THE EFFECT OF PLANT POPULATION AND MULCHING ON GREEN PEPPER (*Capsicum annuum* L.) PRODUCTION UNDER IRRIGATION

by

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ABSTRACT

THE EFFECT OF PLANT POPULATION AND MULCHING ON GREEN PEPPER (*Capsicum annuum* L.) PRODUCTION UNDER IRRIGATION

Green pepper (*Capsicum annuum* L.) is gaining popularity and the production and consumption thereof is increasing worldwide. Semi-arid regions are characterized by variable and unreliable rainfall which necessitates the use of irrigation for sustainable green pepper production. In this study two field trials were conducted. Objectives of the first trial were to quantify the effect of irrigation and plant population on the growth and yield of green pepper and to optimize its plant population for different water regimes. Four water treatments, full irrigation (781 mm), 70% of full irrigation (627 mm), 40% of full irrigation (497 mm) and dryland (303 mm) and five plant populations (17 689, 23 674, 29 526, 34 979 and 41 496 plants ha^{-1}) were used in this trial. A line source sprinkler irrigation system was used for water application. The trial layout was a split plot design with water applications as main treatments and plant populations as sub-treatments. All treatment combinations were replicated four times. The full irrigation and 40% of full irrigation treatment increased marketable yield with 274% and 162%, respectively. The 70% of full irrigation treatment increased marketable yield with 253%. The marketable yield of all irrigation treatments was significantly higher than that of the dryland treatment. The full irrigation's marketable yield was however also significantly higher than that of 40% of full irrigation treatment. The optimum plant population for all water treatments, excluding 40% of full irrigation was not reached in this trial because the yield of plant populations (17 689 to 41 496 plants ha^{-1}) used did not reach a turning point, but still increased linearly beyond 41 496 plants ha^{-1}.

The objective of the second trial was to quantify the effect irrigation and mulching on yield, water use and water use efficiency. Four water treatments, full irrigation (547 mm), 66% of full irrigation (481 mm), 33% of full irrigation (417 mm) and dryland (303 mm) and two mulching (bare and 9 t ha^{-1} maize straw) treatments were used. A line source sprinkler irrigation system was also used for this experiment. The trial layout was a split plot design with water treatments as main treatments and mulching rates as sub-treatments. All treatment combinations were replicated four times. Results indicated that green pepper responded well to irrigation. Full irrigation, 66% and 33% of full irrigation treatment produced marketable yield of 37.54, 29.74 and 20.52 t ha^{-1}, respectively. The marketable yield of irrigation treatments was significantly different from each other and they were all significantly higher than that of the dryland treatment which produced a marketable yield of 11.92 t ha^{-1}. As irrigation proceeded over time, the relationship between water use and leaf area index strengthened. The fully irrigated treatment produced the highest water use efficiency. Mulching conserves water by reducing evaporation and mitigates negative effects of water stress on plant growth and yield under semi-arid conditions. At the end of the season, cumulative water use efficiency from the mulched treatment was 6 g m^{-2} mm^{-1}, significantly higher than that of the bare treatment of 5.3 g m^{-2} mm^{-1}.

Green pepper is very susceptible to water stress and produces poorly under dryland conditions and any irrigation is beneficial to its production. However results also indicated that green pepper has the ability to adapt quite well to high plant populations and has demonstrated its ability to compete for production resources at such populations. The crop also conforms well to the favourable plant growth conditions provided by the mulch.

Keywords: marketable yield, water use, water use efficiency, leaf area index, dryland, full irrigation

UITTREKSEL

DIE INVLOED VAN PLANTPOPULSIE EN DEKLAAG OP SOETRISSIE (*Capsicum annuum* L.) PRODUKSIE ONDER BESPROEIING

Die produksie asook die verbruik van soetrissies (*Capsicum annuum* L.) het wêreldwyd toegeneem. Semi-ariede gebiede word gekenmerk deur onreëlmatige en onbetroubare reënval wat besproeiing vir volhoubare produksie noodsaak. In dié studie is twee veldproewe uitgevoer. Die doel van die eerste proef was om die invloed van besproeiing en plantpopulasie op die groei en opbrens van soetrissie te kwantifiseer asook om plantpopulasie vir verskillende watervlakke te optimaliseer. Vier waterbehandelings naamlik: vol besproeiing (781 mm), 70% van volbesproeiing (627 mm), 40% van volbesproeiing (497 mm) en droëland (303 mm) asook vyf plantpopulasies (17 689, 23 674, 29 526, 34 979 en 41 496 plante ha^{-1}) is in die proef gebruik. Water is toegedien deur middel van 'n lynbronbesproeiingstelsel. Die proef is uitgelê as 'n verdeelde perseelontwerp met watertoediening as hoof behandeling en plantpopulasie as sub-behandeling. Alle behandelingskombinasies is vier keer herhaal. Volbesproeiing en 40% van volbesproeiing het die bemarkbare opbrengs onderskeidelik met 274% en 162% verhoog. Bemarkbare opbrengs is met 253% verhoog deur 70% van volbesproeiing en al die besproeiingsbehandelings was betekenisvol hoër as die droëlandbehandeling. Volbesproeiing se bemarkbare opbrengs was ook betekenisvol hoër as die 40% van volbesproeiingbehandeling. Die optimum plantpopusasie vir al die waterbehandelings, uitsluitende die 40% van volbesproeiingbehandeling is nie bereik nie. Opbrengs het bly toeneem by die hoogste plantpopusisie (41 496 plante ha^{-1}) en nog geen draaipunt is bereik nie.

Die doel van die tweede proef was om die invloed van besproeiing en deklaag op opbrengs, waterverbruik en waterverbruiksdoeltreffendheid te kwantifiseer. Vier waterbehandelings, volbesproeiing (547 mm), 66% van volbesproeiing (481 mm), 33% van vol besproeiing (417 mm) en droëland (303 mm) asook twee deklaagbehandelings (skoon en 9 t ha^{-1} mielie reste) is toegepas. 'n Lynbronbesproeiingstelsel is ook in dié proef gebruik. Die proefuitleg was 'n verdeelde perseeluitleg met waterbehandeling as hoof behandeling en deklaag as sub-behandeling. Alle behandelingskombinasies is vier keer herhaal. Resultate het getoon dat soetrissies goed reageer op besproeiing. Volbesproeiing, 66% and 33% van volbesproeiing het ’n bemarkbare opbrengs van 37.54, 29.74 en 20.50 t ha^{-1} onderskeidelik gelewer. Die bemarkbare opbrengs van die onderskeie besproeiingsbehandelings het betekenisvol van mekaar verskil en dit was ook betekenisvol hoër as die droëlandbehandeling wat ’n bemarkbare opbrengs van 11.92 t ha^{-1} gelewer het. Soos daar voortgegaan is om te besproei het die verwantskap tussen watergebruik en blaararea-indeks versterk. Die volbesproeiingsbehandeling het die hoogste waterverbruiksdoeltreffendheid getoon. Deklaag het evaporasie verlaag en sodoende water bewaar wat weer die negatiewe effek van waterstremming op plantgroei en opbrengs onder semi-ariede toestande verminder het. Die kumulatiewe waterverbruiksdoeltreffendheideffek van die deklaagbehandeling aan die einde van die seisoen was 6 g m^{-2} mm^{-1} en was betekenisvol hoër as die van die geen deklaagbehandeling (5.3 g m^{-2} mm^{-1}).

Soetrissies is baie gevoelig vir waterstremming en opbrengs is swak onder droëlandtoestande. Enige besproeiing kan voordelig wees vir die produksie van soetrissies. Resultate het ook gewys dat soetrissie plante die vermoë het om te kompeteer vir hulpbronne onder hoë plantpopulasies. Die gewas reageer ook goed op die gunstige groeitoestande wat deur die deklaag geskep is.

Sleutelwoorde: bemarkbare opbrengs, watergebruik, watervebruiksdoeltreffendheid, blaararea-indeks, droëland , volbesproeiing

DECLARATION

I declare that the dissertation hereby submitted by me for the qualification of Masters of Science in Agriculture degree at the University of the Free State, is my own independent work and I have not previously submitted the same work for a qualification at/ in another University/ faculty. I furthermore cede copyright of this dissertation in favour of the University of the Free State.

Signature:.. Date:.....................................

DEDICATION

This dissertation is dedicated to my grandmother,
Agatha Nelago Jacobus Tshilunga, *who taught me that one needs to be educated to succeed in life and did everything in her power to see to it that I attend and complete my primary school.*

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Gervasius Hatutale

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CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

Production of vegetables and other crops in semi-arid areas is hampered by the shortage of water, the major part of the growing season usually being characterized by low, erratic rainfall and high evapotranspiration (ET) rates. Rainfall is therefore not adequate for vegetable production in these regions and necessitates the use of irrigation (Unger, 1995). Irrigation has contributed and will continue to contribute significantly toward large scale food production with an aim of feeding the expanding world population, especially in arid and semi-arid regions. Irrigation permits year-round crop production and reduces the risk of agricultural inputs being wasted by crop failure due to inadequate rainfall (Hillel, 2000). However, arid and semi-arid regions do not have enough water for irrigation. In this regard, water use efficiency (WUE) is crucial and should be promoted (Unger, 1995).

One way to achieve this is through mulching, which involves covering of the soil surface with crop residue(s) or other material such as paper or polyethylene film (Unger, 1995). The use of mulch has become an important cultural practice in commercial production of vegetables in many regions of the world in order to maximise water use by the plant (Lamont, 1993). Several organic and inorganic materials can be used as mulches. Organic mulches include lawn clippings, chopped sorghum and sugar cane leaves. Polyethylene films are good examples of inorganic mulches (Messiaen, 1992). Green pepper is highly susceptible to water stress, especially in the early growth stage (Ertek *et al*., 2007). The combination of polyethylene mulch and drip irrigation provides yield improvement in pepper production (Borosic *et al*., 1998).

Another way of improving water-use efficiency (WUE) is through the correct management of plant population. According to Jolliffe & Gaye (1995) plant population is a major determinant of leaf area index (LAI) in most crops. The leaf area index is the leaf area (upper side only) per unit area of soil below it. Evapotranspiration (ET) and photosynthesis are directly proportional to leaf area index (Fang & Liang, 2008). High green pepper yields can be obtained with management practices such as mulching and selection of appropriate plant populations. Mulch and high plant populations increased the LAI of green peppers already at an early growth stage (Jolliffe & Gaye, 1995). Lorenzo & Castilla (1995) reported that a high LAI at high plant populations (3.2 plants m^{-2}) resulted in improved light interception and, consequently, in higher biomass and yield of green pepper than at low plant populations (2 plants m^{-2}).

1.2 OBJECTIVES

The objectives of this study were therefore to:

(i) optimize green pepper plant population for various water regimes,

(ii) quantify irrigation effect(s) on green pepper production, and

(iii) investigate the influence of mulching on water conservation and growth of green pepper.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Green pepper (*Capsicum annuum*) is a fruit-bearing vegetable that belongs to the Solanaceae family that also includes tomato and eggplant. Green pepper originated from South America (Hadfield, 1993). The crop is generally self-pollinating, although cross-pollination is also common (Delaplane & Mayer, 2000). According to Díaz-Pérez *et al.* (2007), green pepper is a non-climacteric fruit which implies that it does not ripen once harvested unripe.

It is used in fresh salads, to add flavours to dishes and for canning (Olivier *et al*., 1981). On the nutritional part, it is rich in Vitamin C (ascorbic acid) and zinc, the two nutrients which are vital for a strong and healthy immune system. It also has high content of Vitamin A, rutin (a bioflavonoid), ß carotene, iron, calcium and potassium (Agarwal *et al*., 2007).

According to W. Wessels (personal communication)[1] the average fresh yield of green pepper in South Africa ranges between 50-100 t ha^{-1}. According to the Directorate of Agricultural Statistics (2009), the total production of peppers in 2008 amounted to about 34 600 tonnes, providing a revenue of R 188 million at a price of R 5 444 per tonne. The 2009 total production amounted to about 36 200 tonnes, providing a revenue of R 220 million at a price of R 6 100 per tonne.

The objectives of this literature review were to:

(i) obtain information from grey, unpublished and published literature on agronomic production practices for green pepper which was used as baseline information to prepare field experiments,

(ii) extract information from literature on how green pepper growth and yield are affected by irrigation and plant population, and

(iii) extract information from literature on the effects of mulching on soil water conservation and green pepper production.

[1] W. Wessels, 2008. Starke Ayres, P.O. Box 13339, Northmead , 1511.

2.2 GUIDELINES ON AGRONOMIC PRODUCTION PRACTICES FOR GREEN PEPPER

2.2.1 Climatic requirements

Green pepper is a warm-season crop, which performs well under an extended frost-free season, with the potential of producing high yields of outstanding quality. It is very vulnerable to frost and grows poorly at temperatures between 5-15°C (Bosland & Votava, 1999). The optimum temperature range for green pepper growth is 20-25°C (Anon., 2000).

The germination of pepper seed is slow if sown too early when soil temperatures are still too low, but seedling emergence accelerates as temperatures increase to between 24-30°C (Bosland & Votava, 1999). The optimum soil temperature for germination is 29°C (Anon., 2000). Low temperatures also slow down seedling growth which leads to prolonged seedling exposure to insects, diseases, salt or soil crusting, any of which can severely damage or kill the seedlings (Bosland & Votava, 1999).

High temperatures adversely affect the productivity of many plant species including green pepper. Green pepper requires optimum day/night temperatures of 25/21°C during flowering. The exposure of flowers to temperatures as high as 33°C for longer than 120 hours leads to flower abortion and reduced yields. Pollen exposed to high temperatures (>33°C) normally becomes non-viable and appears to be deformed, empty and clumped (Erickson & Markhart, 2002). Temperatures lower than 16°C can lead to fruitless plants (Coertze & Kistner, 1994a). Higher yields are obtained when daily air temperature ranges between 18-32°C during fruit set (Bosland & Votava, 1999). Persistent high relative humidity and temperatures above 35°C reduce fruit set. Fruits that are formed during high temperature conditions are normally deformed. Green peppers are also very sensitive to sunscald (Coertze & Kistner, 1994a). Fruit colour development is hastened by temperatures above 21°C (Bosland & Votava, 1999).

2.2.2 Soil requirements

Green peppers can be grown in a wide range of soils, but prefer well-drained, sandy loam or loam soil with a good water-holding capacity and rich in humus. Soils deeper than 400 mm are required. In shallow soils with a poor drainage capacity, plants can be planted on ridges (Coertze & Kistner, 1994a). Their effective rooting depth is between 400-700 mm. Green peppers prefer soils with a $pH_{(H_2O)}$ range of between 5.5 and 6.8 (Anon., 2000). Agricultural lime should be applied to acidic soils before planting to increase the pH (Coertze & Kistner, 1994a).

Green pepper is known to be fairly sensitive to soil salinity. Green pepper yield can be reduced by 50 percent or more with a soil electrical conductivity (EC) of 5 ds m^{-1}.

Certain nematode species damage pepper roots, which leads to a reduction in yield. Soil samples for nematodes are collected the same way as those for soil nutrient testing (including pH), but must be kept moist (Bosland & Votava, 1999).

2.2.3 Fertilizer requirements

The fertilizer programme for green pepper production depends on the type of soil, the nutrient status and the pH of the soil. It is therefore important to analyse the soil before planting to determine any nutrient deficiency or imbalances (Coertze & Kistner, 1994a). The withdrawal amounts for green pepper are 1.5-3.5 kg N, 0.2-0.4 kg P and 2-4 kg K t^{-1} of fruit harvested (FSSA, 2007).

Nitrogen is important for green pepper plant growth and reproduction. The element is mobile in the soil and leaches easily out of the soil. Split applications of nitrogen are therefore necessary to minimise leaching (FSSA, 2007). On sandy soils, topdressing with lower and more frequent split applications is necessary to reduce the risk of leaching. Excess application of nitrogen promotes too much vegetative growth which leads to large plants with few early fruits. Under high rainfall and humidity conditions, too much nitrogen delays maturity, resulting in succulent late maturing fruits (Bosland & Votava, 1999). Phosphorus plays a role in photosynthesis, growth, respiration and reproduction. It is in particular associated with cell division, root growth, flowering and ripening. Potassium is associated with resistance to drought and cold, and fruit quality. It promotes the formation of proteins, carbohydrates and oils (FSSA, 2007). Phosphorus is applied before planting while potassium fertilizers are usually applied at planting time (Ngeze, 1998). Green pepper is sensitive to calcium deficiency, which normally results in blossom-end rot (Pernezny *et al*., 2003). The crop is also sensitive to deficiency of micronutrients such as zinc, manganese, iron, boron and molybdenum (Portree, 1996).

2.2.4 Cultivars

Many green pepper cultivars are available which ripen to colours of red, orange or yellow. Fresh market cultivars should have thick and succulent walls and should be firm and bright in appearance (Bosland & Votava, 1999). Cultivars for processing should have fruit that are firm, flat (with two locules), smooth, thick-fleshed, bluntly pointed and about 150 mm long and 40 mm wide at the shoulders (Bosland, 1992).

California Wonder 300, the green pepper cultivar used in this research is a popular open pollinated sweet green pepper cultivar suitable for open field production. It reaches maturity approximately 73-75 days after transplanting and colours from green to red when over-ripe. The fruit has a bell shape with mostly four lobes and has a size of about 100 x 100 mm (Anon., 2000). According to W. Wessels (personal communication)[2] the cultivar has an exceptionally smooth skin, attractive appearance and dark green colour. The approximate plant height of this cultivar is 710-810 mm. This cultivar is suitable for both fresh market as well as processing (Anon., 2000).

2.2.5 Irrigation

The amount and frequency of irrigations depends on soil type, bed type, plant size, humidity, wind, sunlight and prevailing temperatures (Bosland & Votava, 1999). Monthly evapotranspiration associated with green pepper production in Bloemfontein is illustrated in Figure 2.1. The graph indicates that December, January and February are the hottest months (higher evapotranspiration) during the growing season, which is also reflected by the greatest amount of water required for green pepper production during the same months (Figure 2.3). The long-term mean monthly rainfall and effective rainfall for the same months are illustrated in Figure 2.2.

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[2] W. Wessels, 2008. Starke Ayres, P.O. Box 13339, Northmead , 1511.

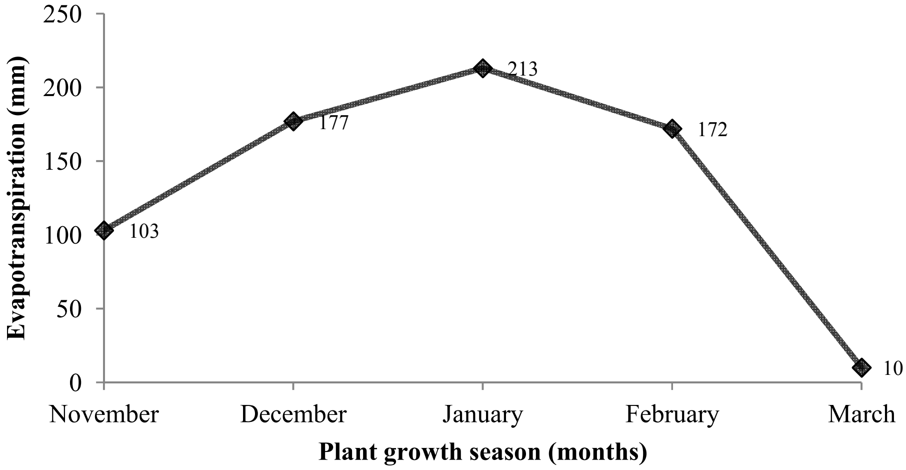

Figure 2.1. Monthly evapotranspiration associated with green pepper production for the growing season in Bloemfontein (Van Heerden *et al*., 2008).

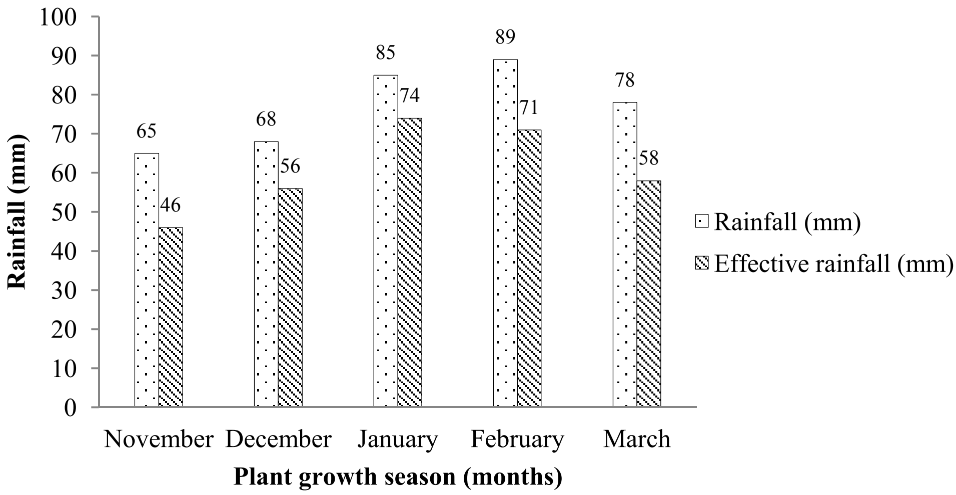

Figure 2.2. Long-term mean monthly rainfall and effective rainfall for the growing season of green pepper in Bloemfontein (Van Heerden *et al*., 2008)

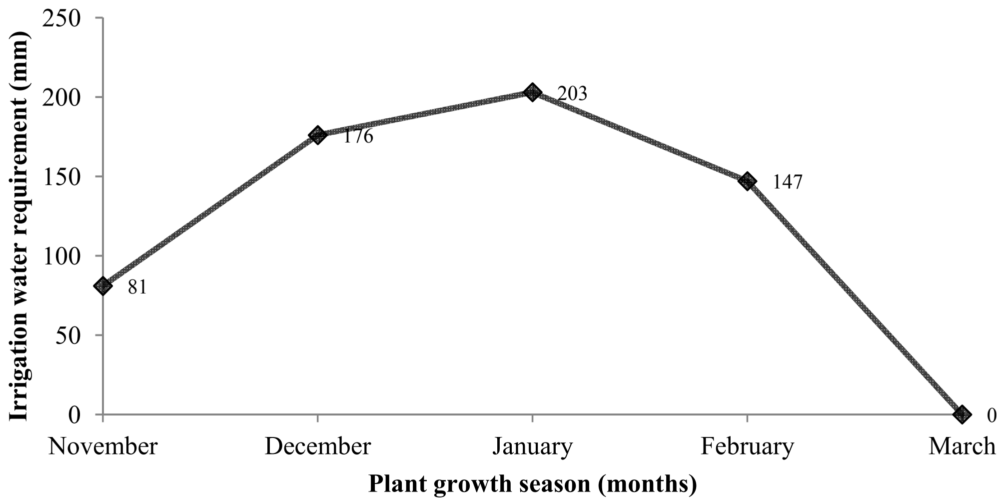

Figure 2.3. Monthly irrigation water requirements for green pepper production over the growing season in Bloemfontein (Van Heerden *et al.*, 2008).

Dry conditions result in premature small sized fruit set which leads to reduced yields (Bosland & Votava, 1999). Green pepper has a total water requirement of about 600 mm and a weekly water requirement of 25 mm during the first five weeks and 35 mm thereafter (Anon., 2000). However, specific water requirements were estimated for the Bloemfontein area using the SAPWAT model (Van Heerden *et al.*, 2008). Accordingly, the crop requires about 607 mm per season (Figure 2.3). The estimated average water requirement is low (2.7 mm day^{-1}) during November, increases to 5.7 mm day^{-1} for December and reaches a peak during January (6.5 mm day^{-1}) and thereafter water use starts to slow down (5.3 mm day^{-1}) during February towards the end of the growing season in March.

Excessive rainfall or water supply can negatively affect flower and fruit formation and eventually lead to fruit rot (Coertze & Kistner, 1994a). Unrestricted water supply to the crop can be as harmful as not enough water. Root rot diseases can be caused by waterlogged conditions that last for more than 12 hours, thus drainage of the field is very important. If plant growth is slowed by water stress during flowering, blossoms and immature fruit are likely to drop (Bosland & Votava, 1999).

Irrigation is essential in arid and semi-arid regions to provide enough water for pepper production (Bosland & Votava, 1999). Furrow irrigation is well-known as a major factor favouring conditions leading to the development of diseases like bacterial wilt (Pernezny e*t* *al*., 2003). Drip irrigation is one method of water application that optimizes water supply for pepper production and conserves water in arid regions. Drip irrigation with cultural practices like mulching generally leads to additional yield increase. Drip irrigation allows for frequent application of low levels of soluble nutrients to the root zone (fertigation). The control over the root environment with drip irrigation is a major advantage over other irrigation systems (Bosland & Votava, 1999). Sprinkler irrigation requires very good quality water and is likely to make bacterial diseases more of a problem through splashing (Grattidge, 1993).

2.2.6 Direct sowing versus transplanting

Green pepper seed may be sown directly in the field, but most commercial farmers in South Africa prefer to transplant seedlings bought from vegetable seedling growers. With direct sowing, laborious and costly activities must be carried out to ensure a good plant stand. Emergence of directly sown peppers is hampered by soil crusts caused by raindrops, which results in poor plant stands. Frequent irrigation prior to emergence solves this problem, but it results in unnecessary increase in water use and production cost (Bosland & Votava, 1999). Direct (in situ) sowing of peppers requires seed of about 2 kg ha^{-1} (Anon., 2000).

Seedlings are produced by sowing seed in seed trays under greenhouse or shade cloth conditions. Pepper seedlings are ready to be transplanted after 6-8 weeks when the seedlings are 150-200 mm tall. Stands established using seedlings are more even and uniform and can achieve earlier maturity than direct-seeded plants. The use of seedlings also reduces thinning cost and can tolerate or escape early unfavourable plant growth conditions (Bosland & Votava, 1999). Seed required to produce enough seedlings for one hectare is 400-800 g (Anon., 2000).

2.2.7 Plant population

Plant population and plant spacing can greatly influence plant development, growth and marketable yield of green pepper. Many studies have been published on the optimum plant population of bell peppers (Bosland & Votava, 1999). Plant population depends on the cultivar used. Green pepper plant population recommended in South Africa is between 20 000 and 55 000 plants ha^{-1} (Anon., 2000).

2.2.8 Mulching

Plastic mulch has been used on peppers since the early 1960's. Some of the advantages of mulches are earlier yield, increased water retention, inhibition of weeds, reduced fertilizer leaching, decreased soil compaction, fruit protection from soil deposits (from splash) and soil micro-organisms and facilitation of fumigation. Plastic mulches are often used in combination with drip irrigation when establishing seedlings. Plastic mulches have been shown to raise soil temperatures and increase fruit quality (Bosland & Votava, 1999). Organic mulches which include lawn clippings, chopped sorghum and sugar cane leaves are also used to improve and increase vegetable production (Messiaen, 1992).

2.2.9 Diseases

Green peppers are susceptible to several diseases and pests which can reduce yield and quality of fruit. Not all the diseases and pests occur in the same region or at the same time. However every region has specific diseases and pests of major importance, reducing pepper yields (Bosland & Votava, 1999). Damping-off, powdery mildew, bacterial spot, bacterial wilt, bacterial soft rot, tobacco mosaic virus and potato virus Y are the major pepper diseases experienced in South Africa (Coertze *et al*., 1994).

Damping-off is caused by *Rhizoctonia solani* and certain *Pythium* species and mainly affects young seedlings (Coertze *et al*., 1994). Symptoms include failure of seedlings to emerge, small seedlings suddenly collapse or are stunted. The development of the disease is enhanced by undecomposed organic matter in the soil and high soil moisture. Seed should be treated with a suitable registered fungicide, nursery beds should be placed on well-drained sites and covered beds should be adequately ventilated to prevent high humidity (Black *et al.*, 1991).

Powdery mildew is caused by *Leveillula taurica* (Coertze *et al*., 1994). The symptoms are chlorotic spots on the upper leaf surface. Numerous lesions may coalesce, causing chlorosis of the leaves. Lower leaf surface lesions develop a necrotic flecking and generally, but not always, are covered with a white to gray powdery growth. It progresses from older to younger leaves and leaf shedding is a prominent symptom. The disease is promoted by warm weather (dry and humid). Fungicides are used to manage the disease during periods of heavy disease pressure (Black *et al.*, 1991).

Bacterial spot is caused by *Xanthomonas campestris* pv. *vesicatoria.* Symptoms are circular, water-soaked spots which become necrotic with brown centres and thin chlorotic borders. Enlarged spots may develop straw-coloured centres. Generally, lesions are slightly sunken on the upper leaf surface and slightly raised on the lower surface. Severely spotted leaves turn yellow and drop. Fruit symptoms occur as raised, brown lesions, wart-like in appearance. Narrow, elongated lesions or streaks may develop on stems. The disease is enhanced by warm, rainy weather and sprinkler irrigation. Clean seed and crop rotation can help manage the disease. Copper sprays reduce the rate of disease development (Black *et al.*, 1991).

Bacterial wilt is caused by *Pseudomonas solanacearum.* The initial symptom in older plants is slight wilting of lower leaves, but upper leaves wilt first in young seedlings. Initial wilting is followed by a sudden, permanent wilt of the entire plant with only slight or no leaf yellowing. It is promoted by relatively high rainfall coupled with warm weather. Crop rotation with non-solanaceous crops helps in managing the disease (Black *et al.*, 1991).

Bacterial soft rot is caused by *Erwinia carotovora* subsp. *carotovora* (Coertze *et al*., 1994). Soft rot begins in the peduncle and calyx tissues of harvested fruit, but infection can occur through wounds on the fruit. Internal tissue near the infection site softens and the expanding lesion reduces the fruit interior to a watery mass. Fruit infected on the plant collapse and hang on the plant like a water-filled bag and when the contents leak out, a dry shell of the fruit is left behind. The disease is serious during rainy periods since the bacteria are splashed from the soil onto the fruit. The decay can be reduced by harvesting dry fruit, reducing injury during handling and controlling insects that cause injury to fruit (Black *et al.*, 1991).

Tobacco mosaic virus (TMV) is a member of the genus *Tobamovirus* (Pernezny *et al*., 2003). Symptoms include mosaic, stunting, systemic chlorosis and, at times, systemic necrosis and leaf drop. It can be eliminated from seed coats by soaking seed in a 10% solution of trisodium phosphate for two hours (Black *et al.*, 1991). The virus can spread widely when peppers are field-grown from transplants or are handled frequently (Pernezny *et al*., 2003).

Potato virus Y (PVY) is the member of the genus *Potyvirus* in the family Potyviridae (Pernezny *et al*., 2003). Mosaic and dark green vein-banding are the most distinctive symptoms. Leaf crinkle, leaf distortion, and plant stunting are also commonly observed. The virus occurs worldwide and it is more prevalent in warmer climates. The use of cultivars resistant to the virus is the best way to manage it (Black *et al.*, 1991).

2.2.10 Physiological disorders

Blossom-end rot and sunscald are the problematic pepper physiological disorders experienced in South Africa (Coertze *et al*., 1994). **Blossom-end rot** is a non-infectious, physiological disorder caused by calcium deficiency in the blossom end of the developing pepper fruit. The disorder is worsened by any factor that reduces the uptake of calcium by the plant. One such factor is water availability. Fluctuations in water availability, even for short periods can result in deficiency symptoms. The symptom first appears as a small, water-soaked, light brown spot on the distal end of a developing fruit. As the fruit grows, the spot enlarges until it covers as much as half the fruit. Over time, the lesion becomes sunken and leathery and ultimately may appear straw-coloured and papery. Fungi and bacteria may invade the weakened tissue, causing it to turn black or appear watery. It is controlled with proper water and fertilizer management. Sufficient but not excessive amounts of water and fertilizer should be provided throughout the growing season. A preplant soil analysis is recommended to determine the level of calcium in the soil (Pernezny *et al*., 2003).

Sunscald occurs on pepper fruit that is directly exposed to intense sunlight. The exposed tissues may become so hot that they become damaged. It is most common on plants with little foliage cover, especially those that are inadequately fertilized with nitrogen. Alternatively, pepper plants may become top-heavy with fruit and branches may break or fall over in a rainstorm, exposing fruit to the sun. Such breakage can also occur when branches are handled too roughly during harvest (Pernezny *et al*., 2003).

Sunscald also occurs on foliage exposed to intense sunlight at high temperatures. It also causes sunken, dead areas to form on fruit, on the side exposed to the sun. Affected areas are light-coloured, soft, and wrinkled. The damaged tissue eventually turns whitish tan in colour and papery in texture. Affected areas are frequently white but may be discoloured if they become infected by fungi. Fruit symptoms are easily confused with those of blossom-end rot, except that sunscald will only occur on the side of the fruit exposed to the sun, whereas blossom-end rot lesions may form on unexposed areas. To help develop an adequate foliage cover over the fruit, adequate levels of nutrients, particularly nitrogen, are essential.

Avoidance of drought stress, through proper irrigation management promotes good leaf production. Plants can be supported with stakes or horizontal wires or strings running along the rows (Pernezny *et al*., 2003).

2.2.11 Insects

The main green pepper insect pests are various aphid species, broad mites and thrips (Pernezny *et al*., 2003). Certain nematode species also cause serious problems on green peppers (Coertze *et al*., 1994). **Aphid** feeding injuries include distortion and mottling of young leaves which become cupped due to downward curling of the leaf margins. Chlorotic spots may occur on the leaves in association with feeding injury. High populations can cause a general chlorosis and leaf drop resulting in sunscald and/ or reduced fruit size. Aphids secrete honeydew which serves as a substrate for the growth of gray-black sooty mould on foliage and fruit surfaces (Black *et al.*, 1991). Cultural control of weeds and crop residues can reduce aphid populations. Certain pesticides are effective in controlling particular species of aphids (Pernezny *et al*., 2003).

Mite feeding injuries are expressed as downward curling of leaves, giving an inverted spoon shape; and suppression of lamina development of young leaves causing them to become narrow. Affected leaves develop a bronze appearance especially on the lower side, become thickened and brittle. Heavy infestation kills apical meristems. Fruit develop a russeted, corky surface and may be distorted (Black *et al.*, 1991). Weeds, e.g. nightshade that serve as hosts for the mites, should be controlled to reduce infestation. Several insecticides and miticides provide effective control of broad mites (Pernezny *et al*., 2003).

Thrips feeding injuries include distortion and upward curling of leaves, developing a boat-shaped appearance. The leaves become crinkled and lamina may be reduced resulting in narrow new leaves. The lower surface of the leaves develops a silvery sheen that later turns bronze, especially near the veins. Damaged fruits are distorted with a network of russeted streaks (Black *et al.*, 1991). The control measures include the use of resistant cultivars and mulching with plastic (Pernezny *et al*., 2003).

Root-knot nematodes are by far the most serious nematode affecting pepper (Pernezny *et al*., 2003). The aboveground symptoms may include stunting, yellowing, wilting and lack of vigour. Root systems are diminished in size and develop small knots or galls (Black *et al.*, 1991). The use of resistant cultivars may be the convenient means of managing root-knot nematodes. Spray, fumigant and granular nematicides can be effective in nematode control. A number of cultural practices such as sanitation, soil solarisation and crop rotation may also be helpful in controlling root-knot nematodes in pepper crops (Pernezny *et al*., 2003).

2.2.12 Weeds

Since tomatoes and green peppers are from the same family, it is believed that the weeds associated with tomatoes are also associated with green peppers and the same applies to the herbicides. Therefore the herbicides used to control weeds in tomatoes can also be used for peppers (Anon., 2004a) as indicated in Table 2.1.

Table 2.1 Herbicides registered in South Africa on green pepper to control different weeds (Anon., 2004a)

Herbicides	Types of weeds
Cycloxydim	Annual and perennial grasses
Haloxyfop- R- methyl ester	Annual and perennial grasses
Metribuzin	Annual grasses and broad-leaved weeds
Rimsulfuron	Annual grasses and broad-leaved weeds
Sethoxydim	Certain annual grasses and broad-leaved weeds
Trifluralin	Annual grasses and certain broad-leaved weeds

2.2.13 Harvesting and handling

According to W. Wessels (personal communication)[3] a green pepper yield between 50 to 100 tons ha^{-1} can be obtained in South Africa, depending on the cultivar grown. Fruit size depends also on the season and on night temperatures (Coertze & Kistner, 1994b). Since green peppers are sensitive to bruising and have weak plants, many producers prefer hand harvesting. Hand-picked fruits are of a higher quality because mouldy, under-ripe, over-ripe and damaged fruit can immediately be discarded. Fruits are also much cleaner and fewer leaves and stems are inadvertently picked during harvesting. Due to less damage of the fruit, there is an increased yield per unit area of marketable fruits of better quality (Bosland & Votava, 1999). Green fruit are harvested as soon as they reach their maximum size, which differs from cultivar to

[3] W. Wessels, 2008. Starke Ayres, P.O. Box 13339, Northmead , 1511.

cultivar. The coloured (red, yellow or orange) cultivars are picked just after attaining their full colour. Peppers have a harvest period of about 45 days (Anon., 2000). Machine-harvesters cause more damage to plants than hand harvesting and plants also take longer to recover and set fruit again (Bosland & Votava, 1999).

Postharvest handling of peppers is very important. Whether the pepper is used as a fresh or processed commodity, appropriate postharvest handling is vital for the product to maintain quality. Peppers harvested during summer time can have a pulp temperature of 32°C or more. Peppers should therefore be harvested early in the morning, placed in the shade and cooled as soon as possible. Failure to do that within 1-2 hours will result in water loss and softening of the fruit. Temperatures above 21°C speed up the ripening process through respiration and ethylene production. Refrigeration extends the shelf-life of pepper by decreasing respiration, water loss, colour change and the development of postharvest diseases. Peppers can be stored for 2-3 weeks at 7-10°C, with a relative humidity of 85-90% (Bosland & Votava, 1999).

2.3 EFFECT OF IRRIGATION AND PLANT POPULATION ON GREEN PEPPER GROWTH AND YIELD

Plant population and layout can have an evident influence on plant development, growth, and marketable yield of many vegetable crops including green pepper (Stoffella & Bryan, 1988). The relationship between plant population and growth can be complicated since growth is a function of the plant genotype (Lower *et al*., 1983). The closeness of neighbouring plants affects their interactions within the root and shoot micro-environments. If such interactions happen to be competitive or allelopathic, plant growth and development might be affected (Winders & Price, 1989). Optimum plant population of a crop should be lower under inadequate soil water conditions. The opposite is also true, plant population can be higher under well watered conditions (Oosthuizen, 1997). Sundstrom *et al.* (1984) reported an increase in the yield of mechanically harvested tabasco pepper (*Capsicum frutescens*) when the intra-row spacing was decreased from 810 mm (8 200 plants ha^{-1}) to 100 mm (65 000 plants ha^{-1}).

Stoffella & Bryan (1988) studied the influence of plant population and arrangement on the growth and yield of green pepper in southern Florida during the winter of 1983 and spring of 1984. Populations ranged from 21 500 to 258 000 plants ha^{-1}. Marketable fruit yield ha^{-1}

increased linearly in response to higher plant populations. However, marketable fruit number and mass per plant decreased with higher plant populations, whereas fruit size (g fruit^{-1}) was unaffected. The higher marketable yield ha^{-1} at higher plant populations was attributed to more plants with less of the same sized fruit per plant. A plant population of 86 000 plants ha^{-1} was therefore recommended for green peppers.

Agarwal *et al*. (2007) investigated the influence of plant population on the productivity of green pepper (*Capsicum annuum* L.) in a greenhouse under full irrigation. Different populations (50 000, 62 500, 83 333, 100 000, 111 111, 160 000 and 200 000 plants ha^{-1}) were planted per bed with four rows per bed. Fruit number and yield per plant decreased when plant population increased from 50 000 to 200 000 plants ha^{-1}. Total fruit yield per hectare increased with an increase in plant population up to 120 000 plants ha^{-1} and thereafter it decreased (Figure 2.4), as was the marketable fruit yield. Individual fruit mass was however not influenced up to a plant population of 120 000 plants ha^{-1} but decreased fast beyond this plant population. The increase in fruit number per plant and individual fruit mass as a result of increased plant population may be ascribed to better utilization of available natural resources such as light and nutrients. Plant populations in the range of 100 000 to 120 000 plants ha^{-1} were optimum in terms of yield and quality.

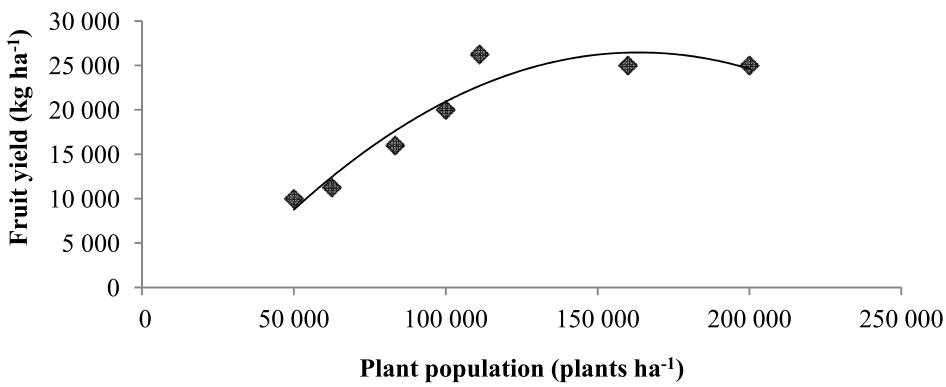

Figure 2.4. Effect of plant population on fruit yield of green pepper (Agarwal *et al.*, 2007).

The response of bell pepper to plant population was studied by Batal & Smittle (1981). Three different plant populations with four plant spacings namely: 27 000 plants ha^{-1}(two plant rows

900 mm apart with intra-row spacing of 410 mm); 40 000 plants ha^{-1} (two plant rows 900 mm apart with intra-row spacing of 280 mm and three plant rows 450 mm apart with intra-row spacing of 410 mm); and 60 000 plants ha^{-1} (three plant rows 450 mm apart with within-row spacing of 280 mm) were investigated. Two irrigation treatments were also included namely: applications of 6.5 mm water at 25 kPa soil water tension and 13 mm water at 50 kPa soil water tension.

The interaction between irrigation and plant population did not have any significant effect on the yield. The total marketable yield was increased as plant populations increased beyond 27 000 plants ha^{-1}. An increase in plant population from 40 000 to 60 000 plants ha^{-1} did not lead to any significant increase in yield. Results indicated that the total plant population per unit area has a greater effect on pepper yield as compared to planting arrangement. Irrigation also significantly increased green pepper yield. Under inadequate soil water conditions, irrigation increased yield by increasing fruit set and size and reducing the amount of unmarketable fruit.

Lorenzo & Castilla (1995) determined the influence of plant population on green pepper growth and yield in a low-cost unheated plastic greenhouse under full irrigation. The total marketable and first grade green pepper yield were significantly higher in the high (3.2 plants m^{-2}) plant population than in the low (2 plants m^{-2}) plant population (Table 2.2). A larger leaf area index (LAI) under a high plant population resulted in improved light interception and, consequently, in higher biomass and yield than in the low plant populations.

Table 2.2. Total, commercial and first grade yield (kg m^{-2}), leaf area index (LAI) and total biomass (g m^{-2}) of green pepper as influenced by plant population (Lorenzo & Castilla, 1995).

Parameters	**Plant population (plants m^{-2})**	
	2	**3.2**
Total yield	4.78A	6.13B
Commercial yield	4.39A	5.68B
First grade yield	3.04A	3.82B
LAI	3.39a	5.01a
Biomass	1.044A	1.29B

Values within rows followed by different letters are significantly different at P = 0.05 (small letters) or P = 0.01 (capital letters).

Tan & Dhanvantari (1985) studied the effect of irrigation and plant population on yield of processing tomatoes using two cultivars (Heinz-2653 and Campbell-28). Plant population treatments were 10 765, 21 527 and 43 054 plants ha^{-1} for Heinz and 10 765 and 21 527 plants ha^{-1} for Campbell. Irrigation treatments were: (a) no supplemental irrigation, (b) irrigation during the growing season preventing available soil water from falling below the 25% level, (c) irrigation during the growing season preventing available soil water from falling below the 50% level, (d) no supplemental irrigation from planting date to one month before harvest, and thereafter supplemental irrigation at 50% available soil water level until harvesting and (e) supplemental irrigation at the 50% available soil water from planting date to one month before harvest and no supplemental irrigation thereafter until harvesting.

The yield of Heinz at the highest plant population (43 054 plants ha^{-1}) was 80% higher than the lowest population (10 765 plants ha^{-1}) under rain-fed conditions. With irrigation, the yield of the highest plant population (43 054 plants ha^{-1}) was 89 and 27% higher than the lowest (10 765 plants ha^{-1}) and medium (21 527 plants ha^{-1}) populations, respectively. The lowest plant population yielded 50% less than the medium plant population. The highest marketable yield for Heinz was obtained where more than 25% soil water was available in combination with a high plant population (43 054 plants ha^{-1}). The highest marketable yield for Campbell was obtained at 50% available soil water and a population of 21 527 plants ha^{-1}. This was 110% higher than the yield obtained under rain-fed conditions and a plant population of 21 527 plants ha^{-1}. The marketable yield was 60% without irrigation in a dry year, but it increased to over 80% with irrigation in the same year.

In an experiment carried out by Jolliffe & Gaye (1995) consisting of three trials with five plant populations (1.4, 1.9, 2.8, 5.6 and 11.1 plants m^{-2}) and different row covers, the total and marketable fresh green pepper yield displayed a linear increase with an increase in plant population (Table 2.3). Plant population also significantly influenced fruit dry mass per unit area from 76 days after transplanting onward. As much as 47% of total yield difference was attributed to population effects.

Table 2.3. Effect of row cover and plant population on cumulative fresh fruit yield of green pepper (Jolliffe & Gaye, 1995).

Treatment	Marketable yield (kg m^{-2})			Total yield (kg m^{-2})		
	Trial					
	1	2	3	1	2	3
Row covers						
Not covered	4.81	4.92	4.28	5.64	5.85	6.64
Covered	6.14	5.66	5.37	7.76	7.37	9
Population (plant m^{-2})						
11.1	7.46	7.48	7.09	9.33	9.56	11.61
5.6	6.1	5.87	5.99	7.8	7.71	9.71
2.8	5.29	4.74	4.25	6.48	5.94	6.93
1.9	4.84	4.69	3.6	5.43	5.46	5.82
1.4	3.68	3.66	3.19	4.43	4.39	5.01
Significance						
Row covers (C)	ns	ns	ns	*	*	*
Population (D)	L***	L***	L***Q*	L***	L***	L***Q*
C X D	ns	ns	ns	ns	ns	ns
SE	0.29	0.2	0.28	0.35	0.23	0.4

ns= not significant; *P<0.05; ***P<0.001; L and Q denote linear and quadratic effects, respectively.

2.4 EFFECT OF MULCHING ON SOIL WATER CONSERVATION AND GREEN PEPPER PRODUCTION

According to Unger (1995), mulching is defined as the soil surface application of any material that was grown and maintained in place, grown, but modified before placement, or processed or manufactured and transported before placement. Pickering *et al*. (1998) defined mulch as any material which, when spread on the ground, has a modifying influence on the characteristics of the underlying soil.

Mulching with organic and inorganic materials has several benefits which include: soil water conservation (Fraedrich & Ham, 1982; Unger, 1995; Schonbeck & Evanylo, 1998; Agele *et al*., 2000), regulation of soil temperatures (Ashworth & Harrison, 1983; Gupta & Gupta, 1983; Agele *et al*., 2000) and reduced crop-weed competition attributed to weed suppression and consequently increased crop production (Gupta & Gupta, 1983; Roe *et al*., 1993; Unger, 1995; Hendrickson, 1997; Schonbeck & Evanylo, 1998). Mulching has an influence on various aspects of soil environments and crop requirements. Mulches improve many soil properties and conditions, either directly or indirectly. These improvements include increased soil water content through runoff control, increased infiltration, decreased evaporation, increased soil nutrients through organic matter additions, improved soil structure and salinity. Soil water content, temperature, structure and salinity are probably the most important aspects associated with agriculture in semi-arid and arid regions. Beneficial effects of surface mulches on soil structure result primarily from mulches absorbing the energy of falling raindrops, thus reducing soil dispersion and surface sealing. Infiltration rates are therefore maintained and subsequent crusting is reduced. Since salts readily move with soil water, a practice that maintains infiltration rates and reduces subsequent evaporation should control the undesirable effects of soil salinity (Unger, 1995).

Kirnack *et al*. (2003) investigated the effects of mulch and different water regimes on green pepper. Four treatment combinations namely: bare soil and water stressed (WS); bare soil and unstressed (control); black polyethylene mulch and water stressed (BPM + WS) were investigated. Fruit yield, fruit mass, fruit number per plant and water use efficiency (WUE) were significantly reduced by water stress as compared to the control. They also found that green pepper's water use efficiency was significantly reduced by water stress as compared to the combination of water stress and black polyethylene treatments. The water stress and black polyethylene treatment had the highest plant water use efficiency and was significantly better than the control and the water stressed treatments.

Borosic *et al.* (1998) investigated the effects of mulching and irrigation systems on the growth of green pepper in the Mediterranean part of Croatia. Two irrigation systems (drip and sprinkler irrigation) and four mulch treatments namely: black polyethylene film, photodegradable transparent polyethylene film, biodegradable paper; and no mulch (control), were used. Sprinkler irrigation and mulching (black and transparent film) yielded about 2 to 5.5 times more fruits than the control. Drip irrigation without mulching and with mulching (black and transparent film) increased fruit number by about 4.5 and 5 to 13 times, respectively. Marketable fruit yield ranged from 29.27 t ha^{-1} (without mulching and with sprinkler irrigation) to 55.37 t ha^{-1} (mulching with black film and drip irrigation). Through mulching, higher average pepper yields were achieved with 5 to 74% in comparison with the control.

Agele *et al*. (2000) studied the effect of tillage and mulching on the performance of post-rainy season tomato in the humid, south of Nigeria. They indicated that soil temperature reduction and improved soil water content were the factors responsible for increased tomato yield as a result of mulching. The data collected over three years were averaged and the means are presented in Table 2.4 and Figures 2.5 and 2.6.

Table 2.4 Effect of mulching on some growth and yield parameters of late-season tomato (Agele *et al.*, 2000).

Plant parameters	Treatments		SE
	Bare ground	Grass mulch	
Fanal plant height (cm)	41.9	34.5	2.5
Root dry weight at final harvest (g)	10.5	12.7	0.7
Shoot dry weight at final harvest (g)	112.4	127.2	0.3
Root:shoot	0.09	0.1	0.05
Leaf area plant^{-1} at 50% flowering date (m^2)	0.1	0.19	0.02
Days to first flowering	50	53.7	1.2
Days to first fruit harvest	87.2	96.3	1.8
Percent fruit set	26.1	29.3	1.3
Number of fruits plant^{-1}	17.4	23.2	1.7
Fruit yield (t ha^{-1})	5.2	7.9	0.7
Harvest index	0.57	0.65	0.02

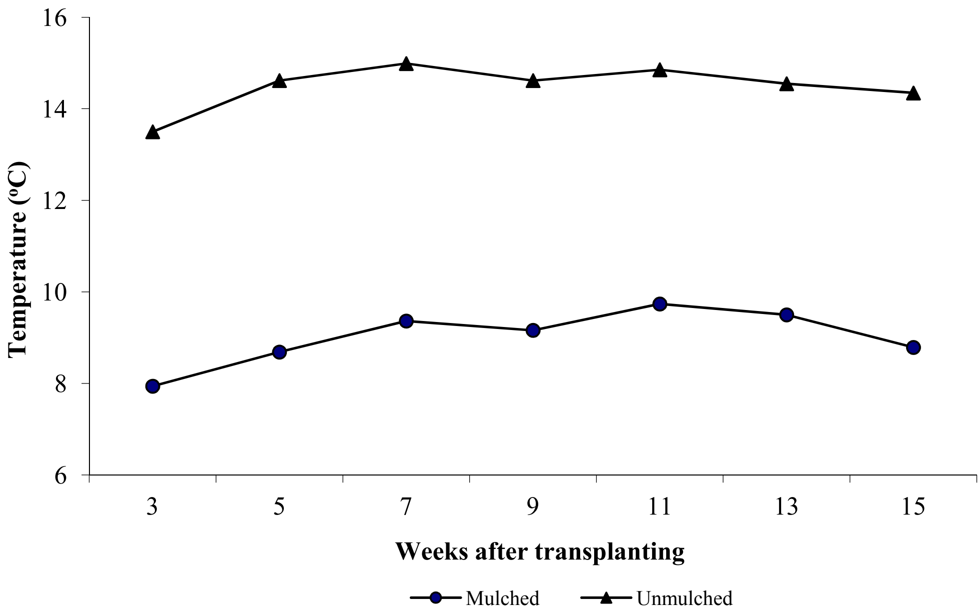

Figure 2.5 Effect of mulching on the soil temperature at 5 cm depth (Agele *et al.*, 2000).

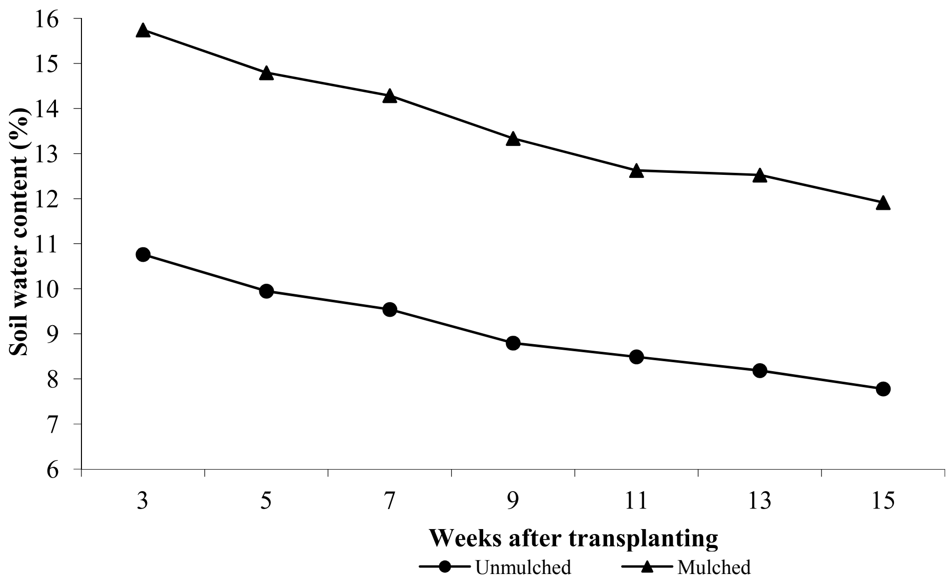

Figure 2.6. Effect of mulching on the soil water content at 10 cm depth (Agele *et al.*, 2000).

Mulching significantly improved the growth and yield performance of tomato compared to no mulch (Table 2.4). Application of grass mulch significantly increased shoot dry mass, leaf area, flowering, fruit set and fruit yield. This observation may be attributed to the favourable soil temperature and soil water status created by mulching. Higher soil temperature and lower soil water content in bare ground could have adversely affected tomato yield due to increased fruit abortion, inadequate photosynthate supply during fruit set and increased intensities of soil water deficits late in the season. Mulching also prolonged the growth period by delaying the onset of flowering and harvesting of tomatoes by 4 and 9 days, respectively. Shorter growth season (increased earliness) in the bare ground treatment was related to a low soil water status and this agrees with findings in terminal drought situations. Early maturity in crops increases the likelihood of water availability for the completion of the reproductive growth before the onset of drought-induced senescence (Agele *et al.,* 2000).

Gupta & Gupta (1983) studied the usefulness of grass mulch in improving the yield of legumes in one of the arid areas of Western Rajasthan, India. In this region, grain legumes such as green gram (*Vigna radiata*), dew gram (*Phaseolus aconitifolius*) and cluster bean (*Cyamopsis tetragonoloba*) are grown during the rainy season, but the rain is generally low and erratic. The temperatures are high and the humidity is low leading to high evaporative demand of the atmosphere. Soil temperatures often rise as high as 50-55°C in the upper root zone and seriously affect root growth. This in turn adversely affects the growth and yield of crops. Grass mulch treatments were 0, 3, 6, 9 and 12 t ha^{-1}.

With increasing amounts of mulch there was a decrease in maximum soil temperature. High differences in soil temperature were only observed between 0 and 6 t ha^{-1} of mulch. Root growth improvement occured only from 0 up to 9 t ha^{-1} of mulching material. There was an increase in leaf area and plant height (40 days after sowing) as the mulching material increased from 0 to 9 t ha^{-1} (Figures 2.7 & 2.8). Mulching increased the dry matter and grain yield of green gram, dew gram and cluster bean (Table 2.5). Application of grass mulch up to the rate of 9 t ha^{-1} increased crop yields. Raising the mulch rate from 9 t ha^{-1} to 12 t ha^{-1} did not bring about a further increase in yield. On the contrary, in certain cases it decreased yields. This might be due to the delay in the maturity of the crops (Gupta & Gupta, 1983).

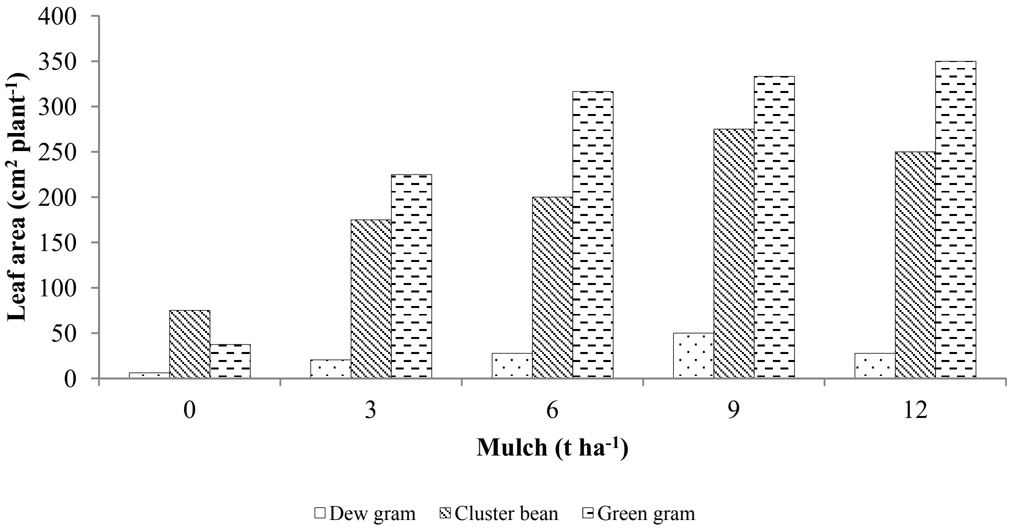

Figure 2.7 Effect of mulching on leaf area of three grain legumes at 40 days (active growing stage) after sowing (Gupta & Gupta, 1983).

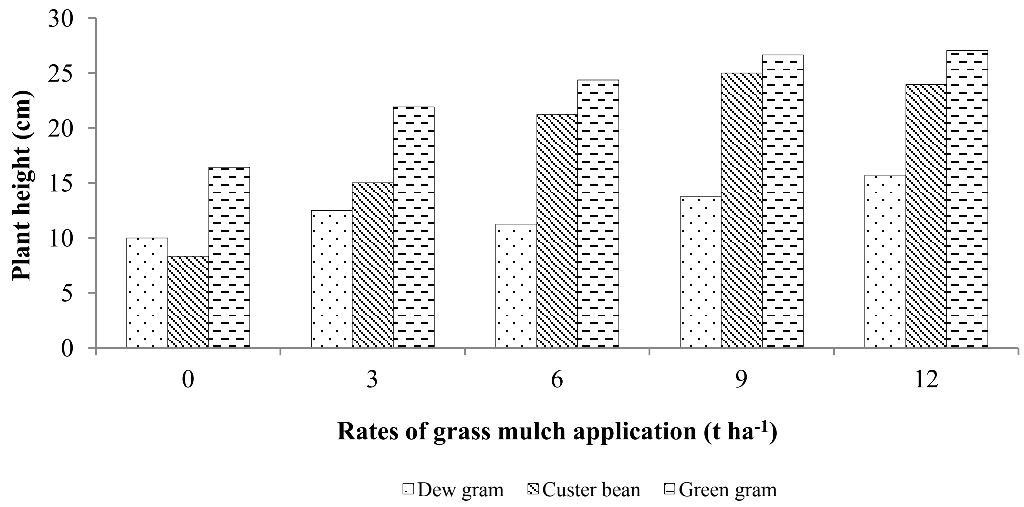

Figure 2.8 Effect of mulching on plant height of three grain legumes at 40 days (active growing stage) after sowing (Gupta & Gupta, 1983).

Table 2.5 Effect of different rates of grass mulch application on the growth and yield of three grain legumes (Gupta & Gupta, 1983).

Rates of grass mulch application (t ha^{-1})	1981 Dry matter yield (kg ha^{-1})			Grain yield (kg ha^{-1})					
				Green gram		Dew gram		Cluster bean	
	Green gram	Dew gram	Cluster bean	1981	1980	1981	1980	1981	1980
0	170	550	1210	40	240	170	260	620	510
3	640	750	1030	230	350	290	310	620	540
6	1060	1120	1660	350	440	410	390	650	650
9	1480	1350	1800	490	480	520	330	730	600
12	1640	1110	1770	560	360	410	290	890	560
LSD$_{(T<=0.05)}$	**350**	**370**	**ns**	**150**	**60**	**210**	**30**	**ns**	**50**

ns = not significant

2.5 CONCLUSION

Most of the literature in this line of study on green pepper investigated the effect of plant population on the crop without using irrigation as a treatment. The crops were either fully irrigated or rain fed. More research still needs to be carried out on the effect of different water regimes (using one irrigation system that supplies different water treatments) and plant population on green pepper production, especially in semi-arid regions. Little information is also available on the effect of irrigation and mulching on green pepper production in semi-arid climate zones, an area that is imperative for year round vegetable production and soil water conservation.

CHAPTER 3

INFLUENCE OF WATER APPLICATION AND PLANT POPULATION ON YIELD OF GREEN PEPPER

3.1 INTRODUCTION

In order for green pepper production to be economically sustainable, it is important not only to produce high yields but also fruit of good quality. This can be achieved by optimizing photosynthesis through management of various aspects such as fertilization, plant population and irrigation. According to Meyer *et al*. (1973), photosynthesis is a carbohydrate synthesis process, where light, water and carbon dioxide are used as raw materials and oxygen is released. The yield of green pepper is determined by the quantity of light absorbed by its leaves while harvestable dry matter is being produced and the efficiency with which the absorbed light is converted by photosynthesis into sucrose (Brewster, 1994). Sucrose is the main form of carbohydrate transported to the fruit where one part remains in a sucrose form and the other is converted to starch in unripe green pepper fruit (Nielsen *et al*., 1991).

As leaf area index (LAI) of a crop increases under high plant populations, light interception improves and consequently increases photosynthesis, resulting in a higher biomass and yield (Lorenzo & Castilla, 1995). However, Meyer e*t al*. (1973) also reported that under very high plant populations, leaves overlap and thereby shading each other, causing inadequate light interception and a decrease in photosynthesis. Low plant populations or any other factor such as pests, diseases and hail causing a low leaf area index, decrease the efficiency of light absorption and photosynthesis (Brewster, 1994).

According to Stoffella & Bryan (1988), marketable green pepper yield increased linearly in response to increased plant populations (21 500 to 258 000 plants ha^{-1}) while fruit size was unaffected. However, the number of marketable fruit and fruit mass per plant decreased as plant population increased. Agarwal *et al*. (2007) reported that a green pepper plant population of 120 000 plants per hectare resulted in the highest marketable fruit yield but fruit mass was not influenced. With a further increase in plant population both green pepper fruit mass and yield decreased significantly. Jolliffe & Gaye (1995) also reported that leaf area, leaf dry mass and shoot dry mass of green pepper were significantly decreased by increased plant populations. High plant populations decreased the photosynthetic rate per unit leaf area.

Light may also have an indirect effect on photosynthesis. Low light intensities favour stomata closure and thus a decrease in carbon dioxide absorption that influences photosynthesis negatively. On the other hand, high light intensities can increase transpiration rate that will reduce plant water content. A negative water potential in leaf cells will then occur, that can result in a decreased photosynthetic rate (Meyer *et al*., 1973).

Reduced photosynthetic rates have been observed in water-deficient soils which is the result of stomata closure. A water deficit in a plant causes the stomata to close, a strategy used to reduce plant water loss through transpiration, thereby causing a decrease in the absorption of carbon dioxide (Devlin & Witham, 1983). The desiccation of leaf tissues of plants growing in water-deficient soils not only inhibits the synthesis of chlorophyll but appears to accelerate the disintegration of the already present chlorophyll and this may have a detrimental effect on photosynthesis (Meyer *et al*., 1973). The flow of water through the plant induced by transpiration provides a transport system for mineral nutrients from the soil. The constant removal of water from the soil has the effect of mobilizing soil nutrients and transporting them to the roots. As a result the plants absorb nutrients from a large volume of soil without the need for the roots to grow extensively. Another beneficial effect of transpiration is that it effectively cools the leaves (Bidwell, 1979).

About 26% of the world's total cultivable land falls in arid and semi-arid areas where water is a limiting factor for crop production (Paylore & Greenwell, 1979). The remaining land also experiences occasional droughts during the cropping season and the obtained yield is less than the potential, unless irrigation is applied. However, it is not possible to irrigate all the land due to insufficient irrigation water (Gupta, 1997). According to Oosthuizen (1997) a lower plant population should be planted under inadequate soil water conditions. The opposite is applicable that a higher plant population can be planted under unlimited soil water conditions.

Quality of green pepper fruit depends on the proportion of photosynthetic output (sucrose) transferred to the fruit (Brewster, 1994), where part of it is converted into starch in unripe green pepper fruit and stored as hexoses (glucose and fructose) in ripe fruit (Nielsen *et al*., 1991). During storage after harvesting, mass losses occur due to respiration and decay. For a high yield of good quality green pepper fruits to be obtained, plant population needs to be optimized and water must be adequately supplied. The objective of this study is therefore to optimize green pepper plant population for various water regimes.

3.2 MATERIALS and METHODS

3.2.1 Experimental site

The research was conducted at Kenilworth Experimental Farm near Bloemfontein using a line source sprinkler irrigation system described by Hanks *et al*. (1976). The trial was carried out on a soil classified as Bainsvlei form of the Amalia family (Soil Classification Working Group, 1991). It occurs on the footslope and has a regular, northern slope of less than 1%. Several morphological characteristics (Van Rensburg, 1996) and chemical characteristics of this deep, apedal, eutrophic soil are summarized in Table 3.1. The silt-plus-clay content increase gradually over depth from 13% in Ap horizon to about 30% at 2 m in the C-horizon. Generally, the soil has a high infiltration and good internal drainage. Several irrigation studies on crops were conducted on the soil. Reports indicated that the soil can be regarded as a high potential soil, with no apparent soil physical, chemical and biological constraints.

3.2.2 Treatments and experimental layout

Water treatments: With the line source sprinkler irrigation system the water application rate decreases approximately linearly at 90^{o} to the line source (water pipe), on both sides of it. Rain Bird sprinklers were attached on 1.5 m high risers (pipe diameter = 20 mm) at 6 m intervals on the water supply pipe (50 mm diameter). The operating pressure was set at 350 kPa throughout the season. It is recommended to irrigate at wind speeds lower than 3 m s^{-1}, but this was not always possible. The lateral distances at 90^{o} from the 50 mm supply pipe were 13.13 m (W_4), 8.87 m (W_3), 5.75 m (W_2) and 2.63 m (W_1), respectively. The dryland (W_4) treatment only received rain (303 mm).

Table 3.1 Some morphological and chemical characteristics of the Bainsvlei Amalia soil.

Morphological characteristics	Horizon*			
	Ap	B1	B2	C
Depth (m)	0-0.35	0.35-1.18	1.18-1.40	1.40-3.00
Texture class	Fine sand	Fine sandy loam	Fine sandy clay loam	Fine sandy clay loam
Structure	Apedal, massive	Course, weak, prismatic	Apedal, massive	Strong course angular blocky
Colour	Red brown (5YR4/4)	Red brown (5YR5/6)	Brown (10YR4/6)	Yellow orange (10YR6/4)
Chemical characteristics				
P(Bray 1) (mg kg^{-1})	7.8	2.4	2.1	1.8
Ca (NH_4OAc)(mg kg^{-1})	112	68	422	564
Mg (NH_4OAc)(mg kg^{-1})	98	60	298	318
K (NH_4OAc)(mg kg^{-1})	70	27	106	164
pH (H_2O)	6.2	6.5	5.9	5.7

***Ap= Orthic A, B1=Red apedal B, B2=Soft plinthic B, C=Weathered mudstone**

Water applications were measured with rain gauges, which were installed just above the canopy in all water treatments. The total irrigation amounted to 194 mm for W_3, 324 mm for W_2 and 478 mm for W_1. Each irrigation application was expressed as a percentage of the amount received at W_1. The normalized irrigation application was then regressed against the lateral perpendicular distances determined for W_1, W_2 and W_3. The coefficients of the fitted linear equation (y = a +bx) was: a = 123.01; b = -9.44; R^2 = 0.933; x = perpendicular distance from the line source (m); y = percentage or relative irrigation application. This equation represents the water-distribution pattern of the line source sprinkler irrigation system. Thus, y was estimated for each water treatment using their perpendicular distance and it amounted to 40% for W_3, 70% for W_2 and 100% for W_1 (full irrigation). Detailed information on soil water measurements and calculations is given in Section 3.2.5

Plant population treatments: Plant rows were fixed at 0.75 m intervals. The intra-row spacings were 0.75, 0.56, 0.45, 0.38 and 0.32 m giving plant populations of 17 689 (PP_1), 23 674 (PP_2), 29 526 (PP_3), 34 979 (PP_4) and 41 496 (PP_5) plants ha^{-1}, respectively.

Experimental layout: The experimental layout was a split-plot design with four water applications as main treatments and five plant populations as sub-treatments. All treatment combinations were replicated four times (Figure 3.1). The total trial size was 1 944 m^2 and plot sizes were 18.9, 21.6, 21.6 and 32.4 m^2 for full irrigation (W_1), 70% of full irrigation (W_2), 40% of full irrigation (W_3) and dryland (W_4) treatments, respectively.

Block 1

W_4PP_1	W_4PP_2	W_4PP_5	W_4PP_4	W_4PP_3
W_3PP_1	W_3PP_2	W_3PP_5	W_3PP_4	W_3PP_3
W_2PP_1	W_2PP_2	W_2PP_5	W_2PP_4	W_2PP_3
W_1PP_1	W_1PP_2	W_1PP_5	W_1PP_4	W_1PP_3

Block 2

W_4PP_5	W_4PP_1	W_4PP_2	W_4PP_4	W_4PP_3
W_3PP_5	W_3PP_1	W_3PP_2	W_3PP_4	W_3PP_3
W_2PP_5	W_2PP_1	W_2PP_2	W_2PP_4	W_2PP_3
W_1PP_5	W_1PP_1	W_1PP_2	W_1PP_4	W_1PP_3

x--------x--------x--------x--------x--------x-------x-Line source---x-------x------x----------x------x--------x------x

W_1PP_1	W_1PP_2	W_1PP_5	W_1PP_4	W_1PP_3
W_2PP_1	W_2PP_2	W_2PP_5	W_2PP_4	W_2PP_3
W_3PP_1	W_3PP_2	W_3PP_5	W_3PP_4	W_3PP_3
W_4PP_1	W_4PP_2	W_4PP_5	W_4PP_4	W_4PP_3

Block 3

W_1PP_5	W_1PP_1	W_1PP_2	W_1PP_4	W_1PP_3
W_2PP_5	W_2PP_1	W_2PP_2	W_2PP_4	W_2PP_3
W_3PP_5	W_3PP_1	W_3PP_2	W_3PP_4	W_3PP_3
W_4PP_5	W_4PP_1	W_4PP_2	W_4PP_4	W_4PP_3

Block 4

Figure 3.1 Trial layout (not to scale): Water application with a single line source experiment (Hanks *et al.*, 1976) and plant population.

3.2.3 Agronomic practices

Before the commencement of the experiment, the area had been used for commercial wheat production. There was no visible top and sub-soil compaction, thus the soil was ploughed using a mouldboard plough to a depth of 250 mm. Fertilizer application was done according to the crop's withdrawal amounts of those mineral elements tested, and an expected yield of 40 t ha^{-1}(FSSA, 2003). The fertilizers were broadcasted at a rate of 49 kg ha^{-1} LAN, 30 kg ha^{-1} superphosphate and 62 kg ha^{-1} potassium chloride before transplanting and then ploughed into the soil. The soil was then rotivated to create a suitable tilth and smooth surface for transplanting. Green pepper seedlings, cv. California Wonder 300, were transplanted on 18 November, 2004. Six weeks after transplanting, 49 kg ha^{-1} LAN was top-dressed. Weeds were controlled by hand at 30 and 60 days after transplanting. No significant diseases or pests were evident during the trial. Some fruit became unmarketable due to sunburn. Light hail damage was experienced once (fifteen weeks after transplanting) during the season. Average long-term and monthly maximum, minimum temperatures and total measured rainfall per month for the 2004/5 season are indicated in Table 3.2.

Table 3.2 Long-term monthly climate data from Glen meteorological station (ARC-ISCW); rainfall and temperature (1922 – 2003); potential evapotranspiration (1958 – 2000) (Botha, 2006). Weather data (temperature and potential evapotranspiration) for the 2004/2005 growing season was obtained from Kenilworth meteorological station (ARC-ISCW), while the rainfall represents rainfall measured during the trial.

Variable	Period	Nov	Dec	Jan	Feb	Mar	Apr	Mean/(Total)
Max. Temp. (^{O}C)	LT	28.3	30.2	30.8	29.5	27.4	23.9	28.4
	2004/5	32	31	30	30	27	22	28.7
Min. Temp. (^{O}C)	LT	12	14	15.3	14.8	12.6	7.8	12.8
	2004/5	16	16	17	17	13	10	14.8
Mean Temp. (^{O}C)	LT	20.1	22	23	22.1	19.9	15.8	20.5
	2004/5	24	23.5	23.5	23.5	20	16	21.8
Precip. (mm)	LT	68	67	83	78	81	49	426
	2004/5	32.4	69	74	65	26	49	315.4
ET_0 (mm)	LT	256	292	277	208	177	126	1335
	2004/5	234	248	234	194	179	125	1214
Aridity index	LT	0.27	0.23	0.30	0.37	0.46	0.39	0.32
	2004/5	0.14	0.28	0.32	0.34	0.15	0.39	0.26

LT= long term; Max= maximum; Min= minimum; Temp= temperature; Precip.= precipitation; ET_o = reference evapotranspiration

3.2.4 Plant measurements

Fruit length was used as harvesting indicator. Green peppers were harvested once a week as soon as they reached a length of 80 mm. This was done over a period of eleven weeks. Marketable green pepper fruits were harvested weekly from six plants randomly selected in each treatment which covered an average area of 3.39, 2.53, 2.03, 1.71 and 1.45 m^2 representative of populations of 17 689 (PP_1), 23 674 (PP_2), 29 526 (PP_3), 34 979 (PP_4) and 41 496 (PP_5) plants ha^{-1}, respectively. At the same time, the unmarketable (sunburnt and hail damaged) fruits were removed and discarded regardless of their size. The fresh mass of all the marketable fruits from each area was recorded using a weighing scale and average fruit mass per plant was calculated. Average number of marketable fruit per plant was also calculated.

3.2.5 Soil water measurements and calculations

Water deficit was calculated according to the reference water level, full irrigation treatment (W_1), which is the drained upper limit (DUL) minus 20 mm. The 20 mm represents the rain storage capacity. Two Campbell Pacific Nuclear (CPN) 503DR hydroprobe neutron water meter tubes were used to calculate the soil water deficits which were cleared on a weekly basis. Two access tubes were installed in each replicate of full irrigation and a population of 29 526 plants ha^{-1} (W_1PP_3), one in the row and the other one between the rows. Both irrigation and rainfall were measured with rain gauges.

The experiment was set up in such a way that runoff would not take place. The irrigation application rate at full irrigated (W_1) plots was lower than the final infiltration rate of the soil. To prevent percolation in case of rainfall, the irrigation filling point was taken to be drained upper limit (DUL) minus 20 mm. The average soil water contents were worked out from the full irrigated (W_1) plots and 29 526 plants ha^{-1} (PP_3) treatment as initial water contents by taking two soil samples at 30 cm depth intervals down to 1.8 m. The samples were weighed using a weighing scale, oven-dried at 105°C for 24 hours and then weighed again. The CPN neutron water meter access tubes were then placed in the holes from where the soil samples were taken.

3.2.6 Data processing

Analysis of variance was done on every measured parameter to determine significance of differences between means of treatments using SAS (Anon., 2004b). Treatment means for each parameter were separated by the least significant difference (LSD_{Tukey}) test at $P \leq 0.05$. Treatment means of the interaction between water treatment and plant population derived from these analyses were then subjected to regression analyses with Excel of the Microsoft Office package (Anon., 2007), using the polynomial equations.

3.3 RESULTS and DISCUSSION

Fruit yield data presented in this section is based only on marketable fruit. Sunburned and hail damaged fruit were not considered. Tables and Figures are presented for the same plant growth data. The Tables indicate the LSD values for the data measured over a period of eleven weeks and the Figures show how plant growth was affected by factors like hailstorm, rainfall and temperature as well as the general plant development trend.

3.3.1 Fruit mass

A summary on the analysis of variance that was done to determine the influence of water treatment and plant population on fruit mass of green pepper harvested per plant over a period of eleven weeks is given in Table 3.3.

Table 3.3 Summary on the analysis of variance showing the significant influence of water treatment and plant population on green pepper fruit mass per plant harvested over a period of eleven weeks.

Weeks after transplanting	Water treatment (W)	Plant population (PP)	W × PP
12	*	ns	ns
13	*	ns	ns
14	*	ns	ns
15	*	*	ns
16	ns	*	ns
17	ns	*	ns
18	*	*	ns
19	*	*	ns
20	*	ns	ns
21	*	ns	ns
22	*	ns	ns

ns = no significant differences, * = significant differences at 5% level of significance

As indicated in Table 3.3 the interaction between water treatment and plant population did not significantly influence fruit mass per green pepper plant harvested over a period of eleven weeks. Apart from weeks 16 and 17 after transplanting, water treatment significantly influenced fruit mass and plant population influenced it from week 15 to 19 after transplanting.

Fruit mass per plant of fully irrigated plants (W_1) was significantly greater than that of dryland (W_4) plants except for weeks 16, 17 and 20 after transplanting (Table 3.4). Plants that received 70% of full irrigation (W_2) also produced significantly higher fruit mass per plant compared to dryland (W_4) treated plants, except for weeks 16 to 18 after transplanting. During the first four weeks of harvesting, 40% of full irrigation (W_3) treated plants showed inconsistent results but from week 18 after transplanting fruit mass of these plants was also significantly higher compared to the dryland (W_4) treatment, apart from week 20.

Table 3.4 Influence of water treatment on green pepper fruit mass per plant (g plant^{-1}) harvested over a period of eleven weeks.

Weeks after transplanting	Water treatment				$LSD_{T(0.05)}$ (W)
	Full irrigation (W_1)	70 % of full irrigation (W_2)	40% of full irrigation (W_3)	Dry land (W_4)	
12	105.60^{a}	80.73^{ab}	36.40^{bc}	11.42^{c}	**47.97**
13	121.74^{a}	72.32^{b}	46.77^{b}	7.88^{c}	**36.96**
14	128.06^{a}	80.69^{b}	31.42^{c}	10.66^{c}	**26.73**
15	102.55^{a}	105.65^{a}	84.79^{ab}	18.41^{b}	**75.33**
16	57.46^{a}	56.46^{a}	46.97^{a}	14.08^{a}	**ns**
17	75.64^{a}	71.27^{a}	40.86^{a}	17.00^{a}	**ns**
18	104.22^{a}	83.83^{ab}	93.90^{a}	26.93^{b}	**58.65**
19	112.68^{a}	107.12^{a}	84.19^{a}	20.73^{b}	**56.48**
20	172.59^{ab}	195.44^{a}	159.33^{ab}	83.35^{b}	**90.37**
21	259.11^{a}	252.26^{a}	202.83^{a}	81.53^{b}	**115.13**
22	178.69^{a}	200.19^{a}	157.48^{a}	66.75^{b}	**74.27**

Means with different letters in the same row differ significantly from each other

During week 16 and 17 after transplanting there was no significant difference in fruit mass between the different water treatments. A hailstorm occurred during week 15 after transplanting that caused considerable damage to the plants and fruits. A combination of sunscald and hail damage was the main cause of the noticeably reduced marketable fruit mass, irrespective of the water treatment (Figure 3.2).

However, the green pepper plants recovered quickly from the hail damage and fruit mass increased again from week 18 after transplanting. Twenty three millimetres of rain were received during week 19 that may also have contributed to fruit mass increase during week 20 and 21 after transplanting (Figure 3.2). From week 18 up to week 22 after transplanting, there were no significant differences in fruit mass between fully irrigated plants (W_1), 70% (W_2) and 40% of full irrigation (W_3) treated plants.

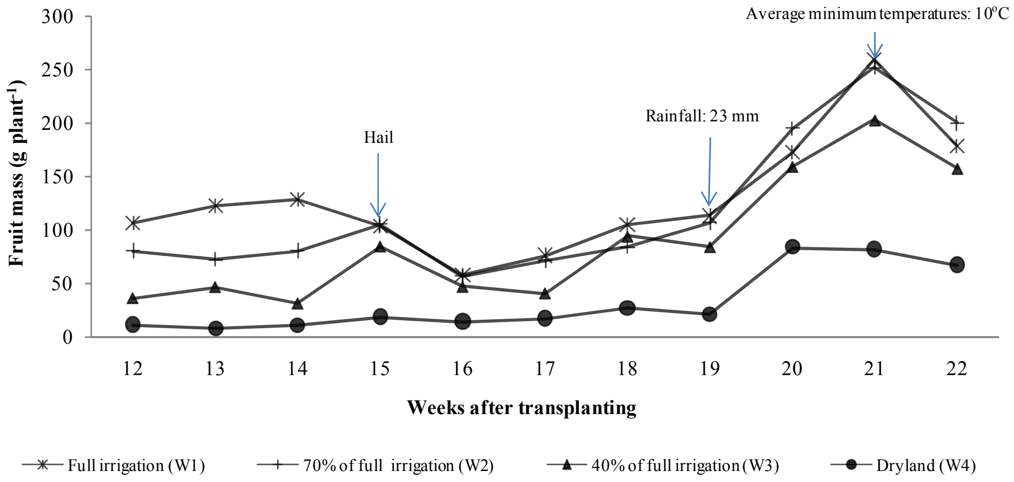

Figure 3.2 Influence of water treatment on green pepper fruit mass harvested over a period of eleven weeks (refer to Table 3.4 for LSD's for each week).

Green pepper is a warm season crop that is very vulnerable to frost and grows slowly at temperatures between 5-15°C. Temperatures lower than 16°C can lead to fruitless green pepper plants (Bosland & Votava, 1999). An average minimum temperature of 10°C was experienced in April (Table 3.2) that may explain the sharp reduction in fruit mass per plant at the end of the season (week 22 after transplanting) (Figure 3.2).

Plant population significantly influenced fruit mass per plant from week 15 to 19 after transplanting (Table 3.5). Fruit mass per plant was significantly higher at a plant population of 17 689 plants ha^{-1} (PP_1) than at 41 496 plants ha^{-1} (PP_5) during week 15 to 18 after transplanting. However, fruit mass of plant population treatments PP_2, PP_3. PP_4 and PP_5 did not differ significantly from each other.

Fruit mass per plant as influenced by plant population, also responded to hail and sunscald damage experienced in week 15 after transplanting (Figure 3.3). The same trends were observed as for water treatment (Figure 3.2). Plants also showed signs of recovery from week 18 and from week 20 after transplanting plants have recovered fully.

Table 3.5 Influence of plant population on green pepper fruit mass per plant (g plant^{-1}) harvested over a period of eleven weeks.

Weeks after transplanting	Plant population (plants ha^{-1})					$LSD_{T(0.05)}$ (PP)
	17 689 (PP_1)	23 674 (PP_2)	29 526 (PP_3)	34 979 (PP_4)	41 496 (PP_5)	
12	81.30^a	44.89^a	57.81^a	41.04^a	67.65^a	ns
13	73.57^a	69.20^a	53.96^a	63.60^a	50.56^a	ns
14	78.79^a	64.37^a	65.33^a	55.59^a	49.46^a	ns
15	125.48^a	100.64^{ab}	54.42^b	63.54^b	45.15^b	**57.86**
16	63.88^a	40.09^{ab}	46.30^{ab}	48.06^{ab}	20.39^b	**34.00**
17	84.53^a	51.95^{ab}	36.05^b	40.59^b	42.85^b	**39.94**
18	136.09^a	84.49^{ab}	60.60^b	64.11^b	40.80^b	**57.32**
19	116.12^a	108.86^{ab}	74.39^{ab}	46.48^b	60.04^{ab}	**66.50**
20	184.46^a	156.91^a	143.52^a	144.75^a	133.73^a	ns
21	255.10^a	231.80^a	181.93^a	189.50^a	136.33^a	ns
22	183.05^a	152.45^a	106.72^a	154.37^a	157.29^a	ns

Means with different letters in the same row differ significantly from each other

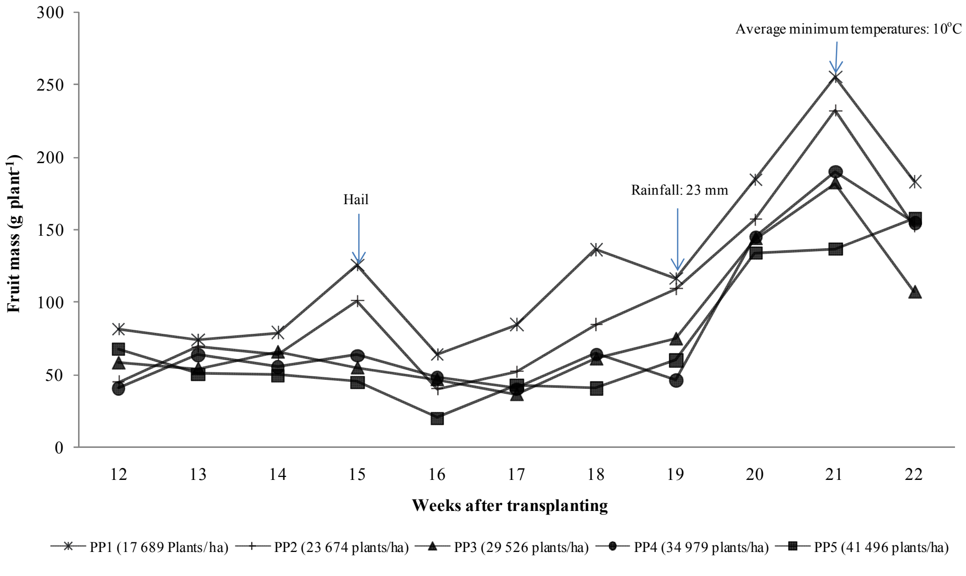

Figure 3.3 Influence of plant population on green pepper fruit mass per plant harvested over a period of eleven weeks (refer to Table 3.5 for LSD's for each week).

As was expected, results indicated that irrigation for most weeks of harvesting significantly increased fruit mass per plant. The highest fruit mass per plant was obtained with full irrigation (W_1). Batal & Smittle (1981) also reported that irrigation increased green pepper fruit mass per plant. Plant population however did not have such a significant effect on fruit mass per plant harvested over a period of eleven weeks apart from the middle of the harvesting period. It is difficult to make a distinct conclusion because hail occurred during this period that may have influenced the results. However, results suggested that the plasticity (ability of a plant to compete for production resources e.g. water, light and nutrients) of green pepper is high. The highest fruit mass per plant was obtained at the lowest plant population of 17 689 plants ha^{-1} (PP_1). Although, Agarwal *et al*. (2007) and Stoffella & Bryan (1988) used higher plant populations (21 500 to 258 000 plants ha^{-1}), they also reported that fruit mass per green pepper plant decreased as plant population increased. When considering both water and plant population treatments, the highest fruit mass per plant harvested per week was obtained during week 21after transplanting.

3.3.2 Fruit number

A summary on the analysis of variance that was done to determine the influence of water treatment and plant population on the number of green pepper fruit harvested per plant over a period of eleven weeks is given in Table 3.6.

Table 3.6 Summary on the analysis of variance showing the significant influence of water treatment and plant population on green pepper fruit number per plant harvested over a period of eleven weeks.

Weeks after transplanting	Water treatment (W)	Plant population (PP)	W × PP
12	*	ns	ns
13	*	ns	ns
14	*	ns	ns
15	*	*	ns
16	ns	*	ns
17	ns	*	ns
18	*	*	ns
19	*	*	ns
20	*	ns	ns
21	*	ns	ns
22	*	ns	ns

ns = no significant differences, * = significant differences at 5% level of significance

As shown in Table 3.6 the interaction between water treatment and plant population did not significantly influence fruit number per plant harvested over a period of eleven weeks. Apart from weeks 16 and 17 after transplanting, water treatment significantly influenced fruit number per plant, while plant population only significantly influenced it from week 15 to 19 after transplanting.

Number of green pepper fruit harvested per plant did not significantly differ between plants that received full irrigation (W_1) and those that received 70% of full irrigation (W_2), apart from weeks 13 and 14 (Table 3.7). Fully irrigated plants (W_1) produced significantly more fruit per plant than plants under dryland (W_4) conditions for all weeks harvested apart from weeks 16, 17 and 20 after transplanting. From week 15 after transplanting and onwards the number of fruit per plant produced by full irrigation (W_1), 70% of full irrigation (W_2) and 40% of full irrigation (W_3) plants did not significantly differ from each other.

Table 3.7 Influence of water treatment on green pepper fruit number per plant (number plant^{-1}) harvested over a period of eleven weeks.

Weeks after transplanting	Water treatment				LSD$_{T(0.05)}$ (W)
	Full irrigation (W_1)	70 % of full irrigation (W_2)	40% of full irrigation (W_3)	Dry land (W_4)	
12	0.67^{a}	0.51^{ab}	0.28^{bc}	0.09^{c}	**0.29**
13	0.75^{a}	0.48^{b}	0.30^{bc}	0.06^{c}	**0.26**
14	0.82^{a}	0.55^{b}	0.22^{c}	0.08^{c}	**0.19**
15	0.59^{a}	0.65^{a}	0.54^{ab}	0.12^{b}	**0.45**
16	0.37^{a}	0.37^{a}	0.31^{a}	0.10^{a}	**ns**
17	0.5^{a}	0.45^{a}	0.28^{a}	0.13^{a}	**ns**
18	0.72^{a}	0.59^{ab}	0.62^{a}	0.18^{b}	**0.41**
19	0.81^{a}	0.75^{a}	0.55^{ab}	0.15^{b}	**0.41**
20	1.16^{ab}	1.26^{a}	1.02^{ab}	0.60^{b}	**0.57**
21	1.71^{a}	1.61^{a}	1.26^{a}	0.52^{b}	**0.69**
22	1.18^{a}	1.26^{a}	0.98^{a}	0.46^{b}	**0.48**

Means with different letters in the same row differ significantly from each other

Fruit number per plant, as influenced by water treatment, follows a trend similar to that of fruit mass per plant (Figure 3.4). Fruit number per plant decreased from week 16 to 17 after transplanting in response to hail and sunscald damage experienced during week 15 after transplanting. From week 18 fruit number per plant started to increase again.

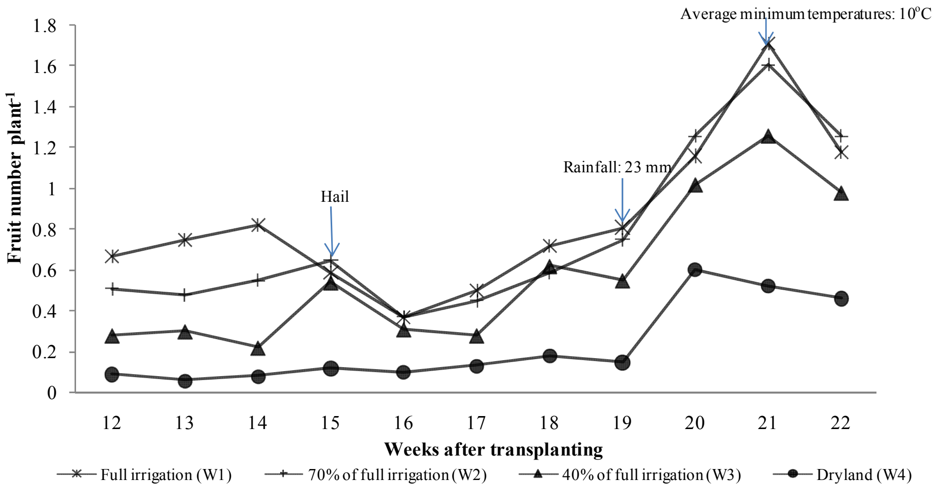

Figure 3.4 Influence of water treatment on green pepper fruit number per plant harvested over a period of eleven weeks (refer to Table 3.7 for LSD's for each week).

Plant population only significantly influenced fruit number per green pepper plant from week 15 to 19 after transplanting (Table 3.8). The number of green pepper fruit per plant was significantly higher at a plant population of 17 689 plants ha^{-1} (PP_1) than at 41 496 plants ha^{-1} (PP_5) from week 15 to 18 apart from week 17 after transplanting. There was no significant difference in the number of fruit per plant at a population of 17 689 plants ha^{-1} (PP_1) and those at 23 674 plants ha^{-1} (PP_2) over the eleven weeks of harvesting. Excluding week 15 after transplanting, fruit number of the four highest plant population treatments (PP_2, PP_3, PP_4 and PP_5) did not significantly differ from each other.

Table 3.8 Influence of plant population on green pepper fruit number per plant (number plant^{-1}) harvested over a period of eleven weeks.

Weeks after transplanting	Plant population (plants ha^{-1})					LSD$_{T(0.05)}$ (PP)
	17 689 (PP$_1$)	23 674 (PP$_2$)	29 526 (PP$_3$)	34 979 (PP$_4$)	41 496 (PP$_5$)	
12	0.54^a	0.27^a	0.40^a	0.29^a	0.43^a	**ns**
13	0.46^a	0.41^a	0.42^a	0.40^a	0.31^a	**ns**
14	0.53^a	0.42^a	0.42^a	0.36^a	0.34^a	**ns**
15	0.76^a	0.61^{ab}	0.32^{bc}	0.41^{bc}	0.27^c	**0.33**
16	0.42^a	0.26^{ab}	0.29^{ab}	0.32^{ab}	0.14^b	**0.22**
17	0.54^a	0.35^{ab}	0.24^b	0.28^{ab}	0.27^{ab}	**0.27**
18	0.92^a	0.57^{ab}	0.41^b	0.45^b	0.29^b	**0.40**
19	0.81^a	0.76^{ab}	0.50^{ab}	0.33^b	0.42^{ab}	**0.47**
20	1.17^a	1.01^a	0.96^a	1.00^a	0.91^a	**ns**
21	1.56^a	1.47^a	1.17^a	1.26^a	0.91^a	**ns**
22	1.13^a	0.96^a	0.69^a	0.98^a	1.08^a	**ns**

Means with different letters in the same row differ significantly from each other

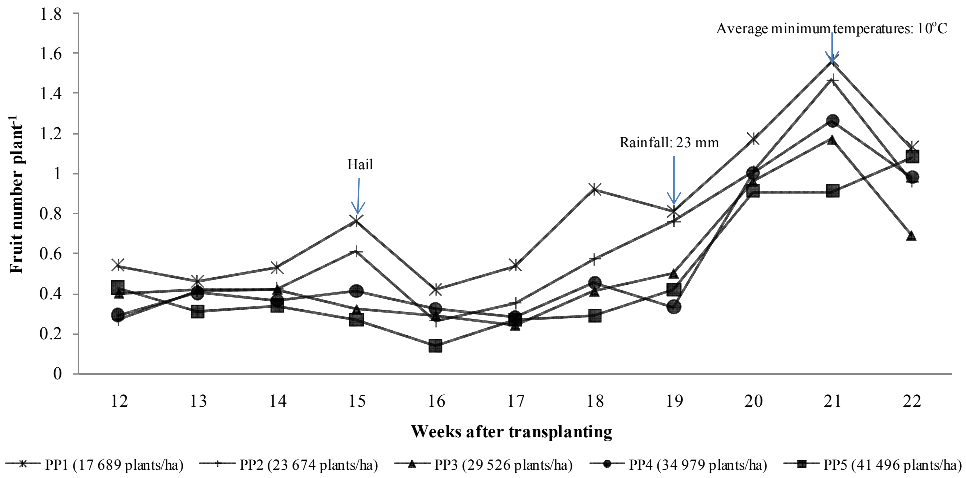

Figure 3.5 Influence of plant population on green pepper fruit number per plant harvested over a period of eleven weeks(refer to Table 3.8 for LSDs for each week).

The significant differences between fruit number per plant as influenced by plant population follows a trend similar to that of fruit mass (Figure 3.5). Similarly, the fruit number per plant as influenced by plant population responded to hail and sunscald damage experienced during week 15 after transplanting, but from week 20 after transplanting plants have recovered fully.

Results indicated that irrigation significantly increased the number of green pepper fruit per plant harvested over a period of eleven weeks apart from weeks 16 and 17 after transplanting. The highest fruit number per plant was obtained where full irrigation (W_1) was applied as compared to the dryland (W_4) treatment. These results are similar to those of Batal & Smittle (1981) who found that the use of irrigation increased the number of marketable green pepper fruit per plant. Fruit number per plant did not significantly differ between full irrigation (W_1), 70% of full irrigation (W_2) and 40% of full irrigation (W_3) from week 18 to 22 after transplanting. This may suggest that the three irrigation treatments do not have a significantly effect on fruit number per plant of green pepper late during the growing season, but the three irrigation treatments have a significant effect on fruit number per plant in comparison with the dryland (control) treatment.

The significant influence of plant population on fruit number per plant harvested over a period of eleven weeks only occurred in the middle of the harvesting period. However, the highest fruit number per plant was obtained at a plant population of 17 689 plants ha^{-1} (PP_1). Agarwal *et al.* (2007) reported similar results on green pepper despite the fact that they used higher plant populations (50 000 to 200 000 plants ha^{-1}) under greenhouse conditions. The number of fruit per plant decreased as plant population increased from 50 000 to 200 000 plants ha^{-1}.

3.3.3 Yield

A summary on the analysis of variance that was done to determine the influence of water treatment and plant population on total fruit mass and number of green pepper fruit harvested over a period of eleven weeks is presented in Table 3.9.

Table 3.9 Summary on the analysis of variance showing the significant influence of water treatment and plant population on green pepper total fruit mass (t ha^{-1}) and number harvested over a period of eleven weeks.

Yield components	Water treatment (W)	Plant population (PP)	W × PP
Total fruit mass	*	*	ns
Total fruit number	*	*	ns

ns = no significant differences, * = significant differences at 5% level of significance

As indicated in Table 3.9, the interaction between water treatment and plant population did not significantly influence green pepper total fruit mass and total fruit number per hectare harvested over a period of eleven weeks. However, water treatment and plant population independently of each other significantly influenced both yield parameters.

Total fruit mass

The total marketable yield (t ha^{-1}) of green pepper plants that received irrigation, irrespective of the amount, was significantly higher than that of the dryland treatment (Figure 3.6). Full irrigation (W_1) increased the yield with 274% (39 t ha^{-1}) compared to dryland, followed by 253% (37 t ha^{-1}) and 162% (27 t ha^{-1}) for the 70% (W_2) and 40% (W_3) of full irrigation treatments, respectively.

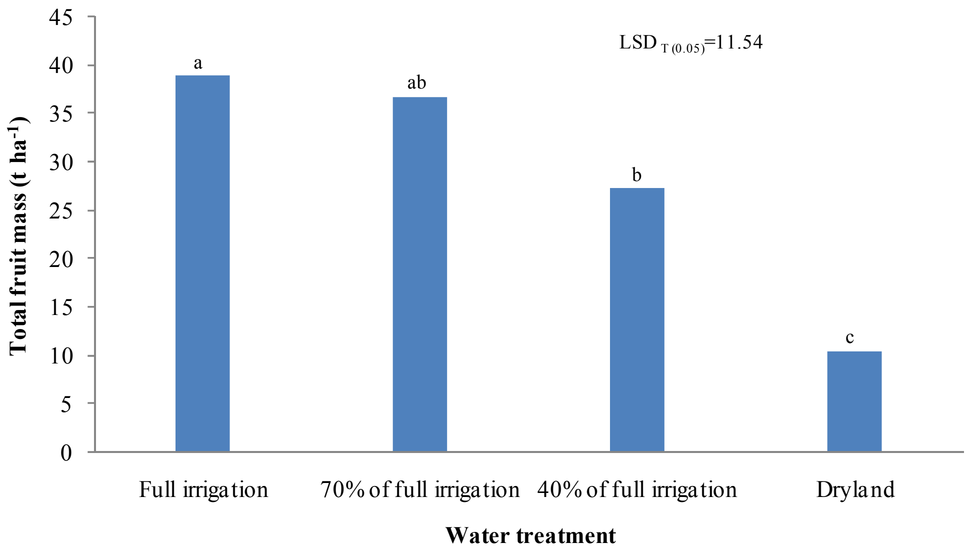

Figure 3.6 Influence of water treatment on total marketable fruit mass of green pepper harvested over a period of eleven weeks. Bars with different letters differ significantly from each other.

The total marketable yield of green pepper plants at 41 496 plants ha^{-1} was significantly higher than that of plants at 17 689 plants ha^{-1} (Figure 3.7). However, the other plant populations did not differ significantly from each other in this respect.

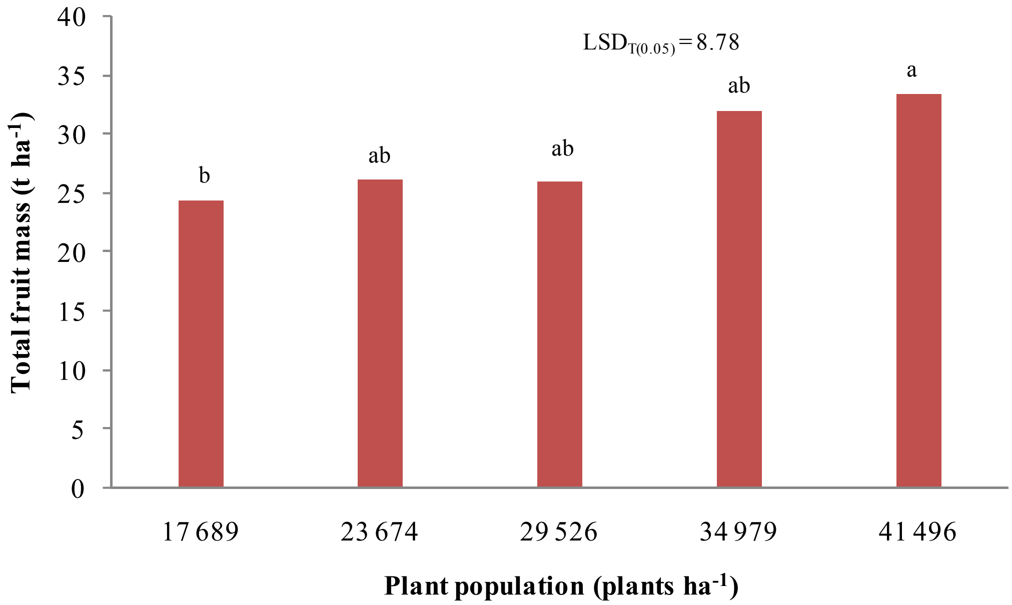

Figure 3.7 Influence of plant population on total marketable fruit mass of green pepper harvested over a period of eleven weeks. Bars with different letters differ significantly from each other.

The selection of green pepper plant populations (17 689 to 41 496 plants ha^{-1}) used in this study to determine the optimum plant populations for different water treatments was based on South African recommendations of 20 000 to 55 000 plants ha^{-1}. Although the interaction between water treatment and plant population was not significant a regression analysis was done to determine the optimum plant population for each water treatment (Figure 3.8). The highest green pepper yield was obtained at 41 496 plants ha^{-1} for the different water treatments apart from that of 40% of full irrigation (W_3) which was at 34 979 plants ha^{-1}. Regression results therefore suggest that for full irrigation (W_1), 70% of full irrigation (W_2) and the dryland (W_4) treatments, the optimum plant population is higher than those used in the trial. In a study conducted by Stoffella & Bryan (1988), a green pepper plant population of 86 000 plants ha^{-1} was recommended after studying different plant populations (21 500 to 258 000 plants ha^{-1}).

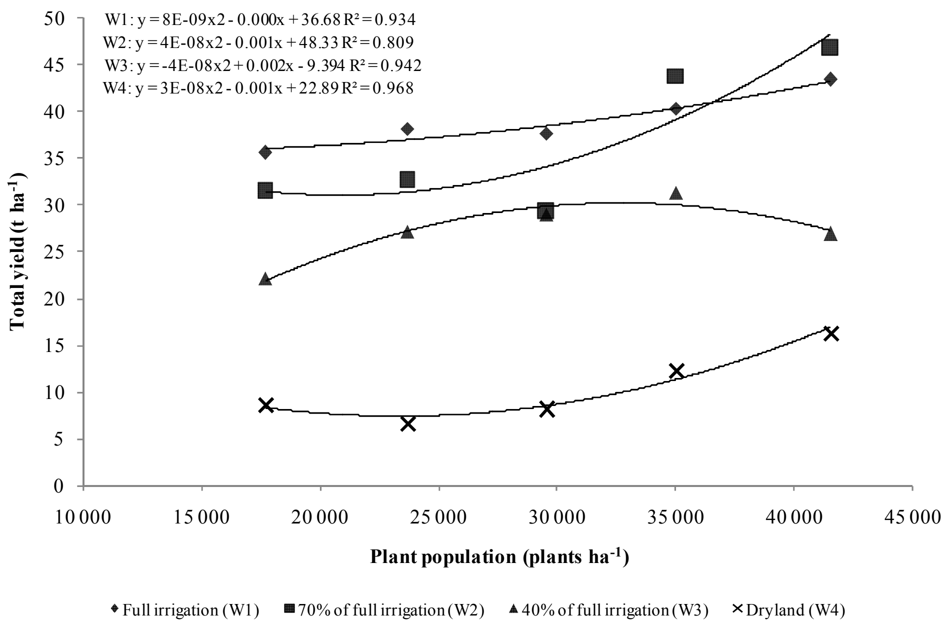

Figure 3.8 Influence of water treatment and plant population on green pepper yield harvested over a period of eleven weeks.

Results indicated that irrigation significantly increased green pepper marketable yield. These results emphasize the importance of water in the growth, development and yield of green pepper plants. In water-deficient soils (W_4) a reduction in photosynthetic rate can be expected as a result of stomata closure reducing transpiration, but consequently also the absorption of carbon dioxide important for photosynthesis. These results are concordant with results presented by Batal & Smittle (1981) who reported that irrigation increased green pepper yield. However, they also looked at the response of green pepper to nitrogen levels and plant population. The highest marketable tomato yield was obtained at 50% available soil water which exceeded the yield obtained under dryland conditions by 110% (Tan & Dhanvantari, 1985). However, in a dry season the marketable yield of tomatoes was 60% without irrigation, but increased to over 80% with irrigation in the same season.

Plant population however, did not have such a significant effect on marketable green pepper yield. The highest yield was obtained at a population of 41 496 plants ha^{-1} (PP_5). These results are in agreement with those of Lorenzo & Castilla (1995) who reported that marketable green pepper yield were significantly higher under a high plant population (3.2 plants m^{-2}) than under a low plant population (2 plants m^{-2}). They concluded that a high leaf area index (LAI) for a high plant population resulted in improved light interception which then led to higher biomass and yield than under a low plant population. In this study, the highest green pepper fruit yield was obtained at the highest plant population of 41 496 plants ha^{-1} (PP_5). This could be attributed to high photosynthetic rates as a result of more effective light interception brought about by an increased leaf area index. Despite using higher plant populations, Agarwal *et al*. (2007) also reported that green pepper marketable fruit yield increased as plant population increased from 50 000 to 200 000 plants ha^{-1} and slightly decreased with a further increase in plant population under greenhouse conditions. The increase in fruit mass per hectare as a result of an increased plant population to a threshold level maybe attributed to better utilization of available light and nutrients.

Total fruit number

The total number of marketable green pepper fruit harvested over a period of eleven weeks was significantly increased by irrigation, irrespective of the amount of water applied (Figure 3.9). Fully irrigated plants (W_1) produced 255% (256 338) more marketable fruit than dryland (W_4) treated plants (72 257). The same trend was observed for the other two water treatments where 70% (W_2) and 40% (W_3) of full irrigation produced 231% (239 376) and 145% (176 750) more marketable fruit, respectively than the dryland treated plants.

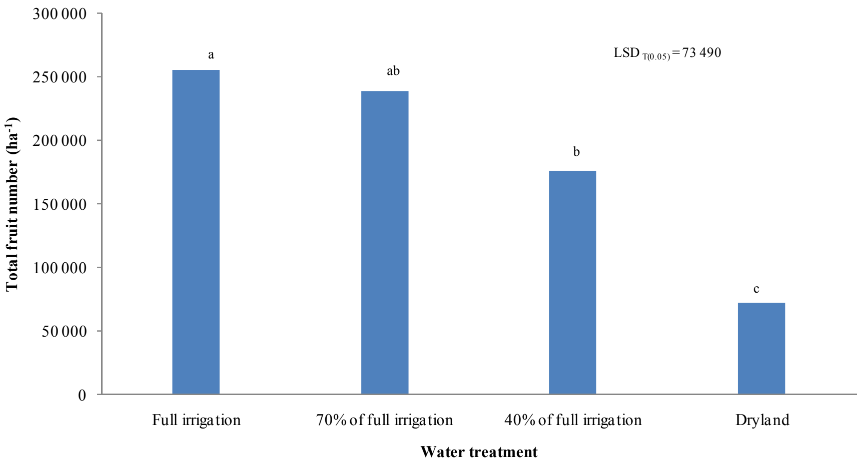

Figure 3.9 Influence of water treatment on total marketable green pepper fruit number harvested over a period of eleven weeks. Bars with different letters differ significantly from each other.

As indicated in Figure 3.10, marketable fruit number at the highest plant population of 41 496 plant ha^{-1} was significantly more (222 609) than the lowest plant population of 17 689 plants ha^{-1} (156 253). This is an increase of 42% in the number of marketable fruit. The other plant population treatments however did not significantly increase the number of marketable green pepper fruit.

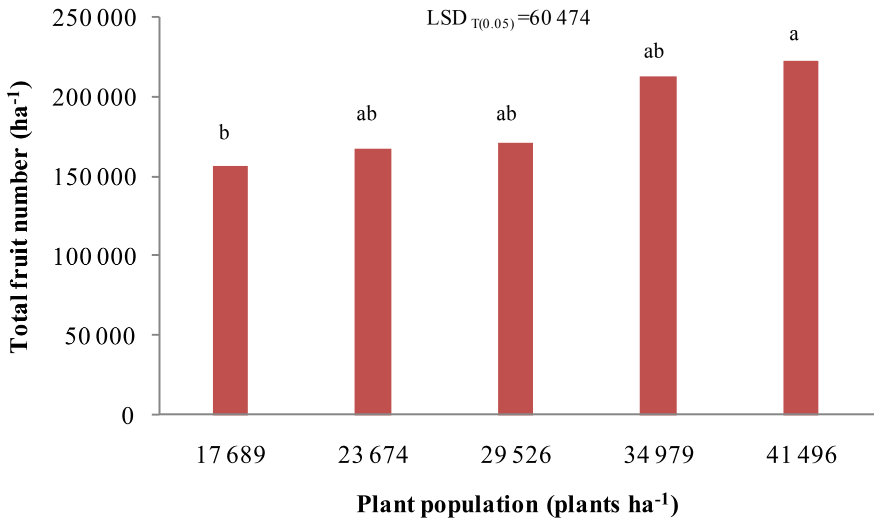

Figure 3.10 Influence of plant population on total marketable green pepper fruit number harvested over a period of eleven weeks. Bars with different letters differ significantly from each other.

As was expected, results indicate that irrigation significantly increased the total number of marketable green pepper fruit harvested over a period of eleven weeks. This can be attributed to the fact that under limited soil water conditions photosynthetic rates are reduced causing significantly less fruit set in the dryland treatment. These results are in agreement with those of Batal & Smittle (1981) who reported that when soil water was inadequate, irrigation increased green pepper fruit set and marketable yield. Interesting however, and although not analyzed statistically, the average individual fruit mass was the highest for the 40% of full irrigation (W_3) (154.46 g) treatment followed by the 70% of full irrigation (W_2) (153.70 g) and then the full irrigation (W_1) (152.10 g) treatments. Average individual fruit mass for the dryland treatment (W_4) was 144.35 g.

Plant population, however did not have such a significant effect on total fruit number. The highest number of fruit was obtained from the highest plant population of 41 496 plants ha^{-1}. Although not analyzed statistically, and although the number of marketable fruit increased with high plant populations, individual fruit mass decreased from 156.50 g at 17 689 plants ha^{-1} to 149.92 g at 41 496 plants ha^{-1}.

3.4 CONCLUSIONS

Utilization of irrigation resulted in an increased green pepper marketable fruit mass and number per plant and consequently the yield (t ha^{-1}). The highest values for all the parameters were obtained from the full irrigation treatment (W_1) as compared to the dryland treatment (W_4). This trend can be attributed to the fact that under unlimited soil water conditions photosynthetic rates are increased resulting in significantly more fruit set in the full irrigation treatment (W_1) in comparison to the dryland treatment (W_4). The total marketable fruit yield of all irrigation treatments is significantly higher than that of the dryland treatment (W_4), but that of full irrigation (W_1) is not significantly different from that of 70% of full irrigation (W_2). Thus, in the absence of full irrigation (W_1), application of 70% of full irrigation (W_2) should be expected to give a yield significantly higher than that of the dryland treatment (W_4).

Plant population did not have much of a significant effect on the marketable yield of green pepper (fruit mass and number per plant). Nevertheless, results indicate that the optimum plant populations for full irrigation (W_1), 70% of full irrigation (W_2) and the dryland (W_4) treatments are beyond the plant population used in the trial. Results also suggest that green pepper plants have a high plasticity (the ability of a plant to compete for production resources e.g. water, light and nutrients).

CHAPTER 4

INFLUENCE OF IRRIGATION AND MULCHING ON YIELD, WATER USE AND WATER USE EFFICIENCY OF GREEN PEPPER

4.1 INTRODUCTION

Green pepper is an important commercial crop in South Africa. Most of the studies carried out on the effect of irrigation on green pepper yield are restricted to sub-humid climate zones. Costa & Giaquinto (2002) reported that water stress significantly reduced green pepper fruit mass in Italy. Accordingly, yield (y in g m^{-2}) was linearly related to irrigation applications (x in mm) which varied between 344 mm and 715 mm (y = 6.827x+3036). Klar & Jadoski (2004) concluded that severe drought in Brazil caused leaf senescence and abscission in green pepper, which significantly affected the production and quality of fruits. Ertek *et al.* (2007) observed that green pepper responded positively to irrigation during the early growth stage in Turkey. Yields increased from 600 to 1600 g m^{-2} as the amount of applied water increased from 233 to 783 mm, respectively.

In literature, water use efficiency (WUE) is expressed as fresh yield per unit area per unit total irrigation (WUE_i) or per unit evapotranspiration (WUE_{ET}). Most of the literature indicated that water use efficiency of green pepper is based on water applied (WUE_i), thus expressed as g m^{-2} mm^{-1}. Costa & Gianquinto (2002) reported that WUE_i decreased as the water application increased, probably due to drainage or runoff that occurred. Kirnak *et al*. (2003) also observed that WUE_i was lower in a stressed treatment as compared to an unstressed treatment (control). In a study conducted in an unheated greenhouse by Demirtas & Ayas (2009), WUE was based on evapotranspiration (ET) in a sub-humid climate zone. They observed that seasonal evapotranspiration (ET) ranged from 115 mm to 740 mm. The WUE_{ET} varied between 1.74 g m^{-2} mm^{-1} at water application of 65 mm and 3.24 g m^{-2} mm^{-1} at an application of 724 mm. From the literature discussed, it is clear that there is a need for information on yield, ET and WUE_{ET} of green pepper in semi-arid climate zones. The sub-humid climate zones receive high rainfall and only require supplemental irrigation as compared to semi-arid climate zones which require full irrigation. The production of vegetable crops like green pepper in semi-arid regions is restricted by the shortage of water. Growing seasons in these regions are characterized by low, erratic rainfall and high evapotranspiration (ET) rates. Thus, rainfall is not adequate for green pepper production in these regions which necessitates the use of full irrigation if maximum or optimum yield is to be obtained (Unger, 1995). The main objective of this chapter was therefore to quantify the effect of irrigation on yield, water use (ET) and water use efficiency (WUE_{ET}) of green pepper in a semi-arid region.

The use of mulches has become an important cultural practice in commercial vegetable production in many regions, with an aim of conserving soil water through the reduction of evaporation from the soil (Fraedrich & Ham, 1982; Lamont, 1993). Apart from conserving water, organic and inorganic mulches have other benefits which include: regulation of soil temperatures (Ashworth & Harrison, 1983) and reduced crop-weed competition (Roe *et al*., 1993). Kirnak *et al*. (2003) concluded that water stress reduced fruit yield of green pepper and the use of black plastic mulch decreased the detrimental effects of water stress on fruit yield in a sub-humid climate zone. However, their study also included various nitrogen treatments and drip irrigation. Their measurements showed that water stress and black polyethylene mulch treatment had the highest WUE_i (3.5 g m^{-2} mm^{-1}) and was significantly better than the bare soil and well-watered treatment (3.1 g m^{-2} mm^{-1}) and the stressed treatment (2.3 g m^{-2} mm^{-1}). Borosic *et al*. (1998) recorded higher (between 5 and 74% more) green pepper yields from mulched treatments, than from treatments without mulch in a sub-humid climate zone in Mediterranean part of Croatia. Green pepper WUE_i was higher in mulched treatments compared to unmulched treatments in a humid climate zone in a protected environment (Klar & Jadoski, 2004). The mulched treatments also showed reductions in water use as compared to those without mulch. The second objective of this chapter was to characterize the effect of mulching on yield, water use (ET) and water use efficiency (WUE_{ET}) of green pepper in a semi-arid region.

4.2 MATERIALS and METHODS

4.2.1 Experimental site

This research was conducted at Kenilworth Experimental Farm near Bloemfontein using a line source sprinkler irrigation system described by Hanks *et al*. (1976). This was the same site as was used to investigate the influence of water application and plant population on green pepper production and is described in detail in Section 3.2.1.

4.2.2 Treatments and experimental layout

Water treatments: The same line source sprinkler irrigation system as described in Section 3.2.2 was used for this experiment. The total irrigation and/ or rainfall amounted to 547, 481, 417 and 303 mm for full irrigation (W_1), 66% of full irrigation (W_2), 33% of full irrigation (W_3) and dryland (W_4), respectively. A detailed explanation on irrigation is given in Section 4.3.2.

Mulching treatments: Mulch treatments were based on results from literature review. An application rate of 0 t ha^{-1} (bare, control) and 9 t ha^{-1} maize straw were used for the experiment.

Experimental layout: The experimental layout was a split-plot design with four water applications as main treatments and two mulching rates as sub-treatments. All treatment combinations were replicated four times (Figure 4.1). The inter and intra-row spacings of the experiment were 0.75 and 0.45 m, respectively. The total trial size was 1 944 m^2 and plot sizes were 47.3, 54, 54 and 81 m^2 for full irrigation (W_1), 66% of full irrigation (W_2), 33% of full irrigation (W_3) and dryland (W_4) treatments, respectively.

Block 1 | **Block 2**

W_4 Bare	**W_4 Mulched**		**W_4 Mulched**	**W_4 Bare**
W_3 Bare	**W_3 Mulched**		**W_3 Mulched**	**W_3 Bare**
W_2 Bare	**W_2 Mulched**		**W_2 Mulched**	**W_2 Bare**
W_1 Bare	**W_1 Mulched**		**W_1 Mulched**	**W_1 Bare**

x--------x------x-------x-------x---------x-Line source----x------x-----x-----x-----x------x-----x

W_1 Mulched	**W_1 Bare**		**W_1 Bare**	**W_1 Mulched**
W_2 Mulched	**W_2 Bare**		**W_2 Bare**	**W_2 Mulched**
W_3 Mulched	**W_3 Bare**		**W_3 Bare**	**W_3 Mulched**
W_4 Mulched	**W_4 Bare**		**W_4 Bare**	**W_4 Mulched**

Block 3 | **Block 4**

Figure 4.1 Trial layout (not to scale): Water application with a single line source experiment (Hanks *et al.*, 1976) and mulching.

4.2.3 Agronomic practices

Agronomic practices, as explained in Section 3.2.3, were also followed for this experiment. The only difference was the transplanting date that was one day later namely 19 November 2004.

4.2.4 Plant measurements

Green peppers were harvested once a week over a period of 11 weeks as soon as they reached a length of 80 mm. Marketable green pepper fruits were harvested weekly from twelve plants randomly selected in each treatment which covered an average area of 4.06 m^2. All the fruit harvested were weighed and yield was expressed as fruit mass in grams per square meter. Fruits were counted and the number expressed per square meter. Weekly fruit mass and number were used to calculate cumulative fruit mass and their corresponding numbers. The weekly harvested fruits were oven dried at 75°C for 48 hours and then weighed again to express the dry mass in grams per square meter.

Two plants from each treatment combination were cut above the ground every fortnight and their leaves were used to measure the leaf area over a period of nine weeks using the leaf area meter (model 3100). These measurements were then used to calculate the leaf area index (LAI).

4.2.5 Soil water balance components

The soil water balance, in its simplest form for the growing season of a crop like green pepper, is expressed as follows (Hensley *et al*., 1997): $\Delta W = (P+I) - (D+R+ET)$ 4.1

Where: ΔW = change in soil water content over a specific soil depth (mm); over the growing season

P = precipitation (mm)

I = Irrigation (mm)

D = Drainage (mm)

R = Runoff (mm) and

ET = Evapotranspiration (mm)

Change in soil water content: Two neutron access tubes were installed to a depth of 2 m in all treatment combination replicates (one in the plant row and the other between the rows).

Volumetric soil water content was indirectly measured with the Campbell Pacific Nuclear (CPN) 503DR hydroprobe soil water content meter on a weekly basis, commencing thirty days after transplanting up to the end of the growing season. The measurements were taken at a depth interval of 300 mm up to 1800 mm. For the period from planting until the first CPN measurements, soil water content was measured gravimetrically and converted to volumetric water content using the following bulk densities: 1.66, 1.68, 1.66, 1.67, 1.68, 1.67 mg m^{-3} from the soil depths of 0-300, 300-600, 600-900, 900-1200, 1200-1500 and 1500-1800 mm, respectively.

Precipitation: Precipitation was measured with rain gauges installed above the canopy in all the water treatments per block.

Irrigation: The water deficit was calculated according to the reference water level, W_1 (DUL minus 20 mm). The 20 mm represents the rain storage capacity. The readings from CPN neutron water meter access tubes installed at all the W_1 treatments were used to calculate the deficit which was replaced on a weekly basis. At the same time rainfall water was taken into consideration. Both irrigation and rainfall water were measured with rain gauges.

Drainage: The concept of drained upper limit (DUL) as described by Chimungu (2009) was used to calculate drainage. Actual soil water content was never above the DUL values, indicating that drainage was neglectable.

Runoff: The application rate of the irrigation system was lower than the soil's final infiltration rate. The final infiltration rate was measured with a double-ring infiltrometer and was mathematically described with a power function ($r^2 = 0.98$):

$$y = 1.1835x^{-0.9973} \qquad 4.2$$

Where x = cumulative time (minute)

y = infiltration rate (cm min^{-1})

Using Equation 4.2 the final infiltration rate calculated after 45 min was 13.2 mm h^{-1}. The maximum application rate of the line source irrigation system was 6.25 mm h^{-1}, and hence runoff was assumed to be zero.

Evapotranspiration: ET can be calculated using equation 4.1 since ΔW, P and I are known and D and R assumed to be zero.

4.2.6 Water use efficiency

The cumulative weekly green pepper water use (ET) was used to calculate the cumulative weekly water use efficiency (WUE) ($g\ m^{-2}mm^{-1}$).

$$WUE = Y/ET \qquad 4.3$$

Where Y = Weekly cumulative fresh fruit mass ($g\ m^{-2}$)

4.2.7 Data processing

Analysis of variance was done at a confidence level of 5% with SAS (Anon., 2004b) on variables, viz. cumulative fresh and dry fruit mass and cumulative fruit number (Table 4.2); cumulative water use, leaf area index and cumulative water use efficiency (Table 4.4). Treatment means for each parameter were separated by the least significant difference (LSD_{Tukey}) test at $P \leq 0.05$. Treatment means of cumulative fresh and dry fruit mass, cumulative fruit number, water use (ET) and leaf area index derived from these analyses were then subjected to regression analyses with Excel of the Microsoft Office package (Anon., 2007), using the polynomial equations.

4.3 RESULTS and DISCUSSION

4.3.1 Meteorological conditions

The weather data for the 2004/5 green pepper production season was not so favourable when long-term climatic data serves as reference (Table 3.2). For example, the total long-term rainfall and potential evapotranspiration exceeded that of the 2004/5 season with 110 and 121 mm, respectively. The low total seasonal rainfall is mainly due to low November and March rainfall. Consequently, the mean 2004/5 aridity index (AI) is lower (0.26) than that of the long term (0.32).

4.3.2 Irrigation

Irrigation amounts measured at W_1, W_2 and W_3 were expressed as a percentage of W_1 (100%) and then plotted against the perpendicular distance from the line source (Figure 4.2). A linear function was fitted to the data. The function represents the water distribution of the line source. The distances from the line source were 2.63, 5.75, 8.87 and 13.13 m for W_1, W_2, W_3 and W_4 treatments, respectively. Thus, W_2 treatment was calculated as 66% of W_1 treatment and W_3 treatment was calculated as 33% of W_1 treatment. Although irrigation was executed carefully, it should be noted that the amounts of water may vary due to the wind effects as indicated in Figure 4.2.

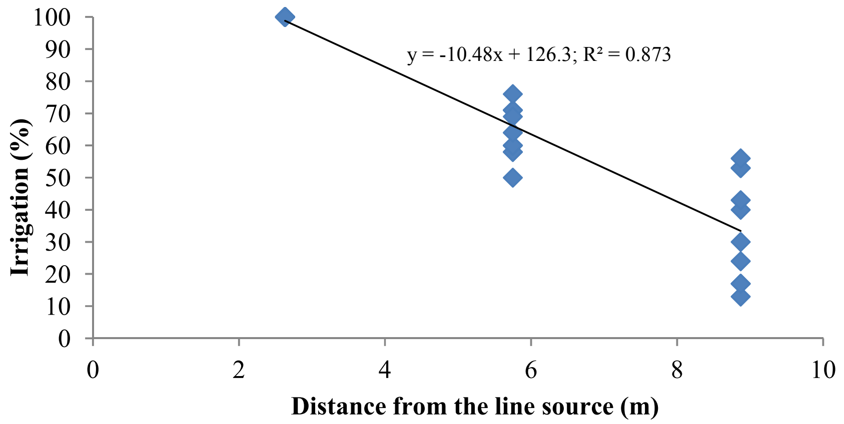

Figure 4.2 Irrigation distribution pattern, perpendicular to the line source.

The cumulative weekly irrigation and rainfall water over a period of eleven weeks (week twelve to twenty two after transplanting) is given in Table 4.1. The total irrigation and rainfall water amounted to 547, 481, 417 and 303 mm for full irrigation (W_1), 66% of full irrigation (W_2), 33% of full irrigation (W_3) and dryland (W_4), respectively (Table 4.1).

Table 4.1 Cumulative water treatments (precipitation plus irrigation, over a period of eleven weeks after transplanting) and their distances from the line source.

Weeks after transplanting	Water			
	W_1 (2.63 m) (mm)	W_2 (5.75 m) (mm)	W_3 (8.87 m) (mm)	W_4(13.13 m) (mm)
12	246	233	222	173
13	262	247	230	173
14	312	301	281	215
15	346	323	297	228
16	368	340	311	233
17	401	363	324	242
18	438	394	342	254
19	454	405	351	254
20	504	447	389	284
21	519	458	397	289
22	547	481	417	303

4.3.3 Yield

Yield in this section is expressed in terms of cumulative fresh and dry fruit mass (g m^{-2}) and cumulative fruit number. A summary on the analysis of variance that was done to determine the influence of water treatment and mulching on yield parameters, namely cumulative fresh and dry fruit mass and cumulative fruit number of green pepper harvested over a period of eleven weeks is presented in Table 4.2. There was no significant interaction between the water and mulching treatments (W x M) over the entire period for the three yield parameters.

Table 4.2 Summary on the analysis of variance showing the significant influence of water treatment and mulching on green pepper cumulative fresh and dry fruit mass (g m^{-2}) and cumulative fruit number (m^{-2}) for weekly harvests over a period of eleven weeks.

Weeks after transplanting	Cumulative fresh fruit mass			Cumulative dry fruit mass			Cumulative fruit number		
	Water (W)	Mulch (M)	W × M	Water (W)	Mulch (M)	W × M	Water (W)	Mulch (M)	W × M
12	ns	ns	ns	ns	ns	ns	ns	ns	ns
13	ns	ns	ns	ns	ns	ns	ns	ns	ns
14	ns	ns	ns	ns	ns	ns	ns	ns	ns
15	*	*	ns	*	*	ns	*	*	ns
16	*	*	ns	*	*	ns	*	*	ns
17	*	*	ns	*	*	ns	*	*	ns
18	*	*	ns	*	ns	ns	*	ns	ns
19	*	ns	ns	*	ns	ns	*	ns	ns
20	*	ns	ns	*	ns	ns	*	ns	ns
21	*	ns	ns	*	ns	ns	*	ns	ns
22	*	ns	ns	*	ns	ns	*	ns	ns

ns = no significant differences, * = significant differences at 5% level of significance

Effect of water: From Table 4.2, it is clear that the water treatment influenced all the yield parameters significantly from week 15 until the last harvest in week 22 after transplanting. Despite the fact that water treatment commenced seven weeks after transplanting, no significant response in the three yield parameters were observed at week 12 when harvesting commenced (Table 4.3). From week 13 to 14 after transplanting, the three yield parameters from fully irrigated plants (W_1) and 66% of full irrigation (W_2) treatment, although not significant, are consistently higher than those from 33% of full irrigation (W_3) and dryland (W_4) treatment. The water treatments started having an effect, and thereby introducing a trend on the yield parameters, from week 13 after transplanting.

Table 4.3 Influence of water treatment and mulching on green pepper cumulative fresh and dry fruit mass (g m^{-2}) and cumulative fruit number m^{-2} harvested weekly over a period of eleven weeks.

Yield parameters	Weeks after transplanting	Water				Mulch	
		Full irrigation (W_1)	66% of full irrigation (W_2)	33% of full irrigation (W_3)	Dryland (W_4)	Bare	Mulch
Cumulative fresh fruit mass (g m^{-2})	12	167^a	79^a	48^a	89^a	89^a	103^a
	13	289^a	178^a	115^a	150^a	158^a	208^a
	14	375^a	244^a	137^a	217^a	191^a	296^a
	15	681^a	427^b	280^b	298^b	317^b	526^a
	16	1142^a	680^b	515^{bc}	365^c	563^b	789^a
	17	1458^a	910^b	690^{bc}	456^c	751^b	1006^a
	18	1839^a	1205^b	864^{bc}	597^c	1019^b	1233^a
	19	2138^a	1475^b	1060^{bc}	695^c	1251^a	1433^a
	20	2623^a	1967^b	1325^c	806^d	1563^a	1798^a
	21	3216^a	2479^b	1664^c	997^d	2010^a	2168^a
	22	3754^a	2974^b	2052^c	1192^d	2403^a	2582^a
Cumulative dry fruit mass (g m^{-2})	12	10^a	5^a	3^a	6^a	6^a	6^a
	13	17^a	13^a	7^a	10^a	11^a	13^a
	14	22^a	17^a	9^a	15^a	13^a	19^a
	15	40^a	28^{ab}	18^b	20^b	20^b	32^a
	16	69^a	44^b	34^{bc}	26^c	37^b	49^a
	17	88^a	59^b	46^{bc}	33^c	49^b	64^a
	18	111^a	76^b	58^{bc}	44^c	67^a	78^a
	19	129^a	93^b	71^{bc}	52^c	82^a	91^a
	20	158^a	121^b	88^c	61^d	101^a	113^a
	21	190^a	153^b	108^c	73^d	127^a	135^a
	22	217^a	179^b	129^c	86^d	150^a	155^a
Cumulative fruit number m^{-2}	12	1.2^a	0.6^a	0.4^a	0.7^a	0.7^a	0.8^a
	13	2.1^a	1.3^a	0.9^a	1.2^a	1.2^a	1.6^a
	14	2.7^a	1.8^a	1.1^a	1.7^a	1.5^a	2.2^a
	15	4.7^a	3.0^{ab}	2.1^b	2.3^b	2.3^b	3.7^a
	16	7.6^a	4.6^b	3.6^{bc}	2.7^c	3.9^b	5.4^a
	17	9.5^a	6.1^b	4.7^{bc}	3.3^c	5.1^b	6.7^a
	18	11.9^a	8.0^b	5.7^{bc}	4.3^c	6.8^a	8.2^a
	19	13.6^a	9.6^b	6.9^{bc}	4.9^c	8.2^a	9.4^a
	20	16.4^a	12.5^b	8.5^c	5.5^d	10.0^a	11.5^a
	21	19.8^a	15.4^b	10.4^c	6.7^d	12.5^a	13.6^a
	22	22.5^a	18.0^b	12.5^c	7.9^d	14.7^a	15.8^a

Means with different letters in the same row differ significantly from each other. Individual Tables with their LSD's are given in Appendix A, Table 4.3a-f.

The first significant effect of water was observed at week 15 after transplanting where cumulative fresh fruit mass of fully irrigated plants (W_1) was significantly higher than that of the rest of the water treatments. During the same week, cumulative dry fruit mass and number of fully irrigated plants (W_1) were significantly higher than that of 33% of full irrigation (W_3) and the dryland (W_4) treatments. At week 16 after transplanting all yield parameters from both fully irrigated (W_1) and 66% of full irrigation (W_2) treatments were significantly higher than that of the dryland (W_4) treatment. This trend continued up to week 19 after transplanting. At week 20 after transplanting, the three yield parameters of all irrigation treatments (W_1, W_2 and W_3) were significantly higher than that of the dryland (W_4) treatment and this trend continued until the end of harvesting (twenty two weeks after transplanting).

In order to quantify the final effect of water treatment on the yield parameters, the cumulative yields at week 22 after transplanting were plotted against the water treatments (P+I) (Figure 4.3). The relationship was quantified using a linear function and the coefficients are presented in Figure 4.3. The R^2 results, which vary between 0.97 and 0.98, indicated that there is a strong relationship between water application and the different yield parameters. All the slopes are positive, indicating that the yield parameters increased with an increase in water application.

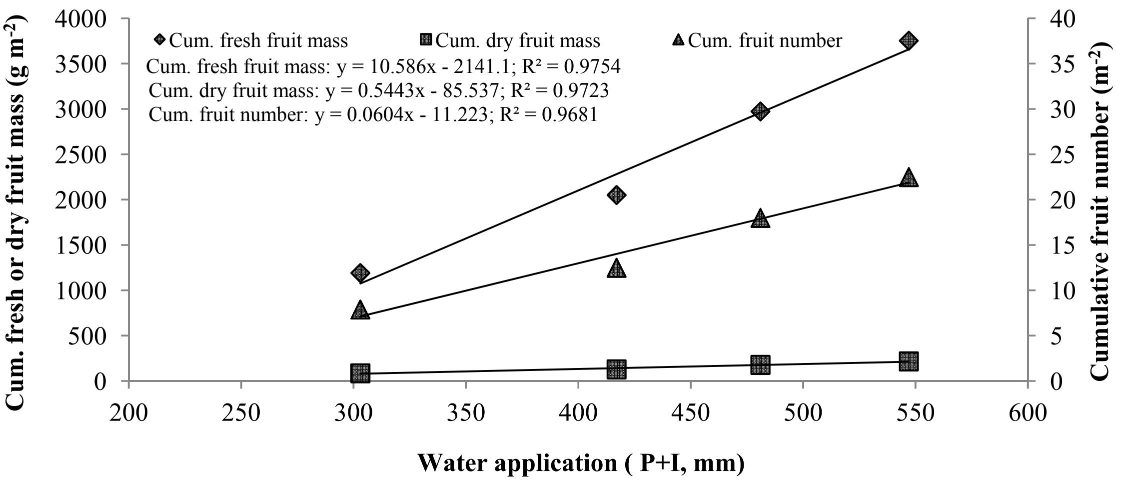

Figure 4.3 Influence of water treatment on cumulative fresh and dry fruit mass and cumulative fruit number of green pepper harvested weekly over a period of eleven weeks (from week 12 to week 22 after transplanting).

It can be concluded that the yield of green pepper responded well to water application in a semi-arid climate zone. From these results it is clear that water treatment mostly significantly increased all the three yield parameters calculated. The highest yield was obtained from fully irrigated treatment (W_1). These results are in agreement with those of Kirnak *et al*. (2003) who reported that green pepper fruit yield was lower in the water stressed treatment as compared to the unstressed treatment in a sub-humid climate zone. However, they also looked at the response of green pepper to nitrogen levels with or without mulch. The lower yield obtained from the dryland (W_4) treatment could be ascribed to the reduction in the rate of photosynthesis brought about by stomata closure. Stomata closure is a plant strategy that reduces plant water loss through transpiration, decreasing the absorption of carbon dioxide at the same time (Devlin & Witham, 1983).

The response of the crop to water application is quantified by the slope of the equations displayed in Figure 4.3. For each millimetre of water applied beyond 300 mm the cumulative green pepper fresh fruit mass will increase by 10.60 g m^{-2}, the dry fruit mass will increase by 0.54 g m^{-2} and the cumulative fruit number will increase by 0.06. Thus, marketable fresh green pepper fruit yield of 11 to 37 t ha^{-1} can be expected for water applications between 300 and 550 mm.

Effect of mulching: As indicated in Table 4.2 mulching only significantly influenced all the yield parameters during the mid-season (week 15 to 17 after transplanting) and continued to week 18 for cumulative fresh fruit mass. Yield parameters in Table 4.3 indicate that the mulched treatment in comparison to the bare treatment started to influence the crop positively (although not significant) in week 13 and 14 after transplanting. The effect became significant from week 15 where all the yield parameters from the mulched treatment were significantly higher than those of the bare treatment. The significant effect only lasted for a few weeks and thereafter it diminished. The bare treatment compensated for the yield probably due to soil canopy shading late in the growth season. The slower yield response in the mulched treatment in the last part of the season could have been caused by the degradation of the crop residue (mulch). At the end of season the average yield of the bare and mulched treatments combined were 2 493 g m^{-2}, 153 g m^{-2} and 15 fruits m^{-2} for cumulative fresh fruit mass, cumulative dry fruit mass and cumulative fruit number, respectively.

Mid-season results on cumulative fruit mass are concordant with those of Borosic *et al.* (1998) who reported that the yield of marketable green pepper fruits ranged from 2 900 g m^{-2} (without mulching and sprinkler irrigation) to 5 500 g m^{-2} (mulching with black film and drip irrigation) in a sub-humid climate zone in Mediterranean part of Croatia. Higher average green pepper yield from the mulched treatments varied between 5 and 74% higher than the treatments without mulch (control). The results are also in agreement with those reported by Klar & Jadoski (2004) in a sub-humid climate zone in a protected environment where green pepper fruit number were higher in the mulched treatments compared to treatments without mulch. The mulched treatment showed 104% higher than the treatment without mulch.

4.3.4 Water use

A summary on the analysis of variance that was done to determine the influence of water treatment and mulching on cumulative water use (ET), leaf area index (LAI) and water use efficiency (WUE) of green pepper harvested over a period of nine (LAI) and eleven (ET and WUE) weeks is given in Table 4.4. There was no significant interaction between the water treatment and mulching for the three parameters, apart from leaf area index which was only significant at week 17 after transplanting.

Table 4.4 Summary on the analysis of variance showing the significant influence of water treatment and mulching on green pepper cumulative water use (mm), leaf area index and cumulative water use efficiency (g m^{-2} mm^{-1}) measured over a period of nine (LAI) and eleven (ET and WUE) weeks.

Weeks after transplanting	Cumulative ET			LAI			Cumulative WUE		
	Water (W)	Mulch (M)	W × M	Water (W)	Mulch (M)	W × M	Water (W)	Mulch (M)	W × M
11				ns	*	ns			
12	*	ns	ns				ns	ns	ns
13	*	ns	ns	*	*	ns	ns	ns	ns
14	*	ns	ns				ns	ns	ns
15	*	ns	ns	*	*	ns	*	*	ns
16	*	ns	ns				*	*	ns
17	*	ns	ns	*	*	*	*	*	ns
18	*	ns	ns				*	*	ns
19	*	ns	ns	*	*	ns	*	ns	ns
20	*	*	ns				*	*	ns
21	*	*	ns				*	*	ns
22	*	*	ns				*	*	ns

ns = no significant differences, * = significant differences at 5% level of significance

Effect of water: From Table 4.4 it is clear that water treatment significantly influenced water use throughout the entire harvesting season (from week 12 to 22 after transplanting). The significant effect on water use was experienced as early as week 12 and continued until the end of harvesting where the water use of both fully irrigated (W_1) and 66% of full irrigation (W_2) treated plants were significantly higher than that of 33% of full irrigation (W_3) and the dryland (W_4) treatments (Table 4.5). The effect of water treatments reached its peak at week 18 where all water treatments were significantly different from each other. This was observed until the end of the harvesting period.

Water use was related to the leaf area index for week 13, 15, 17 and 19 and the results are displayed in Figure 4.4. All slopes are positive, indicating that as the leaf area index increases, water use also increases. It is also evident from the coefficients of determination (R^2), which range from 0.71 to 0.99, that as irrigation proceeds over time, the relationship gets stronger.

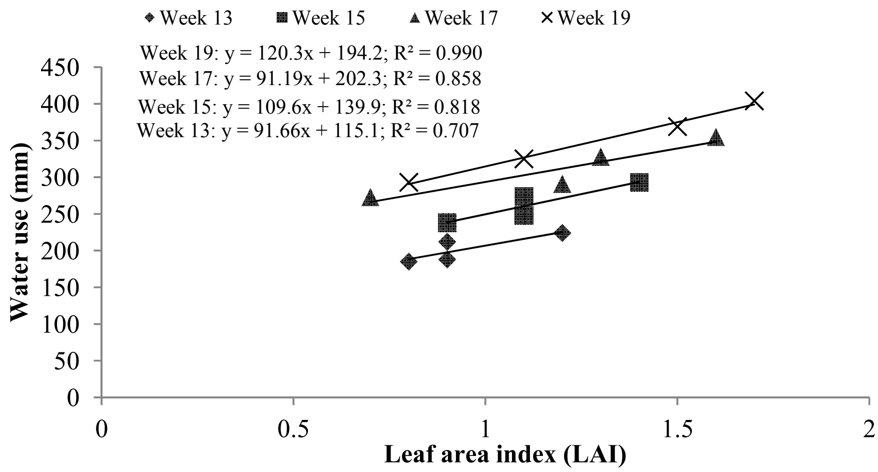

Figure 4.4 The relationship between the means of water use and leaf area index.

Table 4.5 Influence of water treatment and mulching on green pepper cumulative water use (mm), leaf area index and cumulative water use efficiency (g m^{-2} mm^{-1}) measured over a period of eleven (ET & WUE) and nine (LAI) weeks.

Parameters	Weeks after transplanting	Water				Mulch	
		Full irrigation (W_1)	66% of full irrigation (W_2)	33% of full irrigation (W_3)	Dryland (W_4)	Bare	Mulch
Cumulative water use (mm)	12	204^a	194^a	176^b	176^b	187^a	188^a
	13	224^a	212^a	188^b	185^b	202^a	203^a
	14	265^a	247^b	223^c	215^c	239^a	236^a
	15	293^a	274^b	248^c	238^c	266^a	261^a
	16	324^a	303^b	272^c	255^c	291^a	286^a
	17	355^a	328^b	291^c	273^c	314^a	309^a
	18	387^a	355^b	312^c	289^d	340^a	331^a
	19	404^a	369^b	325^c	293^d	352^a	343^a
	20	447^a	405^b	356^c	316^d	391^a	371^b
	21	466^a	422^b	371^c	326^d	407^a	385^b
	22	499^a	455^b	399^c	347^d	436^a	414^b
Leaf area index (LAI)	11	0.9^a	0.9^a	0.8^a	0.7^a	0.7^b	0.9^a
	13	1.2^a	0.9^{ab}	0.9^b	0.8^b	0.7^b	1.2^a
	15	1.4^a	1.1^b	1.1^{bc}	0.9^c	0.8^b	1.4^a
	17	1.6^a	1.3^b	1.2^b	0.7^c	1.0^b	1.5^a
	19	1.7^a	1.5^{ab}	1.1^{bc}	0.8^c	1.0^b	1.5^a
Cumulative water use efficiency (g m^{-2} mm^{-1})	12	0.8^a	0.4^a	0.3^a	0.5^a	0.5^a	0.5^a
	13	1.3^a	0.9^a	0.6^a	0.8^a	0.8^a	1.0^a
	14	1.4^a	1.0^a	0.6^a	1.0^a	0.8^a	1.2^a
	15	2.3^a	1.6^{ab}	1.1^b	1.3^b	1.2^b	2.0^a
	16	3.5^a	2.3^b	1.9^b	1.4^b	1.9^b	2.7^a
	17	4.1^a	2.8^b	2.4^{bc}	1.7^c	2.3^b	3.2^a
	18	4.8^a	3.4^b	2.8^{bc}	2.1^c	2.9^b	3.6^a
	19	5.3^a	4.0^b	3.3^{bc}	2.4^c	3.4^a	4.0^a
	20	5.9^a	4.9^a	3.7^b	2.6^c	3.9^b	4.7^a
	21	6.9^a	5.9^a	4.5^b	3.1^c	4.8^b	5.4^a
	22	7.5^a	6.6^a	5.2^b	3.5^c	5.3^b	6.0^a

Means with different letters in the same row differ significantly from each other. Individual Tables with their LSD's are given in Appendix B, Table 4.5a-f.

From these results it is clear that water treatment significantly increased water use (ET) throughout the season in a semi-arid climate zone. The highest water use was obtained from the fully irrigated treatment (W_1). These results are in agreement with those of Demirtas &

Ayas (2009) who reported that seasonal evapotranspiration (ET) of peppers increased with applied irrigation water and ranged from 115 to 740 mm in a sub-humid climate zone under unheated greenhouse conditions.

Effect of mulching: As indicated in Table 4.4, mulching only significantly influenced water use during the last three weeks of harvesting. Mulching did not have a significant effect on water use from weeks 12 to 19 after transplanting (Table 4.5). This suggests that the water conserved in the mulch treatment during this period was used by the plants for transpiration. This suggestion is supported by a significantly higher leaf area index in the mulched treatment as compared to the bare treatment (Table 4.5) from weeks 11 to 19 after transplanting. Towards the end of the season (last three weeks) the water use from the bare treatment was significantly higher than that of the mulched treatment. This indicates that plants from the bare treatment compensated in terms of growth probably due the soil canopy shading effect, thereby using more water through transpiration. Evaporation from the soil should be low at full canopy, irrespective of the soil surface treatment.

Mulching had a significant effect on water conservation by reducing evaporation from the soil in a semi-arid climate zone. These results are concordant with those reported by Klar & Jadoski (2004) who found that mulched treatments showed reductions in green pepper water use as compared to those without mulch in a sub-humid climate zone in a protected environment.

4.3.5 Water use efficiency

Effect of water: Water treatment significantly influenced water use efficiency from week 15 up to the end of the season (Table 4.4). Table 4.5 indicates that from weeks 12 to 14 after transplanting the water use efficiency of fully irrigated plants (W_1), although not significant, were consistently higher than that of the other three water treatments (W_2, W_3 and W_4). The effect became significant from week 15 where the water use efficiency of fully irrigated plants (W_1) was significantly higher than that of 33% of full irrigation (W_3) and dryland (W_4) treated plants.

At week 16 after transplanting the water use efficiency of fully irrigated plants (W_1) was significantly higher than that of all the other water treatments (W_2, W_3 and W_4). However, the water use efficiency increased when water treatments increased from dryland (W_4) to full irrigation (W_1). This trend continued up to the end of the season. From week 20 up to the end of the season the water use efficiency of the water treatments (W_1, W_2 and W_3) was significantly higher than that of the dryland (W_4) treatment. During the same period (week 20 up to the end of the season), the water use efficiency of fully irrigated (W_1) and 66% of full irrigation (W_2) treatments did not significantly differ from each other. This may therefore suggest that any amount of water higher than 66% of full irrigation (W_2) treatment (481 mm) will not significantly increase water use efficiency.

From these results it is clear that water treatment significantly increased water use efficiency (WUE) in most cases in a semi-arid climate zone. The highest water use efficiency was obtained from the fully irrigated treatment (W_1). These results concur with those of Demirtaş & Ayas (2009) who reported that water use efficiency decreased when irrigation water amount decreased in a sub-humid climate zone under unheated greenhouse conditions. They also found that the highest water use efficiency of 3.24 g m^{-2} mm^{-1} was associated with the highest irrigation treatment of 724 mm and the lowest water use efficiency of 1.74 g m^{-2} mm^{-1} was linked to the lowest irrigation treatment of 65 mm.

Effect of mulching: The water use efficiency of the mulched treatment was significantly higher than that of the bare treatment from week 15 up to the end of harvesting, except for week 19 (Table 4.5). At the end of harvesting the water use efficiency difference between the two treatments was 0.7 g m^{-2} mm^{-1}. It is clear that mulching significantly increased green pepper WUE in a semi-arid climate zone. It is not possible to compare green pepper water use efficiency (g m^{-2} mm^{-1} of water transpired) as influenced by mulching with other research results since most of the findings reported are based on water applied and not on evapotranspiration. However, Klar & Jadoski (2004) reported that green pepper water use efficiency was higher (69 L kg^{-1} fruit) in mulched treatments as compared to treatments without mulch (140 L kg^{-1} fruit) in a humid climate zone in a protected environment, which is not comparable.

4.4 CONCLUSIONS

From the literature study, it was concluded that there is a huge gap in knowledge on the effect of irrigation and mulching on green pepper production in semi-arid climate zones. Results of this research indicated that increasing irrigation applications resulted in a linear increase in yield (cumulative fresh and dry fruit mass and cumulative fruit number), cumulative water use, leaf area index and cumulative water use efficiency. The quantification of this relationship can be deduced from the results which indicate that water application between 300 and 550 mm per season resulted in fresh fruit mass between 11 and 37 t ha^{-1}. From these results it can be concluded that the water use efficiency based on fresh fruit mass will vary between 3.5 to 7.5 g m^{-2} mm^{-1} under semi-arid conditions.

Although mulching did not have a significant effect on yield at the end of the season it was concluded that due to the relationship between water use and leaf area index, mulching contributed to water conservation. The evaporation component saved by the mulch was used by the plants for transpiration, which then resulted in higher water use efficiency (6 g m^{-2} mm^{-1}) than the bare (5.3 g m^{-2} mm^{-1}) treatment. Thus, from a water conservation point of view, mulch (crop residues) can be recommended to conserve water for transpiration for green pepper production in semi-arid climate zones.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

Green pepper is a popular cash crop worldwide, but inadequate accessible water is usually a restrictive factor when it comes to its production. Thus, irrigation is imperative for sustainable production of green pepper in semi-arid climate zones. The objective of this study was therefore to quantify the effect of irrigation, plant population and mulching on growth and yield of green pepper. In order to achieve this, two field trials were conducted using a line source sprinkler irrigation system. Green pepper cultivar, California Wonder 300, was used in both trials.

Influence of water application and plant population on yield of green pepper

The main objective of this trial was to quantify the effect of irrigation and plant population on the growth and yield of green pepper. The second objective was to optimize green pepper plant population for different water regimes.

The crop responded well to irrigation which significantly increased green pepper marketable fruit mass and number per plant and consequently the yield. The yield (t ha^{-1}) of all irrigation treatments, regardless of the amount of water applied was significantly higher than that of the dryland (303 mm) treatment and that of the full irrigation (781 mm) treatment was significantly higher than that of 40% of full irrigation treatment (497 mm). The full irrigation (781 mm) treatment increased marketable yield with 274% (39 t ha^{-1}) and the 40% of full irrigation (497 mm) treatment increased it with 162% (27 t ha^{-1}). The 70% of full irrigation (627 mm) treatment increased marketable yield with 253% (37 t ha^{-1}). Irrigation applications also increased marketable fruit number which ranged between145% (17 6750) and 255% (256 338) for 40% of full irrigation (497 mm) and full irrigation (781 mm) treatment, respectively. Plant population did not have much of a significant effect on the growth and marketable yield of green pepper. Green pepper plants demonstrated a high level of plasticity in terms of their ability to compete for production resources e.g. water, light and nutrients. The optimum plant population for all water treatments, excluding 40% of full irrigation (497 mm) was not reached, yield continued to increase linearly even at the highest plant population (41 496 plants ha^{-1}) used in this trial.

Influence of irrigation and mulching on yield, water use and water use efficiency of green pepper

The second trial was conducted to quantify the effect of irrigation and mulching on yield, water use and water use efficiency of green pepper under different water and mulching treatments. Irrigation significantly increased marketable yield, water use and water use efficiency of green pepper. From irrigation applications between 300 and 550 mm a fresh fruit yield of 11 to 37 t ha^{-1} can be expected. Every millimetre of water applied above 300 mm is expected to increase the cumulative green pepper fresh fruit mass by 10.60 g m^{-2}, the dry fruit mass by 0.54 g m^{-2} and the cumulative fruit number by 0.06.

When water use was related to leaf area index, the relationship indicated that as the leaf area index increases, water use also increases. Coefficients of determination (R^2) indicated that as irrigation proceeded over time, the relationship got stronger. The highest water use efficiency was obtained from the fully irrigated treatment (547 mm). Mulching had a significant positive mid-season effect on yield, but did not have a significant effect on water use. However, mulching conserves water by reducing evaporation. The water saved by the mulch was used by the plants for transpiration, which resulted in high water use efficiency in the mulched treatment as compared to the bare treatment.

The use of irrigation for green pepper production is therefore recommended. The total yields from all three irrigation treatments in the second trial differs significantly from each other and they are all significantly higher than the dryland treatment (303 mm). Thus, any of the irrigation treatments can be recommended depending on the availability and cost of water. The objective of this study to optimise plant population was not achieved and for future research, it is recommended to use higher plant populations with the same water regimes. Although mulching did not have such a significant effect on the yield, its use is recommended to conserve water for transpiration for green pepper production in semi-arid regions.

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APPENDICES

Appendix A

Table 4.3a Influence of water treatment on green pepper cumulative fresh fruit mass (g m^{-2}) harvested over a period of eleven weeks.

Weeks after transplanting	Water (W)				$LSD_{T(0.05)}$ (W)
	Full irrigation (W_1)	66% of full irrigation (W_2)	33% of full irrigation (W_3)	Dryland (W_4)	
12	167.473^{a}	79.012^{a}	48.208^{a}	89.470^{a}	**ns**
13	289.250^{a}	177.951^{a}	114.624^{a}	149.633^{a}	**ns**
14	375.096^{a}	244.154^{a}	136.768^{a}	217.344^{a}	**ns**
15	681.092^{a}	427.282^{b}	279.570^{b}	298.171^{b}	**249.230**
16	1141.990^{a}	679.989^{b}	515.014^{bc}	365.299^{c}	**298.990**
17	1457.720^{a}	910.391^{b}	689.881^{bc}	455.539^{c}	**351.010**
18	1838.860^{a}	1205.020^{b}	863.983^{bc}	597.264^{c}	**384.020**
19	2137.940^{a}	1475.040^{b}	1060.050^{bc}	694.694^{c}	**470.790**
20	2623.420^{a}	1966.940^{b}	1325.480^{c}	805.825^{d}	**405.560**
21	3216.420^{a}	2479.390^{b}	1663.770^{c}	996.631^{d}	**567.050**
22	3753.900^{a}	2974.070^{b}	2051.530^{c}	1192.390^{d}	**605.890**

Means with different letters in the same row differ significantly from each other

Table 4.3b Influence of mulching on green pepper cumulative fresh fruit mass (g m^{-2}) harvested over a period of eleven weeks.

Weeks after transplanting	Mulch (M)		$LSD_{T(0.05)}$ (M)
	Bare	Mulch	
12	89.474^{a}	102.608^{a}	**ns**
13	158.034^{a}	207.696^{a}	**ns**
14	191.071^{a}	295.611^{a}	**ns**
15	317.457^{b}	525.601^{a}	**183.780**
16	562.632^{b}	788.513^{a}	**172.630**
17	750.986^{b}	1005.780^{a}	**183.810**
18	1019.150^{b}	1233.420^{a}	**207.560**
19	1250.540^{a}	1433.320^{a}	**ns**
20	1562.920^{a}	1797.910^{a}	**ns**
21	2010.480^{a}	2167.620^{a}	**ns**
22	2403.490^{a}	2582.450^{a}	**ns**

Means with different letters in the same row differ significantly from each other

Table 4.3c Influence of water treatment on green pepper cumulative dry fruit mass ($g\ m^{-2}$) harvested over a period of eleven weeks.

Weeks after transplanting	Water (W)				$LSD_{T(0.05)}$ (W)
	Full irrigation (W_1)	66% of full irrigation (W_2)	33% of full irrigation (W_3)	Dryland (W_4)	
12	9.693^a	5.453^a	3.026^a	5.829^a	**ns**
13	17.027^a	12.677^a	7.317^a	9.938^a	**ns**
14	22.141^a	16.873^a	8.916^a	14.795^a	**ns**
15	39.750^a	27.683^{ab}	17.918^b	20.398^b	**13.808**
16	68.522^a	43.661^b	33.872^{bc}	25.569^c	**14.688**
17	88.255^a	58.581^b	46.316^{bc}	32.897^c	**17.526**
18	110.545^a	75.965^b	58.120^{bc}	44.151^c	**19.348**
19	128.792^a	92.678^b	71.323^{bc}	52.036^c	**24.126**
20	157.749^a	121.362^b	87.743^c	60.509^d	**19.022**
21	190.048^a	152.688^b	107.993^c	73.364^d	**25.021**
22	216.745^a	178.503^b	129.355^c	85.959^d	**29.075**

Means with different letters in the same row differ significantly from each other

Table 4.3d Influence of mulching on green pepper cumulative dry fruit mass ($g\ m^{-2}$) harvested over a period of eleven weeks.

Weeks after transplanting	Mulch (M)		$LSD_{T(0.05)}$ (M)
	Bare	Mulch	
12	5.85^a	6.151^a	**ns**
13	10.56^a	12.919^a	**ns**
14	12.718^a	18.643^a	**ns**
15	20.388^b	32.487^a	**10.799**
16	36.658^b	49.154^a	**10.408**
17	49.467^b	63.557^a	**11.669**
18	66.786^a	77.605^a	**ns**
19	81.6^a	90.815^a	**ns**
20	100.872^a	112.81^a	**ns**
21	127.018^a	135.028^a	**ns**
22	149.972^a	155.31^a	**ns**

Means with different letters in the same row differ significantly from each other

Table 4.3e Influence of water treatment on green pepper cumulative fruit number m^{-2} harvested over a period of eleven weeks.

Weeks after transplanting	Water (W)				$LSD_{T(0.05)}$ (W)
	Full irrigation (W_1)	66% of full irrigation (W_2)	33% of full irrigation (W_3)	Dryland (W_4)	
12	1.167^{a}	0.584^{a}	0.369^{a}	0.737^{a}	**ns**
13	2.088^{a}	1.321^{a}	0.921^{a}	1.229^{a}	**ns**
14	2.703^{a}	1.781^{a}	1.075^{a}	1.720^{a}	**ns**
15	4.699^{a}	2.979^{ab}	2.058^{b}	2.273^{b}	**1.782**
16	7.617^{a}	4.638^{b}	3.593^{bc}	2.733^{c}	**1.823**
17	9.521^{a}	6.112^{b}	4.699^{bc}	3.348^{c}	**2.138**
18	11.916^{a}	7.955^{b}	5.743^{bc}	4.269^{c}	**2.345**
19	13.636^{a}	9.644^{b}	6.941^{bc}	4.853^{c}	**2.798**
20	16.400^{a}	12.469^{b}	8.477^{c}	5.528^{d}	**2.300**
21	19.779^{a}	15.356^{b}	10.412^{c}	6.665^{d}	**3.232**
22	22.512^{a}	18.028^{b}	12.500^{c}	7.862^{d}	**3.185**

Means with different letters in the same row differ significantly from each other

Table 4.3f Influence of mulching on green pepper cumulative fruit number m^{-2} harvested over a period of eleven weeks.

Weeks after transplanting	Mulch (M)		$LSD_{T(0.05)}$ (M)
	Bare	Mulch	
12	0.676^{a}	0.752^{a}	**ns**
13	1.213^{a}	1.566^{a}	**ns**
14	1.474^{a}	2.165^{a}	**ns**
15	2.319^{b}	3.686^{a}	**1.313**
16	3.900^{b}	5.390^{a}	**1.299**
17	5.098^{b}	6.741^{a}	**1.328**
18	6.772^{a}	8.170^{a}	**ns**
19	8.154^{a}	9.383^{a}	**ns**
20	9.982^{a}	11.456^{a}	**ns**
21	12.546^{a}	13.56^{a}	**ns**
22	14.696^{a}	15.756^{a}	**ns**

Means with different letters in the same row differ significantly from each other

Appendix B

Table 4.5a Influence of water treatment on green pepper cumulative water use (ET, mm) measured over a period of eleven weeks.

Weeks after transplanting	Water (W)				$LSD_{T(0.05)}$ (W)
	Full irrigation (W_1)	66% of full irrigation (W_2)	33% of full irrigation (W_3)	Dryland (W_4)	
12	204.324[a]	193.867[a]	175.875[b]	176.223[b]	**15.712**
13	224.031[a]	211.919[a]	188.368[b]	185.348[b]	**16.549**
14	265.080[a]	247.294[b]	222.961[c]	214.610[c]	**14.837**
15	293.287[a]	274.488[b]	248.350[c]	237.979[c]	**14.411**
16	323.635[a]	302.516[b]	271.844[c]	255.281[c]	**18.649**
17	354.516[a]	327.935[b]	290.722[c]	273.344[c]	**17.474**
18	386.506[a]	354.809[b]	312.299[c]	289.052[d]	**18.511**
19	404.125[a]	369.189[b]	324.613[c]	292.908[d]	**19.955**
20	446.700[a]	404.655[b]	356.031[c]	315.760[d]	**20.086**
21	465.755[a]	422.315[b]	370.996[c]	325.559[d]	**21.386**
22	499.113[a]	455.067[b]	398.696[c]	346.549[d]	**21.145**

Means with different letters in the same row differ significantly from each other

Table 4.5b Influence of mulching on green pepper cumulative water use (ET, mm) measured over a period of eleven weeks.

Weeks after transplanting	Mulch (M)		$LSD_{T(0.05)}$ (M)
	Bare	Mulch	
12	186.757[a]	188.388[a]	**ns**
13	201.536[a]	203.297[a]	**ns**
14	238.884[a]	236.088[a]	**ns**
15	266.480[a]	260.572[a]	**ns**
16	291.112[a]	285.525[a]	**ns**
17	314.130[a]	309.128[a]	**ns**
18	340.135[a]	331.198[a]	**ns**
19	352.448[a]	342.969[a]	**ns**
20	390.918[a]	370.655[b]	**20.196**
21	406.969[a]	385.343[b]	**20.654**
22	435.566[a]	414.147[b]	**21.052**

Means with different letters in the same row differ significantly from each other

Table 4.5c Influence of water treatment on green pepper leaf area index measured over a period of nine weeks.

Weeks after transplanting	Water (W)				$LSD_{T(0.05)}$ (W)
	Full irrigation (W_1)	66% of full irrigation (W_2)	33% of full irrigation (W_3)	Dryland (W_4)	
11	0.936^{a}	0.935^{a}	0.778^{a}	0.673^{a}	**ns**
13	1.199^{a}	0.948^{ab}	0.897^{b}	0.778^{b}	**0.285**
15	1.408^{a}	1.107^{b}	1.064^{bc}	0.904^{c}	**0.173**
17	1.636^{a}	1.348^{b}	1.188^{b}	0.731^{c}	**0.187**
19	1.675^{a}	1.548^{ab}	1.091^{bc}	0.763^{c}	**0.538**

Means with different letters in the same row differ significantly from each other

Table 4.5d Influence of mulching on green pepper leaf area index measured over a period of nine weeks.

Weeks after transplanting	Mulch (M)		$LSD_{T(0.05)}$ (M)
	Bare	Mulch	
11	0.716^{b}	0.945^{a}	**0.217**
13	0.746^{b}	1.165^{a}	**0.161**
15	0.804^{b}	1.438^{a}	**0.163**
17	0.979^{b}	1.472^{a}	**0.131**
19	1.048^{b}	1.490^{a}	**0.389**

Means with different letters in the same row differ significantly from each other

Table 4.5e Influence of water treatment on green pepper cumulative water use efficiency ($g\ m^{-2}mm^{-1}$) measured over a period of eleven weeks.

Weeks after transplanting	Water (W)				$LSD_{T(0.05)}$ (W)
	Full irrigation (W_1)	66% to full irrigation (W_2)	33% to full irrigation (W_3)	Dryland (W_4)	
12	0.805[a]	0.411[a]	0.295[a]	0.506[a]	**ns**
13	1.260[a]	0.851[a]	0.636[a]	0.815[a]	**ns**
14	1.401[a]	1.000[a]	0.627[a]	1.022[a]	**ns**
15	2.320[a]	1.576[ab]	1.139[b]	1.266[b]	**0.921**
16	3.526[a]	2.269[b]	1.911[b]	1.439[b]	**1.006**
17	4.103[a]	2.803[b]	2.382[bc]	1.676[c]	**1.052**
18	4.755[a]	3.413[b]	2.777[bc]	2.075[c]	**1.063**
19	5.290[a]	4.008[b]	3.275[bc]	2.380[c]	**1.251**
20	5.879[a]	4.894[a]	3.741[b]	2.579[c]	**0.997**
21	6.905[a]	5.894[a]	4.499[b]	3.096[c]	**1.295**
22	7.523[a]	6.558[a]	5.167[b]	3.487[c]	**1.353**

Means with different letters in the same row differ significantly from each other

Table 4.5f Influence of mulching on green pepper cumulative water use efficiency ($g\ m^{-2}mm^{-1}$) measured over a period of eleven weeks.

Weeks after transplanting	Mulch (M)		$LSD_{T(0.05)}$ (M)
	Bare	Mulch	
12	0.475[a]	0.534[a]	**ns**
13	0.786[a]	0.995[a]	**ns**
14	0.803[a]	1.223[a]	**ns**
15	1.185[b]	1.966[a]	**0.667**
16	1.900[b]	2.672[a]	**0.587**
17	2.331[b]	3.151[a]	**0.613**
18	2.909[b]	3.601[a]	**0.629**
19	3.438[a]	4.039[a]	**ns**
20	3.855[b]	4.691[a]	**0.661**
21	4.765[b]	5.432[a]	**0.663**
22	5.329[b]	6.038[a]	**0.689**

Means with different letters in the same row differ significantly from each other