the low flow rate. However, this was at no stage visually noticeable.



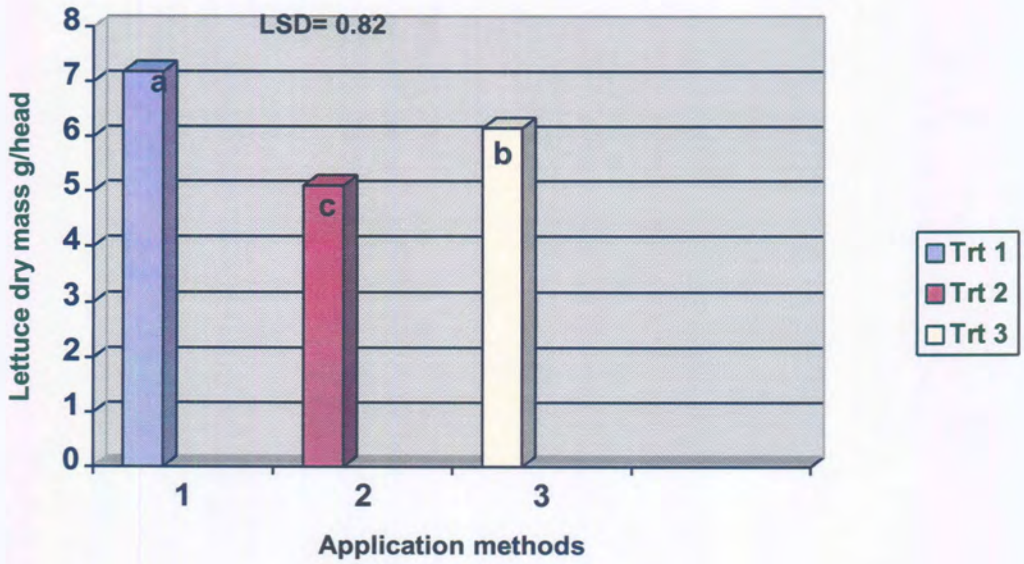


Figure 4.4 Effect of nutrient solution application methods on yield of lettuce

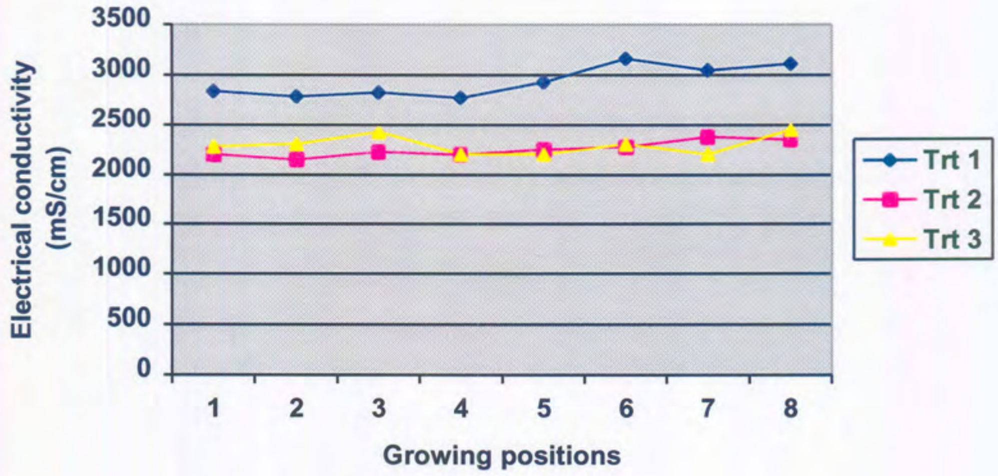
Treatment 1 = Continuous flow - high flow rate
Treatment 2 = Continuous flow - low flow rate
Treatment 3 = Pulse application

2.3 Effect of growing position on yield of lettuce

The total mass (fresh and dry) produced by lettuce plants planted in different positions on the plastic tubes is given in Table 4.2. The top growing pocket performed relatively well with a mean fresh mass of 243.g and dry mass of 9.2g per head. From the second growing position to the bottom (eighth pocket), yield did not differ significantly. The reason for the relatively high yield from the top pockets could be that the plants were exposed to more radiation than the lower, more shaded ones. In the top pockets the nutrient solution was still balanced while with the lower growing pockets it is possible that the nutrient solution become slightly depleted of some nutrient elements. The system of forced ventilation in the glasshouse probably excludes variation in temperature or carbon dioxide concentration as reasons for differences in growth. Figure 4.5 shows the electrical conductivity and pH of the growing media from different growing positions taken after harvesting. All treatments show a slight increase in EC from the top growing pocket to the bottom, however, treatment 1 had the highest EC in all pockets. The pH of the remaining nutrient solutions were very similar for all treatments and pocket positions.

Table 4.2 Effect of growing position on yield of lettuce

Growing position	Fresh mass (g/head)	Dry mass (g/head)
1st pocket (Top)	243.0 a	9.24 a
2nd pocket	183.8 b	6.67 b
3rd pocket	155.2 bc	5.67 bc
4th pocket	167.5 bc	6.19 b
5th pocket	163.6 bc	6.18 b
6th pocket	155.5 bc	5.68 b
7th pocket	140 bc	5.23 bc
8th pocket (Bottom)	111.3c	4.37 c
Mean	165.0	6.16
CV (%)	33.67	27.0
LSD	58.7	1.75



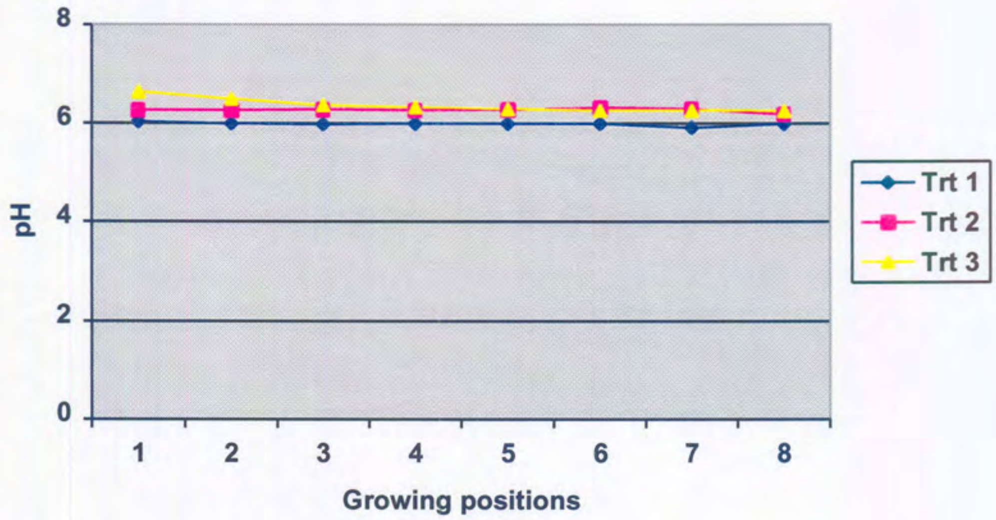
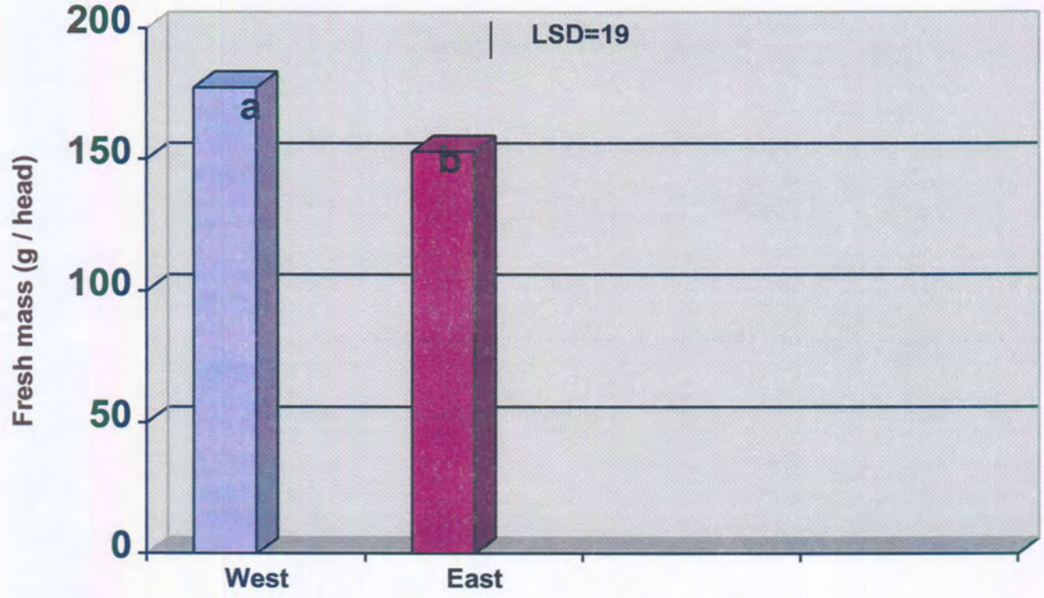


Figure 4.5 EC and pH of the growing media from different growing positions taken after harvesting

Yield of lettuce planted on either the eastern or the western side were recorded separately to see if side has an effect on yield of lettuce. The dry mass shows there is no significant difference, while the fresh mass shows that plants from western side were slightly larger than those from the eastern side (Figure 4.6). No explanation can be offered for this difference in fresh mass.



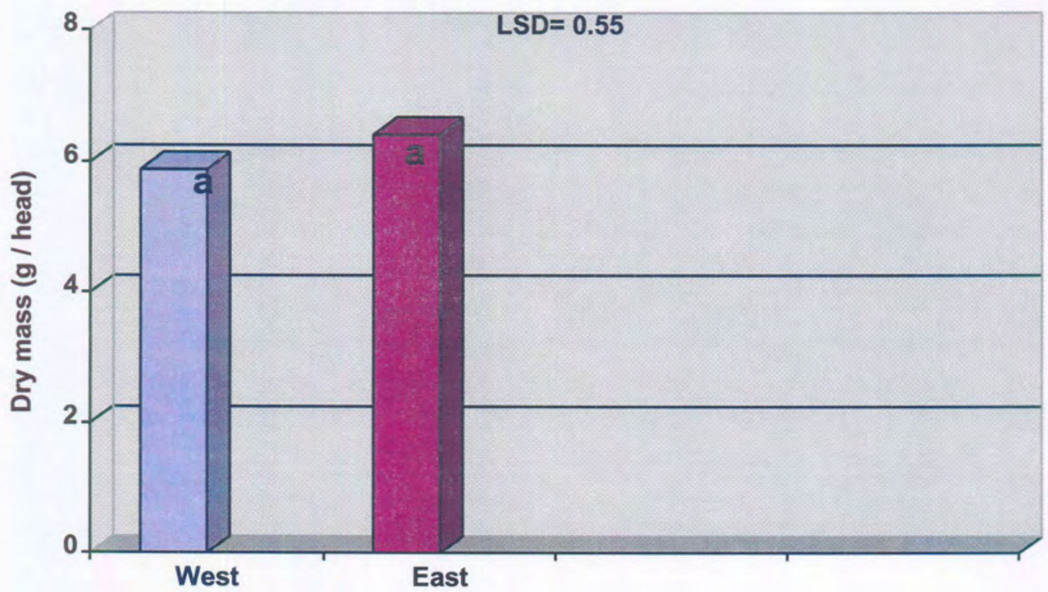


Figure 4.6 Comparison of lettuce yield on eastern and western sides of the vertical containers.

2.4 Interaction effect

The interaction between nutrient solution application method and growing position was significant for dry mass. This interaction is illustrated in Figure 4.7. The graph indicates that for all nutrient solution application methods the top growing position performed better than the other positions. Yield decreased from the top growing position downwards to the last growing position.

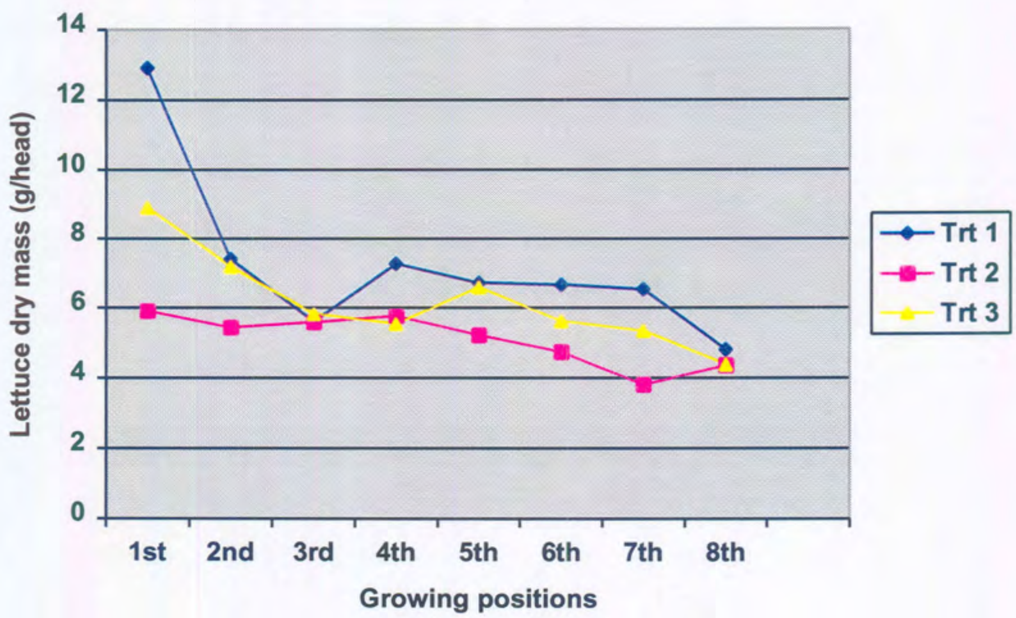


Figure 4.7 Interaction effect between nutrient solution application method and growing position

Treatment 1 = Continuous flow - high flow rate
Treatment 2 = Continuous flow - low flow rate
Treatment 3 = Pulse application

The significant interaction is due to the highly significant negative linear response for continuous flow at a high flow rate (treatment 1) and pulse application method (treatment 3) with the first position performing better than the bottom ones. In case of continuous flow at a low flow rate (treatment 2) the differences in lettuce yield from the top to the bottom growing positions was not significant.

No explanation can be offered for the small but significant interaction between nutrient solution application method and side orientation (east & west) in the dry mass of lettuce (Table 4.3).

Table 4.3 Interaction effect between side orientation and nutrient solution application methods

Side orientation	Nutrient solution application method		
	1	2	3
West	6.41	4.83	6.42 NS
East	7.98	5.40	5.91 *
	NS	NS	NS

1 = Continuous flow - high flow rate
2 = Continuous flow - low flow rate
3 = Pulse application

4.4 Implication of the study to small scale farmers

A general objective of this study was to adapt a vertical hydroponic system to small scale farming situations. Materials used in the experiment were made out of simple structures that are inexpensive and affordable to small-scale farmers.

Small-scale farmers often have limited technologies that they can afford. Typically they have limited or no access to electricity. Evidence suggests that even the least educated farmers when shown superior technologies suited to their farming and social conditions have adopted them (Brady, 1985). One explanation for the poor adoption of technologies is that in many cases no technology is available that is suitable for the farmers' specific needs. Despite this limitation to technology adoption, small-scale farmers will adopt new technology if it is advantageous to do so.

Technologies developed for small-scale farmers should be simple to use while at the same time produce better results. The vertical hydroponic system developed in this study can be an option for small-scale farmers because of its low costs and simplicity. Recycling of the nutrient solution for one to two weeks is feasible. Commercial hydroponic mixtures are available that are easy to use and the instructions are given by the manufactures.

The vertical hydroponic system makes high yields per unit area possible, thus making it even feasible for small-scale farmers to invest in protective structures like shade net. The disadvantage of the vertical system is that it limits the choice of crops to be planted. Only crops with relatively small plants like strawberries and lettuce can be produced successfully.

CHAPTER 5

SUMMARY

Production of vegetable crops under protection is gaining importance worldwide and in South Africa. The aerial environment can be controlled by planting crops in protective structures where temperature, radiation, photoperiod and carbon dioxide concentration can be manipulated to a greater or lesser extent. The rooting environment can be controlled by using the hydroponic systems.

The objectives of the study were:

1. To evaluate the effect of different types of shade netting on tomato production
2. To adapt a vertical hydroponic system for lettuce production to be suitable for use by small-scale farmers.

Tomato plants cv. "Shirley" were grown under six different shade nets, namely 10%, 12% and 18%, white, 30% and 40% black and 40% green shade intensities as well as in full sunlight. Transplants were grown in 18L plastic bags with composted pine bark mixture as a growing substrate. The performance of the tomato plants under different shade netting was monitored over nine harvest dates. Number of fruit per plant, individual fruit mass and total mass of fruit per plant was recorded. The highest number of fruit per plant (47) was produced under 12% white shade and 40% black shade nets, and the lowest fruit number (35) under the 30% black shade net. The highest yield of 6.2 kg per plant was produced under 18% white shade net. The 30% black and 10% white shade nets performed relatively poorly.

An experiment to evaluate the effect of the substrate on lettuce yield grown in a vertical hydroponic system was conducted. Lettuce seedlings cv. "Great Lakes" were transplanted in four different substrates namely saw dust, sand, coconut coir and composted pine bark. The highest yield of 8g dry mass per head was obtained when coconut coir was used. Sand produced the lowest yield of 2.2g per head dry mass. Sawdust and composted pine bark did not differ significantly in yield.

The nutrient solution application methods affected lettuce yield significantly. The highest yield was produced under continuous flow of nutrient solution at a high flow rate. A simplified manual system where the nutrient solution was delivered by gravity from a small reservoir tank resulted in comparable yields.

The procedures adopted in both the shade net study and the vertical hydroponic trial can be used profitably by small-scale farmers to control the growing environment. Shade netting can be used to control the aerial environment while the rooting environment can be controlled by use of the vertical hydroponic system. High yields per unit area of growing space are possible.

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APPENDIX TABLES

Table A1: ANOVA table for fruit mass per plant produced under different shade net structures

Source	DF	Sum of squares	Mean square	F value	Pr >F
Model	48	142.712	2.973	1.18	0.265
Shade	6	55.316	9.219	3.66	0.003
Rep	3	19.362	6.454	2.57	0.0624
Error	63	158.487	2.515		
Total	111	301.200			

R^2 = 0.473

CV = 31.746

Root MSE = 1.586

Mean = 4.99

Table A 2: ANOVA table for individual fruit mass produced under different shade net structures

Source	DF	Sum of squares	Mean square	F value	Pr > F
Model	48	0.068	0.001	1.59	0.042
Shade	6	0.023	0.003	4.30	0.0011
Rep	3	0.0123	0.004	4.56	0.0059
Error	63	0.056	0.0009		
Total	111	0.125			

$R^2 = 0.547$

CV = 25.233

Root MSE = 0.030

Mean = 0.119

Table A 3: ANOVA table for fruit number (marketable) per plant produced under different shade net structures

Source	DF	Sum of squares	Mean squares	F value	Pr > F
Model	48	7031.5	146.489	1.36	0.127
Shade	6	2282	380.354	3.52	0.0046
Rep	3	629	209.67	1.94	0.132
Error	63	6804.06	108.0		
Total	111	13855.5			

R^2 = 0.508

CV = 24.488

Root MSE = 10.392

Mean = 42.43

Table A4: ANOVA table for lettuce dry mass produced on four different growing media

Source	DF	Sum of squares	Mean squares	F value	Pr>F
Model	3	293.22	97.74	11.66	0.001
G. Media	3	293.22	97.74	11.66	0.001
Error	57	477.90	8.38		
Total	60	771.124			

R^2 = 0.380

CV = 51.685

Root MSE = 2.895

Mean = 5.602

Table A5: ANOVA table for fresh mass of lettuce produced on a vertical hydroponic system

Source	DF	Sum of squares	Mean squares	F value	Pr > F
Model	49	5238.251	106.903	3.77	0.0001
Am	2	1068.920	534.460	18.87	0.0001
Side	1	216.335	216.335	7.64	0.0069
Level	7	1825.289	260.755	9.21	0.0001
Rep	2	676.170	338.085	11.94	0.0001
Am*Side	2	138.546	69.27	2.45	0.0922
Am*Gp	14	693.913	9.56	1.75	0.0584
Side*Gp	7	59.45	8.493	0.30	0.9523
Am*Side*Gp	14	559.621	39.972	1.41	0.1733
Error	94	2626.496	28.324		
Total	143	7900.74			

R^2 = 0.663

CV = 32.248

Root MSE = 5.322

Mean = 16.503

Am = Application method

Gp = Growing position

Source	DF	Sum of squares	Mean squares	F value	Pr >F
Model	49	611.109	12.471	3.25	0.0001
Am	2	103.483	51.741	13.47	0.0001
Side	1	10.476	10.476	2.73	0.1020
Gp	7	257.025	36.717	9.56	0.0001
Rep	2	35.377	17.688	4.60	0.0124
Am*side	2	25.921	12.960	3.37	0.0385
Am*Gp	14	112.130	8.009	2.08	0.0194
Side*Gp	7	7.40	1.058	0.28	0.7621
Am*Side*Gp	14	59.289	4.234	1.10	0.3661
Error	94	361.135	3.841	3.23	
Total	143	972.243			

R^2 = 0.628

CV = 31.820

Root MSE = 1.960

Mean = 6.159