GROWTH, YIELD AND QUALITY OF TOMATOES (*LYCOPERSICON ESCULENTUM* MILL.) AND LETTUCE (*LACTUCA SATIVA* L.) AS AFFECTED BY GEL-POLYMER SOIL AMENDMENT AND IRRIGATION MANAGEMENT

M M MABOKO

Growth, yield and quality of tomatoes (*Lycopersicon esculentum* Mill.) and lettuce (*Lactuca sativa* L.) as affected by gel-polymer soil amendment and irrigation management

By

Martin Makgose Maboko

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University of Pretoria
Pretoria

Supervisor: Dr P Soundy
Co-supervisor: Miss D Marais

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DECLARATION

I hereby declare that the work herein submitted as a dissertation for the Masters of Science in Agriculture (Horticulture) degree is the results of my own investigation. Work by other authors that served as sources of information have duly been acknowledged by references to the authors.

MR M M MABOKO
(Student)

DATE

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Abstract

Tomato and lettuce are amongst the most important fresh vegetables used in South Africa. However, growth, yield and quality of tomato and lettuce are constrained by water shortage and poor productivity of sandy soil. In South Africa, large parts of the agricultural land are in a semi-arid region and water is becoming scarcer and more costly. Recognizing the fundamental importance of water-holding amendments like gel-polymers to enhance water use efficiency and soil physical properties, this study was carried out to investigate the effects of pure gel-polymer and fertiliser-fused gel-polymer soil amendments across five irrigation intervals on growth, yield and quality of tomato (*Lycopersicon esculentum* Mill.) and lettuce (*Lactuca sativa* L.).

The response of tomato growth, yield and quality to irrigation interval and gel-polymer soil amendments (pure gel-polymer and fertiliser fused gel-polymer) was conducted in a tunnel. The gel-polymer treatments were: control (sandy soil), two pure gel-polymer levels (8 and 16 $g \cdot 20\ L^{-1}$ sandy soil, equivalent to 400 g and 800 $g \cdot m^{-3}$) and two fertiliser fused gel-polymer levels (20 and 40 $g \cdot 20\ L^{-1}$ sandy soil, equivalent to 1 kg and 2 $kg \cdot m^{-3}$). Irrigation was either applied once daily or every second, third, fourth or fifth day, equivalent to 0.8, 1.25, 1.45, 1.88 and 2.29 L of water per 20 L bag of sand.

Fruit mass, fruit diameter, fruit number, plant height, stem diameter, number of trusses, root fresh and dry mass, total soluble solids, fruit juice pH and titratable acidity were determined. Neither irrigation interval nor gel-polymer amendments had an influence on tomato quality (total soluble solids, pH and titratable acidity). Generally, plant yield, height, stem diameter, number of trusses, and root fresh and dry mass were increased with gel-polymer amendments compared to pure sandy soil. Regardless of irrigation interval, both fertilizer-fused gel-polymer levels appeared to be effective in improving plant growth and yield compared to pure gel-polymer, which gave good results only at the higher level of application. The study revealed that gel-polymer amendments increased productivity of tomato on a sandy soil.

Similarly, the response of lettuce growth, yield and quality to gel-polymers and irrigation intervals was investigated under a tunnel conditions. The gel-polymer treatments were: control, two pure gel-polymer levels (4 and 8 $g \cdot 10\ L^{-1}$ sandy soil, equivalent to 400 g and 800 $g \cdot m^{-3}$) and two fertilizer-fused gel-polymer levels (10 and 20 $g \cdot 20\ L^{-1}$ sandy soil, equivalent to 1 kg and 2 $kg \cdot m^{-3}$). Irrigation was either applied daily or every second, third, fourth or fifth day, equivalent to 0.63, 0.83, 1.04, 1.25 and 1.46 L per 10 L plastic bags.

Measurements were made of fresh head mass, head height, head circumference, head diameter, stem diameter, fresh root mass, dry root mass and dry head mass. The dried head samples were analysed for percentage tissue calcium and nitrogen. Lettuce grown on sandy soil amended with higher level of pure gel-polymer (Stock 8) and both fertiliser fused gel-polymer levels (Aqua 10 and 20) resulted in significantly higher fresh and dry head mass, head circumference, head diameter, head height, stem diameter, and fresh and dry root mass as compared to low level of pure gel-polymer (Stock 4) and sandy soil without gel-polymer (control). All irrigation intervals did not have an effect on growth, yield and quality of lettuce except at irrigation interval of every third day, which significantly lowered head circumference. Gel-polymer did not have a significant effect on percentage calcium and nitrogen concentration in the leaf tissue. Growing lettuce in soil amended with higher pure gel-polymer (Stock 8) level and both fertiliser-fused gel-polymer (Aqua 20 and Aqua 40) would likely be economically advantageous for a grower due to improved growth and higher yield of good quality lettuce.

Keywords: Gel-polymer, irrigation interval, growth, yield, quality, sandy soil, soil amendments, tomato, lettuce

GENERAL INTRODUCTION

Tomato and lettuce are amongst the most important fresh vegetables used in South Africa. They play a particularly important role in human nutrition in supplying essential minerals, vitamins, and dietary fiber (Salunkhe, Bolin & Reddy, 1991; Salunkhe & Kadam, 1995; Niederwieser, 2001). However, the yield and quality of lettuce and tomato is limited by shortage of water with severe economic consequences (Sutton & Merit, 1993; Sen & Sevgican, 1999). It is well known that there is a good correlation between adequate water supply, high yields and good quality in crop production (Sefara, 1994; Byari & Al-Sayed, 1999). Therefore, proper water management is vital for sustainable crop production.

Large parts of the land in South Africa are semi-arid, and water used for agricultural purposes has become more scarce and expensive. As a result, the need for efficient water use in agricultural production has become a major concern so as to reduce cost of water and energy. Water use efficiency can be increased by growing crops in soils enhanced with water-holding amendments like gel-polymers (Johnson & Leah, 1990). These gel-polymers are becoming more and more important in regions where water availability is insufficient. A gel-polymer can absorb water hundred folds its own weight. When a gel-polymer is applied to poor agricultural soil, it can absorb and retain water and dissolved nutrients and release it when required by the plant (Johnson & Leah, 1990). Bouranis, Theodoropoulus & Drossopoulus (1995) reported that there are hundreds of gel-polymers, which, however, differ in their effectiveness in the plant/soil environment.

Previous research has shown that synthetic polymers are useful when added to low nutrient-holding and water-retaining growing media. Low water holding capacity in sand causes rapid infiltration and deep percolation beyond the root zone (Silberbush, Adar & De-Malach, 1993). Therefore, the uses of gel-forming polymers have been tested for some years to increase the water-holding capacity of sandy soils. Gel-polymers are efficient water absorbers, preventing short-term wilting of plants. They retain large amounts of plant available water (Volkmar & Chang, 1995) and have been promoted for use as soil amendments in drought prone regions to aid plant establishment and growth (Johnson, 1984; Baxter & Waters, 1986, Woodhouse & Johnson, 1991). Al-Omran, Falatah & Al-Harbi (2002) observed gel-polymers to improve soil physical properties.

In summary, researchers have widely used gel-polymers as additives to potting media to increase water use efficiency and improve water-holding capacity (Johnson & Leah, 1990; Blodgett, Beattie, White & Elliot, 1993; Hüttermann, Zommorodi & Reise, 1999), reduce irrigation requirements and water consumption (Flannery & Buscher, 1982; Taylor & Halfacre, 1986), increase germination and establishment (Woodhouse & Johnson, 1991), increase seedling survival (Orzolek, 1993), lengthen the shelf-life of pot plants (Gehring & Lewis, 1980), and improve nutrient recovery from applied fertilizers (Smith & Harrison, 1991). In contrast, other studies have shown that gel-polymers did not have an influence on plant growth (Wang & Boogher, 1987; Austin & Bondari, 1992) or irrigation frequency (Keever, Cobb, Stephenson & Foster, 1989; Tripepi, George, Dumroese & Wenny, 1991).

In the present study, two new gel-polymers, Aqua-Soil™ and Stockosorb were used and tested in a sandy soil. A major concern in agricultural productivity is the poor results from sandy soils. Poor water-holding capacity of sandy soils requires frequent watering and limits the use of water by the plant. This is due to the fact that water moving into the subsoil and drains away along with plant nutrients (fertilizers) from the upper layer of the soil. In addition, the high evapotranspiration rate experienced in the South African environment exacerbates the dryness of the growing medium.

With thorough mixing of the gel-polymers with the growth media, water retention can be improved (Woodhouse & Johnson, 1991). This will be accomplished by making use of Stockosorb, a 100% pure gel-polymer without any fertiliser fused to it. On the other hand Aqua-Soil™ comprises of a 40% gel-polymer mechanically fused with 5:1:3 (10) fertiliser, which will act as an effective slow-release fertiliser in addition to the water retention capabilities. According to the manufacturer (Aqua-Soil™ company) the fused N: P: K becomes readily available for plant uptake when it breaks down, and this result in plants benefiting from water and nutrients retained by the gel-polymer. It is also claimed that when Aqua-Soil™ is added to the soil, basal application of N: P: K is not required since transplants will benefit from the fused fertilizer.

Despite published results (Johnson & Leah, 1990; Blodgett *et al*., 1993; Hüttermann *et al.*, 1999), it is not yet clear whether gel-polymers have a beneficial effect on vegetable production under limited water supply. It has been reported by some researchers that gel-polymers are not beneficial to plant growth and survival (Tripepi *et al*., 1991; Bres & Weston, 1993; Bearce & McCollum, 1997) whereas other researchers found it to be detrimental to the plants (Austin & Bondari, 1992). Therefore, it is essential when introducing new soil conditioners like Aqua-Soil^{TM} and Stockosorb gel-polymers for efficient water and nutrient plant uptake and enhanced drought resistance, to test for plant productivity and quality in a drought prone environment.

The purpose of this study was, therefore to determine:

- Growth, yield and quality of lettuce and tomato grown on sandy soil incorporated with gel-polymers (Aqua-Soil^{TM} and Stockosorb polymers)
- Suitable irrigation intervals for lettuce and tomato grown on sandy soil amended with gel-polymers
- N, P and K retention of a sandy soil amended with gel-polymers
- The N and Ca uptake of lettuce on gel-polymer amended sandy soil

CHAPTER 1

LITERATURE REVIEW

1.1 TOMATO

Tomato is one of the most popular and widely grown vegetable crops in the world. It belongs to the genus *Lycopersicon*, which is grown for its edible fruit (Jones, 1999). Tomato is one of the three most important horticultural crops (Dorais, Papadopoulos & Gosselin, 2001), and appears to have originated from tropical America, probably in Mexico and Peru (Gould, 1992). It is widely used as a salad or as cooked or processed food.

A number of studies (e.g. Obreza, Pitts, McGovern & Spreen, 1996; Ho, 1999) indicated that water has an influence on fruit quality, e.g. %Brix, physiological disorders (fruit cracking and blossom-end rot), plant growth and yield. The soil water supply and demand by a crop have been reported to be factors that influence quality and quantity of tomato yield (May & Gonzales, 1994; Obreza *et al*., 1996; Sen & Sevgican, 1999).

1.1.1 Effect of water supply on plant growth, fruit quality and yield

Several researchers have reported that frequency of irrigation and quantity of nutrient solution provided to the plants affect yield and fruit quality (May & Gonzales, 1994; Peet & Willits, 1995; Singandhupe, Rao, Patil & Brahmanand, 2002). Increasing the rate of irrigation of greenhouse tomato plants, according to Tüzel, Ul, Tüzel, Cockshull & Gul, (1993) can lead to a reduction in soluble sugars and dry matter of the fruit. However, this can be explained by higher water content in the fruits which results in the reduction of soluble sugars, organic acids, vitamins, minerals and volatile compounds (McAvoy, 1995; Peet & Willits, 1995).

Deficit irrigation could, however, cause substantial economic loss through decreased crop marketability. Shinohara, Akiba, Maruo & Ito (1995) reported that water stress inhibits photosynthesis and translocation of photosynthates to vegetative organs that may result in decreased plant growth and yield. Other investigators found translocation of photosynthate into the fruit to be promoted by water stress with reduction in plant yield (Shinohara *et al.*, 1995). In supporting the view to water stress, they confirmed that the water content of the fruit decreases and the concentration of fruit constituents increases due to concentration effects. Pulupol, Behboudian & Fisher (1996) found that reduced water content, resulting in an increase in soluble solid concentration, is desirable in processing tomatoes where paste production is the objective.

In a study with irrigation, Yrisarry, Losada & Del Rincón (1993) concluded that over-and under-irrigation in processing tomato production could lead to low soluble solid contents with high crop yield or poor crop yield but high soluble solid contents, respectively. It is widely known that higher sugar content in processing tomato is usually associated with deficit irrigation. In one study, Tüzel *et al.* (1993) agreed that increasing the rate of irrigation of greenhouse tomato plants could result in reduction in soluble solids and dry matter. Sefara (1994) found improved fruit quality when irrigation intervals were increased rather than by late season irrigation cut-offs. A study conducted by Mitchell, Shennan, Grattan & May (1991) reported that irrigation cutoff at 50 days before harvest resulted in an increase in total soluble solids concentration without reducing marketable yield. Recently, Zegbe-Domínguez, Behboudian, Lang & Clothier (2003) found deficit irrigation and partial root zone drying to have a positive effect in increasing total soluble solid contents of processing tomato fruits. Most importantly, processors nowadays have begun to establish pricing according to soluble solid contents (%Brix), as the higher the %Brix the lower the processing costs (Yrisarry *et al.*, 1993). This has brought a challenge to growers as their focus was only based on producing higher yield without taking into account the importance of soluble solids (%Brix). Numerous studies were conducted on irrigation water management strategies in order to achieve higher yield and quality combination (Yrisarry *et al.*, 1993; May & Gonzales, 1994; Obreza *et al.*, 1996; Byari & Al-Sayed, 1999; Sen & Sevgican, 1999; Renquist & Reid, 2001). Through the studies conducted, it is well understood that irrigation management is an imperative tool for economic returns in processing tomato production.

Yrisarry *et al.* (1993) mentioned that the failure of a crop to reach its water demand will result in reduced plant size and reduced total crop yield. Number of clusters/plant, number of flowers/plant, number of fruit set/plant and yield was negatively affected by water deficit (Byari & Al-Sayed, 1999). Others indicated that excessive irrigation delays maturity and harvesting, encourages vine growth, and reduces the soluble solid content of tomato (Hagan *et al*., 1967 as cited by Ramalan & Nwokeocha, 2000). In addition, excess irrigation can also produce epinasty, reduction of stem elongation, premature senescence of leaves, high concentration in abscisic acid, and poor root health (Basiouny, Basiouny & Maloney, 1994), which indirectly influences fruit quality. Researches have frequently found tomato growth and yield to be reduced by deficit irrigation. Pulupol *et al*. (1996) confirmed reduced plant growth and fruit yield, size and count. Other investigators (Renquist & Reid, 2001; Zegbe-Domínguez *et al*., 2003) noted that increasing the water supply increased fruit yield, but fruit quality (soluble solids) was negatively affected.

Inconsistencies in water application have been reported to increase physiological disorders such as blossom end rot (BER) (Saure, 2001) and fruit cracking (Peet & Willits, 1995). Fruit cracking and BER are among the soil moisture related physiological disorders that cause quality and yield losses in tomato production.

1.1.2 Tomato fruit cracking

1.1.2.1 Description

The quality of fresh tomato fruit for consumption is determined by appearance e.g. free from physiological disorders. All fruits and vegetables have limited marketable life due to physiological disorders (Moy, 1989). However, fruit cracking is reported to be one of the most widespread physical defects of softer fruits that limit the production and delivery of sound, blemish-free tomato fruit (Peet & Willits, 1995; Opara, Studman & Banks, 1997; Dorais, Demers, Papadopoulos & Van Ieperen, 2004). In America, for instance, tomato yield loss due to fruit cracking reaches up to 35% in some areas (Dorais *et al*., 2001).

A number of reports have addressed consequences of fruit cracking: (1) it reduces the attractiveness (Peet & Willits, 1995), (2) leads to a reduced shelf life (Opara *et al*., 1997), (3) increases susceptibility to insects, diseases and decay organisms (Ceponis, Cappellini & Lightner, 1987; Peet, 1992; Peet & Willits, 1995) and (4) leads to economic losses (Peet, 1992; Peet & Willits, 1995; Lichter, Dvir, Fallik, Cohen, Golan, Shemer & Sagi, 2002).

There are two types of cracking i.e. concentric rings encircling the stem end of the fruit or radial cracks which is a splitting of the epidermis starting at the stem end and extending sometimes to the blossom end (Jones, 1999). Fig. 1.1 shows the cracks radiating from the stem scar (radial cracking) and in circles around the stem scar (concentric cracking) of tomato fruit (Zitter & Reiners, 2004).

The reason for the occurrence of physiological disorders such as fruit cracking is not well understood. However, researchers suggested the involvement of a number of environmental factors, cultural practices, and anatomical factors that result in a high incidence of fruit cracking. The interaction with environmental conditions makes the prediction of the occurrence of fruit cracking difficult (Cheryld, Emmons & Scott, 1997).

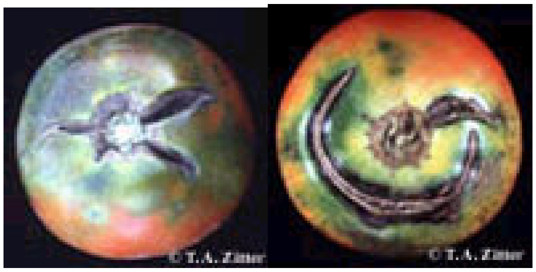

Fig. 1.1 Tomato fruit with radial (left) and concentric cracking (right) (Zitter & Reiners, 2004)

1.1.2.2 Causes

Fruit cracking is a problem that can lead to serious economic losses. According to Peet (1992) and Jones (1999), fruit cracking is caused by several factors, mainly associated with the water balance of the fruit. Recently, Dorais *et al*. (2001) indicated that fruit cracking is generally associated with the rapid movement of water and sugars towards the fruit when cuticle elasticity and resistance are weak. Hence, fruit cracking has been reported to be the result of physical failure of the fruit skin and which is believed to result from the stresses acting on the skin (Milad & Shackel, 1992).

Bakker (1988) stressed that fruit cracking occurs mostly six to seven weeks after fruit set. Following observations by Jones (1999), it was found that during the ripening stage, the fruit may crack, particularly during warm wet periods, if there has been a preceding dry spell. At harvesting, cracked fruit do ripen more rapidly than uncracked fruit (Peet & Willits, 1995).

In summary, the anatomical characteristics of crack-susceptible cultivars have been clearly noted by Peet (1992) as follows: (1) large fruit size, (2) low skin tensile strength and/or low skin extensibility at the turning to pink stage of ripeness, (3) thin skin, (4) thin pericarp, (5) shallow cutin penetration, (6) few fruit per plant and (7) fruit not shaded by foliage. Several authors (Den Outer & van Veenendaal, 1987; Guichard, Bertin, Leonardi & Gary, 2001) reported that thicker cell walls, however, could reduce the extensibility of the epidermis and increase fruit cracking.

Lack of resistance to cracking among tomato cultivars, has been reported to exacerbate the incidence of fruit cracking (Dorais *et al*., 2001). In contrast, Cheryld *et al*. (1997) concluded that even the most resistant cultivars will have some percentage of severely affected fruit under conditions conducive to the disorder. It has been noted that very few cultivars resistant to radial cracking are currently available for greenhouse production (Peet & Willits, 1995). The following cultural and environmental conditions have been reported to be the cause of fruit cracking:

Leaf and fruit pruning, and plant staking

The cultural practices that lead to high incidence of fruit cracking are pruning of fruit, deleafing and staking. For example, high foliage: fruit ratio due to fruit pruning significantly increased fruit affected by cracking as was found by Ehret, Helmer & Hall (1993). Reducing the number of fruit per plant, results in an increase in fruit size, which, however, favored the incidence of fruit cracking. The increase in fruit size results in more physical stress applied to the epidermis, which leads to susceptible fruit to crack (Considine & Brown, 1981). Peet (1992) explained the cracking as due to rapid inflow of water to the remaining fruit. The availability of higher number of fruits per plant was shown to intensify the competition between fruit for carbohydrates.

Deleafing of tomato plant is a disastrous practice as it leaves the fruits exposed to direct sunlight and higher temperatures. Researchers have noted that under conditions where severe deleafing occurred, it resulted in the exposure of fruit to high solar radiation which in turn favored the incidence of physiological disorders such as fruit cracking and also uneven ripening of fruit (Peet, 1992; Cheryld *et al.*, 1997; Dorais *et al.*, 2001). According to the research of Cheryld *et al.* (1997), 49.1% of exposed fruit were observed to have incidence of fruit cracking while only 19.7% fruit cracked where fruit was protected. The position of the fruits on the plant (Peet & Willits, 1995; Cheryld *et al.*, 1997) and number of fruits per plant (Peet, 1992; Dorais *et al.*, 2001) are important factors as they may induce fruit cracking.

Other studies (Cheryld *et al.*, 1997) have shown that tomato plants grown without staking are more prone to fruit cracking due to exposure of fruits to direct sunlight and higher fruit temperature, according to McAvoy (1995), direct sunlight and higher fruit temperature reduce cuticle resistance and firmness of the fruit. Furthermore, these authors found highly significant differences in cracked fruit of plants without staking than in staked plants (Table 1.1). They also noted that fruits on non-staked plants had nearly four times as much crack incidence as fruit from staked plants.

Table 1.1 Incidence of fruit cracking in staked and non-staked plants for three cultivars (Cheryld *et al.*, 1997)

Cultivar	Staked	Non-staked
Fla. 7181	12.6 b[z]	48.5 a
Suncoast	14.0 b	44.3 a
Fla. 7497	4.5 b	20.3 a
Mean	10.4 b	38.4 a

[z] Means in the same column followed by same letter do not differ significantly from each other

Soil moisture

Erratic soil moisture content is the most conducive condition for tomato fruit cracking. When the availability of soil moisture surrounding the roots is inconsistent, physiological disorders such as fruit cracking could occur. In the greenhouse, more frequent watering was shown to increase the incidence of radial cracking, and there are also a few reports in field tomato crops of increased cracking at higher levels of soil moisture (Peet & Willits, 1995). A high irrigation regime reduces fruit quality due to the tendency of the fruit to crack as was found by Kamimura, Yoshhikawa & Ito (1972). Regardless of fertilizer applied to the plant, other studies have reported that plants receiving high amounts of water were more prone to cracking (Peet & Willits, 1995). Irregular irrigation, especially when dry a soil becomes moist and subsequently dry again, favours the incidence of fruit cracking (Peet, 1992; Pascual, Moronto, Bardisi, López-Galarza, Algarda & Bautista, 1999; Dorais, Demers, Papadopoulos & van Leperen, 2004). Abbott, Peet, Willits, Sanders & Gough (1986) observed the reduction of the incidence of fruit cracking when daily irrigation frequency was changed from 1 to 4 waterings per day, while total daily irrigation quantity remained the same.

It was shown (Kamimura *et al*., 1972) that a sudden increase in the growing media's water content, reduced the elasticity of the tomato cuticle and increased root pressure. Under higher soil moisture conditions, the water-uptake will also be higher which rapidly increased turgor pressure. Cheryld *et al*. (1997) reported that fruit cracking would be the result of cell expansion, placing pressure on the epidermis and cuticle. Furthermore, limited elasticity or weakness in the cuticular layer would then lead to fruit cracking. The skin strength of the tomato fruit is mostly affected by changes in soil moisture. It was reported by Peet (1992) that when the soil moisture content decreased, the skin strength increased. Conversely, it was also mentioned that when the soil moisture content increased, the skin strength decreased. Inadequate watering on fruit cracking has also been reported for field grown tomato (Emmons & Scott, 1997).

Humidity

Fruit cracking is associated with high temperatures followed by low temperatures with low relative humidity (Drews, 1978 as reported by Kalloo, 1986). Recently, Dorais *et al.* (2004) noted that high relative humidity decreases leaf transpiration, which might result in increased fruit water supply and turgor pressure. Under such conditions, a greater physical stress applied to the fruit skin, which will then increase the likelihood of the development of fruit cracking. The use of misting to increase relative humidity during summer increases the incidence of fruit cracking (Leonardi, Guichard & Bertin, 2000). This is due to a better plant water status, lower plant transpiration, and an increase in the water and carbon fluxes entering the fruit (Guichard, 1999 as cited by Dorais *et al.*, 2004).

Temperature and light

The incidence of fruit cracking also increases with temperature. Fruits that are positioned at the upper clusters are more prone to high temperature and direct sunlight than the lower clusters. A significant increase in fruit cracking on the upper clusters has been observed (Peet & Willits, 1995), with the percentage of fruit affected by cracking increasing from 21% (1st cluster) to 38%, 41%, and 45% for clusters 5, 6, and 7, respectively. In addition, temperature and irradiance were the factors that contributed to a greater fruit cracking on the upper clusters. It has been reported that these factors tend to favour the pulp expansion towards the interior of the fruit and, consequently, a weakening of the cuticle (Dorais *et al.*, 2001). In an earlier review, Dorais *et al.* (2001) reported that the fluctuation of temperature, for instance low night temperature, favours a negative pressure in fruit, whereas high day temperature increases both gas and hydrostatic pressure of fruit pulp on the epidermis, resulting in cracking of the fruit. In fact, high temperatures play a role in reducing cuticle resistance and firmness (McAvoy, 1995).

In a literature review, Peet (1992) reported that high light intensity raises temperatures, especially on exposed fruit and it is associated with a high incidence of fruit cracking. Under high light conditions, fruit soluble solids and fruit growth rates are higher; both of these factors are associated with increased cracking (Peet, 1992). Pascual *et al.* (1999) also confirmed that higher temperatures and higher radiation, which coincides with the reproductive period ‘summer’, lead to greater incidence of fruit cracking.

1.1.2.3 Control of fruit cracking

The control of fruit cracking plays a vital role for economic profitable production of a tomato crop. Picking of fruit before the full-ripe stage reduces the incidence of radial cracking. Researchers have found harvesting fruit at the green mature or breaker stage (Peet, 1992; Cheryld *et al*., 1997) to be the easiest way to reduce fruit cracking. In most cases selecting cultivars with resistance to fruit cracking (Cheryld *et al*., 1997; Jones, 1999) has been found to be an important consideration. It is also important to use cultural practices that minimize fruit exposure to high temperature and light. Peet (1992) suggested that close rows and shading would reduce fruit cracking, due to the fact that fruit size, soluble solids, and fruit temperature would be at their minimal. Staking plants has been found to significantly lower the incidence of fruit cracking than allowing plants to grow without staking (Cheryld *et al*., 1997). Proper pruning and leaf removal are considered important to reduce exposure of fruits to sunlight and higher temperatures.

Since soil moisture content plays an important role in the occurrence of fruit cracking, Peet (1992) and Peet & Willits (1995) reported that consistent soil moisture to avoid extreme fluctuations in water supply to the plant would minimize fruit cracking. Furthermore, Peet (1992) suggested that by providing plants with low to medium soil moisture is preferable in the greenhouse. Abbott *et al*. (1986) observed the reduction in the incidence of fruit cracking when daily irrigation frequency was changed from 1 to 4 waterings per day while total daily irrigation quantity remained the same. Peet & Willits (1995) suggested that the amount of water provided to the plants should be based on the amount of water plants are using at a specific time.

1.1.3 Blossom-end rot (BER)

1.1.3.1 Introduction

Blossom-end rot is a physiological disorder of tomato fruits that occurs under both greenhouse and field conditions. Blossom-end rot is a non-infectious disease or disorder in tomato, usually observed in the early developmental stage, when the fruit growth rate is fast (Saure, 2001). This disorder is usually referred to by its acronym BER. Recent work has shown that economic losses attributed to BER vary depending on interactions of several factors such as cultivar, climate, soil moisture, and fertility level (Saure, 2001).

It is well known that calcium is an essential macronutrient, which is thought to play a role in holding cell wall components together in the form of calcium pectate. The cause of BER appears to be the loss of integrity of the cell membranes, resulting in leakage of the cell contents (Simon, 1978 as cited by Adams & Ho, 1995). A number of researchers have reported that BER is a local deficiency of Ca in tomato fruit (Adams & Ho, 1993; Obreza *et al*., 1996; Saure, 2001). However, the cause of calcium deficiency is often brought by environmental and cultural factors, rather than calcium deficiencies in the soil or growth media (Papadopoulos, 1991).

1.1.3.2 Characteristics of BER

The occurrence of BER in tomato fruit has been associated with low levels of Ca and is one of the classical symptoms of Ca deficiency. Blossom-end rot becomes visible first as one or more tiny lesions slightly depressed below the surface at or near the blossom end of the fruit, close to the base of the style (Saure, 2001). Hansen (2002) pointed out that as the spot increases in size, the tissue becomes shrunken and the area becomes flattened or concave and the affected fruit becomes black and leathery in appearance (Fig. 1.2). According to Latin (2002) the symptoms of BER first appear as small, light brown or water-soaked spots at the blossom-end of immature fruit. Lesions generally dry up and can vary in size (Latin, 2002). Secondary damage can then be caused by fungi and bacteria, which commonly invade dead tissue of fruit affected by BER (McLaurin, 1998; Hansen, 2002).

Fig. 1.2 Blossom-end rot. Secondary damage caused by fungi, which have begun to invade the rotted tissue (Hansen, 2002)

Blossom-end rot is most frequently observed on fruit that is 1/2 to 2/3 its mature size (McLaurin, 1998). Adams & Ho (1993) observed lower concentrations of Ca in the distal locular tissue rather than in the distal pericarp with most of the Ca situated in the proximal half of the fruit (Table 1.2). They agreed that earlier symptoms appear at the locular tissue, before it extends into the placenta (internal BER), or to the blossom-end pericarp (external BER).

Table 1.2 Distribution of Ca in a tomato fruit (cv. Counter) (Adams & Ho, 1993)

Fruit Part	Dry weight per fruit (g)	Total dry weight (%)	Ca (%)	Ca in fruit (mg)	Total Ca (%)
Proximal half (complete)	2.11	50.7	0.208	4.38	63.7
Distal pericarp	1.14	27.4	0.138	1.65	24.0
Distal placenta and associated locular contents	0.91	21.9	0.094	0.85	12.4

1.1.3.3 Causes

Low calcium content resulting from inadequate calcium supply in the soil and/or as a result of conditions that reduce calcium translocation into the fruit has been reported to increase the incidence and severity of BER (Grierson & Kader, 1986, Papadopoulos, 1991; Saure, 2001).

According to Jones (1999), when soils are "low" in Ca and tomato plant is under moisture stress, BER is likely to occur in the fruit.

Adams & Ho (1993) found that the basic cause of BER is a lack of co-ordination between the transport of assimilates by the phloem and of calcium by the xylem during the rapid cell enlargement in the distal placenta tissue, i.e. an interaction between the rates of fruit growth and of calcium acquisition at the distal end of the fruit. Whilst changes in the environment have a marked influence on the incidence of BER, genetic susceptibility is a major cause of the disorder.

Failure of sufficient calcium to reach the blossom-end of fruit early in the fruit development stage, causes the cells in the blossom-end to die (Hansen, 2002). However, researchers have noted several reasons for depletion of calcium at the distal end. The incidence of BER, has been found not to be Ca-deficiency but the combination of factors that restrict the movement of Ca into the fruit (Jones, 1999). When cells of tomato fruits rot at the blossom-end, it is due to the depletion of Ca concentration in the blossom-end of the fruit as confirmed by Nonami, Fukuyama, Yamamoto, Yang & Hashimoto (1995). The uneven distribution of Ca within the fruit is caused mainly by poor development of the xylem in the distal tissue (Belda & Ho, 1993). This exacerbates the problem of low deposition rates of calcium pectate and calcium phosphate fractions in the distal part of the locular tissue (Minamide & Ho, 1993). The incidence of BER increases markedly when the concentration of calcium in the fruit falls below 0.08% (on a dry weight basis) whiles above 0.12% the disorder seldom occurs (Grierson & Kader, 1986).

Nonami *et al*. (1995) found differences in susceptibility among cultivars to BER. They concluded that the calcium content in fruit is not directly related to BER. They proposed that this physiological disorder results from the expression of some genes under conditions of stress.

A summary of factors affecting the uptake and distribution of Ca in tomato plants, and the rate of fruit growth are as follows:

Relative humidity

Relatively humidity plays a major role in the distribution of calcium. Large variation in relative humidity is reported to induce calcium deficiency in plants (Papadopoulus, 1991). Humidity plays a role in competition for water between the leaves and fruits, which in turn inhibit the distribution of calcium. Adams & Ho (1993) asserted that daytime low humidity and high temperature increase transpiration, which favours the allocation of Ca to leaves than fruit. In contrast, they reported that high humidity decreases transpiration, thereby decreasing accumulation of calcium in the leaves and increasing the calcium content of fruits. In subsequent studies, Adams & Ho (1995) also found that the %Ca accumulated in the fruit increased with high humidity during the day. Tadesse, Nichols, Hewett & Fisher (2001) reported that higher relative humidity promoted the accumulation of Ca in fruit particularly towards fruit maturity. High humidity at night also increases fruit calcium uptake, but more calcium is absorbed during the day than at night on an absolute basis (Adams & Ho, 1993). The increase in calcium uptake at high night-time relative humidities has been attributed to high root pressure as reported by Banuelos, Offermann & Seim (1985). Constant high (95%) relative humidity in growth chambers, however, reduced calcium concentration and increased BER relative to constant relative humidity of 55% (Banuelos *et al.*, 1985). Authors (Banuelos *et al.*, 1985) felt that maintaining constantly high relative humidity prevented the build-up of night-time and the associated high levels of calcium uptake.

Root environment

An adequate supply of calcium is important to ensure the calcium status in the plant. Ho (1999) found that the root environment plays a major role in calcium uptake by roots. Root environment includes water availability, salinity, NH_4^+, cation imbalance and root temperatures are as discussed below:

Moisture

Moisture supply plays a major part in calcium uptake and distribution within the plant. Since Ca moves in the plant by means of the transpiration stream, a reduction in the movement within the plant reduces the amount of water carrying calcium reaching the developing fruit (Jones, 1999).

Waterlogging can result in unavailability of Ca due to poor water uptake caused by poor soil aeration. Anonymous (2001) stated that fields should be well drained in the wet season. The incidence of BER was severe under deficit irrigation as was found by Obreza *et al.* (1996). BER incidence was five times more severe in the 30% deficit treatment compared with full irrigation (Obreza *et al.*, 1996). However, this can be explained by reduced water uptake, calcium transport and distribution to the fruit.

Salinity

Saline conditions predispose fruit to BER. Salinity decreased both total calcium uptake and calcium content of the fruit (Adams & Ho, 1993). Salinity reduces Ca uptake mainly by restricting water uptake. As the movement of Ca in tomato is virtually confined to the xylem, transport of absorbed Ca to the shoots is subdued by salinity (Ho, 1989; Adams & Ho, 1993). Adams & Ho (1995) observed reduction in water and Ca uptake (15%) when raising salinity to 8 $mS\cdot cm^{-1}$. Thus, high salt contents in the soil appeared to be the cause of reduced Ca uptake, which may lead to high incidence of BER.

Imbalance of cations

Competition from other cations such as K^+, Mg^{++}, Na^+ and NH_4^+ can, to a large of extent, slow down calcium uptake by the plant (Jones, 1999), and therefore, decrease the Ca content in the fruit. Other authors reported that high levels of K and Mg in the nutrient solution may interfere with the absorption of Ca and/or cause high growth rate and the demand for calcium ions raised beyond the uptake rate of calcium (Hodges & Steingger, 1995). Adams (1999) concluded that K and Mg should be maintained at about 400 and 80 $mg\cdot L^{-1}$, respectively, but up to 500 $mg\cdot L^{-1}$ Na has little effect on Ca uptake or BER incidence. On the other hand, Jones (1999) stated that high NH_4-N availability after initial fruit set will results in adverse effects of NH_4-N toxicity, particularly by increasing the incidence of BER.

Root temperature

Low temperature in the root zone can discourage the uptake of Ca (Adams & Ho, 1993). Experimental data obtained by Adams & Ho (1993) indicated that as root temperature increased from 14 to 26°C, the Ca uptake also increased. However, Ho (1999) postulated that extreme root temperatures might increase the severity of BER. In fact extreme root temperature favors high transpiration, ion uptake and plant growth rate which results in more ions accumulating in vegetative parts than the plant's reproductive organs. Thus, good care should be taken to maintain optimum root temperature in order to enhance Ca uptake from the soil solution.

1.1.3.4 Control

First in importance is assuring that the root zone calcium supply is adequate and that concentrations of competing cations are not excessive. Researchers have shown that high levels of K and Mg in the nutrient solution replace Ca. Recently, Adams (1999) reported that K and Mg should be maintained at about 400 and 80 $mg \cdot L^{-1}$, respectively, but up to 500 $mg \cdot L^{-1}$ Na has little effect on Ca uptake or BER incidence.

Ho (1999) proposed that by optimizing growing conditions for fruit growth and Ca uptake and transport of Ca, and regulating fruit expansion, the incidence of BER can be largely reduced.

Among others, Adams & Ho (1995) suggested that humidity in the glasshouse should be controlled to optimize Ca distribution for both, leaves and fruit, in order to obtain good quality fruit. They reported that leaves and fruits respond differently to changes in humidity.

Quite importantly, optimizing the root activity through irrigation frequency to avoid water stress or fluctuations, maintaining good soil aeration, maintaining high/low electrical conductivity, ensuring a balance among cations, and optimizing nitrogen availability; nonetheless, obtaining optimum temperature can enhance the uptake of Ca (Peet, 1992; Adams & Ho, 1995; Hodges & Steingger, 1995; Jones, 1999).

Tomato cultivars have been shown to differ in susceptibility to BER incidence. Ho (1999) indicated that there is a wide range of susceptibility among tomato cultivars producing round fruit which are related to both, plant and fruit growth characteristics. However, Latin (2002) noted that elongated pear- or plum-shaped tomato fruit used for processing and canning are most prone to BER. The susceptibility to BER in tomato is hardly known in cherry tomato, while it is notoriously bad in plum and beefsteak tomato (Ho, 1999). Therefore, Nonami *et al*. (1995) recommended using cultivars that are resistant to BER, as a control measure.

According to Hodges & Steingger (1995) reported that tomato fruits do not have openings in the epidermis (skin) where moisture can be lost or where calcium can enter the fruit from surface application. In contrast, Ho (1999) indicted the preventative way to combat BER in a susceptible cultivar is by spraying the rapidly expanding fruit with 0.5% Ca solution. Therefore, further investigation is required to determine whether direct application of calcium to fruit might be an effective way to prevent or correct BER.

1.2. LETTUCE TIPBURN

1.2.1. Introduction

Tipburn in lettuce was first observed over a 100 years ago, but the reason for its occurrence is still poorly understood. Many contradictions on occurrence of tipburn exist between the conclusions of innumerable experiments and observations (Saure, 1998). Tipburn is generally considered to be a calcium-related disorder, caused by localized calcium deficiency of leaves or leaf margins (Saure, 1998; Cubeta, Cody, Sugg & Crozier, 2000). Tipburn is a serious problem when both temperatures and radiation levels are high, as can be experienced both in glasshouses and field production conditions (Collier & Tibbitts, 1982). The occurrence of tipburn is unpredictable from field to field and from season to season, but it has been reported to be related to weather, variety and soil fertility practices (Cubeta *et al*., 2000). The problem is of concern also under controlled environments where high levels of artificial radiation are utilized to accelerate vegetative growth (Soundy, 1989).

According to Misaghi, Oebker & Hine (1992) tipburn is the most serious abiotic disorder of lettuce (*Lactuca sativa* var. *capitata* L.). Soundy (1989) postulated that abiotic disorders could reduce yields and sometimes kill plants or prevent them from reaching maturity. Tipburn is the most important physiological disorder of head forming vegetable crops such as lettuce and cabbage (Cresswell, 1991; Brumm & Schenk, 1993). It causes necrosis at the margins of young developing leaves in the inner part of vegetable plants around the growing point and is caused by Ca deficiency (Brumm & Schenk, 1993; Saure, 1998) and resulting in substantial economic loss (Goto & Takakura, 1992; Saure, 1998).

Since the vegetative growth of lettuce is vital for fresh marketing, tipburn can cause serious economic loss due to the discolouring and desiccation of inner developing leaves, which may in turn result in a whole crop with no value. Saure (1998) noted that it is not known why the incidence varies substantially from year to year, from location to location, and between different dates, nor what the role of external factors in this variation is. Also, the mechanism(s) responsible for tipburn development and symptom expression are not well understood (Palta, 1996).

1.2.2 Symptomatology

Barta & Tibbitts (2000) found tipburn injury to develop in lettuce on the ninth, tenth or eleventh leaf at 22 days after seeding and continued to develop on all successive developed leaves. Other authors (Kleinhenz, Palta, Gunter & Kelling, 1999) asserted that tipburn begins during various stages of crop development but they indicated that it is mostly common and problematic when appearing soon before reaching marketing maturity.

Different incidences of tipburn have been reported. Brumm & Schenk (1993) characterized tipburn by three symptoms: necrotic plant tissue at the edge of leaves, as well as brown veins resulting in soft tissue and brown dots. Initial symptoms, which first develop on young inner leaves, are small translucent spots close to the leaf margins (Cresswell, 1991). These lesions darken; leaf margin tissues die, and affected tissues provide openings for secondary damage caused by bacterial pathogens (Cresswell, 1991). Tipburn injury is restricted to the leaf apex and distal margin, which is characterised by water, soaked, laminal and veinal chlorosis, and lacticifer rupture (Barta & Tibbitts, 2000). Moreover, darkening of the leaf margins results from laticifer enlargement and rupture, which releases latex into surrounding tissue and causes collapse of parenchyma and occlusions of xylem elements (Collier & Tibbitts, 1982). Investigation by Barta & Tibbitts (2000) found exposed leaves not to exhibit any injury symptoms. Cresswell (1991) summarized three symptoms in lettuce, as glassiness, purple spotting and cupping, and all appeared to be aspects of tipburn injury. In summary, the following developmental sequence was noted (Cresswell, 1991):

(i) Glassiness is the first recognisable stage of tipburn and likely occurs in the mornings under high relative humidity conditions.
(ii) The purple spots present in tissues affected by glassiness soon become desiccated producing the characteristic scorch symptoms of tipburn.
(iii) Cupping is the final stage in the development of tipburn, which occurs because of the margins of young leaves damaged by tipburn fail to expand fully.

Symptoms generally are restricted to leaves inside the heads and, thus, are evident only after removal of several outer leaves. It was found that inner leaves with tipburn contain less calcium than inner leaves without tipburn (Collier & Wurr, 1981 as cited by Collier & Tibbitts, 1982).

Leaves with tipburn are unsightly and damaged leaf margins are weaker and susceptible to decay. In fact, tipburn causes the leaves to deteriorate and can result in diseases, such as soft rot, contaminating both whole and bulk shredded lettuce produce (Anonymous, 2000). Lettuce with tipburn is susceptible to secondary fungal and bacterial infections and its shelf life is reduced (Cresswell, 1991). Anonymous (2003) noted symptoms for lettuce which are dark brown spots near the leaf margin, followed by marginal necrosis of leaves (Fig. 1.3) and inner leaves (Fig. 1.4).

Fig. 1.3 Dark brown spots near the leaf margin followed by marginal necrosis of leaves (Anonymous, 2003)

Fig. 1.4 Dark brown spots near the leaf margin followed by marginal necrosis of inner leaves (Anonymous, 2003)

Through personal communication, Soundy (2003) pointed out that tipburn occurs when cabbage is not able to take up and distribute sufficient calcium to meet the demands of rapid growth in an experiment performed under a shade net (Fig. 1.5).

Fig. 1.5 Symptoms of tipburn on cabbage grown under a shade net (Soundy, 2003)

1.2.3 Growth-related Ca- deficiency and tipburn incidence

Ca deficiency is considered a major cause of the tipburn disorder, and the term calcium deficiency is used synonymously for tipburn (Brumm & Schenk, 1993; Saure, 1998). Tipburn is known to be related to localized Ca deficiency in rapidly growing tissues, and many authors consider Ca deficiency the cause of tipburn. Actually, in the young leaves of vigorously growing plants, and especially in the margins of young leaves, the calcium content is very low (Collier & Wurr, 1981 as reported by Collier & Tibbitts, 1982).

An increased incidence of tipburn is associated with conditions favouring vigorous growth and head development. Saure (1998) reported that tipburn can be promoted both, by factors encouraging luxuriant vegetative growth and by factors causing reduced vegetative growth.

Collier & Tibbitts (1984) reported that prevention of transpiration during night-time promoted Ca distribution to enclosed young leaves and thus prevented tipburn in cabbage and lettuce, probably by promoting root pressure flow of Ca. Cresswell (1991) observed reduced tipburn in lettuce receiving water at night because Ca was more effectively translocated to margins of the enclosed leaves. However, this shows that new leaves depends more on transport driven by root pressure. Moreover, root pressure normally develops at night when roots absorb water faster than it is lost through the leaves. On the other hand, factors that discourage development of root pressure such as dry, windy conditions, excessive fertilization, higher salinity, warm dry nights and poor root health do promote tipburn (Collier & Tibbitts, 1984). In addition, Ho & Adams (1989) mentioned that root pressure was not the principal driving force for the import of Ca to rapidly growing parts but a driving force to low transpiring organs.

Creswell (1991) observed a higher concentration of calcium in mature leaves, which was about three times the concentration in young leaves. Furthermore, it was noted that Ca was very immobile in the phloem and tended to accumulate in plants, with age. Older leaves transpire more than young leaves, so it is the newer leaves, which first show deficiency symptoms (Creswell, 1991).

Tipburn in lettuce is recognised as a stress-related calcium deficiency disorder, which can be influenced by light, temperature, humidity, soil condition, and crop growth rate (Brumm & Schenk, 1993; Saure, 1998). Brumm & Schenk (1993) reported that inductions of Ca deficiency are of climatic influence, which induce intervals of insufficient calcium transport to non-transpiring inner leaves. Several factors may affect Ca absorption and translocation, which induce incidence of tipburn. Some of the factors that causes incidence of tipburn are as follows:

Light

Light is regarded as a primary factor regulating plant growth and development (Gaudreau, Charbonneau, Vezina & Gosselin, 1994). Increasing photosynthetic photon flux and lengthening photoperiods consequently increases occurrence of tipburn in lettuce and its severity (Gaudreau *et al*., 1994; Saure, 1998). Wissemeier & Zuhlke (2002) supported the view that long daylights and hence short nights, are positively correlated with the likelihood of tipburn. According to Koontz & Prince (1986) as cited by Saure (1998), at identical total daily radiation, longer photoperiods induce more tipburn than higher light intensities.

Salinity

Vegetable crops grown in a region where water supply for irrigation is of saline nature have a negative impact on soil-water relationships. A high sodium and chloride concentration causes mineral nutrient deficiency (De Pascale & Barbieri, 1995). Lettuce appears to be sensitive to tipburn and had necrotic symptoms when grown under saline-sodic conditions. De Pascale & Barbieri (1995) reported that the symptoms may be attributed to a low uptake rate of calcium, decreased xylem transport of this element or to a different partitioning of cations in plant tissues at high concentration of sodium ions in soil solution. The induction of Ca absorption in solution of high electrical conductivity was also observed by Norrie, Graham, Charbonneau & Gosselin (1995). De Pascale & Barbieri (1995) observed a reduction in physiological parameters, net photosynthetic rate (P_n), transpiration rate (T_r) and stomatal conductance (C_s) when roots were exposed to high salt concentrations.

De Pascale & Barbieri (1995) noted an increased incidence of tipburn at higher soil salinity levels that significantly reduced total head leaf area and increased dry matter percentage. Therefore, it is obvious that salinity influences Ca uptake and distribution throughout the plant.

Humidity

There is a correlation between high ambient humidity (RH) and occurrence of tipburn. High relative humidity interferes with the distribution of Ca as mentioned by Saure (1998). Adams & Ho (1995) agreed that high relative humidity depresses the rate of transpiration and distribution of Ca to the leaves, particularly to the terminal leaflets of rapidly growing leaves. Cresswell (1991) reported that glassiness occurred mostly on mornings with high relative humidity. Therefore, lower relative humidity actually improves Ca distribution in plants, which may be helpful in reducing tipburn.

Temperature

Temperature in the root zone also affects the uptake of Ca (Adams & Ho, 1993). According to Ho (1999), uptake of Ca increases between 14 and 26^{o}C, but at higher root temperature it will be reduced. Higher temperatures enhanced tipburn incidence by promoting growth and, thus, reducing stress tolerance (Saure, 1998). Therefore, the severity of tipburn may be caused by extremes of root temperature.

Nitrogen application

Nitrogen is an essential element that improves vegetative growth and yield in plants. Conversely, researchers noted that nitrogen increases the incidence of tipburn. Brumm & Schenk (1993) reported an increase in tipburn when growth was accelerated by nitrogen application. Rayder & Waycott (1998) attributed the occurrence of tipburn to late application of nitrogen. Supplying more nitrogen than necessary for maximum growth was found to exacerbate or enhance tipburn (Brumm & Schenk, 1993). The authors also recognized a decrease in root/shoot ratio, which occurred simultaneously with an enhancement of tipburn.

1.2.4 Tipburn prevention and control

Several researchers mention that tipburn is a physiological disorder caused by localized calcium deficiency in the foliage (e.g. Cresswell, 1991, Wissemeier & Zuhlke, 2002). It occurs when a plant is not able to take up and distribute sufficient calcium to meet the demands of rapid growth. More importantly, calcium is required for both cell wall and cell membrane structure.

Other researchers noted that restricting N supply to the optimum could decrease the risk of tipburn (Brumm & Schenk, 1993). High relative humidity and long photoperiods should be minimized. Also, extreme root temperature must be avoided. Although increased irrigation may lower the root temperature, Ho (1999) indicated that great care should be taken to avoid waterlogging which may reduce aeration in the root zone. This view is in accordance with a report by Saure (1998) that a reduction of growth, e.g. by lowering temperature, reducing light, or limiting nitrogen fertiliser, may reduce the risk of tipburn.

The supply of air to inner developing leaves was observed to be effective in preventing tipburn (Goto & Takakura, 1992). The authors concluded that the effect was due to an increase in transpiration from leaves, which encouraged water and calcium uptake by the root, and increase the Ca concentration in leaves.

Tipburn can be controlled by planting tolerant cultivars (Wissemeier & Zuhlke, 2002), increasing soil calcium supply prior to planting, liming highly acid soils, foliar calcium sprays on leafy-types, slowing growth through lighter fertilizer application (particularly N), and by keeping an ample and uniform supply of soil moisture (Cresswell, 1991). It might be suggested that by slowing crop growth rates, it will aid in calcium movement through the plant and help reduce the incidence of tipburn in lettuce crops.

Although adequate supply of Ca is essential to ensure the correct Ca status in the plant, it has to be taken up by the plant roots and Ho (1999) asserts that the root environment affects the uptake of Ca by the roots. When lettuce receives inadequate amounts of water, the uptake of Ca and distribution through the transpiration stream will be reduced together with a reduction in water uptake. On the other hand, several researchers (Ho, Adams, Li, Shen, Andrews & Xu, 1995) agreed that Ca uptake can be greatly reduced particularly by high EC in the water even though the root zone is well supplied with water. Moreover, too much saline water or saline soil reduces Ca uptake and results in severe incidence of tipburn. Therefore, by adjusting irrigation frequency and EC the uptake of calcium can be optimized.

1.3 IMPORTANCE OF GEL-POLYMERS

1.3.1 Introduction

Gel-polymers were known in the early 1950s with the introduction of synthetic polyelectrolytes for the stabilization and fortification of soil structure (Hedrick & Mowry, 1952 as cited by Chatzoudis & Valkanas, 1995). Gel-polymers are commonly sold in horticultural markets as super-absorbers with the capability of absorbing 400 g to 1500 g of water per gram of dry gel-polymer and as such can build an additional water reservoir in the soil (Johnson, 1984; Woodhouse & Johnson, 1991; Bouranis *et al.*, 1995).

It has been reported that gel-polymers upon contact with water expand to form gel that, in a growing medium constitutes a reservoir of moisture available for uptake by plants (Johnson & Leah, 1990). According to Bouranis *et al*. (1995) hundreds of gel-polymers exists. However, studies have shown differences in effectiveness of gel-polymers on plant growth and soil improvement. The introduction of alternative soil conditioners like gel-polymers for conserving soil moisture and nutrients, for efficient water and nutrient utilization by the plants are becoming important especially where water availability is limited.

1.3.2 Gel-polymers and their effect on soil characteristics

Studies have shown that gel-polymers can improve soil properties due to their ability to absorb 400 g to 1500 g of water per gram of dry gel-polymer. Investigations by Woodhouse & Johnson (1991) found positive response of gel-polymers as soil conditioners to aid plant establishment in drought-prone soils. It is well documented that gel-polymers have a potential to increase water-holding capacity of sandy textured soils and delay the onset of permanent wilting where evaporation is intense (Johnson, 1984). Other researchers found a reduction in the evaporation rate of soils amended with gel-polymers (Choudhary *et al*., 1995).

Most authors agree that when gel-polymers are incorporated in the soil, the following can be observed: (1) control of soil erosion and water runoff (Wallace & Wallace, 1990), (2) increased infiltration capacity (Zhang & Miller, 1996), (3) increased soil aggregate size (Wallace & Wallace, 1986), (4) reduced soil bulk density (Al-Harbi *et al*., 1999), (5) increased water retention (Johnson, 1984; Bres & Weston, 1993), (6) improved survival of seedlings subjected to drought (Hüttermann *et al*., 1999), (7) improved nutrient recovery from applied fertilizers (Smith & Harrison, 1991; Bres & Weston, 1993) and (8) reduced irrigation frequency (Taylor & Halfacre, 1986). Conversely, other authors reported that the addition of gel-polymers did not have any beneficial effect to the soil (Wang & Boogher, 1987; Tripepi *et al*., 1991; Austin & Bondari, 1992). Bres & Weston (1993) explained that such differences might be related to gel-polymer type and quantity applied.

1.3.3 Gel-polymers and its effects on seed germination

Poor moisture levels especially in dry regions and low rainfall areas often restrict the successful establishment of a good stand of agricultural crops from seed. Hadas (1970) as cited by Woodhouse & Johnson (1991) stated that water uptake by seeds and their subsequent germination rates are strongly influenced by the moisture potential at the seed-soil interface. Interestingly, incorporation of gel-polymers was shown to decrease pre- and post-germinative stresses such as soil crusting and rapid drying of the soil (Levy, Levin, Gal, Ben-Hur, & Shainbeet, 1992; Hüttermann *et al*., 1999).

Woodhouse and Johnson (1991) incorporated gel-polymers in air-dried silica sand (0.2-2.0 mm) leading to enhanced germination rates due to the increase in water availability. They reported that gel-polymer products with binding tensions for water in the plant-available range have the potential to increase moisture level around germinating seeds. Woodhouse & Johnson (1991) found that incorporating gel-polymer into sand improved soil structure, which aided germination of barley (*Hordeum vulgare*), white clover (*Trifolium repens*), and lettuce (*Lactuca sativa*). They reported 10% germination in the control treatment while improvement in germination over the control was brought by gel-polymers in the order of three to six-fold. On the other hand, the effect of gel-polymers has been noted to reduce the germination of some plants (Baxter & Waters, 1986; Woodhouse & Johnson, 1991). However, it was explained that gel-polymers damaged the seeds by supplying too much water, which lead to suffocation of the seeds (Sachs, Cantliffe & Nell, 1982; Baxter & Waters, 1986). Henderson & Hensley (1987) found no significant differences in seed germination percentage, seedling height and dry weight of seedling treated with or without gel-polymers.

1.3.4 Effect of gel-polymers on plant growth and yield

Several studies have shown gel-polymers to increase germination and establishment (Woodhouse & Johnson, 1991), increase seedling survival (Orzolek, 1993) and also to lengthen shelf-life of pot plants (Gehring & Lewis, 1980). Some studies did, however, not show any benefits to plant growth when adding gel-polymers to the soil (Ingram & Yeager, 1987; Tripepi *et al*., 1991).

Findings on seedling survival on soil incorporated with gel-polymers have been inconsistent. Al-Harbi *et al.* (1999) concluded that addition of gel-polymers stimulated cucumber seedling growth. Johnson & Leah (1990) found increased dry weight of *Lactuca sativa* (lettuce), *Raphanus sativa* (radish), and *Triticum aestium* (wheat) seedlings when gel-polymers were incorporated into sand media. In an experiment conducted by Theron (2002), a 830%, 750% and 340% increase, respectively, for the mean root and shoot mass and mean height of *Pinus patula* were found when seedlings were grown on Aqua-Soil^{TM} (gel-polymer) in comparison to the control.

Other researchers, among them Bres & Weston (1993) and Bearce & McCollumn (1997), observed that the incorporation of gel-polymers into the soil was not beneficial to seedling survival, growth and dry weight of tomato. Austin & Bondari (1992) reported that mixing the growing media with a gel-polymer were detrimental to plant survival. Deghan, Yeager & Almira (1994) mentioned that growth response to gel-polymer amendments varied with plant species and number of irrigations.

An experiment conducted by Boatright, Balint, Mackay & Zajicek (1997) found an increased number of flowers and dry weight for *Petunia parviflora* (petunia) in a soil incorporated with gel-polymers in dry conditions. On the other hand, Tripepi *et al.* (1991) mentioned that the addition of a gel-polymer into the growing medium had little effect for container production of birch. They mentioned that gel-polymers held higher amounts of moisture than a medium without gel-polymers. However, the moisture was retained by the expanded gel-polymer rather than being available for plant uptake.

Studies on incorporation of gel-polymers in a poor soil resulted in improved nutrient uptake by plants and minimizing nutrient losses through leaching. Under highly leached conditions, Mikkelsen (1994) found an improved growth of *Festuca arundinacea* L. (fescue) with increased accumulation of N and reduced nitrogen leaching. Magalhaes, Rodrigues, Silva & Rocha (1987) found higher retention of NH_4^+, K^+, Ca^{++}, Mg^{++}, Zn^{++}, and Fe^{++} on an oxisol treated with gel-polymers compared to the untreated soil. In addition, an increase in radish shoot growth and also better N, K, and Fe uptake was found in soil amended with gel-polymers. Mikkelsen (1994) concluded that the gel-polymers act as slow-nutrient release fertilizers. Mikkelsen (1995) experimented with four formulations of manganese to soils containing *Glycine max* (soybean) plants to determine response when a gel-polymer was in the soil. All of the *G. max* plants were higher in manganese content and showed increased biomass except where no gel-polymer was added. In an experiment comparing the leaching effects of 2000 mm of rainfall on fertilizers in sandy soil, it was found that Aqua-Soil^{TM} retained up to 400% more nitrogen and 300% more potassium than standard quick release and slow release fertilizers (Bredenkamp, 2000). This implies that addition of gel-polymers not only could increase yield and conserve moisture, but minimized the leaching of nutrients, thus preventing groundwater pollution.

CHAPTER 2

EFFECT OF GEL-POLYMER AND IRRIGATION ON TOMATO GROWTH, YIELD AND QUALITY

2.1 INTRODUCTION

Tomato is one of the most popular and widely grown vegetable crops in the world. It belongs to the genus *Lycopersicon,* which is grown for its edible fruit (Jones, 1999). It is widely used as a salad, or in cooked or processed form.

Researchers acknowledge that tomato has a higher acreage of any vegetable crop in the world (Ho, 1996), and it also requires a high water potential for both, optimal vegetative and reproductive development (Arturo *et al*., 1995; Jones, 1999). However, in South Africa, the cost of water and its availability are increasing problems in agricultural production due to poor rainfall. Tomato growth, yield and quality have shown to be reduced by water deficit (Sefara, 1994; Byari & Al-Sayed, 1999). Other authors (Obreza *et al*., 1996; Ho, 1999) acknowledged that soil water and crop water supply have an influence on tomato total soluble solids (%Brix) and physiological disorders, e.g. tomato fruit cracking (Peet & Willits, 1995) and blossom-end rot (Saure, 2001) that are known to deteriorate the quality of tomatoes.

One of the major concerns in agricultural production is poor productivity of sandy soils, of which production is limited by their low water-holding capacity and excessive deep percolation. A good soil physical structure is important for water and nutrient availability for plant growth, development and yield. Several studies have been conducted on sandy soil to test the effect of gel-polymer soil amendment on water retention (Johnson, 1984; Johnson & Leah, 1990; Blodgett *et al*., 1993; Choudhary *et al*., 1995; Al-Harbi *et al*., 1999; Hüttermann *et al*., 1999). It is well documented that the addition of gel-polymers has the potential to improve plant vegetative growth, soil structure, soil texture, to reduce the evaporation rate and soil bulk density (Johnson, 1984; Choudhary *et al*., 1995; Al-Harbi *et al*., 1999, Eiasu, 2004). Johnson (1984) and

Hüttermann *et al*. (1999) reported that the addition of gel-polymer to sandy soil could change the water-holding capacity to be comparable to that of silty clay or loam soils.

It is well recognized that hundreds of different gel-polymers exist (Bouranis *et al*., 1995) and that they influence the soil physical structure, plant growth and yield differently. According to Bres & Weston (1993), differences in effectiveness of gel-polymers might be due to gel-polymer type and amount applied.

In this study, two new released gel-polymers known as Stockosorb and Aqua-Soil^{TM} were tested on sandy soil. Aqua-Soil^{TM} (fertiliser-fused gel-polymer) is a blend of nutrients and cross-linked co-polymers forming a super absorbent polymer specifically designed to store water and nutrients which are then slowly released on demand (www.aqua-soil.co.za). What makes Aqua-Soil^{TM} unique is that it contains 40% gel-polymer and is a potassium rather than sodium-based polymer and it is fused with nutrients (N: P: K). Stockosorb is a 100% pure gel-polymer with a similar structure to that of Aqua-Soil^{TM} but without fused fertilisers.

The present study was undertaken to determine the influence of various irrigation intervals applied to a sandy soil amended with pure gel-polymer (Stockosorb) or fertiliser-fused gel-polymer (Aqua-Soil^{TM}) on growth, yield and quality of tomato as well as on nutrient retention by sandy soil.

2.2 MATERIALS AND METHODS

2.2.1 Locality

The study was carried out in a plastic tunnel (10 m x 30 m in size) at the Experimental Farm of the University of Pretoria (25^{o} 45’ S and 28^{o} 16’ E latitude and longitude respectively, at an altitude of 1327 m above sea level) from February to August 2003. The tunnel was equipped with two fans and a wet wall. During the entire growing period, air temperature varied between 28.4 and 34.5^{o}C during the day and between 15.8 and 21.1^{o}C at night.

2.2.2 Treatments and experimental design

Tomato seeds of cultivar 'Floradade' (Straathof's Seeds Ltd., Honeydew, South Africa) were sown in 128 cell seedling trays on 28 February 2003. The seedlings were raised in Hygromix growth media. Water was applied twice a day. After the seedlings had two fully expanded leaves, the irrigation was changed to once a day with a Multifeed fertiliser. Foliar fertiliser was prepared by adding 5 g of Multifeed into 5 L of water.

Six weeks after emergence the tomato seedlings were transplanted into 20 L black plastic bags containing a growing media comprising out of 95.0% coarse sand, 0.4% silt and 4.6% clay. Irrigation was applied through drippers with one dripper per plant having a discharge rate of 2.5 L per hour controlled by a computerised irrigation system. The experiment was laid-out as a split plot design where irrigation interval was assigned to main plots and gel-polymer treatments to subplots with 12 replications. The water that was used for irrigation was ground water and the chemical analysis of the water is presented in Table 2.1.

Table 2.1 Chemical composition of the ground water used for irrigation

pH	EC	Minerals ($mg{\cdot}L^{-1}$)									
	$mS{\cdot}m^{-1}$	Ca	Mg	K	Na	Fe	Cu	Mn	Zn	P	Cl
7.3	28.9	22	10	1.0	7	0.02	0.00	0.01	0.03	0.3	46.8

The gel-polymers used in this experiment as soil amendment were fertiliser-fused gel-polymer (Aqua-Soil^{TM}) and a pure gel-polymer (Stockosorb). Pure gel-polymer application rates were 8 g and 16 g per 20 L sandy soil (equivalent to 400 g and 800 $g{\cdot}m^{-3}$ of sandy soil, designated by Stock 8 and 16, respectively) and fertiliser-fused gel-polymer application rates were 20 g and 40 g per 20 L sandy soil (equivalent to 1 kg and 2 $kg{\cdot}m^{-3}$ of sandy soil, designated by Aqua 20 and 40, respectively) and the control (sandy soil). A basal placement of twenty grams (equivalent to 571 $kg{\cdot}ha^{-1}$) of Wonder fertiliser 2:3:2 (22) was applied at transplanting to the control and pure gel-polymer treatments. Sandy soil amended with fertiliser-fused gel-polymer did not receive fertiliser application during transplanting since it is a fused-fertiliser gel-polymer, with 3:1:5 (10) fertiliser, which is believed to be available to the transplants. The gel-polymers and the sand soil were mixed uniformly with the use of a concrete mixer. The plant spacing between the plants within a double-row was 50 cm x 50 cm while the spacing between the rows was 90 cm. The transplants were given enough water every day for a period of two months.

Two months after transplanting during the first flowering stage, differential irrigation intervals were applied. Irrigation intervals applied were daily, every second, every third day, fourth day or every fifth day, equivalent to 0.8, 1.25, 1.45, 1.88 and 2.29 L of water per 20 L bag.

2.2.3 Cultural practices

Twisting trellis twine around the main stem and fixing it to a stay wire supported the tomato plants. Two months after transplanting, i.e. on 24 April 2003, 20 g 2:3:2 (22), Wonder fertiliser (equivalent to 571 $kg \cdot ha^{-1}$) was applied as side-dressing to all treatments. Lateral branches, suckers and auxillary branches were cut and pinched off in order to retain a single stem. Pruning was done regularly. To aid proper pollination and fertilization, the trellis twines connected to the plants were shaken regularly. Plants were kept weed free by repeated hand weeding whereas insect pest and diseases were controlled chemically.

On 26 April 2003, 20 g of foliar fertilizer known as Feed All was dissolved into 5 L of water and mixed thoroughly to alleviate nutrient deficiencies. The nutrient solution (Table 2.2) was then applied to leaves through foliar application.

Table 2.2 Nutrient analysis of Feed All

Element	Concentration
Nitrogen	160 g/kg
Phosphorus	50 g/kg
Potassium	220 g/kg
Calcium	11 g/kg
Magnesium	3 g/kg
Boron	335 mg/kg
Iron	356 mg/kg
Zinc	100 mg/kg
Manganese	12.5 mg/kg
Copper	12.5 mg/kg

On 29 April 2003 plants showed recovery from nutrient deficiency. On 13 May 2003, 10 mL NITROSOL ® (Table 2.3), which is a natural organic plant food, was diluted in 3 L of water (1: 300) to alleviate micronutrient deficiencies. Thus, 200 mL of dilute concentration of the plant nutrients are applied to the sandy soil.

On 29 May 2003, 6 g (equivalent to 171 $kg \cdot ha^{-1}$) of calcium nitrate (19.5% Ca and 15.5% N) were applied per bag. Final fertiliser application occurred on 12 June 2003 where 20 g of 2:3:2 (22) Wonder fertiliser (equivalent to 571 $kg \cdot ha^{-1}$) was applied to the individual plants.

Table 2.3 Nutrient analysis of NITROSOL®

Element	Concentration (%)
Nitrogen	8
Phosphorus	2
Potassium	5.8
Magnesium	0.7
Calcium	0.6
Sulphur	0.4
Iron	0.6
Copper	0.01
Zinc	0.01
Manganese	0.4
Boron	0.23
Molybdenum	0.15
Growth Stimulant	Gibberllic Acid
Wetting Agent	0.0003

2.2.4 Harvesting and fruit sampling

Tomato fruit were hand-harvested at the fully ripe stage. Yield components for tomato including fruit mass, fruit size and fruit number were determined. Fruit sizes were estimated by measuring the fruit diameter with the use of a vernier calliper. Fruit quality evaluations were determined by randomly picking firm fruit at the ripe stage from the second truss, i.e. 4 fruits from 4 plants per block per treatment were sampled. Harvested fruits were immediately transported to the Soil Laboratory at the University of Pretoria for chemical analysis. At the termination of the experiment, all the unripened fruits were harvested and their overall mass was recorded.

2.2.5 Plant growth measurements and soil analysis

During the entire growing period of the plant, early leaf senescence was observed. The following measurements were recorded in all plants at the termination of the experiment: plant height, stem diameter, number of trusses, and fresh and dry root mass. Plant root fresh mass was taken by selecting two plants per treatment per block per irrigation treatment. Plant roots were washed under running tap water and the root fresh mass determined. The roots were then oven dried for a period of 48 h at a temperature of 65°C and then weighed. Soil samples were taken from irrigation interval 2 (i.e. of every second day) which comprised out of 10 samples from 2 blocks. Soil samples were transferred to the Soil Science Laboratory where they were analysed for NO_3^-, NH_4^+, P, and K. NO_3^- and NH_4^+ were analysed using KCl extract, P was analysed using Extractable Phosphorus: BRAY 2, and K was analysed using Ammonium Acetate (1 mol dm^{-3}, pH 7).

2.2.6 Fruit chemical analysis

Fruit samples were chemically analysed for the following quality parameters: fruit juice pH, titratable acidity and total soluble solids (%Brix) at the physiology laboratory of the Department of Plant Production and Soil Science.

Fruit samples were washed with tap water and wrapped with tissue paper to dry. Each sample was grounded with a blender to produce a puree. The puree was then filtered through a Whatman No.4 filter paper in order to obtain serum. The collected serum was then used to determine the fruit pH, TSS (%Brix) and titratable acidity. The pH of the tomato serum was measured using a pH meter. The %Brix was measured using a digital refractrometer (ATAGO N1, Japan) where a drop of serum was placed on a clean prism. The prism was cleaned between samplings using a distilled water. The titratable acidity was determined by titration of 20 mL serum to a pH = 8.1 with 0.1N NaOH using a D150 *Graphix* instrument (METTLER TOLEDO, Switzerland). The acidity was then articulated as a percentage in terms of the predominant acid found in tomatoes, citric acid according to Gould (1983):

$$Z = \frac{V \times N \times \text{meq.wt}}{Y} \times 100$$

Where

Z = citric acid,

V = volume of NaOH (mL),

N = normality of NaOH,
meq.wt = milliequivalents of acid which is 0.064 for citric acid
Y = volume (mL) of sample titrated

2.2.7 Statistical Analysis

The SAS statistical package (SAS Institute Inc., 2004) was used to analyse the data. ANOVA was used to determine the effect of irrigation interval and gel-polymer for the dependent variables. LS-means was used for the post-hoc (multiple comparisons) testing.

2.3 RESULTS

2.3.1 Effect of gel-polymer

Data of fruit mass, fruit diameter and number of fruit picked with different gel-polymer application rates is shown in Table 2.4. The greatest fruit mass was obtained from plants grown in sandy soil amended with any level of fertiliser-fused gel-polymer (Aqua 20 and 40) and the highest pure gel-polymer (Stock 16) level (Table 2.4). Plants grown from sandy soil amended with Stock 8 resulted in significantly smaller fruit mass compared to plants grown from Aqua 20, Aqua 40 and Stock 16 treatments. Plants that were grown in sandy soil without gel-polymer amendment (control) had significantly smaller fruit mass compared to plants grown from gel-polymer amended sandy soil.

Larger sized fruit was attained on sandy soil amended with Aqua 40, Aqua 20 and Stock 16, but were not significantly different to each other (Table 2.4). However, plants grown on sandy soil amended with low levels of pure gel-polymer (Stock 8) showed a significantly smaller fruit size compared to those of plants grown in Aqua 20, Aqua 40 and Stock 16. Plants from the control treatment had significantly smaller sized fruit compared to plants grown from gel-polymer amended sandy soil.

Plants grown on sandy soil amended with any level of pure gel-polymer or fertilizer-fused gel-polymer generally resulted in a higher number of fruit. The number of fruit per plant grown on sandy soil amended with gel-polymers were, however, not significantly different from each other. The lowest fruit number was recorded for the control treatment which was, however, not statistically different from the Stock 8 treatment.

Table 2.4 Effect of sandy soil amended with gel-polymers on tomato fruit mass, fruit diameter and fruit number

Treatment	Fruit mass (g)	Fruit diameter (mm)	Number of fruit per plant
Control	57.46 c^z	45.12 c	12.12 b
Stock 8	73.37 b	48.61 b	13.53 ab
Stock 16	80.54 a	50.37 a	14.47 a
Aqua 20	80.94 a	49.95 a	14.19 a
Aqua 40	78.40 a	49.85 a	14.02 a

^{z} Means followed by the same letter within the column are not significantly different at 5% level of probability. Control: sandy soil (without gel-polymer); Stock 8 and Stock 16: pure gel-polymer (400 g and 800 g$\cdot$m^{-3} of sandy soil respectively); Aqua 20 and Aqua 40: fertiliser-fused gel-polymer (1 kg and 2 kg$\cdot$m^{-3} of sandy soil respectively).

There were significant differences between the plant heights in all treatments (Table 2.5). Plant height was found to increase with an increase in gel-polymer application rate. A superior performance was attained by both fertiliser-fused gel-polymer treatments (Aqua 20 and 40) followed by pure gel-polymer (Stock 8 and 16) treatments and the control plants were shortest. Plants grown in sandy soil amended with Aqua 40 were not only the tallest, but had also a significantly larger stem diameter (Table 2.5). The stem diameters of the remaining treatments were not significantly different from each other.

Plants from the control treatment produced significantly fewer trusses than all the other treatments (Table 2.5). Type and level of gel-polymer did not significantly influence number of trusses produced.

Plants grown on sandy soil amended with Stock 16, Aqua 20 and Aqua 40 gel-polymers had a significantly higher fresh root mass (Table 2.5). However, the differences were not statistically significant. Plants grown in sandy soil amended with Stock 8 had a significantly lower fresh root mass compared to plants grown in sandy soil amended with Stock 16, Aqua 20 or 40. Plants grown in sandy soil without gel-polymer amendment, produced the least fresh root mass.

Table 2.5 Effect of sandy soil amended with gel-polymers on tomato plant height, stem diameter and number of trusses at termination of the experiment

Treatment	Plant height (cm)	Stem diameter (mm)	Number of trusses	Fresh root mass (g)	Dry root mass (g)
Control	52.74 e[z]	9.28 b	3.10 b	39.15 c	7.29 b
Stock 8	64.44 d	9.24 b	3.71 a	67.30 b	11.26 a
Stock 16	69.71 c	9.16 b	4.00 a	104.68 a	16.18 a
Aqua 20	70.06 b	8.95 b	3.86 a	79.74 a	12.66 a
Aqua 40	72.18 a	10.00 a	3.91 a	121.50 a	18.29 a

[z] Means followed by the same letter within the column are not significantly different at 5% level of probability. Control: sandy soil (without gel-polymer); Stock 8 and Stock 16: pure gel-polymer (400 g and 800 $g \cdot m^{-3}$ of sandy soil respectively); Aqua 20 and Aqua 40: fertiliser-fused gel-polymer (1 kg and 2 $kg \cdot m^{-3}$ of sandy soil respectively)

Type and level of gel-polymer did not significantly influence dry root mass (Table 2.5). Plants grown in sandy soil without gel-polymer (control) amendment resulted in significantly lower dry root mass compared to plants grown in sandy soil amended with gel-polymers (Aqua 20, Aqua 40, Stock 8 and Stock 16).

Lower green fruit mass were recorded for the control, then for soil amended with pure gel-polymer and lastly for soil amended with fertiliser-fused gel-polymer (Fig 2.1). The results were not statistically analysed (Fig. 2.1).

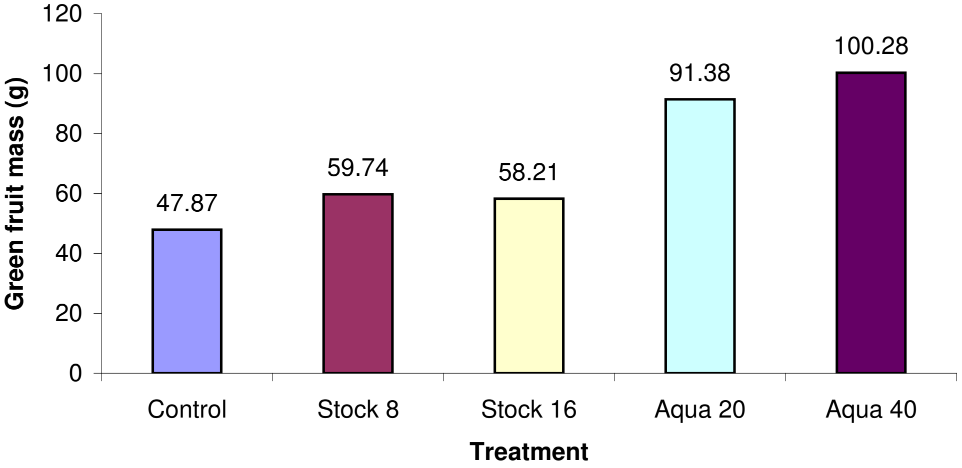

Fig. 2.1 Effect of gel-polymers on green fruit mass at final harvest. Control: sandy soil (without gel-polymer); Stock 8 and Stock 16: pure gel-polymer (400 g and 800 g·m^{-3} of sandy soil respectively); Aqua 20 and Aqua 40: fertiliser-fused gel-polymer (1 kg and 2 kg·m^{-3} of sandy soil respectively)

A higher percentage of early leaf senescence was found on sandy soil without gel-polymers (control) compared to plants grown on gel-polymer treated sandy soil (Fig. 2.2). However, the results were not statistically analysed (Fig. 2.2). It was observed that plants grown without gel-polymer (control) had a reduced canopy. However, plants grown in sandy soil amended with gel-polymers had good canopy cover. The gel-polymer treatments did not induce major visual symptoms of physiological disorders on the fruits harvested. However, only minute percentages of fruits had fruit cracking and blossom-end rot (BER), but there were not treatment related.

In terms of fruit quality, gel-polymer did not significantly affect fruit juice pH, titratable acidity and total soluble solids (Table 2.7).

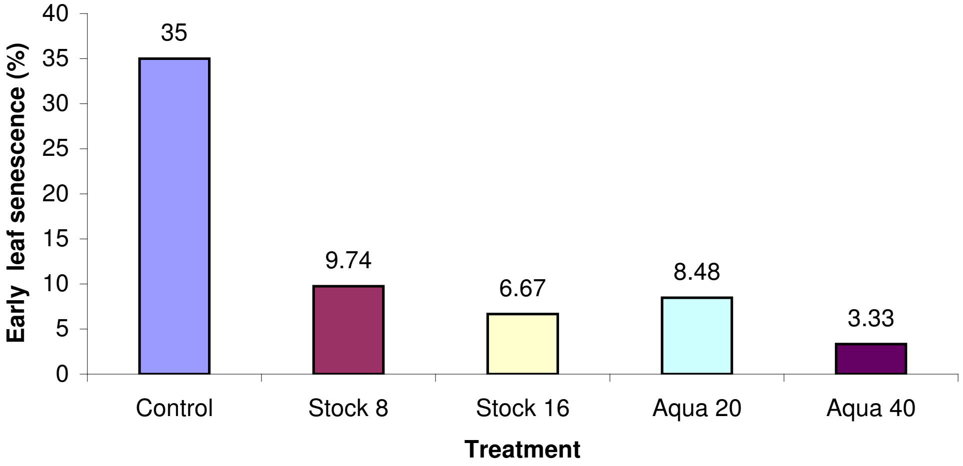

Fig. 2.2 Effect of gel-polymers soil amendment on early leaf senescence. Control: sandy soil (without gel-polymer); Stock 8 and Stock 16: pure gel-polymer (400 g and 800 g·m^{-3} of sandy soil respectively); Aqua 20 and Aqua 40: fertiliser-fused gel-polymer (1 kg and 2 kg·m^{-3} of sandy soil respectively)

2.3.2 Effect of irrigation interval

Irrigation interval did not significantly affect fruit mass, diameter and number (Table 2.6). Furthermore, irrigation interval did not significantly affect plant height, stem diameter, number of trusses, and fresh and dry root mass (Table 2.6). Similarly, fruit quality parameters (%Brix, fruit juice pH and titratable acidity) were not significantly affected by irrigation interval (Table 2.7).

Table 2.6 Fruit mass, fruit diameter, fruit number, plant height, stem diameter, number of trusses, and fresh and dry root mass of tomato as affected by irrigation interval

Irrigation	Fruit			Plant	Stem	Number	Fresh root	Dry root
Interval (days)	mass (g)	diameter (mm)	number	height (cm)	diameter (mm)	of trusses	mass (g)	mass (g)
1	76.31 a[z]	49.19 a	13.80 a	64.15 a	9.39 a	4.03 a	84.62 a	14.82 a
2	76.90 a	49.00 a	14.59 a	67.38 a	9.32 a	4.17 a	84.57 a	11.19 a
3	73.11 a	48.34 a	13.66 a	64.31 a	9.37 a	3.47 a	81.20 a	12.99 a
4	72.14 a	48.87 a	13.58 a	67.13 a	8.89 a	3.46 a	77.17 a	11.35 a
5	71.64 a	48.36 a	12.65 a	65.39 a	9.45 a	3.42 a	84.80 a	15.31 a

[z] Means with the same letter within a column are not significantly different at 5% level of probability. Irrigation interval: 1, 2, 3, 4 and 5 (daily, every second, third, fourth or fifth day respectively)

Table 2.7 %Brix (TSS), fruit juice pH and titratable acidity (TA) of tomato fruit as affected by irrigation interval

Irrigation Interval (days)	%Brix (TSS)	Fruit juice pH	Titratable acidity (TA)
1	4.46 a[z]	4.1 a	0.42 a
2	4.43 a	4.1 a	0.40 a
3	4.73 a	4.0 a	0.46 a
4	4.92 a	3.9 a	0.48 a
5	5.06 a	4.0 a	0.48 a

[z] Means with the same letter within a column are not significantly different at 5% level of probability. Irrigation interval: 1, 2, 3, 4 and 5 (daily, every second, third, fourth or fifth day respectively)

2.3.3 Interactive effect of irrigation interval and gel-polymer

There were no interactions between irrigation intervals and gel-polymers found for fruit yield and plant growth. With respect to fruit quality, no significant differences were observed between the interaction of gel-polymers and irrigation intervals for %Brix (TSS), fruit juice pH and titratable acidity.

2.3.4 Effect of gel-polymer on nutrient retention

Soil samples to determine nutrient retention analysis were taken only from the second day irrigation interval, since all irrigation intervals did not have a major influence on plant growth, yield and quality. Gel-polymers did not have a significant effect on P, K, NH_4^+ and NO_3^- retention (Table 2.8).

Table 2.8 Effect of nutrient (phosphorus, potassium and nitrogen) retention in sandy soil amended with gel-polymers

Treatment	P ($mg \cdot kg^{-1}$)	K ($mg \cdot kg^{-1}$)	NH_4^+ ($mg \cdot kg^{-1}$)	NO_3^- ($mg \cdot kg^{-1}$)
Control	18.55 a[z]	9.5 a	43.26 a	57.54 a
Stock 8	22.35 a	10.5 a	36.40 a	52.64 a
Stock 16	26.35 a	10.0 a	54.18 a	65.66 a
Aqua 20	26.15 a	14.0 a	55.16 a	68.60 a
Aqua 40	25.75 a	15.5 a	34.72 a	60.06 a

[z] Means with the same letter within a column are not significantly different at 5% level of probability. Control: sandy soil (without gel-polymer); Stock 8 and Stock 16: pure gel-polymer (400 g and 800 $g \cdot m^{-3}$ of sandy soil respectively); Aqua 20 and Aqua 40: fertiliser-fused gel-polymer (1 kg and 2 $kg \cdot m^{-3}$ of sandy soil respectively)

2.4 DISCUSSION AND CONCLUSIONS

Results of the study indicate that variables that were affected by gel-polymer soil amendment were plant growth and yield. Irrigation interval did not have a significant influence on plant growth and yield. Quality parameters (TSS, pH and titratable acidity) were not affected by either gel-polymer or irrigation treatments.

Several research works have been undertaken with the application of gel-polymers into sandy soils in order to improve soil physical properties and productivity (Johnson & Leah, 1990; Choudhary *et al*., 1995; Al-Harbi *et al*., 1999; Bredenkamp, 2000). Fertiliser-fused (Aqua-Soil^{TM}) gel-polymer was found to retain up to 400% more nitrogen and 300% more potassium than standard quick release and slow release fertiliser when comparing leaching effects of 2000 mm of rainfall on fertiliser in sandy soil (Bredenkamp, 2000). Furthermore, the improved plant growth and yield might have brought by improved nutrient retained in sandy soil amended with gel-polymer.

The improved growth and yield of tomato on sandy soil amended with pure gel-polymer and fertiliser-fused gel-polymer might have been attributed to improved soil physical properties of the sandy soil. None of the irrigation intervals had an influence on plant growth, fruit yield and quality. This is in disagreement with Byari & Al-Sayed (1999) who found a reduction in fruit mean mass and yield by increased time of irrigation intervals between successive irrigations. Our findings can be explained by the fact that plants were not under water stress. Although irrigation interval has a major influence on the soil moisture profile, in this experiment it had no or little effect on tomato performance. Pulupol *et al*. (1996) and Byari & Al-Sayed (1999) ascribed poor plant development, growth and yield to plants grown under water stress or increased time of irrigation intervals between successive irrigation.

After transplanting, plants grown on sandy soil amended with fertiliser-fused gel-polymer (Aqua-Soil^{TM}) that contained 3:1:5 (10) fertiliser showed superior performance than plants which received a basal fertiliser application of 20 g (i.e. 571 kg·ha^{-1}) of 2:3:2 (22) per growing bag. The transplants might have benefited more from the fused-fertiliser in Aquas-Soil^{TM}. Side-dressing should ideally be applied during or before flowering stage to avoid any nutrient deficiency problems.

Researchers have elucidated that soil properties and management have a major influence on root and plant growth (Klepper, 1991; Sainju *et al*., 2001; Anikwe, Obi & Agbin, 2003). Sainju, Singh & Rahman (2000) mentioned that optimum root growth and distribution within the soil profile play a major role in water and nutrient uptake. Data in the present study indicate a clear direct relationship between tomato root growth, and yield. The good development of roots brought on by sandy soil amended with gel-polymer, therefore, enhanced plant growth and yield of tomato.

Al-Harbi *et al*. (1999) reported reduced soil bulk density when gel-polymer was amended into sandy soil. In addition, Eiasu (2004) found fertiliser-fused gel-polymer and pure gel-polymer amendments to sandy soil to reduce evaporative losses and to reduce soil bulk density. Perhaps in the present study, the soil without addition of gel-polymer might have resulted in reduced root biomass due to higher soil bulk density. Tubeileh, Groleau-Reaud, Plantureux & Guckert (2003) mentioned that soil compaction does hamper root growth and delays leaf appearance, thereby decreasing plant height, shoot and root mass, and leaf area. The poor soil characteristics of sandy soil without soil conditioners like gel-polymer, might have contributed to restricting root growth, plant growth and yield in the control.

Control plants experienced premature leaf senescence. This might also be explained by poor root development because of the absence of soil amendments, like gel-polymer, which can improve soil physical characteristics. Rate of application of the fertiliser-fused gel-polymer (Aqua-Soil^{TM}) did not influence tomato growth and yield. The performance of plants grown on sandy soil amended with a high level of pure gel-polymer (Stock 16) was similar to plants grown in both fertiliser-fused gel-polymer application rates. Apparently, the low level of pure gel-polymer (Stock 8) applied, resulted in the relatively low improvement of plant performance, growth and development.

Tomato juice pH, titratable acidity and %Brix were not affected by any treatment. Previous results (Mitchell *et al*., 1991; Yrisarry *et al*., 1993; Sefara, 1994; van der Westhuizen *et al*., 2001; Zegbe-Dominguez *et al*., 2003) showed that plants under water shortage have a high total soluble solid content but poor plant growth and yield. Other investigators found translocation of photosynthates into fruit to be promoted by water stress (Shinohara *et al*., 1995). This implies that the irrigation intervals in the present study were not far apart enough to cause water to be a limiting factor for tomato growth and changes in quality of tomatoes. The TSS (%Brix) range of 4.1 to 5.5 was relatively high compared to the results (3.5 – 4.19) found by Sefara (1994). In the present study, the applied water was, therefore, able to reach sufficient evapotranspiration demand across all five irrigation intervals.

No conclusion can be drawn regarding the effect of irrigation interval on gel-polymer amended sandy soil on tomato performance, since no significant effect on tomato fruit quality was observed. However, it is of importance to introduce gel-polymers that are fused with fertiliser, such as Aqua-Soil^{TM}, for improving plant growth, yield and quality as plants seemed to benefit more from fused fertiliser gel-polymers than from pure gel-polymers. This study reveals that gel-polymer amendments have a defined role in increasing the productivity of tomato in sandy soils.

2.5 SUMMARY

The effects of pure gel-polymer and fertiliser-fused gel-polymer across five irrigation intervals on growth, yield and quality of tomato (*Lycopersicon esculentum* Mill.) were investigated. The treatments were control (sandy soil), two pure gel-polymer levels (8 and 16g·20 L^{-1} sandy soil, equivalent to 400 and 800 kg·m^{-3}) and two fertiliser-fused gel-polymer levels (20 and 40 g·20 L^{-1} sandy soil, equivalent to 1 kg and 2 kg·m^{-3}). Irrigation was applied either daily or every second, third, fourth or fifth day, equivalent to 0.8, 1.25, 1.45, 1.88 and 2.29 L of water per 20 L bag.

Fruit mass, fruit diameter, fruit number, plant height, stem diameter, number of trusses, fresh and dry root mass, total soluble solids, fruit juice pH and titratable acidity, early leaf senescence, and P, K, NH_4^+ and NO_3^- retention were determined.

Neither irrigation interval nor gel-polymer had a significant influence on tomato quality (total soluble solids, pH and titratable acidity). There were no interactions between irrigation interval and gel-polymer found for plant growth and yield. However, tomato plants that were grown in sandy soil amended with any level of fertilizer-fused gel-polymer (Aqua 20 and 40) or the higher level of pure gel-polymer (Stock 16) resulted in significantly higher plant yield, plant height, stem diameter, number of trusses, and fresh and dry root mass. Plants that were grown on sandy soil amended with pure gel-polymer showed an increase in growth and yield with an increase in pure gel-polymer application rate. There was a higher percentage of early leaf senescence for plants grown in sandy soil without gel-polymers (control) compared to plants grown on sandy soil amended with gel-polymers. However, gel-polymers did not have a significant effect on P, K, NH_4^+ and NO_3^- retention. Regardless of irrigation interval, both fertiliser-fused gel-polymer levels appeared to be effective in improving plant growth and yield compared to pure gel-polymer, which gave good results only at the higher level. The study demonstrated that gel-polymer amendments increased productivity of tomato in sandy soils.

CHAPTER 3

EFFECT OF GEL-POLYMER AND IRRIGATION ON LETTUCE GROWTH, YIELD AND QUALITY

3.1 INTRODUCTION

Lettuce (*Lactuca sativa* L.) belongs to the sunflower family and is known to be native to the Mediterranean basin (Harris, 1987). This crop is becoming an increasingly important vegetable in salads, which is reported to rank second after tomato in South Africa in terms of salads (Harris, 1987). In South Africa, lettuce has become more popular as production and consumption increases, since it is nutritious and a good source of vitamins (Salunkhe *et al*., 1991; Niederwieser, 2001). Niederwieser (2001) stated that lettuce is often prescribed for overweight people because of its low energy level.

In lettuce, where the harvested part of the plant is the photosynthetic leaf area, it is especially important to maintain optimal growth through the application of water and fertiliser throughout the growing period (Gallardo *et al*., 1996). Lettuce is one of the vegetable crops with a shallow root system. The crop is very sensitive to water stress and it requires frequent irrigation at short irrigation intervals. Sutton & Merit (1993) reported the ideal soil moisture content for lettuce to be around field capacity.

Higher leaching of nitrogen and percolation of water infiltrated below the root zone was reported when lettuce was grown on sandy soil resulting in poor growth, yield and quality (Sanchez, 2000). The retention of water and nutrients by addition of gel-polymers to sandy soils has been reported to reduce the amount of water lost through deep percolation (Hüttermann *et al*., 1999). That is, the alternative use of gel-polymer soil amendments might enhance water and nutrient use efficiency in sandy soils (Anonymous, 2002).

The purpose of the study was to determine growth, yield and quality of lettuce grown on sandy soil amended with pure gel-polymer (Stockosorb) or fertiliser-fused gel-polymer (Aqua-Soil^{TM})

under various irrigation intervals. The effect of sandy soil amended with gel-polymers on calcium and nitrogen plant uptake was also studied.

3.2 MATERIALS AND METHODS

3.2.1 Locality

The trial was conducted at the University of Pretoria's Experimental Farm from 04 February to 18 May 2004 in a plastic tunnel similar to the experiment in Chapter 2. During the entire growing period, air temperature varied between 26.8 and 31.5°C during the day and between 12.8 and 18.1°C at night. The soil texture and the quality of water used for irrigation were as described in Chapter 2.

3.2.2 Treatments and experimental design

Lettuce seeds (*Lactuca sativa*, cv. Empire 2000) were sown on 04 February 2004 and raised in a glasshouse. Seedlings were raised in 200 cavity seedling trays using Hygromix as a growth media. Seedlings were irrigated twice a day and after they had two fully developed leaves, they were fertigated once a day with a foliar fertiliser (Multifeed). Foliar fertiliser was prepared by adding 5 g of Multifeed into 5 L of water.

The experiment comprised of five gel-polymer treatments, i.e. control (sandy soil without gel-polymer), two pure gel-polymer (Stockosorb) rates of 4 and 8 g (equivalent to 400 g and 800 $g{\cdot}m^{-3}$, designated as Stock 4 and Stock 8, respectively) per 10 L sandy soil; and two fertiliser-fused gel-polymer (Aqua-Soil^{TM}) rates of 10 and 20 g per10 L sandy soil (equivalent to 1 kg and 2 $kg{\cdot}m^{-3}$, designated by Aqua 10 and Aqua 20, respectively). The sandy soil amended with pure gel-polymer (Stockosorb) and control received 20 g 2:3:2 (22) Wonder fertilizer (equivalent to 1100 $kg{\cdot}ha^{-1}$) while treatments amended with fertiliser fused gel-polymer (Aqua-Soil^{TM}) received 10 g 2:3:2 (22) Wonder fertiliser (equivalent to 550 $kg{\cdot}ha^{-1}$) as a basal placement. The fertiliser-fused gel-polymer (Aqua-Soil^{TM}) treatment received low fertiliser because the manufacturer indicated that the fused 3:1:5 (10) fertiliser becomes available to the plants. The treatments were mixed uniformly with soil using a concrete mixer and then 10 L black plastic bags, were filled.

The experiment was laid out as a split plot design with 12 replications. The main plots were 5 irrigation intervals and the sub-plots were the control, Stock 4, Stock 8, Aqua 10 and Aqua 20 applications. The irrigation intervals were set-up as follows: daily, every second, third, fourth or fifth day, equivalent to 0.63, 0.83, 1.04, 1.25 and 1.46 L per 10 L plastic bags. A drip irrigation system was used, with a discharge rate of 2.5 L per hour. The plant spacing between the plants within the double rows was 30 cm x 30 cm while spacing between the rows was 90 cm.

Thirty day-old lettuce seedlings were transplanted to the 10 L plastic bags on 04 March 2004. The treatments were given enough water in order to allow full expansion of the gel-polymer and allow good establishment of transplants for a period of 7 days. Seven days after transplanting, the different irrigation treatments were applied.

3.2.3 Cultural practices

Pests were controlled only when the infestation was seen to be a serious threat to normal plant growth. Hand weeding was done when necessary. On 13 March 2004, 5 g (equivalent to 275 $kg\cdot ha^{-1}$) $CaNO_3$ which constitutes 15.5% N and 19.5% Ca was applied. On 6 April 2004, 10 g (equivalent to 550 $kg\cdot ha^{-1}$) of 2:3:2 (22) Wonder fertiliser was applied per 10 L bag as a final application.

3.2.4 Harvesting, measurements and sampling

First harvesting took place on 3 May 2004. The outer leaves of lettuce were trimmed off. The following growth parameters were evaluated in all fully developed head lettuce: Head fresh mass, head height, head circumference, head diameter, stem diameter, stem height, fresh root mass, dry root mass and dry head mass. Fresh and dry root mass of individual roots was taken from samples of 4 randomly selected plants per treatment per irrigation interval. The roots were washed with running tap water. Both head and fresh root mass were oven dried at a temperature of 65°C for 48 h. The dry head samples were milled in order to analyse for percentage tissue calcium and nitrogen at the Soil Science Laboratory. The percentage tissue N was analysed using H_2SO_4 acid digestion while percentage tissue Ca was analysed using $HClO_4 + HNO_3$ digestion.

3.2.5 Statistical analysis

The SAS statistical package (SAS Institute Inc., 2004) was used to analyse the data. ANOVA was used to determine the effect of irrigation interval and gel-polymer for the dependent variables. LS-means was used for the post-hoc (multiple comparisons) testing.

3.3 RESULTS

3.3.1 Effect of gel-polymer

The analysis of variance indicates that addition of gel-polymers to sandy soil has a highly significant effect on growth, quality and yield of lettuce. The results of this experiment were nearly similar to observations made in the previous experiment reported in Chapter 2.

The fresh head mass was significantly higher when plants were grown on sandy soil amended with Stock 8, Aqua 10 and 20 than when grown in Stock 4 amendment or the control (Table 3.1). The dry head mass of lettuce grown in sandy soil amended with low level of pure gel-polymer (Stock 4) was similar to the control treatment (Table 3.1). In comparison with the control and Stock 4 treatment, plants grown on sandy soil amended with Stock 8, Aqua 10 and 20 had a significantly higher dry head mass.

Plants grown in soil amended with a higher level of pure gel-polymer (Stock 8) and any level of fertiliser-fused gel-polymer (Aqua 10 and 20) significantly increased head diameter, head circumference and head height compared to pure gel-polymer (Stock 4) and the control. Although both pure gel-polymer applications rate, i.e. Stock 4 and 8, were not significantly different from each other, Stock 8 tended to increase head circumference.

Table 3.1 Response of lettuce grown on sandy soil amended with gel-polymers on fresh and dry head mass, head diameter, circumference and height

Treatment	Fresh head mass (g)	Dry head mass (g)	Head diameter (mm)	Head circumference (mm)	Head height (mm)
Control	222 c[z]	11.2 b	97 b	322c	132 b
Stock 4	223 c	11.6 b	102 b	342 bc	129 b
Stock 8	287 b	14.6 a	115 a	362 ab	143 a
Aqua 10	342 ab	15.4 a	115 a	380 a	149 a
Aqua 20	348 a	17.4 a	120 a	388 a	149 a

[z] Means followed by the same letter within the column are not significantly different at 5% level of probability. Control: sandy soil (without gel-polymer); Stock 4 and Stock 8: pure gel-polymer (400 g and 800 $g \cdot m^{-3}$ of sandy soil respectively); Aqua 10 and Aqua 20: fertiliser-fused gel-polymer (1 kg and 2 $kg \cdot m^{-3}$ of sandy soil respectively)

Plants grown on sandy soil amended with Stock 8, Aqua 10 and Aqua 20 resulted in significantly higher stem diameter than the control and Stock 4 treatments (Table 3.2). Plants grown on sandy soil amended with Stock 8, Aqua 10 or Aqua 20 produced significantly greater fresh and dry root mass as compared to that of plants grown in the control and Stock 4 treatments.

Table 3.2 Response of lettuce stem diameter, and fresh and dry root mass to sandy soil amended with pure and fertiliser-fused gel-polymers

Treatment	Stem diameter (mm)	Fresh root mass (mg)	Dry root mass (mg)
Control	17.89 b[z]	14180 b	1560 b
Stock 4	17.66 b	16740 b	2040 b
Stock 8	18.58 ab	27050 a	2930 a
Aqua 10	19.59 a	27050 a	2630 a
Aqua 20	20.14 a	30660 a	3190 a

[z] Means with different letters in their respective columns are significantly different at 5% level. Control: sandy soil (without gel-polymer); Stock 4 and Stock 8: pure gel-polymer (400 g and 800 $g \cdot m^{-3}$ of sandy soil respectively); Aqua 10 and Aqua 20: fertiliser-fused gel-polymer (1 kg and 2 $kg \cdot m^{-3}$ of sandy soil respectively)

3.3.2 Effect of irrigation interval

The irrigation interval did not have any significant effect on fresh and dry head mass, head diameter, stem diameter, or fresh and dry root mass. However, plants that were irrigated daily, and every second, fourth or fifth day had a significantly higher head circumference than plants irrigated every 3rd day (Table 3.3). The reason why there was a poorer performance of lettuce in terms of head circumference at irrigation interval of every third day is not clearly understood.

Table 3.3 Effect of irrigation interval on fresh and dry head mass, head circumference, height and diameter; stem diameter, fresh and dry root mass of lettuce

Irrigation Interval (days)	Fresh head mass (g)	Dry head mass (g)	Head			Stem diameter (mm)	Fresh root mass (g)	Dry root mass (g)
			circumference (cm)	height (mm)	diameter (mm)			
1	296.42 a[z]	13.53 a	37.75 a	95.15 a	116.19 a	18.80 a	18.80 a	2.09 a
2	313.93 a	16.66 a	35.65 a	100.20 a	109.66 a	19.89 a	29.90 a	3.29 a
3	262.23 a	13.17 a	34.09 b	97.10 a	105.62 a	18.54 a	21.46 a	2.59 a
4	281.54 a	13.46 a	35.86 a	96.77 a	109.06 a	18.59 a	26.47 a	2.59 a
5	275.98 a	13.46 a	36.05 a	103.40 a	107.88 a	18.13 a	19.72 a	1.89 a

[z] Means with different letters in their respective columns are significantly different at 5% level. Irrigation interval: 1, 2, 3, 4 and 5 (daily, every second, third, fourth or fifth day respectively)

3.3.3 Interaction effect of irrigation interval and gel-polymer

There were no interactions between irrigation interval and gel-polymer for fresh head mass, dry head mass, head circumference, head height, stem diameter, and fresh and dry root mass. Significant interactions between irrigation interval and gel-polymer were, however, found for head diameter (Table 3.4). In general, the application of Stock 8, Aqua 10 and Aqua 20 improved lettuce head diameter and reduced the influence of irrigation interval on head diameter compared to the control and Stock 4 treatments.

Table 3.4 Interaction effects of irrigation interval and gel-polymer on lettuce head diameter

	Gel-polymers				
Irrigation Interval (days)	Control	Stock 4	Stock 8	Aqua 10	Aqua 20
1	94.18 f[z]	93.89 f	128.50 a	128.50 a	133.30 a
2	93.45 g	106.25 d	115.38 ab	113.91 ab	119.08 a
3	91.30 g	115.67 ab	105.38 d	108.57 b	113.63 ab
4	103.22 de	102.25 e	115.75 ab	107.36 c	115.64 ab
5	104.29 de	94.86 f	109.13 ab	109.11 ab	118.44 ab

[z] Means with different letters within a row or columns are significantly different at 5% level. Irrigation interval: 1, 2, 3, 4 and 5 (daily, every second, third, fourth or fifth day respectively)

3.3.4 Effect of gel-polymer on calcium and nitrogen uptake

Figure 3.1 displays the effect of both fertiliser-fused gel-polymer and pure gel-polymer rates on calcium and nitrogen uptake in head lettuce. These results were obtained only from plants that were grown with irrigation interval of every second day due to the fact that no major significant differences were obtained among the various irrigation intervals on lettuce performance. No significant differences were found in calcium and nitrogen uptake by plants regardless of treatment (Fig. 3.1). However, plants in the Aqua 10 and 20 gel-polymer treatments tended to have somewhat higher %N than the control plants, as well as Stock 4 and 8 treatments.

Furthermore, lettuce plants that were grown in sandy soil amended with Stock 8 and Aqua 20 tended to have higher %Ca followed by Aqua 10, the control and then Stock 4 treatment.

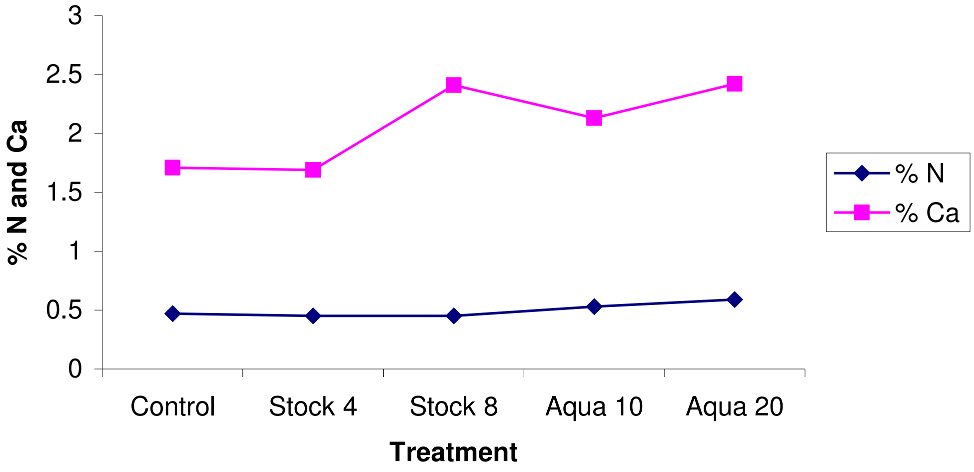

Fig. 3.1 Effect of gel-polymers on percentage nitrogen and calcium uptake in head lettuce. Control: sandy soil (without gel-polymer); Stock 4 and Stock 8: pure gel-polymer (400 g and 800 $g{\cdot}m^{-3}$ of sandy soil respectively); Aqua 10 and Aqua 20: fertiliser-fused gel-polymer (1 kg and 2 $kg{\cdot}m^{-3}$ of sandy soil respectively)

3.4 DISCUSSION AND CONCLUSIONS

Growing lettuce in sandy soil without gel-polymer amendments or with a low level of pure gel-polymer (Stock 4) would likely to be economically disadvantageous for a grower due to lower growth and yields with poor quality. Lettuce had improved head quality, fresh and dry head mass, stem diameter, and fresh and dry root mass in sandy soil amended with a higher level of pure gel-polymer (Stock 8) and any level of fertiliser-fused gel-polymer (Aqua 10 and Aqua 20).

Plants grown in sandy soil amended with Stock 8, Aqua 10 and 20 partitioned more dry matter to roots and heads (Tables 3.1 and 3.2). The gel-polymer treatments also led to bigger lettuce heads as evidenced by improved head diameter, head height and head circumference. Root growth also followed the same trend as above ground growth. The results, therefore, suggest a correlation between root growth and above ground growth.

Addition of fertiliser-fused gel-polymer at both levels (Aqua 10 and Aqua 20) and at the higher level of pure gel-polymer (Stock 8) resulted in better lettuce performance than the low level of pure gel-polymer (Stock 4) and the control. In Chapter 2, we observed that lower level of pure gel-polymer performed better than the control, which is in contrast to these findings where a low level of pure gel-polymer gave similar results to the control. It is apparent that the improved lettuce yield and quality in a soil amended with pure gel-polymer (Stockosorb) is due to increased application rate. This is in agreement with Bres & Weston (1993) who noted differences in plant growth that was related to the quantity of gel-polymer applied. The fused-fertiliser in gel-polymer seems to be highly available for plant uptake since superior plant growth and yield was obtained from it.

Plants grown on sandy soil amended with pure gel-polymer (Stockosorb) and without gel-polymer (control) received 20 g 2:3:2 (22) Wonder fertiliser (i.e. 1100 $kg \cdot ha^{-1}$) while treatments amended with fertiliser-fused gel-polymer (Aqua-Soil^{TM}) received 10 g 2:3:2 (22) Wonder fertiliser (i.e. 550 $kg \cdot ha^{-1}$) as a basal placement. However, plants grown on any level of fertiliser fused gel-polymer (Aqua 10 and Aqua 20) showed significant increase in plant growth, yield and quality. This confirmed that less N: P: K is required for plants when grown on sandy soil amended with fertiliser fused gel-polymer.

There were interactions between irrigation interval and gel-polymer found with lettuce head diameter. In general, the application of Stock 8, Aqua 10 or Aqua 20 improved lettuce head diameter and reduced the influence of irrigation interval on head diameter compared to the control and Stock 4 treatments. This could have been as a result of better water retention that was available even to plants that were irrigated less frequently in the gel-polymer amended soils.

Numerous factors, as reported previously, seem to have contributed to the superior performance of lettuce growth, yield and quality, grown on sandy soil amended with pure and fertiliser-fused gel-polymer. The decrease in soil bulk density, storage of soil moisture, improved soil aeration and efficient use of dissolved nutrients retained brought by gel-polymers could be some vital factors for improved plant growth. These factors might have improved physical structure of the sandy soil, which created a better environmental condition for root growth. Pure gel-polymer soil amendment was reported to alleviate soil compaction by reducing soil bulk density (Eiasu, 2004). As indicated in Chapter 2, it is evident from these results that the better the root growth, the better the above ground growth and yield with improved lettuce quality. Recently Eiasu (2004) found pure gel-polymer at a rate of 1.5 kgm^{-3} to change the hydraulic properties of a sandy soil to the same level as that of a sandy clay loam soil. These results are supported by Johnson & Leah, 1990, Klepper, 1991, Choudhary *et al*., 1995, Al-Harbi *et al*., 1999, Sainju *et al*., 2001, Bredenkamp, 2000 and Anikwe *et al*., 2003.

3.5 SUMMARY

The trial was conducted at the University of Pretoria's Experimental Farm in a plastic tunnel. The effects of pure gel-polymer and fertiliser-fused gel-polymer across five irrigation intervals on growth, yield and quality of lettuce (*Lactuca sativa* L.) were investigated. The treatments were: control, two pure gel-polymer levels (4 and 8 $g{\cdot}10\ L^{-1}$ sandy soil, equivalent to 400 g and 800 $g{\cdot}m^{3}$) and two fertiliser fused gel-polymer levels (10 and 20 $g{\cdot}20\ L^{-1}$ sandy soil, equivalent to 1 kg and 2 $kg{\cdot}m^{-3}$). Irrigation was either applied daily or every second, third, fourth or fifth day (equivalent to 0.63, 0.83, 1.04, 1.25 and 1.46 L per 10 L plastic bag).

The following growth parameters were evaluated in all fully developed lettuce heads: fresh and dry head mass, head height, head circumference, head diameter, stem diameter, fresh and dry root mass. The dry head samples were analysed for percentage tissue calcium and nitrogen.

Growing lettuce plants on sandy soil amended with the higher level of pure gel-polymer (Stock 8) or both levels of fertiliser fused gel-polymer (Aqua 10 and 20) resulted in significantly better fresh and dry head mass, head circumference, head diameter, head height, stem diameter, and fresh and dry root mass as compared to low the level of pure gel-polymer (Stock 4) treatment and the control. Irrigation interval had a significant effect on head circumference only, among all growth, yield and quality parameters of lettuce measured. Plants that were irrigated daily and every second, fourth or fifth day, resulted in significantly better head circumference as compared to irrigation interval of every third day. Significant interactions were found between irrigation interval and gel-polymer for head diameter. In general, the application of Stock 8, Aqua 10 and

Aqua 20 improved lettuce head diameter and reduced the influence of irrigation interval on head diameter compared to the control and Stock 4 treatments. This could have been as a result of better water retention that was available even to plants that were irrigated less frequently in the gel-polymer amended soils.

Gel-polymer soil amendment did not influence calcium or nitrogen uptake. However, plants obtained from sandy soil amended with Aqua 10 and 20 gel-polymer tended to have somewhat greater head tissue N than those under the control, Stock 4 and Stock 8 treatments. Also, lettuce plants grown in sandy soil amended with Stock 8 and Aqua 20 had somewhat greater head tissue Ca followed by Aqua 10 and then the control treatment.

This experiment demonstrated that gel-polymer soil amendment improved sandy soil and resulted in greater lettuce yields of good quality heads.

GENERAL DISCUSSION AND CONCLUSIONS

Tomato and lettuce are amongst the most important fresh vegetables used in South Africa. However, growth, yield and quality of tomato and lettuce are constrained by water shortage and poor productivity of sandy soil. In South Africa, large part of the agricultural land is in semi-arid region and water is becoming scarcer and more costly for agricultural purposes. A major concern for agricultural productivity is the poor results from sandy soils. Poor water-holding capacity of sandy soils requires frequent watering and limits the use of water by the plants. As a result, water moves into the subsoil and drains away along with plant nutrients (fertilisers) from the upper layers of the soil. A good soil physical structure is important for water and nutrient availability for plant growth, development and yield.

Investigations by Woodhouse & Johnson (1991) found positive response of gel-polymers as soil conditioners to aid plant establishment in drought prone soils. Johnson (1984) reported that gel-polymers have a potential to increase water-holding capacity of sandy textured soils and delay the onset of permanent wilting where evaporation is intense.

There is no or little information whether gel-polymers have a beneficial effect to improve vegetable production under limited water supply. Therefore, the study was carried out in a sandy soil to determine:

- Growth, yield and quality of lettuce and tomato grown on sandy soil incorporated with gel-polymers
- Suitable irrigation intervals for lettuce and tomato grown on sandy soil amended with gel-polymers
- N, P and K retention of a sandy soil amended with gel-polymers
- The N and Ca uptake of lettuce on gel-polymer amended sandy soil

In general, neither irrigation interval nor the interaction effect of irrigation interval and gel-polymer did have a significance influence on tomato growth, yield and fruit quality parameters (total soluble solids, fruit juice pH and titratable acidity). This might be an indication that the irrigation intervals in the present study were not far apart enough to cause water to be a limiting factor for growth, yield and quality of tomatoes. However, it was clear that tomatoes reacted positively to gel-polymer amended sandy soil.

Fruit mass, fruit diameter, fruit number, plant height, stem diameter, number of trusses, and fresh root and dry root mass were significantly increased with gel-polymer amendments as compared to pure sandy soil (control). Plants grown in sandy soil amended with fertiliser-fused gel-polymer (Aqua 20 and 40) did not receive a basal fertiliser application of 20 g 2:3:2 (22) (equivalent to 571 $kg \cdot ha^{-1}$) per bag, since it contains fertiliser (3:1:5 (10)). Based on the results of this investigation, transplants grown on sandy soil amended with fertiliser-fused gel-polymer might have benefited from the fertiliser-fused gel-polymer. Fertilizer-fused gel-polymer treatments showed superior performance at both application levels than pure gel-polymer treatments, which performed better only at high level. This indicates that less or no N: P: K fertiliser is required at transplanting. However, side-dressing should ideally be applied during or before flowering stage to avoid nutrient deficiency symptoms.

It was found that the lower levels of pure gel-polymer performed better than the control treatment, but could not sustain the high plant growth and yield obtained from the other gel-polymer treated soils. Differences in response can be explained by the level of application. Rate of application for the fertiliser-fused gel-polymer (Aqua-Soil^{TM}) did not influence tomato growth and yield, except that taller plants with thicker stems were obtained at higher fertiliser-fused gel-polymer levels (Aqua 40). The results indicate that the addition of a fertiliser-fused gel-polymer in small quantities to sandy soil could be more beneficial to plant growth and yield than pure gel-polymer (Stockosorb) in small quantities.

The improved growth and yield of tomato on sandy soil amended with gel-polymers could be attributed to improved soil physical properties of sandy soil. Although the amendment of sandy soil with gel-polymer did not show a significant effect on nutrient retention, plants grown on amended soil might have utilized nutrients more efficiently which, therefore, resulted in better plant growth and yield. Yield reduction and retarded plant and root growth which might be brought on by soil compaction in sandy soil (control) can be improved by treating the soil with a gel-polymer which imbibes water and, therefore, improves soil porosity. Such evidence proves that gel-polymer soil amendments alleviate soil compaction by reducing soil bulk density (Eiasu, 2004). As a result, plants grown on sandy soil amended with gel-polymers experienced less premature leaf senescence than the control (sandy soil). However, this might be explained by poor root development in the absence of soil amendments, like gel-polymer, which can improve soil properties. The data also indicated a direct correlation between root and above ground growth and yield. In addition, this indicates that good root growth is to the benefit of plant growth and tomato yield. The benefits from gel-polymer amendment were evident in improved root development and plant growth and yield.

Growing lettuce plants in sandy soil amended with higher level of pure gel-polymer (Stock 8) and any level of fertiliser fused gel-polymer (Aqua 10 and 20) resulted in significantly higher fresh head mass, dry head mass, head circumference, head diameter, head height, stem diameter, and fresh and dry root mass as compared to low level of pure gel-polymer (Stock 4) and sandy soil without gel-polymer (control). Lower levels of pure gel-polymer as well as untreated sandy soil (control) resulted in similar poor lettuce growth, quality and yield. Importantly, plants grown on sandy soil amended with fertiliser fused gel-polymer received 10 g of 2:3:2 (22) Wonder fertiliser (equivalent to 550 $kg \cdot ha^{-1}$) per 10 L plastic bag while the control and pure gel-polymer received 20 g of 2:3:2 (22) Wonder fertiliser (equivalent to 1100 $kg \cdot ha^{-1}$) per 10 L plastic bag as a basal application. Although less N: P: K fertiliser was applied to the transplants grown on sandy soil amended with fertiliser-fused gel-polymer, improved growth and yield of lettuce was achieved in both application levels. This implies that the fused-fertiliser in a gel-polymer benefited the plants, as a result of superior lettuce growth and yield with good quality heads.

Irrigation interval did have a significant influence on lettuce head circumference. Plants that were irrigated every day, second, fourth and fifth day resulted in significantly higher head circumference as compared to irrigation interval of every third day. Interaction of irrigation interval and gel-polymer was obtained only on head diameter. The application of Stock 8, Aqua 10 and Aqua 20 to sandy soil improved lettuce head diameter and reduced the influence irrigation interval on head diameter compared to the control and Stock 4 treatments. This could have been as a result of better water retention that was available even to plants that were irrigated less frequently in the gel-polymer amended soils. There were no major significant differences in plant growth, yield and quality across five irrigation intervals. The reason might be irrigation intervals were not far apart enough to cause water to be a limiting factor for lettuce growth, yield and quality.

No significant differences were found in calcium and nitrogen uptake among any of sandy soils amended with gel-polymer. However, plants obtained from sandy soil amended with Aqua 10 and 20 gel-polymer tended to have somewhat greater N uptake as compared to other treatments. And also, lettuce plants that were grown in sandy soil amended with Stock 8 and Aqua 20 had somewhat greater Ca uptake followed by the Aqua 10 and then the control treatment. The ability of gel-polymer to retain nutrients might have enhanced nutrient uptake of lettuce head tissue.

No conclusion can be drawn regarding the effect of irrigation intervals on gel-polymer amended sandy soil on tomato and lettuce performance, since no significant differences were observed. Further studies are still required to determine the water and nutrient use efficiency of tomato and lettuce yield and quality as affected by the adding of a gel-polymer to sandy soil under water stress conditions. Sandy soil is characterized by poor water and nutrient-holding capacity. However, gel-polymer amendments offer a potential solution in areas where the land is dominated by sandy soil to improve plant growth and yield.

The results of this study demonstrated that gel-polymer soil amendment improved sandy soil and resulted in greater tomato plant growth and yield while in lettuce greater yields of good quality heads were obtained. However, irrigation interval did not show any major significant effect on tomato and lettuce growth, yield and quality. Furthermore, this led to a conclusion that water applied was, therefore, not far apart enough to cause water to be a limiting factor for tomato and lettuce growth, yield and quality.

GENERAL SUMMARY

A trial was undertaken in a plastic tunnel to determine the response of tomato growth, yield and quality to gel-polymer amended soil of five irrigation intervals. The treatments were: the control (sandy soil), two pure gel-polymer levels (8 and 16 $g{\cdot}20\ L^{-1}$ sandy soil) and two fertiliser-fused gel-polymer levels (20 and 40 $g{\cdot}20\ L^{-1}$ sandy soil). Irrigation was either daily or every second, third, fourth or fifth day (equivalent to 0.8, 1.25, 1.45, 1.88 and 2.29 L of water per 20 L bag of sandy soil). Measurements were made of fruit mass, fruit diameter, fruit number, plant height, stem diameter, number of trusses, fresh and dry root mass, total soluble solids, fruit juice pH and titratable acidity, early plant leaf senescence, and P, K, NH_4^+ and NO_3^- retention.

Tomato fruit quality parameters (total soluble solids, pH and titratable acidity) were not affected by either irrigation interval or gel-polymer. There were no interactions between irrigation interval and gel-polymer amendment in terms of tomato growth, yield and quality. However, tomato plants grown in sandy soil amended with any of the two levels of fertiliser-fused gel-polymer (Aqua 20 and 40) and high levels of pure gel-polymer (Stock 16) resulted in significantly higher plant yield, plant height, stem diameter, number of trusses, and fresh and dry root mass. It was found that lower levels of pure gel-polymer (Stock 8) performed significantly better than the control treatment, however, it resulted in lower plant growth and yield in comparison to other gel-polymer treated soils. Plants that were grown on sandy soil amended with pure gel-polymer have shown an increase in growth and yield with an increase in pure gel-polymer level. Lower green fruit mass was recorded for the control as compared to sandy soil conditioned with pure and fertiliser-fused gel-polymer.

A higher percentage of early leaf senescence was recorded on sandy soil without gel-polymer compared to plants grown on gel-polymer treated soil. It was observed that plants grown on sandy soil without gel-polymer (control) had a reduced plant canopy as compared to plants grown on sandy soil amended with gel-polymer, which had good canopy cover. Amendment with gel-polymer did not have any significant effect on nutrient retention (P, K, NH_4^+ and NO_3^-). However, plants grown on sandy soil amended with higher levels of pure gel-polymer (Stock 16)

and any of the two levels of fertiliser-fused gel-polymer (Aqua 20 and 40) resulted in improved plant growth and yield.

A trial was established in a tunnel to determine the response of lettuce growth, yield and quality to gel-polymer amended soil at five irrigation intervals. The treatments were the control, two pure gel-polymer levels (4 and 8 $g \cdot 10\ L^{-1}$ sandy soil) and two fertiliser-fused gel-polymer levels (10 and 20 $g \cdot 10\ L^{-1}$ sandy soil). Irrigation was either daily or every second, third, fourth or fifth day (equivalent to 0.63, 0.83, 1.04, 1.25 and 1.46 L per 10 L plastic bag).

Measurements were made of fresh and dry head mass, head height, head circumference, head diameter, stem diameter, and fresh and dry root mass. Dry material of the head were analysed for percentage tissue calcium and nitrogen in the tissue.

Lettuce plants grown on sandy soil amended with high levels of pure gel-polymer (Stock 8) and any level of fertiliser-fused gel-polymer application rate (Aqua 10 and 20) displayed a significantly better fresh and dry head mass, head circumference, head diameter, head height, stem diameter, and fresh and dry root mass as compared to low level of pure gel-polymer (Stock 4) and sandy soil without gel-polymer (control). Irrigation interval had a significant effect on head circumference only, among all growth, yield and quality parameters of lettuce measured. The significant interaction between irrigation interval and gel-polymer was only true for head diameter. In general, the application of Stock 8, Aqua 10 and Aqua 20 improved lettuce head diameter and reduced the influence of irrigation interval on head diameter compared to the control and Stock 4 treatments. This could have been as a result of better water retention that was available even to plants that were irrigated less frequently in the gel-polymer amended soils.

Gel-polymer soil amendment did not influence calcium or nitrogen uptake. However, plants obtained from sandy soil amended with Aqua 10 and 20 gel-polymer tended to have somewhat greater head tissue N than those under the control, Stock 4 and Stock 8 treatments. Furthermore, lettuce grown in sandy soil amended with Stock 8 and Aqua 20 had somewhat greater tissue Ca followed by Aqua 10 and then the control treatment. Although less N: P: K fertiliser was applied to the transplants grown on sandy soil amended with fertiliser-fused gel-polymer, improved growth and yield of lettuce was achieved in both application levels.

This experiment demonstrated that gel-polymer soil amendment improved sandy soil and resulted in greater lettuce yields of good quality heads.

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APPENDICES

APPENDIX A: SUMMARISED ANALYSIS OF VARIANCE FOR THE TOMATO EXPERIMENT

Table A1 Analysis of variance for fruit mass, fruit diameter, fruit number, root characteristics, and plant growth parameters as affected by irrigation interval and gel-polymers

Source	DF	Mean square ^{z}							
		Fruit			Root		Plant	Stem	Number
		mass (10^{3}g)	diameter (10^{-3}cm)	number (10^{-2})	fresh mass (10^{-3}g)	dry mass (10^{-3}g)	height (10^{-3}cm)	diameter (10^{-3}mm)	of trusses (10^{-3})
Irrigation interval (IR)	4	108	570	28450	430	320	970	1990	3650
Gel-polymer (P)	4	12480^{**}	8920^{**}	51980^{*}	4540^{**}	3000^{**}	21690^{**}	6070^{**}	2530^{**}
IR X P	16	690	570	14210	750	720	600	1040	640
Block (BL)	1	5660	4230	2590	2270	7320	2600	1150	1110
IR X BL	4	700	670	40170	1560	670	1300	2070	3060
Error	258	850	870	4210	750	770	790	920	800

^{z} F values significant at 5% level of probability (*) or highly significant at 1 % level of probability (**)

Table A2 Analysis of variance for %Brix (TSS), fruit juice pH and titratable acidity (TA) as affected by irrigation interval and gel-polymer

Source	DF	Mean Square [z]		
		%Brix (TSS) (10^{-3})	Fruit juice pH (10^{-5})	Titratable acidity (TA) (10^{-3})
Irrigation Interval (IR)	4	430	550	1390
Gel-polymer (P)	4	560	180	1170
IR*P	16	220	380	610
Block (BL)	1	670	4500	1290
IR*BL	4	280	700	1240
Error	20	490	6800	830

[z] F values significant at 5% level of probability (*) or highly significant at 1 % level of probability (**)

Table A3 Analysis of variance for P, K, NH_4^+ and NO_3^- as affected by gel-polymer

Source	DF	Mean Square [z]			
		P (mg/kg)	K (mg/kg)	NH_4^+ (mg/kg)	NO_3^- (mg/kg)
Gel-polymer (P)	4	22.74	32.75	184.92	81.09
Block (BL)	1	71.23	72.90	505.81	304.26
Error	4	3.92	5.67	7.97	11.90

[z] F values significant at 5% level of probability (*) or highly significant at 1 % level of probability (**)

APPENDIX B: SUMMARISED ANALYSIS OF VARIANCE FOR THE LETTUCE EXPERIMENT

Table B1 Analysis of variance for fresh head and dry mass, head circumference, height, diameter, stem diameter, fresh and dry root mass as affected by irrigation interval and gel-polymer

Source	DF	Mean squares ^{z}							
		Head					Stem	Fresh root	Dry root
		fresh mass (10^{-3}g)	dry mass (10^{-3}g)	circumference (10^{-3}cm)	height (10^{-3}cm)	diameter (10^{-3}mm)	diameter (10^{-3}mm)	mass (10^{-3}g)	mass (10^{-3}g)
Irrigation interval (IR)	4	2870	1920	1600	1210	1610	1330	850	860
Gel-polymer (P)	4	40290**	5160**	7530**	4550**	8550**	3010**	5630**	3020**
IR X P	16	10430	430	1110	980	1440*	830	1380	980
Block (BL)	1	6410	300	11110	5200	7400	750	960	670
IR X BL	4	1050	2840	230	340	680	1960	1490	1360
Error	168	870	930	860	910	830	930	790	820

^{z} F values significant at 5% level of probability (*) or highly significant at 1% level of probability (**)

Table B2 Analysis of variance for % N and Ca uptake in dry head lettuce

Source	DF	Mean square [z]	
		N (10^{-3} %)	Ca (10^{-4} %)
Gel-polymer (P	4	520	200
Block (BL)	1	330	200
Error	14	550	1900

[z] F values significant at 5% level of probability (*) or highly significant at 1 % level of probability (**)

APPENDIX C:

Fig. C1 Well-established transplants of tomato growing in a tunnel

Fig. C2 Full-ripened fruit ready for harvesting

Fig. C3 Ten-day-old lettuce transplants growing in a tunnel

Fig.C4 Lettuce plants ready to be harvested