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**AMELIORATION OF DROUGHT STRESS IN PURPLE PASSION FRUIT
(*Passiflora edulis* f. *edulis* Sims.) USING IRRIGATION AND MULCH
IN A POLYFILM COVERED RAIN SHELTER**

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A Thesis Submitted to the Graduate School in Partial Fulfillment of the
Requirements for the Award of Master of Science Degree in Horticulture of Egerton
University

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DECLARATION

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DEDICATION

To Margaret, Millicent, Patricia, Morris and John with all my love.

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ABSTRACT

Purple passion fruit is an important fruit, ranking third in export volumes in Kenya. Its yields drastically declined over the period 1994 to 2005 from 948,000 to 32,000 tonnes partly due to drought stresses. Without irrigation, it is difficult to maintain year-round production of purple passion fruits on a commercial basis. The present study evaluated the effects of irrigation rate and mulch type on drought stress amelioration in purple passion fruits. The experiment was set up in a plastic covered rain shelter, measuring 60m x 8m and located at Egerton University, Njoro-Kenya. The experiment was set up in randomized complete block design, replicated four times, with four irrigation rates (2.5, 5, 10 and 20 L of water applied once weekly per plant) and three mulch types (black plastic, wheat straw and no mulch). Each treatment had three plants spaced at 1.5m x 1.5m. Purple passion fruit seedlings, measuring 30 cm tall, were transplanted into 45cm x 45cm holes and trellised onto posts and wires. A trench lined with plastic film was dug between main plots and blocks to prevent water seepage across treatments. Plants were maintained uniformly during the first four weeks to recover from transplanting shock. Treatments were applied at the beginning of the fifth week after planting (WAP). Data were recorded bi-weekly from the 9th up to the 56th WAP on: vegetative growth, plant physiology, reproductive growth and fruit quality. Data were subjected to analysis of variance using the SAS programme. Higher irrigation rates promoted greater leaf area and weight than lower irrigation rates. Black plastic and wheat straw significantly ($P < 0.05$) increased leaf weight. Irrigation significantly ($P < 0.05$) increased laterals, total florals (intact flowers, dropped flowers and immature fruits) and dropped flowers. Black plastic mulch significantly increased florals, dropped flowers and immature fruits. The 20 L significantly increased stomatal conductance, while no mulch significantly increased net photosynthesis. The cumulative fruit weight of 6016 g/plant for 20 L was significantly greater than the 5052 g/plant for 2.5 L. Irrigation and mulch did not affect fruit quality. Higher irrigation rate decreased water use efficiency to 0.2 fruits/L or 5 g/L. Generally, when irrigating with over 5 L, there was no additional benefit of mulching, but mulch ameliorated drought stress when deficit irrigation rate of 2.5 L was applied. Wheat straw and 10 L per plant once per week was generally optimal and should be adopted towards mitigating drought stress effects in purple passion fruits in Kenya.

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ABBREVIATIONS AND ACRONYMS

CAN	=	Calcium Ammonium Nitrate
HCDA	=	Horticultural Development Authority
KARI	=	Kenya Agricultural Research Institute
KHDP	=	Kenya Horticultural Development Programme
LAI	=	Leaf Area Index
MAP	=	Months After Planting
MOA	=	Ministry of Agriculture
MSWC	=	Minimum Soil Water Content
NPK	=	Nitrogen Phosphorous and Potassium
Pn	=	Net Photosynthesis
SAS	=	Statistical Analysis Software
TSS	=	Total Soluble Solids
WAP	=	Weeks After Planting
WUE	=	Water Use Efficiency

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Passion fruit is an attractive crop for small-scale farmers because it has good local and export markets, can be harvested throughout the year, is easily transported, and has a short maturity period according to Kenya Horticultural Development Program (KHDP, 2004). Of the estimated 500 species of *Passiflora* in the family Passifloraceae only one, *P. edulis* Sims, has the exclusive designation of passion fruit, without qualification. Within this species, there are two distinct forms, the standard purple (*P. edulis* f. *edulis*), and its variant yellow (*P. edulis* f. *flavicarpa*) passion fruits. The purple form may be referred to as purple, red, or black granadilla (Morton, 1987). In terms of export, passion fruits are among the most important fruits exported, ranking third after mangoes and avocados in Kenya. The purple passion fruit is commonly grown in Kenya for juice extraction and for fresh markets, both locally and internationally. Among the cultivated varieties, purple passion fruit (*P. edulis* f. *edulis*) is the most important in the Kenyan juice industry (MOA, 1997).

Fintrac International Tropical Fruit Network Information Bulletin (No. 8 of 2004) reported that the primary markets for Kenyan passion fruits, accounting for 95% of all passion fruit exports, are the Netherlands, the United Kingdom, Belgium, and France. Kenya could be the largest producer of passion fruits in the region and perhaps the biggest exporter. Kenya Times Newspaper (April 2006) reported that the Kenyan passion fruit has entrenched itself in the regional market with Ugandan traders flooding Kenyan markets to purchase the fruits to supply Kampala, Tanzania, Rwanda and Burundi. The Kenya Agricultural Research Institute (KARI) has concluded that passion fruit is labour- and skill-intensive, making it ideal for small-scale growers who rely on their farms for a living. The fruit is also easily intercropped with seasonal or perennial crops.

Kenya Horticultural Development Program (KHDP, 2006) monthly update for February reported that regional demand for passion fruits is taking most of the production at

present, with relatively little being left for foreign export. In 2005, at least 32,000 tonnes of passion fruits were produced, of which only 998 tonnes or 3.1% were exported to European markets, earning KES 300 million. The bulk of balance was consumed locally and regionally. An increasing amount of passion fruits is also being used by local fruit processors to produce juice for local and regional markets (HCDA, 2005). However, the potential of this fruit has not been fully exploited, and could double in both yields and profits, if well harnessed.

Drought is a very common stress, generally characterized by a combination of water shortage, high temperatures and high light intensities (Kramer, 1980; Cornic, 1994; Lawlor, 1995). Photosynthesis and its capacity are progressively decreased under drought-induced stomatal closure, which reduces CO₂ availability in chloroplasts. Consequently, lower light intensity is required to saturate photosynthesis under droughty conditions than under well-watered conditions (Kramer, 1980; Cornic, 1994; Lawlor, 1995). At high light intensity, light is in excess of what can be used for photosynthesis as drought progresses. This may increase the susceptibility of drought-plants to photo-inhibition (Osmond, 1994). Different processes have been developed to safely dissipate excess light energy under drought to avoid severe photo-inhibition and photo-oxidation. Photorespiration might serve as a safety valve to dissipate excess electron transport under low CO₂ concentration prevailing in chloroplasts during drought (Osmond and Björkman, 1972; Powels and Osmond, 1978; Osmond et al., 1980). Droughty conditions and effects prevailing in Kenya similarly apply for purple passion fruits, and hence remedial measures need to be established.

1.2 Statement of the Problem

The purple passion fruit vine is shallow-rooted. During drought, dry soil conditions cause passion fruits to have poor fruit set, fruit drop and leaf defoliation, which culminate in low yield, poor fruit quality and high economic loss to farmers (Owen, 1971). Drought stress makes year-round production of commercial purple passion fruits difficult to maintain without irrigation. The period before rains when high temperatures combined with windy conditions prevail, lead to high transpiration demand causing plants to “shut

down”, according to Richard Collins, Director of Kakuzi Estates Horticulture Division (Chemonics Intrn Inc, 2002). In addition, grass mulch is difficult to procure in large amounts and breaks down too quickly under hot weather (Chemonics Intrn Inc, 2002). In Kenya, documented data on total acreage of purple passion fruits under irrigation, recommended irrigation schedule, irrigation rate per growth cycle, and mulch regime for production of purple passion fruit does not exist. This research aimed at providing data on optimal irrigation rate and mulch regime for purple passion fruit production under drought stress conditions in Kenya.

1.3 Justification of the Study

Supply of irrigation water to supplement precipitation during droughty conditions would prevent premature passion fruit drop, provide water to meet passion fruit growth requirements, enhance plant nutrient uptake from the soil, and ensure production of passion fruits all year-round. This would result in high income for farmers and foreign exchange for the country. Enhanced production would also contribute to the country’s food security, provision of raw materials for the existing juice processing industries, and increased rural incomes, consumption, employment and savings (Bujulu, 2002).

Irrigation could play a vital role in increasing crop yields and stabilizing production. During dry seasons in arid and semi-arid regions, irrigation is essential for economically viable passion fruit production, while in semi-humid and humid areas, it is often required on a supplementary basis. At the farm level, basic information required to make irrigated passion fruit farming a success includes knowledge of the amount of water required to be applied and proper water application schedule to ensure all year-round production. This research aimed at providing this information for small-scale growers.

1.4 Objectives

1.4.1. General objective

The general objective of this research was to boost growth, yield and quality of purple passion fruits through amelioration of drought stress using irrigation water and mulch.

1.4.2. Specific objectives

- (1) To determine the effect of irrigation rate on growth, yield and quality of purple passion fruits.
- (2) To determine the effect of mulch type on growth, yield and quality of purple passion fruits.
- (3) To determine the combined effects of irrigation rate and mulch type on growth, yield and quality of purple passion fruits.

1.5. Hypotheses

- 1.5.1. Irrigation rate does not affect the growth, yield and quality of purple passion fruits through amelioration of drought stress.
- 1.5.2. Mulch type does not affect the growth, yield and quality of purple passion fruits through amelioration of drought stress.
- 1.5.3. Combined irrigation rate and mulch type do not affect the growth, yield and quality of purple passion fruits through amelioration of drought stress.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin, World Distribution and Importance

The edible commercial species of passion fruit originated on the edges of South American rain forests in the Amazon region of Brazil and possibly in Paraguay and North Argentina (John and Violet, 1979; Morton, 1987). Brazil has long had a well-established passion fruit industry with large-scale juice extraction plants. The purple passion fruit is preferred there for consuming fresh. In Europe, in the 17th Century it was grown as an ornamental plant under glasshouse conditions for its attractive flowers. Passion fruit became naturalized in regions covering South Africa, Hawaii, California and Florida by the end of the 19th Century. Kenya, Sri Lanka and Fiji were naturalized with the crop by about the middle of the 20th Century. Commercial culture of purple passion fruit in Kenya begun in 1933 and expanded in 1960, when the crop was also introduced into Uganda for commercial production. In both countries, the large plantations were devastated several times by easily-spread diseases and pests. It became necessary to abandon them in favour of small and isolated plantings which could be better protected (Morton, 1987).

In Kenya, the main cultivated type of passion fruit is *Passiflora edulis* Sims., also known as purple passion fruit. It was initially introduced in Kisii district by European settlers. It is currently grown in several districts on small holdings East of the Rift Valley (1200 to 1800 m above sea level) in Taita Taveta and Machakos, middle zones of central highland areas such as Thika, Murang'a, Meru and Nyeri, West of the Rift Valley (2000 m above sea level) in Kisii, Bungoma, Kakamega, Kitale and Baringo (Njuguna et al., 2005).

The crop is very attractive for small-scale farmers because it is a relatively quick cash crop and fetches good market price both in the local and export markets compared to other horticultural crops. In 2005, passion fruit production in Kenya covered approximately 5,450 ha and 998 tonnes of fruits were exported (Njuguna et al., 2005).

According to the Department of Agriculture of Sri Lanka (2006), passion fruit production in South Africa, Kenya and New Zealand depends on lines of the purple passion fruit (*P. edulis* f. *edulis*). In 1965, the Laboratoire de Recherche des Produits Nestlé, Vevey, Switzerland, placed passion fruit among the three insufficiently-known tropical fruits having the greatest potential for nectar processing for European markets. It is obvious then that in spite of the handicaps of passion fruit culture, the crop offers revenue-earning opportunities for developing countries with low labour costs.

Passion fruit is used as juice, in cold drinks, yoghurt, ice-cream and in flavours. Passion fruit juice can be boiled into syrup, used to make sauces, gelatin desserts, candy, ice cream, sherbets, cake icing, cake filling, meringue or chiffon pie, cold fruit soups or cocktails. The seeded pulp is made into jelly or blended with pineapple or tomato to make jam (John and Violet, 1979; Morton, 1987). In 100 g of edible portion there is 75.1 g moisture, 2.2 g protein, 0.7 g fat, 21.2 g carbohydrate, 0.8 g ash, 13 mg calcium, 64 mg phosphorous, 1.6 mg iron, 28 mg sodium, 348 mg potassium, 700 IU vitamin A, 0.13 mg riboflavin, 1.5 mg niacin, and 30 mg ascorbic acid (Tindal, 1969). The seeds yield 23% oil which is similar to sunflower and soybean oils; consequently, it has edible, as well as industrial uses (Seale and Sherman, 1960; Morton, 1987). The seed oil contains 84.1% unsaturated fatty acids and 8.9% saturated fatty acids, with 6.8% palmitic, 1.8% stearic, 0.34% arachidic, 19% oleic, 59.9% linoleic and 5.4% linolenic acids (Morton, 1987).

There is a revived interest in the pharmaceutical industry, especially in Europe, in the use of the glycoside *passiflorine* as a sedative or tranquilizer. Italian chemists have extracted *passiflorine* from air-dried leaves of *P. edulis*. In Madeira, the juice is used as a digestive stimulant and treatment for gastric cancer (John and Violet, 1979; Morton, 1987).

Nearly two decades ago, average annual yields of passion fruits in Kenya were 15,000 kg/ha (Morton 1987). When Kakuzi (Kenya) Limited maintained a plantation on a 3-year-cycle of production, with one-third of the total area (78 ha) being replanted each year, the yields of purple passion fruits were 14, 16 and 3.5 tonnes for 7 - 18, 19 - 30, and 31 - 36 months after planting, respectively. For hybrid passion fruits, yields were 20, 25

and 9 tonnes for 7 - 18, 19 - 30, and 31 - 36 months after planting, respectively (Chemonics International Inc, 2002).

2.2 Description of Passion Fruit

Morton (1987) describes the passion fruit as a shallow-rooted woody perennial vine that grows upright using tendrils to support itself on structures. The deep-green alternate, evergreen leaves are deeply 3-lobed when mature, finely toothed, 7.5 - 20 cm long, glossy above the surface, paler and dull beneath the surface. The young stems and tendrils are tinged with red or purple, especially in the yellow form. A single, fragrant flower, 5 - 7.5 cm wide, is borne at each node on new growth. The bloom, clasped by 3 large, green leaf-like bracts, consists of 5 greenish-white sepals, 5 white petals, a fringelike corona of straight white-tipped rays which are rich purple at the base, and 5 stamens with large anthers. The ovary and the triple-branched style form a prominent central structure. The flower of the yellow passion fruit is showy, with intense colour. The nearly round or ovoid fruit is 4 - 7.5 cm wide, has a tough, smooth, waxy rind ranging in hue from dark-purple with faint, fine white specks to light-yellow or pumpkin-colour. The rind is 3 mm thick and adheres to a 6 mm layer of white pith. Within is a cavity filled with an aromatic mass of double-walled membranous sacs containing orange-coloured, pulpy juice and about 250 small, hard, dark-brown or black pitted seeds. The flavour is appealing, musky, guava-like, sub-acid to acid (Morton, 1987).

The passion fruit varieties that have been developed include: 'Australian Purple' or 'Nelly Kelly'—a purple selection of mild, sweet flavour, grown in Australia and Hawaii; 'Common Purple'—the form growing naturally in Hawaii and has a thick-skin, small seed cavity, but of fine flavour and low acidity; 'Pratt Hybrid'—apparently a natural cross between the 'Common Purple' and a yellow strain that is susceptible to rot, but juice is of fine colour, flavour and low in acidity (Morton, 1987).

2.3 Passion Fruit Culture

Purple passion fruit is propagated from seed, which should be fresh (less than 1-year-old) because seeds lose viability rapidly (Nakasone and Paull, 1998; Isutsa, 2004). Seeds may

be sown in flats or pots of sterile soil kept in a moist place and shaded from direct sunlight. Seeds ordinarily germinate in 10 to 20 days and young plants grow rapidly (Samson, 1980). Seedlings should be potted individually soon after germination. They can be transferred to a permanent location when they are 25 to 40 cm tall (Knight et al., 1994). Cleaned and stored seeds have a lower and slower rate of germination rate. Sprouting may be hastened by allowing the pulp to ferment for a few days before separating the seeds, or by chipping or rubbing the seeds with fine sandpaper. Soaking, often recommended, has not proved helpful. Seeds are planted 1.3 cm deep in beds, and seedlings may be transplanted when 25-40 cm high. If taller—up to 90 cm—the tops should be cut back and the plants heavily watered soon after the pruning (Morton, 1987).

Passion fruits are also propagated through cuttings, grafting or by tissue culture techniques (Isutsa, 2006). However, seedling progenies segregate and show genetic variation (Mincom et al., 2001). Propagation through cuttings poses a problem of propagating systemic viruses and providing a weak root system. If approach grafting is to be done, a row of potted scions must be placed close alongside the row of rootstocks so that the union can be made at about 3/4 of the height of the plant (Morton, 1987). Rootstock seedlings can also be wedge-grafted at 15 cm above the ground level using scions of a desired variety (Isutsa, 2006). In Kenya, planting material is also propagated by grafting the purple passion fruit (*Passiflora edulis*) on the yellow passion fruit (*P. edulis f. flavicarpa*), which is resistant to the fusarium wilt, tolerant to phytophthora root rot, nematodes and brown spot (Fraser, 2000; Mincom et al., 2001; Isutsa, 2006). After the graft union has healed, plants are transplanted to a permanent growing site.

Currently, 1.8 m × 3 m is the recommended spacing for the small-scale farmers of purple passion fruits in Kenya (Gachanja and Ochieng, 2004). However, 3-year trials of 1.2 m spacing between rows, with light pruning in the second and third years resulted in the highest fruit yields (50% of the crop being from the first year). But such close planting can lead to disease problems and replanting after the third year (Gachanja and Ochieng, 2004). Commercially, vines are trained to strongly supported wire trellises, measuring at least 2 m high. The average life of a plantation in Fiji is 3 years. Judicious pruning of

lateral branches after fruiting helps control diseases and can extend plantation life to 5 or 6 years. In South Africa, at elevations between 1,200 and 1,460 m above sea level, plantations are kept in full production for as long as 8 years (Morton, 1987).

2.4 Fertilizer Requirements

Passion fruit flowers need a regular supply of nutrients if they are to grow well. Within a year, feeding is adjusted to the growth accordingly. Nitrogen, phosphorous and potassium should be contained in flowers at 10% - 12%, 8% - 12% and 10% - 15% concentration, respectively (Torsten et al., 2004). Since all flowers occur on new growth, there is a high demand for nitrogen during fruiting stage. Leaf nitrogen levels higher than 4.5% are recommended. In Hawaii, mineral analysis of fruit indicates that production of 1000 kg/ha of fruits requires at least 66 kg/ha of 10N-5P-20K fertilizer (Abanto and Muller, 1976; Abanto and Muller, 1977a, 1977b).

2.5 Climatic Requirements

The purple passion fruit (*Passiflora edulis*) is adapted to the coolest subtropics or to high altitudes in the tropics. It grows and produces well within altitudes of 650 to 1,300 m in India. In Java, it grows well in lowlands but flowers and fruits only above 1,000 m above sea level. *Passiflora edulis* has temperature requirements ranging from 15°C to 28°C. In more tropical areas the plant remains productive all year round (Morton, 1987). Purple passion fruit needs protection from wind. Generally, annual rainfall should be at least 900 mm. It is reported that annual rainfall in passion fruit-growing areas of India ranges from 1000 to 2500 mm. A well-distributed annual rainfall is necessary for passion fruit culture, especially if supplemental irrigation is not available. However, rainfall must be minimal during the flowering period as pollen wetted by free moisture bursts open and becomes non-functional. Furthermore, rain minimizes insect activity and hinders pollination (Nakasone and Paull, 1998), which results in poor fruit set and subsequently fruit yields.

2.6 Soil Requirements

Passion fruit vines grow on many soil types, but light to heavy sandy loams of medium texture are most suitable (Samson, 1980, Nakasone and Paull, 1998). The pH should

range from 6.5 to 7.5. If the soil is too acidic, lime must be applied or growth becomes severely impaired (Isutsa, 2006). Good drainage is essential to minimize the incidence of collar rot and root suffocation (Morton, 1987).

2.7 Crop Water Use

To obtain maximum yields, water should be applied to crops before the soil moisture potential reaches a level at which the evapotranspiration rate is likely to be reduced below its potential. The relationship of actual and maximum yields to actual and potential evapotranspiration is illustrated in the following equation (Doorenbos and Kassam, 1979):

$$\left(1 - \frac{Y_a}{Y_m}\right) = ky \left(1 - \frac{ET_a}{ET_m}\right)$$

Where: Y_a = actual harvested yield, Y_m = maximum harvested yield, ky = yield response factor, ET_a = actual evapo-transpiration, and ET_m = maximum evapo-transpiration.

Several methods are available to determine optimum irrigation scheduling. The factors that determine irrigation scheduling are: available water holding capacity of the soils, depth of rooting zone, evapo-transpiration rate, amount of water to be applied per irrigation, irrigation method and drainage conditions. Farmers use many different methods to irrigate crops. They range from watering individual plants from a can of water to highly automated irrigation using a center pivot system. Localized irrigation is where water is applied around each plant or a group of plants so as to wet locally the root zone only (e.g. drip irrigation, bubblers, and micro-sprinklers). The application rate is adjusted to meet evapo-transpiration needs so that percolation losses are minimized (Doneen and Westcot, 1988).

Regular watering keeps a vine flowering and fruiting almost continuously. Water requirement is high when fruits are approaching maturity. If soil is dry, fruits may shrivel and fall prematurely (Morton, 1987). The yellow passion fruit has been grown quite successfully in Hawaii with rainfall ranging from 1000 mm to 1500 mm plus supplemental irrigation during dry periods, although the amount of irrigation water or

plant spacing is not stated. Isutsa (2006) applied 15 L of water per plant per week empirically which sustained growth of 3 m x 3 m spaced purple and yellow passion fruit varieties when rains failed in Molo, Njoro and Lare locations in Kenya. In Australia, 300 to 400 L of water per passion fruit vine per week is required during the summer (Nakasone and Paull, 1998). However, the plant spacing is not stated in the Australian passion fruit study.

Sousa et al., (2003) studied the effect of four irrigation rates applied through drip irrigation system on the yellow passion fruit (*P. edulis* f. *flavicarpa*) in Brazil. The four irrigation rates were: 0.25 V (927 L), 0.50 V (1,528 L), 0.75 V (2,117 L) and 1.00 V (2,706 L), where V is the average volume of water applied in Lysimeters to each passion fruit plant per year. The researchers found that commercial yield was significantly affected by irrigation. The significant values of passion fruit commercial yield were obtained with the application of 1,528 L and 2,117.28 L of water. This amount translated to between 4.25 L and 5.8 L per plant per day.

Sousa et al., (2005) also evaluated the effects of irrigation on the water use efficiency (WUE) of *P. edulis* f. *flavicarpa* at 22°42'30" S and 47°38'00" W in São Paulo, Brazil. The irrigation rates were established from the average water consumed in Lysimeters (L), namely: 0.25, 0.50, 0.75 and 1.00 L. The WUE was determined from the relationship between the commercial yield (CY) of passion fruits and water rates (V). The highest (34 kg/ha/L) and lowest (7.85 kg/ha/L) values of WUE by passion fruits were achieved for the respective lower and higher water volumes applied. Increase of water reduced the WUE, and the simple increase of yield, as a function of amount of water applied did not optimize the water used. This differs from the fact that there is a direct relationship between evapo-transpiration and plant growth (Doorenbos and Kassam, 1994).

2.8 Effect of Mulch on Plants

Phadung et al., (2005) conducted field experiments to study the effect of irrigation and mulching materials on growth, yield and quality of 'Perlette' grape vine berries. Irrigation with 18 L per vine was applied daily as a control, or applied when soil moisture tension

reached 20 kPa or 40 kPa. Irrigation was combined with no mulch control, straw mulch and plastic mulch. The results showed that under no mulch leaf water potential of vines and soil moisture decreased when irrigated at the soil moisture tension of 40 kPa and 20 kPa. Irrigation at soil moisture tension of 20 kPa and 40 kPa had comparable shoot length to that of control irrigation, while straw mulch gave highest shoot length. Leaf size was not affected by irrigation and mulch. Fruit weight and number of fruit clusters per vine were not different among irrigated levels. Fruit clusters, cluster weight, fruit yield per vine and total soluble solids were highest when irrigated at the soil moisture tension of 20 kPa. However, titratable acidity and total soluble solids were not affected by irrigation. Straw and plastic mulches increased fruit weight and number of fruit clusters per vine more than no mulch control, but fruit cluster weight and total soluble solids were not different among mulch types. Fruit yield and titratable acidity were highest, but total soluble solids were lowest for plastic mulch. From pruning to harvesting, a combination of irrigation at the soil moisture tension of 20 kPa and plastic mulch reduced water supply by 60.3% and tended to increase fruit cluster weight, number of fruit clusters per vine and yield per vine.

Araujo et al., (1995) found that irrigation and mulch affect root distribution. In drip-irrigated vines, there was a confined soil wetted zone beneath the emitter that largely coincided with a confined and shallow-root system, while furrow-irrigated vines had deeper and more widespread root systems. Van der westhuizen (1980) studied the effect of black plastic mulch on growth, production and root development of 'Chenin Blanc' vines under dry land conditions. Black plastic mulch doubled the root to shoot ratio and berry weight. The increased growth of mulched vines was attributed to improved weed control and to conservation of soil moisture, more uniform soil temperature, and less soil compaction. The above-mentioned experiments indicate positive correlations between plant water use efficiency and particular water levels, as well as straw and plastic mulches. There is a need, therefore, to determine whether the same would apply to purple passion fruits grown under tropical conditions in Kenya.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Research Site

The present research was conducted in a plastic-covered rain shelter located on Field 3 of Tatton farm at Egerton University, Njoro-Kenya. The temperature in the rain shelter ranged from 22°C at night to 42°C at noon. The site lies at 2185 m asl and experiences mean maximum and minimum ambient temperatures of 23.1°C and 9.1°C, respectively. Annual rainfall that falls at the site is 1012 mm. The soils at the site are Vintric mollic andosols, well drained, dark to very dark-reddish brown, friable and silt clays with humic tops (Jaetzold and Schmidt, 1983) and pH 6.6 (Isutsa, 2006).

3.2 Experimental Design and Layout

The experiment was laid out in a randomized complete block design (Figure 1). The 12 treatment combinations comprised of four irrigation rates (2.5, 5, 10, and 20 L of water applied once weekly) by three types of mulch (wheat straw, black plastic film and no mulch control). Each treatment had three plants, replicated four times. The experiment was conducted for 56 weeks after planting (WAP). Irrigation levels were adjusted to 0.5, 2.0, 4.0, and 8.0 L between 15 WAP and 29 WAP when plants were still growing vegetatively and to related drought stress. Thereafter irrigation rates were correspondingly adjusted back upwards to 2.5, 5, 10, and 20 L up to 56 WAP. This was justified by the fact that water requirement is high once fruits start setting and approaching physiological maturity. If the soil is dry, fruits may shrivel and fall prematurely (Morton, 1987). For purposes of clarity, the higher irrigation rates (2.5, 5, 10, and 20 L) were used to report the results for this study. Plastic mulch was applied 4 WAP to cover each hole leaving a perforation around each plant for use in watering plants. Irrigation water was applied through the perforation to the base of each plant throughout the experimental period. Wheat straw mulch was similarly applied on holes as for plastic mulch. The thickness and span of the wheat straw mulch was 10 cm aboveground by 30 cm from each plant. Plastic mulch was replaced whenever it got torn, while wheat straw was topped up regularly whenever it decomposed and started exposing the soil surface.

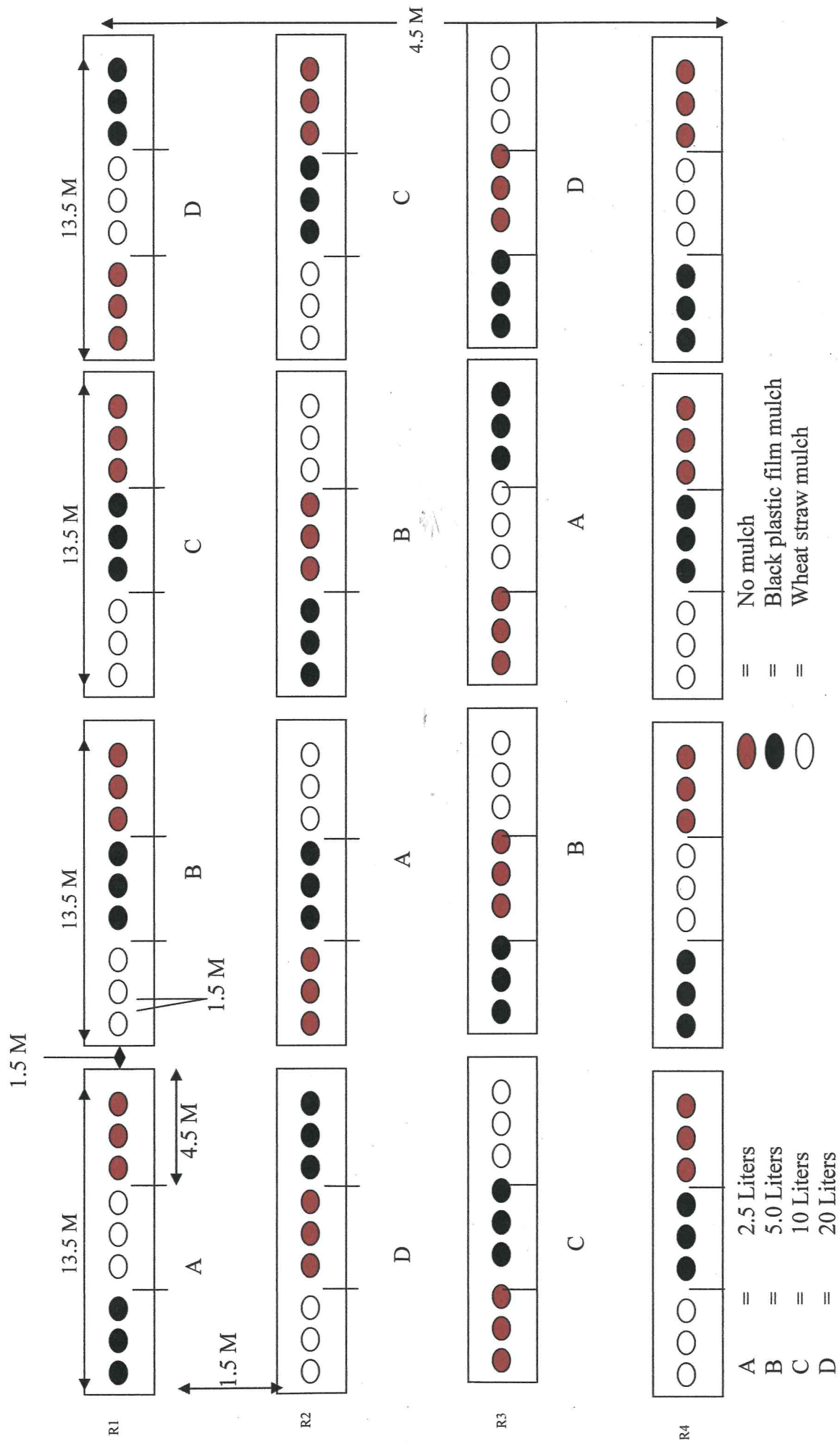


Figure 1. Experimental layout

3.3. Experiment Set up Limitations

The experiment was set up in a plastic-covered rain shelter that measured 60 m x 8 m and accommodated 144 plants at a spacing of 1.5 m x 1.5 m each. Therefore a larger sample size than 144 plants could not be used during experimentation even if desired. It was also not possible to control subsurface water, if any, from seeping from underground below 60 cm during heavy rainfall period and reaching plant roots of all treatments. The enclosed plastic-covered rain shelter had few side openings to allow entry of pollinators. High temperatures in the plastic tunnel during the day possibly hindered anthesis in favour of vegetative growth of passion fruit plants.

3.4. Land Preparation and Planting in Plastic Covered Rain Shelter

Land was prepared by digging, harrowing and hand-pulverizing to a fine tilth to attain a level ground. Experimental plots were set up whereby rows represented blocks. Planting holes measuring 45 cm by 45 cm were dug up and all soil removed. Planting holes were spaced at 1.5 m intra-row x 1.5 m inter-row spacing (Gachanja and Ochieng, 2004). Top soil was dug from outside near the rain shelter to ensure homogeneity in all treatments. The top soil was used to re-fill the planting holes. About 5 kg poultry manure was mixed thoroughly with the top soil inside the planting hole, one month before transplanting the passion fruit seedlings.

Seeds were extracted from ripe purple passion fruits obtained from one vine to minimize genetic variation. They were fermented, washed to remove mucilage, and then air-dried. The dry seeds were soaked in water for 48 hours before planting in soil under shade and high temperature in a glasshouse in Mid-November 2007 to hasten germination. The seedlings were then pricked out at the fourth leaf stage and transplanted into black polythene bags measuring 15 cm diameter by 23 cm depth (Gachanja et al., 1980). The polythene bags were filled with loam soil. Top dressing was done four weeks later with CAN at 1 g/bag. Seedlings were nurtured in the bags for 16 weeks until they attained 30 cm height before transplanting to a permanent site (Morton, 1987). At transplanting, 170 g of 17N:17P:17K fertilizer was applied as basal fertilizer to each seedling (Torsten et al., 2004). All seedlings were left unmulched and were irrigated uniformly with 20 L of

water per week for 4 Weeks after planting (WAP) until they completely recovered from transplanting shock then mulch and watering treatments were varied as planned.

A trellis with 40-cm cross bars on top of each 2.1-m tall post and two wires (gauge 14) fastened at the ends of the cross bars to run parallel to each other was constructed to support the passion fruit vines (Nakasone and Paull, 1998). A 60 cm deep trench was dug between main plots and on the perimeter of the experimental area and lined with plastic film to prevent cross-seepage of irrigation water and rain water into experimental area.

Seedlings had the terminal bud nipped to break apical dominance to stimulate growth of lateral shoots. Two main shoots selected from close to the base of each seedling were trained on a sisal twine up to the wires and then to the same direction on the wires. All other shoots were pruned off, leaving leaves only on the main shoots. Laterals on the two main shoots on the wire were left to grow hanging down while frequently pruning off the tendrils up to 15 cm above the ground to bear fruits.

Compound fertilizer of 17N:17P:17K was applied as a topdress at a rate of 100 g per vine at the beginning and 70 g per vine in the middle of the fruiting period (Torsten et al., 2004). Recommended fungicides and insecticides were applied once earliest signs of disease and insect pest incidences were noticed. Weeding was done regularly. Pruning of laterals that had completed bearing fruits was done selectively by cutting them back to a newly developing lateral or sub-lateral near the top wire (Nakasone and Paull, 1998).

3.5 Variables Measured

Plant response measurements were taken on growth, physiology, fruit yield and quality. More specifically, data were recorded for vegetative growth (plant height, leaf area, number of leaves, lateral shoots, and leaf weight), plant physiology (transpiration, net photosynthesis, stomatal conductance, intercellular CO₂), reproductive growth (number of flowers, number of fruits and fruit weight), water use efficiency and fruit quality (total soluble solids, pulp volume, pulp weight, fruit diameter and number of seeds).

3.5.1 Growth, Physiological and Flowering Measurements

In the present research, growth referred to the irreversible increase in size of plant parts and the plant itself as a whole (Wavering and Phillips, 1981). Vegetative growth data were taken on number of fully expanded leaves and plant height. Plant height was measured from the base of a stem to the shoot apex of the vine using a measuring tape. The numbers of fully expanded leaves were counted on main shoots up to 21 WAP. Leaf area was measured at 21 WAP at the widest part of the lamina and length from lamina tip to the petiole intersection, using a graph paper. The leaves used were sampled at 1 m above ground. The leaves were then oven-dried at 80°C for 48 hours and weight. Plant height, number of leaves and leaf area measurements was terminated once vines reached the top wire and started developing laterals. The number of laterals per vine were counted and recorded until flower buds started developing on them.

Physiological measurements were taken at 34 WAP using an infra red gas analyzer. Chlorophyll content was measured at 35 WAP using a chlorophyll content meter (CCM-200, Opti-Sciences Inc.) on leaves located in the middle of fruiting laterals. The number of intact and dropped flowers, as well as the number of immature fruits were counted per plant and recorded until fruitlets attained full expansion.

3.5.2 Fruit yield and yield components measurements

Yield and quality attributes were determined bi-weekly and monthly, respectively, starting from the ninth month after planting. Harvesting was done as soon as the fruits reached physiological maturity, indicated by color change from green to purple. All harvested fruits were counted and weighed. Number and fresh weight of fruits per plant were used for analysis of variance.

3.5.3 Fruit quality measurements

Quality referred to attributes or characteristics that made purple passion fruits attractive to eat or desirable for conversion into juice, ice-cream and other products, i.e. the extent

to which the products met the requirements of the consumer (Teranishe and Barrera-Beritez, 1981). Quality was determined for two months on a fortnightly basis. Quality was based on fruit size (diameter), total soluble solids, number of seeds and juice volume.

Fruit size (diameter) for nine randomly selected ripe fruits per treatment was measured using a ruler. Total soluble solids (TSS) were measured on the nine randomly selected ripe fruits per treatment using a hand-held refractometer (Atagon Unicon N-Labequip). Fruit size and TSS were assessed bi-weekly from the 36th to 52nd WAP. Number of seeds was counted per fruit and fruit juice volume was measured using a graduated cylinder.

3.7 Data Analysis

Data were transformed to natural logarithm before analysis to standardize variance and then subjected to analysis of variance using the SAS statistical program version 6.0. Significantly different means were separated using the Tukey's HSD test at $P=0.05$.

The two-factor RCBD model for data analysis was:

$$Y_{ijk} = \mu + R_i + I_j + M_k + IM_{jk} + \varepsilon_{ijk},$$

Where: $i = 1, 2, 3, 4$; $j = 1, 2, 3, 4$; $k = 1, 2, 3$;

Y_{ijk} = response to i^{th} replication, j^{th} irrigation and k^{th} mulch;

μ = general mean;

R_i = the i^{th} replication effect;

I_j = the j^{th} irrigation effect;

M_k = the k^{th} mulch effect;

IM_{jk} = the effect of the interaction between j^{th} irrigation and k^{th} mulch; and

ε_{ijk} = the error term normally distributed with mean zero and variance σ^2 .

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Effects of Irrigation and Mulch on Plant Growth

4.1.1. Effects of irrigation on plant growth

There was no significant ($P>0.05$) difference among irrigation rates on the number of leaves during assessment period (Figure 2). However, the higher irrigation rates tended to produce many leaves compared to lower irrigation rates (Figure 2). The increase in leaf number with increasing water supply could be attributed to the role played by water in promoting cell division and cell elongation. Reduction in number of leaves due to water stress could have been attributed to its direct effect in reducing nucleic acid synthesis and/or enhancing of its breakdown (Ashraf et al., 1996). Elsewhere, the reduction in leaf number in response to stress has been attributed to enhancement of leaf abscission due to hormonal imbalance, evidenced by increased abscisic acid (ABA) and decreased indole-3-acetic acid (IAA) levels in treated plants (Wu et al., 2005). Sahid et al., (1998) found that reducing the water content of wheat plants resulted in a similar retardation in the time of leaf emergence in seedlings, decline in their rate of growth and in their number.

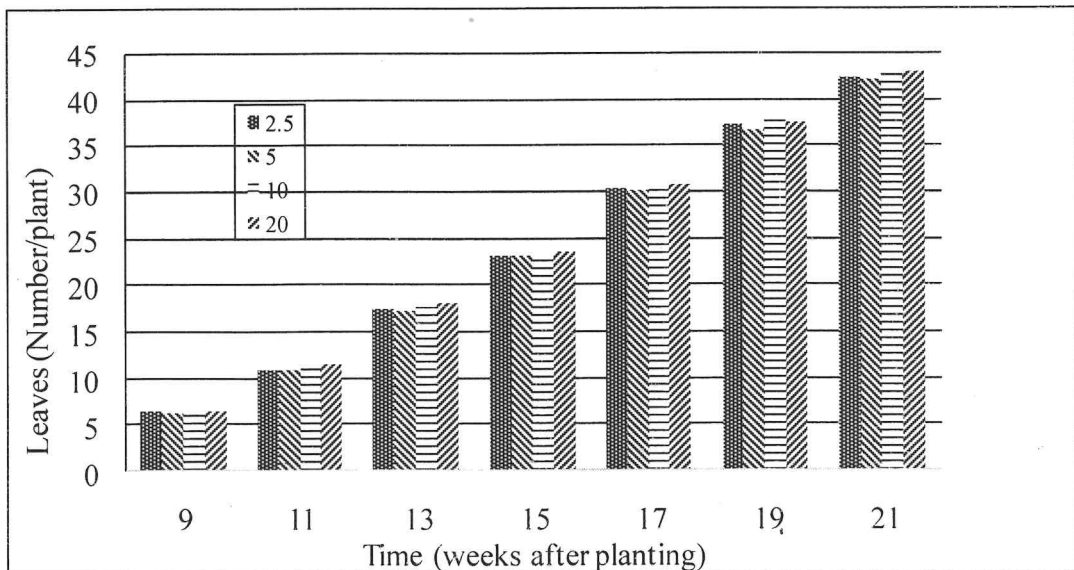


Figure 2. Effect of irrigation on number of leaves per plant

There was no significant effect ($P>0.05$) of irrigation treatments on plant height throughout the assessment period (Figure 3). The plants attained an average height of 2.8 m for all irrigation rates, with 10 L irrigation rate attaining the tallest height of 2.88 m (Figure 3). The lack of significant difference between the 2.5 L and the 5, 10 and 20 L irrigation rates suggested that the plants withstood drought stress at this stage of growth (Kramer, 1980). The 10 L had the highest height throughout the vegetative growth phase, implying that it was an optimal rate for the plants. The 20 L of water had the least plant height. This response was attributed to the fact that the 20 L was in excess of plant water requirement in relation to plant age. Excess water has previously been reported to retard growth of passion fruits (Isutsa, 2006). Excess water is known to cause anaerobic soil conditions that impede root functions such as respiration, nutrient uptake and translocation, which ultimately manifest in stunted overall plant growth (Faust, 1989).

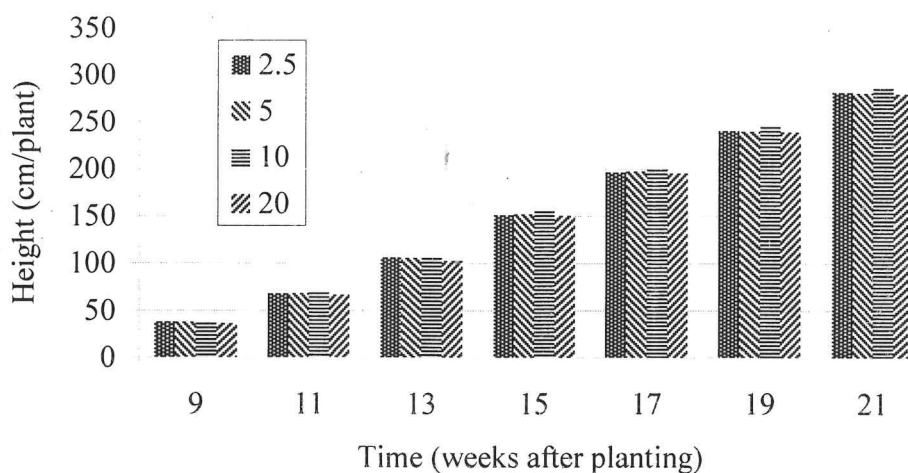


Figure 3. Effect of irrigation on plant height

There was a significant effect ($P<0.05$) of irrigation in influencing number of laterals attained at 29 WAP (Table 1). The number of laterals increased with increase in irrigation rate, implying that the increased water was being used in growth of laterals. The 2.5 L irrigation rate had the fewest number of laterals, while the 5, 10 and 20 L irrigation rates had equally higher number of laterals than the 2.5 L irrigation rate. Laterals are essential

in fruit production in passion fruit plants and hence treatments that promote their growth are highly valued for increase in fruit yields.

Leaf area varied significantly ($P < 0.05$) amongst the irrigation rates (Table 1). The leaf area increased in direct proportion to irrigation rates, implying that more water was being used in leaf cell division, cell elongation and growth (Siebe and Goudriaan, 1996). Various studies have indicated that water stress has an inhibiting effect on leaf area of treated plants (Kameli et al., 1996; Nelson et al., 1998; Kawakami et al., 2006). Munns and Sharp (1993) observed a decrease in soil water potential due to drought stress and decreased rate of leaf expansion, whereas root expansion was much less affected. If the root water potential decreases suddenly, the response of leaf expansion is so rapid and large (Cramer and Bowman, 1991), indicating a change in the rate of expansion of cells. However, when plants have grown for some time in soils of low water potential, smaller leaves with fewer cells are formed (Randall and Sinclair, 1988; Lecoeur et al., 1995).

According to Ute et al., (1998) water stress caused the rate of elongation of the wheat leaf blade to decrease to 51% of the unstressed plants for the first day. There after, the elongation rate of the unstressed plants slowed down, and that of the stressed plants continued for several more days, with the result that the final blade length of the stressed plants reached 73% of the unstressed plants and then to an average of 41% for the next four days. As water stress reduces rates of cell expansion in roots (Sharp et al., 1988) and leaves (Spollen and Nelson, 1994; Durand et al., 1995), it is more likely that it slows down the rate of cell expansion during the cell-enlargement phases of the cell cycle.

According to Davies et al. (2001), the pH of the sap transferred to the xylem and through the transpiration stream increases when a root zone water deficit is sensed. This causes an increase in the concentration of ABA in the leaf tissue, leading to stomatal closure and a reduction in leaf growth. The cause of this increase in pH could be a change in the nitrate reductase activity that occurs when the soil is drying. This increase in the pH of the xylem sap can only take place when there is ABA flux from the roots to the leaves (Davies et al., 2001). This change in pH also causes increased uptake of ABA by xylem

vessels in roots. These observations suggest that reduced cell formation during water stress limited final leaf size of purple passion fruit plants.

There was a significant ($P < 0.05$) difference between the 2.5 L irrigation rate and the other irrigation rates, which were not significantly different in influencing leaf weight (Table 1). However, the leaf weight increased with increase in irrigation up to 10 L, and then decreased for 20 L irrigation rate. This could possibly imply that the high irrigation water up to 10 L per week was optimum for cell division, cell elongation and photosynthesis, which contributed to dry matter accumulation in leaves. According to Siebe and Goudriaan (1996), substantial increase in individual leaf weight results primarily due to increase in leaf thickness and accumulation of non-structural carbohydrates.

Table 1. Effect of irrigation on laterals, leaf area and leaf weight at 29 WAP

Irrigation (L/plant)	Laterals (number/plant)	Leaf area (cm ² /leaf)	Dry weight (g/leaf)
2.5	11.3 ^{b*}	106.5 ^c	2.00 ^b
5	12.0 ^{ab}	113.1 ^b	2.3 ^a
10	13.0 ^{ab}	117.8 ^{ab}	2.4 ^a
20	16.8 ^a	122.1 ^a	2.4 ^a
CV (%)	27.3	6.8	10.5
LSD _{0.05}	3.0	6.5	0.2

*Means followed by the same letter or no letter, within each column are not significantly different at $P=0.05$, according to the Tukey's HSD test.

4.1.2 Effect of mulch on plant growth

The effect of mulch on the number of leaves was significant ($P < 0.05$) only at 9 WAP, when wheat straw mulch had a greater number of leaves than black plastic mulch or no mulch control (Table 2). Wheat straw had the highest number of leaves followed by black plastic. Mulch apparently benefited plants during early growth stages when root depth was still shallow. This was probably because of the cooling effect on soil and the water conserved under wheat straw, which was used in leaf growth.

The number of leaves increased with time for all mulch types with wheat straw maintaining higher number of leaves and no mulch control having the least number of leaves up to 21 WAP (Table 2). Organic mulches such as wheat straw are known to conserve moisture that is in turn used in plant growth. According to findings of Acharya and Sharma (1994), mulched plants generally had significantly greater total uptake of N, P and K than corresponding non-mulched ones. Bu et al., (2002) found that surface-applied mulches reduced evaporative soil water loss, which in turn reduced salt accumulation on the soil surface in addition to controlling weeds.

Table 2. Effect of mulch on number of leaves

Mulch type	Time (weeks after planting)						
	9	11	13	15	17	19	21
Black plastic	6.4 ^{ab*}	11.1	17.6	23.3	30.5	37.3	42.6
Wheat straw	6.8 ^a	11.2	18.1	23.6	30.6	37.6	42.6
None	6.0 ^b	10.9	16.8	22.6	29.8	36.6	42.1
CV (%)	14.8	13.1	11.0	10.1	7.7	5.7	5.5
LSD _{0.05}	0.7	NS	NS	NS	NS	NS	NS

*Means followed by the same letter or no letter, within each column are not significantly different at $P=0.05$, according to the Tukey's HSD test.

There was no significant effect ($P>0.05$) of mulch on plant height (Figure 4). These results could be attributed to the increase in soil temperature by the black plastic mulch that probably inhibited uptake of water by the roots since the temperatures inside the plastic tunnel were also very high during the day (up to 42°C). Lack of significant differences could be attributed to the ability of the plants to withstand water stress. Nevertheless, black plastic and wheat straw mulches effectively suppressed infestation by weeds, thereby preventing them from consuming some of the irrigation water.

Jamil et al., (2005) conducted an experiment using black plastic film and straw mulches in garlic and found that plants under plastic mulch had maximum height compared to those under other treatments. Similarly, the duration of mulch significantly increased

height in all treatments. Plants attained maximum height when mulched, particularly with plastic mulch, due to the increased soil temperature (Tuli and Yesilsoy, 1997). Chung (1987) also reported that growth rate is always accelerated under plastic mulch.

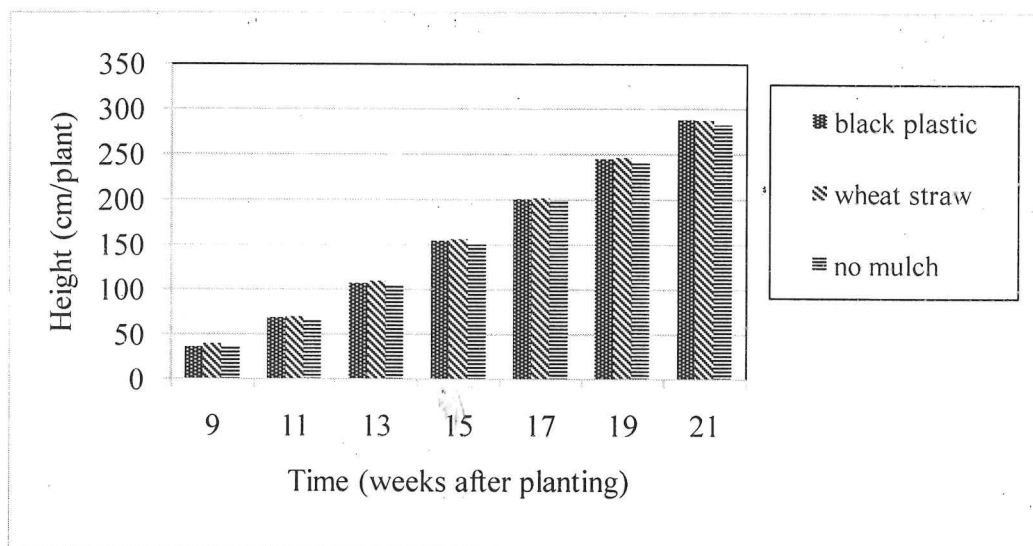


Figure 4. Effect of mulch on plant height

There was no significant effect ($P > 0.05$) of mulch on number of laterals (Table 3). However, black plastic mulch had the highest number of laterals possibly because it increased soil temperatures which encouraged increased uptake of nutrients used in growth of more laterals. Wheat straw had fewest laterals possibly because of lowering soil temperature which lowered metabolic activities necessary in growth of laterals. Organic mulches help cool the soil, conserve soil moisture, and reduce annual weed growth (Dickerson, 1996).

The effect of mulch on leaf area was not significant ($P > 0.05$), although black plastic mulch had the highest leaf area followed by wheat straw mulch (Table 3). This effect was attributed to the irrigation water conserved by mulches and used in leaf area growth.

The effect of mulch on leaf weight was significant ($P < 0.05$) (Table 3). Black plastic mulch and wheat straw mulch had the greater leaf weight than the control possibly

because of combined effect of moisture conservation and/or soil warming that promoted enhanced dry matter synthesis and accumulation in leaves of passion fruit plants (Tuli and Yesilsoy, 1997).

Table 3. Effect of mulch on laterals, leaf area and leaf weight at 29 WAP

Mulch type	Laterals (number/plant)	Leaf area (cm ² /leaf)	Dry weight (g/leaf)
Black plastic	14.7*	117.4	2.3 ^a
Wheat straw	12.5	114.3	2.3 ^{ab}
No mulch	12.7	112.9	2.1 ^b
CV (%)	27.3	6.8	10.5
LSD _{0.05}	NS	NS	0.17

*Means followed by the same letter or no letter within, each column is not significantly different at $P=0.05$, according to the Tukey's HSD test.

4.1.3 Effect of interaction between irrigation and mulch on plant growth

The effect of interaction between irrigation and mulch was significant ($P<0.05$) on leaf area and leaf weight (Tables 4 and 5).

Table 4. Effect of interaction on leaf area 29 WAP

Treatment	Leaf area (cm ² /leaf)
20 L, No mulch	129.0 ^{a*}
10 L, Black plastic	123.8 ^{ab}
20 L, Black plastic	120.8 ^{ab}
5 L, Black plastic	118.5 ^{ab}
20 L, Wheat straw	116.5 ^{ab}
10 L, No mulch	115.8 ^{ab}
5 L, Wheat straw	114.8 ^{ab}
10 L, Wheat straw	114.5 ^{ab}
2.5 L, Wheat straw	111.3 ^{ab}
2.5 L, Black plastic	107.3 ^{ab}
5 L, No mulch	106.0 ^{ab}
2.5 L, No mulch	101.0 ^b

* Means followed by the same letter are not significantly different. SED = 6.8, P = 0.18

The interactive effect was such that higher irrigation rates could ameliorate the negative stress exerted by not mulching plants. Mulched plants attained even greater leaf area and leaf weight than the no mulch control (Tables 4 and 5). Lower irrigation rates had a synergistic effect with mulching, thereby ending up with higher leaf area and leaf weight as did higher irrigation rate in combination with no mulch (Tables 4 and 5).

The lowest irrigation rate (2.5 L) did not counteract the negative effects of drought stress in non-mulched passion fruit plants, which had reduced significantly leaf area and leaf weight growth. Highest irrigation rate (20 L) alone was able to combat drought stress and enhance leaf area (Tables 4 and 5). Therefore, there is no need of mulching when applying high amount of irrigation water. However, when applying minimal amount of irrigation water, then mulching is beneficial.

Table 5. Effect of interaction on leaf weight 29 WAP

Treatment	Leaf weight (g/leaf)
10 L, Black plastic	2.55 ^{a*}
5 L, Wheat straw	2.48 ^{ab}
20 L, None	2.45 ^{ab}
5 L, Black plastic	2.43 ^{ab}
10 L, None	2.38 ^{abc}
20 L, Black plastic	2.38 ^{abc}
10 L, Wheat straw	2.25 ^{abc}
20 L, Wheat straw	2.23 ^{abc}
2.5 L, Wheat straw	2.10 ^{abc}
2.5 L, Black plastic	2.03 ^{abc}
5 L, None	1.93 ^{bc}
2.5 L, None	1.83 ^c

*Means followed by the same letter are not significantly different. SED = 0.16, P = 0.0254

4.2 Effects of Irrigation and Mulch on Plant Physiology

4.2.1 Effects of irrigation on plant physiology

Transpiration rates of the plants were not affected by the irrigation treatments applied in this experiment ($P > 0.05$) (Table 6). Nevertheless, plants irrigated with 20 L of water had the highest rate of transpiration. This was probably because the plants stomates remained open hence more water loss that was above their requirement. Plants irrigated with 2.5 L

of water lost the least amount of water possibly because they closed down their stomata as a survival mechanism (Salisbury and Ross, 1991). Ahmed et al., (2005) observed that water-stressed peach trees responded (acclimated) to stress by progressively reducing their transpiration rate as the severity of stress increased.

There was no significant ($P>0.05$) effect of irrigation rate on leaf temperature (Table 6). Nevertheless, plants receiving 2.5 L or 5.0 L of water had higher leaf temperatures than those receiving 10 L or 20 L of water, probably because the former had lower rates of transpiration that normally brings about evaporative cooling (Faust, 1989). Elsewhere, studies have also shown that leaf temperatures increase during the day as a function of increasing water deficits (Stevenson and Shaw, 1971; Jackson et al., 1977). Water deficits cause stomatal closure, leading to higher leaf temperatures (Grant et al., 2007).

Table 6. Effect of irrigation on plant physiology 34 WAP

Irrigation (L/plant)	Transpiration (millimol m ⁻²)	Leaf temperature (°C)	Stomatal conductance (mol m ⁻² s ⁻¹)	Net photosynthesis (μmol m ⁻² s ⁻¹)	Intercellular CO ₂ (microbars)	Chlorophyll content index (%)
2.5	7.08*	36.8	0.12 ^{cd}	0.53	702.9	71.2 ^a
5	7.42	35.9	0.13 ^{bc}	6.59	889.4	70.0 ^{ba}
10	7.42	37.2	0.14 ^{b a}	2.51	683.0	64.5 ^{ba}
20	7.50	37.9	0.15 ^a	-4.10	466.7	61.1 ^b
CV (%)	13.00	4.77	10.24	3.29	12.50	16.1
LSD _{0.05}	NS	NS	0.0115	NS	NS	8.92

* Means followed by the same letter or no letter, within each column are not significantly different at $P=0.05$, according to the Tukey's HSD test.

The effect of irrigation on stomatal conductance was significant ($P<0.05$). Stomatal conductance increased with increase in irrigation rate, with the 20 L of water having the highest conductance (Table 6). When the plants go through a period of water stress, abscisic acid (ABA) biosynthesis increases in roots and this is translocated to the shoot via the xylem, causing stomatal closure (Zhang and Davies, 1987; Gowing et al., 1990; Zhang and Davies, 1990; Parry and Horgan, 1991; Parry et al., 1992; Gomes et al., 1997). Although ABA can also be translocated from the shoot to the roots via the phloem,

experiments involving blockage of the phloem vessels demonstrated that the roots are able to synthesize ABA. This hormone in turn influences water conductivity (Cornish and Zeevaart, 1985). Increase in ABA content in plants, especially in roots, can be related to soil water content (Zhang and Davies, 1987; Gowing et al., 1990; Zhang and Davies, 1990; Gomes et al., 1997; Gomes et al., 2003).

There was no significant difference ($P>0.05$) in net photosynthesis for the different irrigation rates (Table 6). However, 20 L irrigation rate had negative net photosynthesis (Table 6). This was probably due to excessive vegetative growth which resulted in shading and development of many sinks that were noted through visual observations. The 2.5 L irrigation rate had low net photosynthesis. This could have been caused by photo-respiration due to high leaf temperatures and low water availability (Osmond, 1994).

Idso et al., (1995) measured the net photosynthetic rates of leaves of sour orange trees growing out-doors in clear-plastic-wall open-top chambers maintained at 400 and 700 ppm CO₂ under the searing summer sun of Phoenix, Arizona. It was so hot during that experiment that most of their measurements were made at temperatures above the trees' optimum temperature. As a result, foliage net photosynthetic rates dropped lower and lower as the air temperature climbed higher and higher into the middle of each afternoon. In fact, the rates dropped so low that at a leaf temperature of 47°C, the net photosynthetic rates of the leaves on the trees growing in air of 400 ppm CO₂ dropped all the way to zero and actually became negative thereafter, as the temperature rose higher still. These findings suggest that the negative net photosynthesis observed in purple passion fruits resulted from increasing leaf temperatures. This is evidenced by the fact that as the leaf temperatures increased due to low transpiration the net photosynthesis decreased towards zero and was negative at 37.92°C.

The effect of irrigation on intercellular CO₂ was not significantly different among irrigation treatments ($P>0.05$). However, there was a general trend whereby the intercellular CO₂ decreased with increase in irrigation level. The 2.5 L irrigation rate had 702.9 microbars intercellular CO₂, while the 20 L irrigation rate had 466.6 microbars

intercellular CO₂. Meidner and Mansfield (1965) suggested that diurnal increase in leaf temperature may induce midday closure, increasing respiration rate and intercellular CO₂ concentration. The closure is maintained until opening is induced by turgor recovery, or by photosynthetic depletion of intercellular CO₂.

The effect of irrigation on chlorophyll content was significantly different among irrigation rates ($P < 0.05$). Chlorophyll content was highest for the 2.5 L irrigation rate and least for the 20 L irrigation rate (Table 6). The chlorophyll content decreased with increase in irrigation rate, suggesting dilution by irrigation water (Table 6). Mensah et al., (2006) found that subjecting sesame to drought stress caused leaf chlorophyll to increase and then remain unchanged. Beeflink et al., (1985) reported increase in chlorophyll in onion under drought stress. These previous results are comparable with passion fruit results that showed an increase in chlorophyll content under drought stress.

4.2.2 Effects of mulch on plant physiology

The effect of mulch on transpiration was not significant ($P > 0.05$), although both black plastic and wheat straw mulch had the highest transpiration rate of 7.44 millimolm⁻² (Table 7). This was attributed to conservation of moisture by the mulches enabling the plant to lose the excess to the atmosphere through transpiration. Non-mulched plants transpired less, indicating the plants acclimation to withstand drought stress through closure of stomata.

Table 7. Effect of mulch on plant physiology 34 WAP

Mulch type	Transpiration (millimol m ⁻²)	Leaf temperature (°C)	Stomatal conductance (mol m ⁻² s ⁻¹)	Net photosynthesis (µmol m ⁻² s ⁻¹)	Intercellular CO ₂ (microbars)	Chlorophyll content index (%)
Black plastic ^z	7.44	36.88	0.14	-4.20 ^b	433.4 ^b	63.50
Wheat straw	7.44	36.81	0.14	-1.89 ^b	424.8 ^b	67.06
No mulch	7.19	37.19	0.13	10.23 ^a	1198.4 ^a	69.50
CV (%)	13.00	4.77	10.24	3.29	12.50	16.11
LSD _{0.05}	NS	NS	NS	10.60	686	NS

^z Means followed by the same letter or no letter, within each column are not significantly different at $P = 0.05$, according to the Tukey's HSD test.

The effect of mulch on leaf temperature was not significant ($P>0.05$), although both black plastic and wheat straw mulches had the least leaf temperatures (Table 7). Both mulches probably conserved moisture which was transpired by the plants, resulting in cooling and lowering of leaf temperatures. Abu-Awwad (1999) observed in onion mulch experiment that at low water level, transpiration in covered soil surface was significantly higher than that in open soil surface treatment. Thus the available soil water under a covered soil surface remains higher than that in open surface, because of the high loss of water via evaporation in the first few days (potential evaporation) after irrigation in the open soil surface. With the decrease in soil water, actual transpiration in open surface treatment decreased, and with further extraction of soil water, unsaturated hydraulic conductivity decreased, causing reduction in transpiration.

The effect of mulch on stomatal conductance was not significant ($P>0.05$), although both black plastic and wheat straw mulches had the highest conductance of $0.14 \text{ mol m}^{-2}\text{s}^{-1}$ (Table 7). This result was attributed to more moisture conservation, which was transpired by the plants (Al-Masoum et al., 1998).

The effect of mulch on net photosynthesis was significant ($P<0.05$) (Table 7). Both black plastic and wheat straw mulches had negative net photosynthetic values. Visual observation revealed that mulched plants had too many leaves that probably shaded each other more, thereby reducing net photosynthesis of their plants.

The effect of mulch on intercellular CO_2 was significant ($P<0.05$) (Table 7). The intercellular CO_2 was very high for non-mulched plants (1198 microbars), compared to 433.4 microbars and 424.8 microbars for black plastic and wheat straw mulches, respectively, translating to 2.8 times higher (Table 7). This result was possibly because with no mulch, CO_2 was not being fixed due to shortage of water in cells, and hence it just accumulated in leaf cells. Moreover, closed up stomata were probably locking up photo-respired CO_2 inside plant cells (Salisbury and Ross, 1991).

The effect of mulch on chlorophyll content was not significant ($P>0.05$), although both black plastic and wheat straw mulched plants had lower chlorophyll contents of 63.50 and 67.06, respectively, in comparison to plants that had not been mulched, which had 69.50 (Table 7). The chlorophyll content of plants was highest for non-mulched treatments followed by wheat straw and black plastic, suggesting dilution by water conserved under the two mulch types (Table 7). Mensah et al., (2006) found that subjecting sesame to drought stress caused leaf chlorophyll to increase and then remain unchanged. Beeflink et al., (1985) reported increase in chlorophyll in onion under drought stress. These results are comparable with passion fruit results that showed an increase in chlorophyll under drought stress occasioned by not mulching to conserve moisture.

4.2.3. Effect of interaction between irrigation and mulch on plant physiology

The effect of interaction between irrigation and mulch was significantly different ($P=0.068$) on stomatal conductance (Table 8). Treatments that received higher amounts of water and no mulch had high stomatal conductance, implying that the higher amounts of water were able to compensate for not mulching. Mulch alone on the other hand was also able to compensate for lower irrigation rates, implying that mulching is able to keep stomata conductance albeit at a lower rate.

Table 8. Effect of irrigation and mulch on stomatal conductance 34WAP

Treatment(mulch)	Stomatal conductance ($\text{mol m}^{-2}\text{s}^{-1}$)
20L, Black plastic	0.160 ^{a*}
10L, Wheat straw	0.155 ^{ab}
10L, Black plastic	0.143 ^{ab}
20L, No mulch	0.138 ^{ab}
20L, Wheat straw	0.138 ^{ab}
5.0L, Wheat straw	0.135 ^{ab}
5.0L, No mulch	0.135 ^{ab}
10L, No mulch	0.128 ^{ab}
2.5L, Black plastic	0.125 ^b
5.0L, Black plastic	0.125 ^b
2.5L, Black plastic	0.123 ^b
2.5L, No mulch	0.123 ^b

*Means followed by the same letter are not significantly different. SED = 0.00997, P = 0.068

4.3 Effect of Irrigation and Mulch on Flowering and Fruiting

4.3.1 Effect of irrigation on flower and fruiting

The effect of irrigation on combined florals and total dropped flowers was significantly different ($P < 0.05$), with 20 L having the greatest number, while 2.5 L having the least number (Table 9). However, irrigation had no significant effect ($P > 0.05$) on immature fruits and intact flowers. The high combined florals for the highest irrigation rate is in agreement with Morton (1987), who stated that water requirement is high when fruits are approaching maturity and that regular watering keeps a vine flowering and fruiting almost continuously. The number of intact flowers and immature fruits slightly increased as irrigation rate increased (Table 9). This was probably because water was utilised in keeping flowers turgid, thereby preventing their abscission. Combined florals and total dropped flowers were significantly ($P < 0.05$) fewer for 2.5 L and 5 L irrigation rates, compared to 10 L and 20 L irrigation rates. This was probably because the increased water was being utilized to initiate more florals, excess of which also self-thinned to adjust fruit load or balance fruit load with photosynthate sources (leaves).

Table 9. Effect of irrigation on floral development

Irrigation (L/plant)	Immature fruits	Intact flower	Total flowers	dropped	Combined florals
2.5	63.1*	16.2	170.5 ^b		249.5 ^b
5.0	69.3	15.5	167.1 ^b		251.8 ^b
10.0	69.8	15.1	205.4 ^{ab}		290.3 ^{ab}
20.0	74.2	17.0	241.3 ^a		332.1 ^a
CV (%)	28.6	15.3	28.25		22.7
LSD _{0.05}	NS	NS	46.0		52.0

*Means followed by the same letter or no letter, within each column are not significantly different at $P = 0.05$, according to the Tukey's HSD test.

4.3.2 Effect of mulch on flower and fruiting

The effect of mulch was significant ($P < 0.05$) on immature fruits, combined florals and total dropped flowers (Table 10). Black plastic mulch had the highest number of immature fruits of 75.5, while no mulch control had the least number of immature fruits of 58.8. There was no significant difference ($P > 0.05$) between black plastic mulch and

wheat straw mulch in influencing floral development. This implies that the two mulches equally conserved moisture, which was used by plants in development of more florals. The black plastic mulched plants produced the greatest number of florals probably because of the warming effect on the soil. Solaiman et al., (2008) assessed the effect of traditional mulches on the flower production and petal colouration in China Aster (*Callistephus chinensis*) using control (no mulch), straw mulch and black plastic mulch treatments. Mulches significantly increased total number of flowers produced. Highest cumulative number of flowers resulted under black plastic mulch at 62 days after transplanting. Flower initiation in the plants under black plastic mulch was earlier than under straw mulch or control. They suggested that soil temperature arising from black plastic mulch treatment was directly related to early initiation of flowers. Al-Masoum et al., (1998) reported that black plastic mulch is better because it preserves the soil structure and retains soil moisture in addition to warming the soil, eliminating weeds, and increasing CO₂ content around the plants. Black plastic mulch reflects beneficial spectra of light back onto plants and increases root proliferation (Solaiman et al., 2008).

Table 10. Effect of mulch on floral development

Mulch	Immature fruits	Intact flowers	Total dropped flowers	Combined florals
Black plastic	75.5 ^{*a}	16.1	234.6 ^a	326.3 ^a
Wheat straw	72.9 ^{ab}	15.2	165.8 ^b	253.4 ^b
No mulch	58.8 ^b	16.5	187.9 ^b	263.1 ^b
CV (%)	28.6	15.3	28.3	22.7
LSD _{0.05}	15.0	NS	41.9	48.0

*Means followed by the same letter or no letter, within each column are not significantly different at $P=0.05$, according to the Tukey's HSD test.

4.4 Effect of Irrigation and Mulch on Fruit Yield up to 54 WAP

4.4.1. Effect of irrigation on fruit yield

The effect of irrigation was significant ($P<0.05$) on fruit number per plant at 52 WAP when the 2.5 L had significantly fewer fruits compared to the other irrigation rates (Table

11). This was probably because fewer flowers had been initiated leading to fewer fruits due to the low water supply for the 2.5 L irrigation rate. The higher rates of irrigation had higher number of fruits possibly because the plants were able to sustain development of more flowers to fruit maturity stage (Table 11).

The lack of a significant difference in cumulative fruit number at 54 WAP for irrigation rates was attributed to the catch up effect, whereby plants receiving low amount of water adapted and developed as many fruits as the ones that were receiving high amount of water right from the beginning. Alternatively, plants receiving high amount of water did not support the numerous flowers initiated to maturity stage, as evidenced by the plentiful number of flowers that also dropped. Plants normally self-thin flowers in order to remain with a number they can nourish and support well (Faust, 1989).

Table 11. Effect of irrigation on mature fruit yield (number/plant)

Irrigation (L/plant)	Time (weeks after planting)										
	40	43	45	47	48	49	51	52	53	54	54CFN
2.5 ^z	0.9	4.1	7.7	4.6	5.3	19.2	7.5	6.3 ^b	6.0	12.3	72.9
5	1.1	3.7	7.5	8.0	7.2	21.7	6.6	10.4 ^a	5.8	11.6	82.2
10	0.3	3.8	7.1	6.5	5.3	24.3	6.3	10.3 ^a	6.7	12.8	82.4
20	0.8	5.3	9.1	5.8	8.0	28.1	8.3	11.8 ^a	7.0	16.3	98.3
CV (%)	5.5	12.	11.8	13.6	8.0	10.3	8.3	5.9	10.3	6.3	8.8
LSD _{0.05}	NS	NS	NS	NS	NS	NS	NS	2.94	NS	NS	NS

^z Means followed by the same letter or no letter, within each column are not significantly different at $P=0.05$, according to the Tukey's HSD test. CFN = Cumulative fruit number at 54 WAP.

Effect of irrigation on fruit weight was significant ($P<0.05$) at 48 and 52 WAP (Table 12). The 20 L irrigation rate had consistently higher fruit weight throughout the fruiting experimental period. The other irrigation rates had inconsistent fruit weights. The effect of irrigation was also significant ($P<0.05$) on cumulative fruit weight at 54 WAP. The cumulative fruit weight at 54 WAP increased with increase in rate of irrigation. However,

there was no significant difference in fruit weights between 2.5 L and 5 L or among 5 L, 10 L and 20 L of water.

The 2.5 L irrigation rate had lower fruit weight probably due to reduced dry matter accumulation. Thus, the plants receiving 2.5 L of water were under drought stress, while those receiving at least 5 L were not. This concurs with observations made by Isutsa (2006). Jaimez et al., (2000) observed low water availability reduce number of flowers and subsequent fruits. Dorji et al., (2005) reported that the number of fruits per plant was reduced by deficit irrigation.

4.4.2 Effect of mulch on fruit yield

The effect of mulch on fruits per plant was significant ($P < 0.05$) only at 43 WAP (Table 13) when black plastic mulch had the greatest fruit number followed by wheat straw mulch and lastly no mulch control. However, there were no significant differences in fruit number among other mulch treatments (Table 13).

Table 12. Effect of irrigation on mature fruit weight (g/plant)

Irrigation (L/plant)	Time (weeks after planting)										
	40	43	45	47	48	49	51	52	53	54	54 CFW
2.5	25*	74	132	115	113 ^b	503	174	138 ^b	121	280	1674 ^b
5	23	74	153	164	137 ^{ba}	466	155	245 ^a	123	270	1810 ^{ab}
10	13	74	150	172	117 ^b	613	148	222 ^{ba}	145	339	1993 ^a
20	11	129	199	173	203 ^a	749	213	280 ^a	155	434	2544 ^a
CV (%)	20	33	25	29	19	10	13	10	8	12	11
LSD _{0.05}	NS	NS	NS	NS	76.9	NS	NS	95.4	NS	NS	784

*Means followed by the same letter or no letter, within each column are not significantly different at $P=0.05$, according to the Tukey's HSD test. CFW = Cumulative fruit weight

The trend in number of fruits varied throughout the fruiting season. This was probably because passion fruits differentiated at different rates and hence the constant variation in number of passion fruits harvested.

Table 13. Effect of mulch on mature fruit (number/plant)

Mulch type	Time (weeks after planting)										
	40	43	45	47	48	49	51	52	53	54	54 CFN
Black plastic	0.62*	6.94 ^a	8.75	6.38	6.69	24.00	6.50	8.88	6.13	11.8	86.7
Wheat straw	0.81	3.13 ^{ba}	8.81	6.25	6.13	23.56	8.25	9.75	6.38	14.6	87.7
No mulch	0.88	2.56 ^b	5.94	6.00	6.56	22.38	6.75	10.44	6.63	13.4	81.5
CV (%)	5.5	12.6	11.8	13.6	8.0	10.3	8.3	5.9	10.3	6.3	8.8
LSD _{0.05}	NS	4.22	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Means followed by the same letter or no letter, within each column are not significantly different at $P=0.05$, according to the Tukey's HSD test. CFN = Cumulative fruit number.

At 54 WAP, wheat straw had the highest number of cumulative fruits (Table 13). It was followed by black plastic mulch and lastly by no mulch. Mulches are known to increase soil temperature since the sun's energy passes through them and heats the air and soil beneath directly as heat is trapped by the "greenhouse effect" phenomenon (Hu et al., 1995). Mulches also promote crop development, early harvest and yields increase. Other reported benefits of mulch include microclimate and texture improvement, conservation of soil moisture and fertility, and control of weeds, pests and diseases (Niu et al., (1998). Very little weed growth occurs under dark mulches as they prevent penetration of light or exclude certain wavelengths of light that are needed by weed seedlings to grow (Ossom et al., 2001). Hanada (1991) indicated that mulching could have benefits on soils and their environment. Ramakrishna et al.,(2006) observed more favourable soil environment under the polythene and straw mulch mulches, especially during the early part of the growing season, increase the number of pods per plant, pod mass, test weight, striking pod and stover yields in ground nuts.

The effect of mulch on fruit weight was significant ($P<0.05$) only at 43 WAP (Table 14), when black plastic mulch had the greatest fruit weight followed by wheat straw mulch and lastly no mulch control. At 43 WAP, there were no significant differences in fruit weight for black plastic and wheat straw mulches, as well as for wheat straw mulch and no mulch.

Table 14. Effect of mulch on mature fruit weight (g/plant)

Mulch	Time (weeks after planting)										
	40	43	45	47	48	49	51	52	53	54	54CFW
Black plastic	18.7 [*]	162.2 ^a	183.4	176.4	153.3	618.0	151.3	189.2	133.1	294.9	2080.4
Wheat straw	12.2	59.6 ^{ba}	180.4	147.1	130.6	566.9	197.5	238.4	136.5	357.1	2026.1
No mulch	23.2	40.8 ^b	111.6	144.9	143.7	562.6	168.1	236.2	137.9	341.1	1909.7
CV (%)	20	33	25	29	19	10	13	10	8	12	11
LSD _{0.05}	NS	106	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Means followed by the same letter or no letter, within each column are not significantly different at $P=0.05$, according to the Tukey's HSD test. CFW = Cumulative fruit weight.

During the other growth stages, there was no consistency among the mulches since the trend in fruit weight varied throughout the fruiting season. This was probably because fruits accumulated dry matter at different rates and hence the variation in the weight of those harvested. According to Halil et al. (2001), both black plastic mulch and wheat straw mulches improved the fruit yield and fruit size of stressed treatments. Mulch substantially decreased electrolyte leakage in strawberry fruits. However, mulch enhanced the concentrations of nutrients in leaves and strawberry fruits. These results clearly indicate that mulch mitigates negative effects of water stress on plant growth and fruit yield in the field, particularly in semi-arid situations.

The effect of mulch was not significant ($P>0.05$) both on fruit weight and cumulative fruit weight at 54 WAP (Table 14). Nevertheless, wheat straw had the highest fruit weight, while black plastic had the highest Cumulative fruit weight (Table 14). Black plastic mulch had the highest cumulative fruit weight possibly because the fruits had higher density compared to those of wheat straw and no mulch plants.

4.5. Effect of Irrigation and Mulch on Fruit Quality

4.5.1. Effect of irrigation on fruit quality

Irrigation treatments used in this experiment did not affect fruit quality attributes (Figure 5). Nevertheless, total soluble solids were highest for 5 to 20 L of water. The 2.5 L treatment had the least TSS probably because 2.5 L of water was inadequate for TSS

synthesis (Figure 5). Water stress have been found to increase the levels of soluble sugars (glucose, sucrose and fructose) in grape and wheat plants (Ndung'u et al.,1997; Sawhney and Singh, 2002), while it reduces the amounts of starch and total sugars.

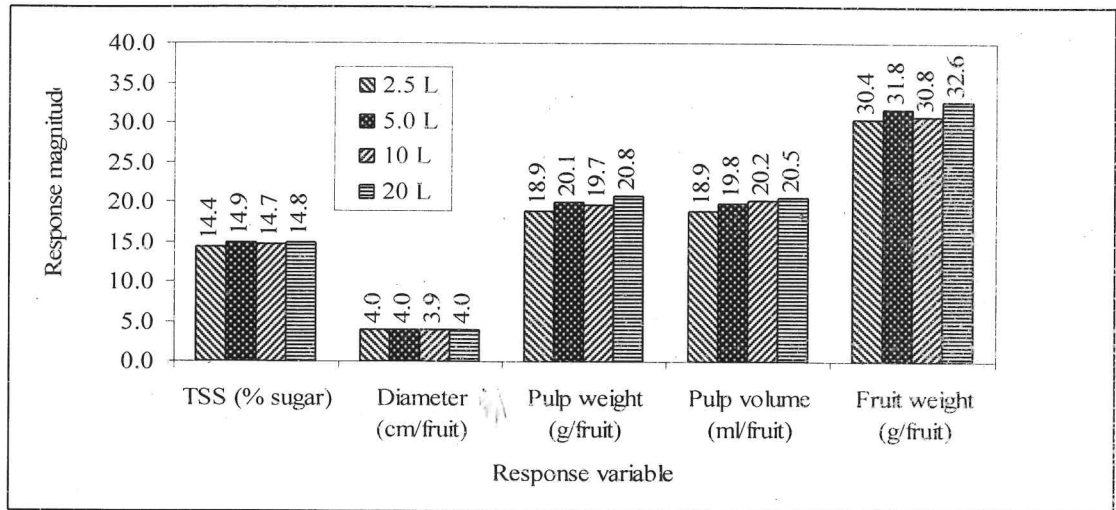


Figure 5. Effect of irrigation on fruit quality attributes

Fruit diameter varied across the irrigation rates with 5 L of water having the greatest diameter and 10 L having the least diameter (Figure 5). This was contrary to the expected increase in fruit diameter with increase in irrigation rate. It seems some of the excess irrigation water was being diverted to promote vegetative growth at the expense of fruit growth in diameter.

The pulp weight increased in direct proportion with fruit weight across all irrigation rates (Figure 5). The 20 L treatment had the highest pulp weight of 20.75, while the 2.5 L had the lowest pulp weight of 18.92 (Figure 5). This was attributed to the high amount water for 20 L irrigation rate being utilised in synthesis of fruit pulp.

The number of seeds per fruit increased slightly as the rate of the irrigation increased (Figure 6). The number of seeds per fruit was: 102 for 2.5 L, 115 for 5 L, 113 for 10 L, and 118 for 20 L. This was probably because irrigation water interacted with other factors such as pollination during seed formation.

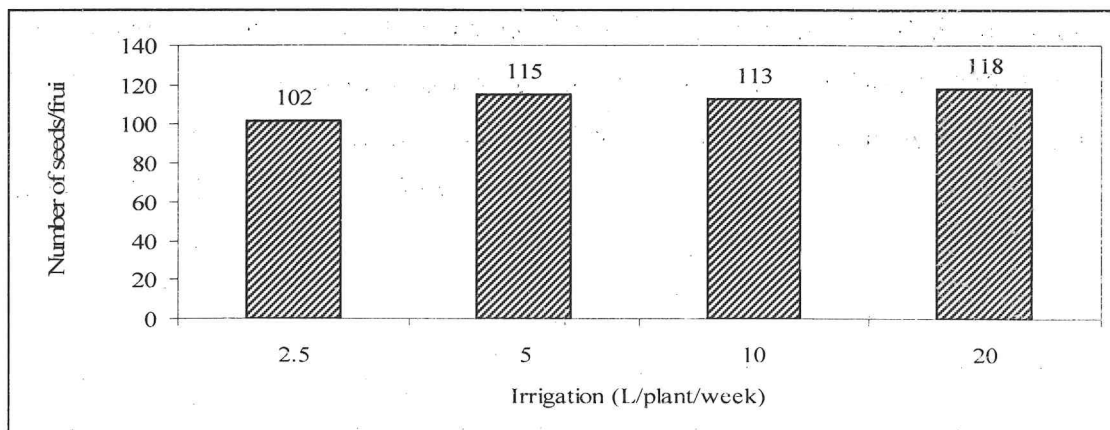


Figure 6. Effect of irrigation on number of seeds per fruit

4.5.2. Effect of mulch on fruit quality

Mulch had no significant effect ($P>0.5$) on fruit quality (Table 15). Wheat straw had the greatest total soluble solids (TSS) of 14.81. No mulch treatment had TSS of 14.69, which was higher than that of black plastic mulch of 14.63. No mulch treatment had the highest fruit diameter, which was greater than that of wheat straw and black plastic mulch. Wheat straw mulch had the highest pulp weight and pulp volume suggesting that it was able to conserve more moisture than the black plastic mulch. No mulch pulp control had higher fruit density compared to that of black plastic mulch. However, the number of seeds per fruit was higher for wheat straw and black plastic mulches, compared to no mulch control. A trend was observed whereby wheat straw was superior to black plastic mulch and no mulch in all fruit quality attributes (Table 15).

Table 15. Effect of mulch on fruit quality

Type of mulch	TSS	Fruit diameter (cm/fruit)	Pulp weight (g/fruit)	Pulp volume (ml/fruit)	Seeds (number/fruit)	Fruit weight (g/fruit)
Black plastic	14.6*	3.9	19.2	19.3	108	30.4
Wheat straw	14.8	4.0	20.9	21.1	121	32.9
No mulch	14.7	4.0	19.4	19.2	106	30.9
CV (%)	4.6	4.3	18.6	17.2	22.2	16.7
LSD0.05	NS	NS	NS	NS	NS	NS

* Means followed by the same letter or no letter, within a column are not significantly different at $P=0.05$, according to the Tukey's HSD test.

4.6. Effect of Irrigation and Mulch on Mature Fruits at 56 WAP

4.6.1. Effect of irrigation on fruit maturity

There was no significant ($P>0.05$) effect of irrigation on number of fruits or on weight of fruits harvested at 56 WAP (Table 16). Nevertheless, the 2.5 L had slightly more fruits than the 5 L and 10 L irrigation rates, while the 20 L had the highest number of fruits.

The cumulative weight of fruits was significantly ($P<0.05$) different, but cumulative number of fruits was not significantly ($P>0.05$) different (Table 16). The cumulative weight of fruits for the 2.5 L irrigation rate was the lowest, implying that the weight of individual fruits was lower compared to that of other irrigation rates. The cumulative weight of fruits increased with increase in irrigation rate probably because of the role irrigation water plays in dry matter synthesis and accumulation of synthates in fruits.

The water supplied at 2.5 L, 5 L and 10 L treatments generally promoted fruit growth to the same extent. However, the cumulative weight of fruits for 2.5 L and 20 L were significantly different. These results implied that the 2.5 L did not provide enough water to support dry matter accumulation in fruits as did the 20 L of water (Isutsa, 2006).

Effect of irrigation was significant ($P<0.05$) on water use efficiency (WUE) for cumulative number of fruits and on WUE for cumulative weight of fruits (Table 16). The 2.5 L irrigation rate had the highest WUE, while 20 L irrigation rate had the least. This was possibly because low irrigation rates did not significantly reduce production of assimilates by purple passion fruits. The plants receiving 2.5 L of water can tolerate droughty conditions and continue carrying out physiological processes (Isutsa, 2006). Otherwise, Ibrahim et al., (1995) reported that water stress significantly reduced WUE of millet, which is an annual monocot crop indicating its inability to withstand drought stress compared to perennial dicot plants such as passion fruits.

The effect of irrigation was significant ($P < 0.05$) on harvest index (HI) expressed as cumulative number of fruits versus leaf area or cumulative weight of fruits versus leaf area (Table 16). The 2.5 L irrigation rate had the lowest HI, while the 20 L irrigation rate had the highest (Table 16). Thus the 20 L of water produced more fruit yield per unit of leaf area and hence sustained productivity while the 2.5 L had the opposite effect. These findings are supported by similar results by Isutsa (2006).

4.6.2. Effect of mulch on fruit maturity

Mulch had no ($P > 0.05$) effect on number and weight of fruits harvested at 56 WAP (Table 17). Mulch also had no significant ($P > 0.05$) effect on cumulative number of fruits and cumulative weight of fruits (Table 17). Nevertheless, mulched plants had more fruits and higher fruit weights compared to the non-mulched plants. Khalid et al., (2005) conducted an experiment on weed control in okra using wheat straw mulch, black plastic mulch and herbicide. The study showed that straw mulch produced better results, yielding 6.01 t/ha, while black plastic mulch yielded 5.55 t/ha. Halil et al., (2001) found that both black plastic mulch and wheat straw mulch improved fruit yield, fruit size, plant dry matter and leaf area index of strawberries in the water-stressed treatments.

Halil et al., (2001) stated that water stress enhanced electrolyte leakage by impairing membrane integrity. Black plastic or wheat straw mulch substantially decreased electrolyte leakage from fruits. Levent and Ankara (2001) found that wheat straw had highest yield of 4.482 kg of tomatoes followed by black polyethylene (3.768 kg) and control (3.757 kg), although the differences were not significant. These results clearly indicate that mulching mitigates negative effects of water stress on plant growth and fruit yield, particularly in water-stressed situations.

Mulch had no significant ($P > 0.05$) effect on water use efficiency for cumulative number of fruits and weights of fruits (Table 17). However, black plastic mulch and wheat straw mulch had higher WUE compared to no mulch control. Both plastic and wheat straw mulches had higher WUE for both cumulative number and weight of fruits.

Table 17. Effect of mulch on mature fruits, Water Use Efficiency and Harvest Index at 56 WAP

Type of mulch	Response attribute									
	Number of fruits	Cumulative number of fruits	Weight of fruits (g/plant)	Cumulative weight of fruits (g)	WUE for cumulative fruits (fruits/L)	WUE for cumulative weight of fruits (g/L)	Cumulative fruits vs. leaf area (cm ² /natural log wt (g)	Cumulative weight of fruits vs. leaf area (cm ² /natural log fruits)		
Black plastic	131*	216	3413	5493	0.71	18.11	50.0	31.4		
Wheat straw	132	218	3502	5528	0.69	17.40	48.8	30.7		
No mulch	118	198	3212	5122	0.64	16.54	48.8	30.5		
LSD _{0.05}	NS	NS	NS	NS	NS	NS	NS	NS		

*Means followed by the same letter or no letter, within each column are not significantly different at $P=0.05$, according to the Tukey's HSD test.

It has been reported that mulching is among the water management practices for increasing water use efficiency (Gajri et al., 1994; Khurshid et al., 2006). Different types of materials such as wheat straw and plastic films moderate soil temperature and increase water infiltration. Present findings indicate that black plastic mulch had higher WUE than the wheat straw mulch, although it had lower cumulative number of fruits as well as cumulative weight of fruits (Table 17).

Mulch had no significant ($P>0.05$) effect on harvest index (HI) expressed either as cumulative number or weight of fruits versus leaf area. The black plastic mulch however had a higher HI compared to wheat straw and no mulch.

4.6.3. Effect of Interaction on Cumulative Fruit Yield Versus Leaf Area

The effect of interaction between irrigation and mulch was significant ($P<0.05$) on harvest index expressed either as cumulative number of fruits versus leaf area or cumulative weight of fruits versus leaf area (Tables 18 and 19). The 20 L irrigation rate and no mulch had the highest HI, while the 2.5 L irrigation and no mulch had the lowest HI. These two treatments were significantly different. The results are supported by earlier studies which showed that applying high amount of irrigation water alone ameliorated drought effectively, resulting in high fruit production per unit leaf area (Isutsa, 2006). Additionally, there was no additional benefit of mulching when applying 5 L to 20 L of water, with regard to fruit production per unit leaf area.

Application of little amount of irrigation water alone subjected plants to intense drought stress that depressed fruiting. Plants that received 2.5 L of water tolerated drought stress better when mulched, resulting in fruit yields that were at par with those of plants receiving high amounts of irrigation water with or without mulch, except the 20 L plus no mulch treatment. Thus mulching provided additional benefit when practicing limited small amount of irrigation. High harvest index indicated that the treatments promoted high fruit production relative to the leaf area of corresponding plants. Low harvest index on the other hand indicated that the treatments promoted low fruit production relative to the leaf area of corresponding plants.

Table 18. Leaf area versus cumulative natural log number of fruit at 56 WAP

Treatment	Harvest index (leaf area /cumulative natural log number of fruits)
20L, No mulch	55.73 ^{a*}
10L, Black plastic	53.40 ^{ab}
20L, Black plastic	50.53 ^{ab}
5.0L, Black plastic	50.27 ^{ab}
10L, No mulch	49.35 ^{ab}
2.5L, Wheat straw	49.20 ^{ab}
10L, Wheat straw	48.79 ^{ab}
5.0L, Wheat straw	48.76 ^{ab}
20L, Wheat straw	48.39 ^{ab}
5.0L, No mulch	46.64 ^{ab}
2.5L, Black plastic	45.76 ^{ab}
2.5L, No mulch	43.68 ^b

*Means followed by the same letter are not significantly different. SED = 3.24, P = 0.1090

Table 19. Leaf area versus cumulative natural log weight of fruit at 56 WAP

Treatment	Harvest index (leaf area /cumulative natural log number of fruits)
20L, No mulch	34.80 ^{a*}
10L, Black plastic	33.50 ^{ab}
20L, Black plastic	31.81 ^{ab}
5.0L, Black plastic	31.72 ^{ab}
10L, No mulch	30.89 ^{ab}
2.5L, Wheat straw	30.82 ^{ab}
5.0L, Wheat straw	30.71 ^{ab}
10L, Wheat straw	30.70 ^{ab}
20L, Wheat straw	30.61 ^{ab}
5.0L, No mulch	28.94 ^{ab}
2.5L, Black plastic	28.74 ^{ab}
2.5L, No mulch	27.31 ^b

*Means followed by the same letter are not significantly different. SED = 1.92, P = 0.0877

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Irrigation does not significantly effect vegetative growth of purple passion fruit. However, 10 litres irrigation rate produces the greatest number of leaves and the plants attain the tallest height. The number of laterals increases with increase in irrigation rate. The difference between the 20 L irrigation rate and the other irrigation rates is significant in influencing number of fruiting laterals. The leaf area increases in direct proportion to irrigation rates, implying that the increase in water drives leaf cell division, cell elongation and hence leaf growth. Therefore, irrigation does ameliorate drought stress in purple passion fruits. Irrigation affects stomatal conductance and chlorophyll content index, but does not significantly affect other physiological processes of the passion fruit plants. Plants receiving high amount of irrigation water exhibit high stomatal conductance, while those receiving low amount of irrigation water exhibit high amount of chlorophyll content. Purple passion fruit plants lower stomatal conductance as a means of reducing transpiration in order to cope with drought stress. Irrigation affects cumulative fruit weight, but does not affect the cumulative number of fruits. Probably water is utilized more in fruit enlargement and development of juice vesicles and fruit pulp after pollination rather than in fruit initiation, explaining lack of significant difference in number of fruits formed. Irrigation affects water use efficiency and harvest index of purple passion fruits. The water use efficiency decreases with increase in irrigation rates, while harvest index increases with increase in irrigation rate. The differences are significant mainly between the 20 L and 2.5 L irrigation rates.

Mulch does not significantly affect vegetative growth of purple passion fruits. However, wheat straw promotes the tallest height and greater number of leaves, while no mulch leads to the least height and leaf number. Therefore, mulch slightly ameliorates drought stress. Black plastic mulch significantly increases floral development of purple passion fruits, most likely due to modification of soil temperature and conservation of water used in development of florals. Black plastic mulch also promotes the highest number of dropped flowers compared to no mulch, most likely due to promoting initiation of excess

number of flowers than the plants can handle. Black plastic and wheat straw mulches lead to decreased intercellular CO₂ and net photosynthesis. Leaf temperature and intercellular CO₂ are highest for no mulch. This was possibly due to photo-respiration as a coping strategy for drought stress. Although mulch does not significantly affect fruiting of passion fruit, wheat straw results in the highest number and cumulative weight of fruits harvested, while no mulch promotes the least. These results are attributed to the ability of mulch to conserve water used in development of fruits. Mulch does not significantly affect any fruit quality attribute. This result implies that passion fruit quality is not mediated through the mechanisms that mulch uses to influence plant growth and development. Mulch does not significantly affect water use efficiency of purple passion fruits. However, mulches result in higher water use efficiencies than no mulch. No mulch treatments consume a lot of water through evaporative loss, thereby subjecting plants to drought stress that in turn depress fruit yields. The end result of the ratio between depressed fruit yields and high amount of water lost is low water use efficiency.

The effect of interaction is significant on leaf area and leaf weight, where higher irrigation rates ameliorate the negative stress exerted by not mulching plants. Therefore, there is no need of mulching when applying high amount of irrigation water. Lower irrigation rates exhibit a synergistic effect with mulching, thereby producing high leaf area and leaf weight. The lowest irrigation rate (2.5 L) is not able to counteract the negative effects of drought stress in non-mulched passion fruit plants. Therefore, when applying minimal amount of irrigation water, then mulching is beneficial. This study demonstrated that the effect of interaction between irrigation and mulch is significant on stomatal conductance. Treatments that applied higher amounts of water and no mulch exhibit high stomatal conductance, implying that the higher amounts of water are able to compensate for not mulching. Mulch alone keeps stomata conducting albeit at a lower rate. Applying high amount of irrigation water alone ameliorates drought effectively, resulting in high fruit production per unit leaf area. There is no additional benefit of mulching when applying 5 to 20 L of water. Plants receiving 2.5 L of water tolerate drought stress better when mulched, implying that mulching provides additional benefit.

5.2 Recommendations

- 5.2.1. When only 2.5 L of irrigation water is available to each plant once a week then it must be combined with mulching to effectively ameliorate drought stress in purple passion fruits.
- 5.2.2. Farmers should use supplemental irrigation of 5 L per plant once per week alone or together with wheat straw mulch to ameliorate drought stress because there is no statistically significant difference between it and the other higher irrigation rates.
- 5.2.3. When up to 20 L of irrigation water is supplied once per week to each plant, then mulching should not also be done for the sole purpose of ameliorating drought stress. Mulching can be done under such circumstances only if its other benefits are desired.
- 5.2.4. Further research with other passion fruit varieties including grafted ones to be conducted to establish their water and mulching requirements.
- 5.2.5. The experiment to be repeated in an open dry land to accord plants maximum reported spacing (3 m between-plants x 4 m between rows) to avoid intra-plant and inter-plant interference and confirm present results.

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