I.J.A.B.R., VOL. 2(1) 2012:46-52 ISSN 2250 - 3579

INTERNATIONAL JOURNAL OF ADVANCED BIOLOGICAL RESEARCH

www.scienceandnature.org

IRRIGATION RATE AND MULCH TYPE SIGNIFICANTLY AFFECT SOME PHYSIOLOGICAL PROCESSES OF PURPLE PASSION FRUIT *(Passiflora edulis* f. *edulis* Sims.) UNDER DROUGHT STRESS

Gaturuku, J. K., *Isutsa, D. K. & Aguyoh, J. N.
Egerton University, P. O. Box 536-20115, Egerton, Nakuru, Kenya

ABSTRACT
The effects of irrigation rate and mulch type on physiology of purple passion fruit plants were evaluated. The experiment was set up in a rain shelter in randomized complete block design, replicated four times and repeated once. The study tested four irrigation rates (2.5, 5, 10 and 20 L/plant) and three mulch levels (black plastic film, wheat straw and no mulch). Each treatment had 12 plants in 45 cm x 45 cm holes spaced at 1.5 m x 1.5 m and trellised onto posts and wires. A plastic film was buried between main plots and blocks to prevent water seepage across treatments. Plants were maintained uniformly until the fifth week after planting when treatments were imposed. Data were subjected to analysis of variance using the SAS software. The 20 L irrigation rate significantly ($P<0.05$) increased and decreased stomatal conductance and chlorophyll content, respectively. Mulch significantly increased net photosynthesis. The 2.5 L irrigation rate significantly increased water use efficiency (WUE) (36 g/L) over the 20 L (5 g/L). The 20 L irrigation rate had significantly higher leaf area to fruit weight or source to sink ratio (32 cm^2/g of fruits) than the 2.5 L irrigation rate (29 cm^2/g of fruits). Irrigation and mulch did not significantly ($P>0.05$) influence all other physiological parameters of purple passion fruit plants. The fact that irrigation rate significantly influenced leaf area to fruit (source to sink) ratio of purple passion fruit than mulch implies that it should be given first priority over mulch in mitigating drought stress in purple passion fruits.

KEY WORDS: Photosynthesis, Stomatal conductance, Source:sink ratio, Water use efficiency.

INTRODUCTION

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 (Morton, 1987). Passion fruit became naturalized in 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. In the family Passifloraceae, there are approximately 500 species, including *Passiflora edulis* Sims, which has the exclusive designation of passion fruit, without qualification. Within this species, there is the standard purple passion fruit (*P. edulis* f. *edulis*), and its variant yellow passion fruit (*P. edulis* f. *flavicarpa*) (Morton, 1987). The purple passion fruit is adapted to the coolest subtropics or to high altitudes in the tropics. It grows and produces well within 650 to 1,300 m asl. *Passiflora edulis* has temperature requirements ranging from 15°C to 28°C. Purple passion fruit needs annual rainfall ranging from 1000 to 2500 mm and protection from wind for proper growth and fruiting. Rainfall must be well-distributed and minimal during flowering as pollen wetted by free moisture bursts open and becomes non-functional. Rain also minimizes insect activity, resulting in poor pollination, fruit set and subsequent fruit yields (Nakasone and Paull, 1998).

Drought is a common stress, generally characterized by a combination of water shortage, high temperatures and light intensities (Cornic, 1994; Lawlor, 1995). Photosynthesis and its capacity are progressively decreased under drought-induced stomatal closure, which reduces CO_2 availability in chloroplasts. Consequently, lower light intensity is required to saturate photosynthesis under droughty conditions than under well-watered conditions. This may increase the susceptibility to photo-inhibition and photo-oxidation (Osmond, 1994). Photorespiration might serve as a safety valve to dissipate excess electron transport under low CO_2 concentration prevailing in chloroplasts during drought (Osmond *et al*., 1980).

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 (Doorenbos and Kassam, 1994). The factors that determine irrigation scheduling are: soil water holding capacity, rooting zone depth, evapo-transpiration rate, water volume to be applied, irrigation method, and drainage conditions. Methods used to irrigate crops range from watering individual plants with a can to highly automated centre pivot irrigation systems. Localized irrigation is done around each plant or a group of plants to wet the root zone only, meet evapo-transpiration needs and minimize percolation losses (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). In Brazil, increase of water reduced water use efficiency (WUE), and the simple increase of yield as a function of amount of water applied did not optimize the water used (Sousa *et al*., 2005). Destructive effects of drought similarly apply in purple passion fruits, necessitating establishment of remedial measures.

MATERIALS AND METHODS

Research Site

The present study was conducted in a plastic-covered rain shelter located 2185 m asl. The site experiences 9.1°C to 23.1°C temperature and 1012 mm per annum rainfall. The soils at the site are Vintric molic andosols, well-drained, dark to very dark-reddish brown, friable and silt clays with humic tops (Jaetzold and Schmidt, 1983).

Experimental Design

The experiment was laid out in a randomized complete block design, with four irrigation rates: 2.5, 5, 10, and 20 L/plant once per week and three types of mulches: wheat straw, black plastic film and no mulch. Each treatment had three plants, replicated four times. The experiment was conducted for 56 weeks after planting (WAP) and repeated once. Plastic mulch was applied 4 WAP to cover each hole leaving a perforation around each plant for use in watering plants. Plastic mulch was replaced whenever it got torn. Wheat straw mulch was similarly applied around holes as for plastic mulch. The thickness and span of the wheat straw mulch was 10 cm high by 30 cm wide. Wheat straw was topped up regularly whenever it decomposed and started exposing the soil surface.

Experiment Establishment and Maintenance

Land was dug and pulverized to a fine tilth to attain a level ground. Experimental plots were set up whereby rows represented blocks. Planting holes, measuring 45 cm x 45 cm, were dug up and all soil removed. Planting holes were spaced at 1.5 m x 1.5 m (Gachanja and Ochieng, 2004). The top soil used to re-fill the planting holes was dug outside near the rain shelter to maintain homogeneity. About 5 kg poultry manure was mixed thoroughly with the top soil inside each 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 planted in soil under shade and high temperature in a glasshouse to hasten germination. The seedlings were transplanted at the fourth leaf stage into black polythene bags, measuring 15 cm diameter by 23 cm depth and filled with loam soil. Top dressing with 1 g CAN/seedling was done four weeks later. Seedlings were nurtured in the bags until they attained 30-cm height that indicated readiness for transplanting to the research site (Morton, 1987).

Soon after transplanting a trellis, with a 40-cm cross bar on top of each 2.1-m tall post and two, 14-gauge wires fastened at the ends of the cross bar to run parallel to each other, was constructed to support the passion fruit vines (Nakasone and Paull, 1998). A 45-cm deep trench was dug between main plots and on the perimeter of the rain shelter, followed by lining with a plastic film to prevent seepage of irrigation and rain water into the experimental area.

Seedlings were tipped soon after planting to stimulate branching. Two main shoots, selected from close to the base of each seedling, were trained upwards on a sisal twine and towards the same direction on the top wires. Leaves on the two main shoots and fruit-bearing laterals arising from the two main shoots on the top wires were left to grow continuously. Tips of the laterals were pruned off at 15 cm above the ground.

At transplanting, 170 g of 17N:17P:17K fertilizer was applied as basal fertilizer to each seedling. The same fertiliser was applied as a topdress at a rate of 100 g and 70 g per vine at the beginning and in the middle of the fruiting period, respectively (Torsten *et al*., 2004). Pruning of spent laterals was done selectively by cutting them back to a newly developing lateral or sub-lateral and tendrils were regularly removed (Nakasone and Paull, 1998).

Variables Measured

Leaf area was assessed at 21 WAP by tracing the width of leaves at the widest part of the laminar and leaf length from laminar tip to the petiole intersection, along the laminar midrib on a graph paper. The leaves used were destructively sampled on young vines at 1 m above the ground level. 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 mid-section of fruiting laterals. Fruit yields were determined bi-weekly, starting from the ninth month after planting. Harvesting was done as soon as the fruits reached physiological maturity, indicated by colour change from green to purple. All harvested fruits were counted and weighed. Number and fresh biomass of fruits per plant were used to calculate water use efficiency and source to sink (leaf area to fruit) ratio.

RESULTS AND DISCUSSION

Effects of Irrigation on Passion Fruit Physiology

Transpiration of the passion fruit plants was not affected by the irrigation treatments applied in this study ($P>0.05$) (Table 1). Nevertheless, the trend was that plants irrigated with 20 L had the highest rate of transpiration, probably because the plants could afford to lose water that was above their requirement. Plants irrigated with 2.5 L lost the least amount of water possibly because they closed their stomata as a survival mechanism. Ahmed *et al*., (2005) observed peach plants acclimate by progressively reducing transpiration rate as the severity of water-stress increased.

There was no significant ($P>0.05$) effect of irrigation on leaf temperature (Table 1). Nevertheless, the trend was that plants receiving 2.5 L and 5.0 L had slightly higher leaf temperatures than those receiving 10 L and 20 L, probably because the latter had higher rates of transpiration that normally brings about evaporative cooling (Faust, 1989). Grant *et al*., (2007) demonstrated that leaf temperatures increase during the day as a function of increasing water deficit.

The effect of irrigation on stomatal conductance was significant ($P<0.05$). Stomatal conductance increased with increase in irrigation rate, making the 20 L have the highest conductance (Table 1). This result was possibly caused by opening of stomata by plants during transpiration. When plants go through a period of water stress, abscissic acid (ABA) biosynthesis increases in roots and is translocated to shoots where it influences water conductivity (Cornish and Zeevaart, 1985) by triggering stomatal closure (Parry *et al*., 1992; Gomes *et* *al*., 1997). Increase in ABA content in plants, especially in roots, can be related to soil water content (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 1). However, the trend was that 20 L had negative net photosynthesis probably due to excessive vegetative growth, which resulted in shading and development of high sink strength, and also waterlogging effects. On the other hand, the 2.5 L had low net photosynthesis probably due to photo-respiration occasioned by high leaf temperatures, low water availability and low transpiration (Osmond, 1994). This result was similar to that of orange trees (Idso *et al*., 1995).

The effect of irrigation on intercellular CO_2 was not significant (P>0.05). However, the trend was that the intercellular CO_2 decreased with increase in irrigation level. The 2.5 L irrigation rate had 702.9 CO_2 microbars, while the 20 L irrigation rate had 466.6 CO_2 microbars. The increase was attributed to closure of stomata under the deficit irrigation, whereas the decrease was attributed to assimilation into dry matter.

Irrigation had a significant (P<0.05) effect on chlorophyll content of passion fruit leaves. Chlorophyll content was highest and least for the 2.5 L and 20 L, respectively (Table 1). The chlorophyll content decreased with increase in irrigation rate, suggesting dilution effect, also observed by Mensah *et al*., (2006) in Sesame.

TABLE 1. Effect of irrigation on passion fruit physiological processes

Irrigation (L/plant)	Transpiration (millimol m^{-2})	Leaf temperature (^oC)	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[c]	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 a column are not significantly (NS) different at *P*=0.05, according to Tukey's HSD test.

Effects of Mulch on Passion Fruit Physiology

Mulch did not significantly (P>0.05) affect transpiration, although the trend was that both black plastic and wheat straw mulch had the highest transpiration rate of 7.44 millimolm^{-2} (Table 2). This result was attributed to conservation of moisture by the mulches, enabling the plants to lose the excess to the atmosphere through transpiration. Non-mulched plants transpired less, indicating that the plants acclimated to withstand drought stress through closure of stomata.

The effect of mulch on leaf temperature was not significant (P>0.05), although the trend was that both black plastic and wheat straw mulches had the least leaf temperatures (Table 2). Both mulches probably conserved moisture which was transpired by the plants, resulting in cooling and lowering of leaf temperatures. Abu-Awwad (1999) observed that at low water level, transpiration of onion in covered soil surface was significantly higher than that in open soil surface. With the decrease in soil water, actual transpiration in open surface decreased, and with further extraction of soil water, unsaturated hydraulic conductivity decreased, causing reduction in transpiration.

TABLE 2. Effect of mulch on passion fruit physiological processes

Mulch type	Transpiration (millimol m^{-2})	Leaf temperature (^oC)	Stomatal conductance (mol $m^{-2}s^{-1}$)	Net photosynthesis (µmol $m^{-2}s^{-1}$)	Intercellular CO (microbars)	Chlorophyll content index (%)
Black plastic	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

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

Stomatal conductance was not significantly (P>0.05) affected by mulch, although the trend was that both black plastic and wheat straw mulches had the highest conductance of 0.14 mol $m^{-2}s^{-1}$ (Table 2). This result was attributed to more moisture conservation, which was transpired by the plants (Al-Masoum *et al*., 1998).

Mulch had a significant (P<0.05) effect on net photosynthesis (Table 2). Both black plastic and wheat straw mulches had negative net photosynthetic values. Mulched plants had too many leaves that probably shaded each other and became sinks, thereby reducing net photosynthesis.

The effect of mulch on intercellular CO_2 was significant (P<0.05) (Table 2). The intercellular CO_2 concentration was very high for no mulch (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 2). This result was possibly because with no mulch, CO_2 was not being fixed due to shortage of water in plant cells, and hence CO_2 just accumulated in leaf cells. In addition, closed stomata for non-mulched plants were probably locking up photo-respired CO_2 inside plant cells (Osmond, 1994; Idso *et al*., 1995).

Mulch had no significant (P>0.05) effect on chlorophyll content, although the trend was that plants for both black plastic and wheat straw mulches had lower chlorophyll content indices in comparison to no mulch (Table 2).

The low chlorophyll content suggested dilution by water conserved under the two mulch types and taken up by their plants" (Table 2). The passion fruit results are similar to those of sesame (Mensah *et al*., 2006) under drought stress.

Effect of Interaction between Irrigation and Mulch on Passion Fruit Plant Physiology

The effect of interaction between irrigation and mulch on stomatal conductance was significant (P=0.068) (Table 3). Treatments receiving high amount of water alone had high stomatal conductance, implying that the high amount of water compensated for not mulching and kept stomata open. Mulch alone on the other hand could not compensate for deficit irrigation and kept stomata closed or conducting at a lower rate.

TABLE 3. Effect of irrigation and mulch on passion fruit stomatal conductance

Treatment	Stomatal conductance (mol $m^{-2}s^{-1}$)
20 L, Black plastic	0.160[a]
10 L, Wheat straw	0.155[ab]
10 L, Black plastic	0.143[ab]
20 L, No mulch	0.138[ab]
20 L, Wheat straw	0.138[ab]
5.0 L, Wheat straw	0.135[ab]
5.0 L, No mulch	0.135[ab]
10 L, No mulch	0.128[ab]
2.5 L, Black plastic	0.125[b]
5.0 L, Black plastic	0.125[b]
2.5 L, Black plastic	0.123[b]
2.5 L, No mulch	0.123[b]
SED	0.00997
P-Value	0.068

Means followed by the same letter are not significantly different

TABLE 4. Effect of irrigation on passion fruit water use efficiency and source/sink ratio

	Response attribute			
Irrigation (L/plant)	Water use efficiency (fruits/L)	Water use efficiency (g/L)	Source/Sink ratio (cm^2/fruits)	Source/Sink ratio (cm^2/g)
2.5	1.43[a]	36[a]	46.2[b]	29.0[c]
5	0.73[b]	19[b]	48.6[ab]	30.5[b]
10	0.36[c]	9[c]	50.5[ab]	31.7[a]
20	0.20[d]	5[c]	51.5[a]	32.4[a]
CV (%)	26.01	30.06	25.74	32.39
$LSD_{0.05}$	0.15	4.33	1.87	1.11

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

Effect of Irrigation on Passion Fruit Water Use Efficiency and Source/Sink Ratio

Effects of irrigation was significant (P<0.05) on WUE for cumulative number and weight of fruits (Table 4). The 2.5 L had the highest WUE, while 20 L had the least. This was possibly because low irrigation rates used little water to support growth of purple passion fruits. The plants receiving 2.5 L tolerated droughty conditions and continued carrying out physiological processes albeit to a limited extent (Isutsa, 2006). The low WUE for 20 L implied that fruit yield did not concomitantly increase at the same rate as the increase in irrigation rate.

The effect of irrigation was significant (P<0.05) on leaf area to fruit yield transformed to natural logarithm (Table 4). The 2.5 L had the lowest leaf area to fruit yield (source to sink) ratio, while the 20 L had the highest (Table 4). Thus the 20 L produced more leaf area per unit fruit yield, thereby sustaining productivity better than the 2.5 L (Isutsa, 2006).

Effect of Mulch on Passion Fruit Water Use Efficiency and Source/Sink Ratio

The WUE for cumulative number or weight of passion fruits was not significantly (P>0.05) affected by mulch (Table 5). However, the trend was that black plastic and wheat straw mulches had a slightly higher WUE compared to no mulch. It has been reported that mulching is one of the management practices used to increase WUE by reducing water consumed through evapotranspiration (Gajri *et al*., 1994; Khurshid *et al*., 2006).

Mulch had no significant (P>0.05) effect on leaf area to fruit yield transformed to natural logarithm (Table 5). Nevertheless, the general trend was that black plastic mulch had a slightly higher leaf area to fruit yield (source to sink) ratio compared to wheat straw or no mulch.

TABLE 5. Effect of mulch on passion fruit water use efficiency and source/sink ratio

Type of mulch	Response attribute			
	Water use efficiency (fruits/L)	Water use efficiency (g/L)	Source/Sink ratio (cm^2/fruit)	Source/Sink ratio (cm^2/g)
Black plastic	0.71	18.11	50.0	31.4
Wheat straw	0.69	17.40	48.8	30.7
No mulch	0.64	16.54	48.8	30.5
$LSD_{0.05}$	NS	NS	NS	NS

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

Effect of Interaction on Passion Fruit Source/Sink Ratio

The effect of interaction between irrigation and mulch was significant (P<0.05) on leaf area to fruit yield or source to sink ratio (Table 6). The 20 L and no mulch had the highest source to sink ratio, while the 2.5 L and no mulch had the lowest source to sink ratio. It is only these two treatments that were significantly different. The results implied that applying high amount of irrigation water alone ameliorated drought stress effectively, resulting in high leaf area growth (Isutsa, 2006). Additionally, there was no additional benefit of mulching when applying 5 L to 20 L with regard to source to sink ratio (Isutsa, 2006). Deficit irrigation (2.5 L) alone subjected plants to intense drought stress that depressed leaf area growth. Plants that received 2.5 L tolerated drought stress better when mulched, resulting in growth that was at par with that of plants receiving high amounts of irrigation water alone or with mulch. Thus mulching provided additional benefit when practicing deficit irrigation.

TABLE 6. Interaction of irrigation and much on passion fruit source/sink ratio

Treatment	Source/sink ratio (cm^2/fruit)	Treatment	Source/sink ratio (cm^2/g)
20 L, No mulch	55.73^{a}	20 L, No mulch	34.80^{a}
10 L, Black plastic	53.40^{ab}	10 L, Black plastic	33.50^{ab}
20 L, Black plastic	50.53^{ab}	20 L, Black plastic	31.81^{ab}
5.0 L, Black plastic	50.27^{ab}	5.0 L, Black plastic	31.72^{ab}
10 L, No mulch	49.35^{ab}	10 L, No mulch	30.89^{ab}
2.5 L, Wheat straw	49.20^{ab}	2.5 L, Wheat straw	30.82^{ab}
10 L, Wheat straw	48.79^{ab}	5.0 L, Wheat straw	30.71^{ab}
5.0 L, Wheat straw	48.76^{ab}	10 L, Wheat straw	30.70^{ab}
20 L, Wheat straw	48.39^{ab}	20 L, Wheat straw	30.61^{ab}
5.0 L, No mulch	46.64^{ab}	5.0 L, No mulch	28.94^{ab}
2.5 L, Black plastic	45.76^{ab}	2.5 L, Black plastic	28.74^{ab}
2.5 L, No mulch	43.68^{b}	2.5 L, No mulch	27.31^{b}
SED	3.240	SED	1.920
P-value	0.109	P-value	0.088

Means followed by the same letter within a column are not significantly different, according to Tukey's HSD test

CONCLUSION AND RECOMMENDATIONS

Plants receiving high amount of irrigation water exhibit significantly high stomatal conductance, while those receiving low amount of irrigation water develop high chlorophyll content. Purple passion fruit plants lower stomatal conductance as a means of reducing transpiration in order to cope with drought stress. The WUE and source/sink ratio of purple passion fruits are significantly affected by irrigation. With increase in irrigation rate, the WUE decreases, while the source to sink ratio increases. The differences are significant for the 20 L and 2.5 L irrigation rates, meaning that 2.5 L to 10 L are equally economical in use of water to produce passion fruits, while

5 L to 20 L are equally effective in ameliorating drought stress so as to increase leaf area.

Black plastic and wheat straw mulches significantly reduce intercellular CO_2 and net photosynthesis by conserving more water. Leaf temperature and intercellular CO_2 are highest when passion fruit plants are not mulched. This result is possibly due to closure of stomata during photo-respiration as a copping strategy for drought stress. Mulch does not significantly affect the water use efficiency of purple passion fruits. However, mulched plants have higher water use efficiencies than non-mulched plants. Treatments without mulch consume a lot of water through evaporative loss, thereby subjecting plants to drought stress that in turn depresses yields. The end result of the ratio between depressed yields and high amount of water lost is low water use efficiency.

Treatments that receive high amount of water alone exhibit high stomatal conductance, implying that the high amount of water is able to compensate for not mulching. Mulch alone on the other hand keeps stomata closed or conducting at a lower rate. Applying high amount of irrigation water alone ameliorates drought stress effectively, resulting in high leaf area per unit of fruit produced. There is no additional benefit of mulching when applying 5 L to 20 L of water. Applying little irrigation water alone subjects plants to intense drought stress that depresses leaf area production. Plants that receive 2.5 L of water tolerate drought stress better when mulched, implying that mulch provides additional benefits. Since irrigation rate significantly influences the most important physiological processes (source to sink ratio) of purple passion fruit, it should be given first priority over mulch in mitigating drought stress in the passion fruit plants.

REFERENCES

Abu-Awwad, A. M. (1999) Irrigation wáter management for efficient water use in mulched onions. *J. Agr. Crop Sci.* **183**, 1-7.

Ahmed, M., M. DeJong, T. Cao and K. Shackel (2005) Water stress and crop load effects on vegetative and fruit growth of 'Elegant Lady' peach trees. *Fruits* **60**, 55-68.

Al-Masoum, A. A., A. A. Hashim and K. Jafer (1998) Effect of two mulch types for solarization on soil temperature. *Agri. Mechanization in Asia, Africa and America* **29**: 73-75.

Cornic, G. (1994) Drought stress and high light effects on leaf photosynthesis, In: *Photo-inhibition of Photosynthesis: From Molecular Mechanisms to the Field*. N. R. Baker and J. R. Bowyer (Eds.), pp. 297-313. Oxford, BIOS Scientific.

Cornish, K. and J. A. D. Zeevaart (1985) Abscisic acid accumulation by roots of *Xanthium strumarium* L. and *Lycopersicon esculentum* Mill. in relation to water stress. *Plant Physiol.* **79**, 653-658.

Doneen, L. D. and D. W. Westcot (1988) Irrigation practice and water management. Irrigation and Drainage Paper No. 1, Rome, FAO.

Doorenbos, J. and A. H. Kassam (1994) Efeito da água no rendimento das culturas. Campina Grande: UFPB, 306 pp.

Faust, M. (1989) *Physiology of Deciduous Fruit Trees*. Wiley-Interscience, New York, USA.

Gachanja, S. P. and P. O. Ochieng (2004) Effect of row spacing of purple passion fruit (*Passiflora edulis* Sims.) on fruit yield in Kenya. *Acta Hortic.* **218**, 23-28.

Gajri, P. R., V. K. Arora and M. R. Chaudhary (1994) Maize growth, response to deep tillage, straw mulching and farmyard manure in coarse textured soils of N. W. India. *Soil Use Manag*. **10**, 15–20.

Gomes, M., A. Lagôa, E. Machado and E. Furlanix (1997) Gas exchange and abscisic acid quantification in two upland rice cultivars subjected to water deficiency. *Braz. J. Plant Physiol.* **9**, 177-183.

Gomes, M., A. Lagôa, E. Machado and C. Medina (2003) Abscissic acid and indole-3-acetic acid contents in orange trees infected by *Xylella fastidiosa* and subjected to cycles of water stress. *Plant Growth Regul.* 39:263-270.

Grant, O. M., L. Tronina, H. G. Jones and M. M. Chaves (2007) Exploring thermal imaging variables for the detection of stress responses in grapevine under different irrigation regimes. *J. Exp. Bot.* **58**, 815-825.

Isutsa, D. K. (2006) Performance of micro-propagated and conventional passion fruit (*Passiflora edulis* Sims.) varieties in three contrasting agro-ecological zones. *Eger. J.: Sci. Technol. Series* **6**, 87-102.

Jaetzold, R. and H. Schmidt. (1983) Farm Management Handbook of Kenya. Natural Conditions and Farm Management Information. Ministry of Agriculture and the German Agricultural Team of the German Agency for Technical Cooperation, Rossdorf, W. Germany.

Khurshid, K., M. Iqbal, M. S. Arif and A. Nawaz (2006) Effect of tillage and mulch on soil physical properties and growth of maize. *Int. J. Agric. Biol.* **5**, 593-596.

Lawlor, D. (1995) Effects of water deficit on photosynthesis. In: *Environment and Plant Metabolism: Flexibility and Acclimation*. N. Smirnoff (Ed.), pp. 129-160. Oxford, BIOS Scientific.

Mensah, J. K., B. O. Obadoni, P. G. Eroutor and F. Onome-Irieguna (2006) Simulated flooding and drought effects on germination, growth, and yield parameters of Sesame (*Sesamum indicum* L.). *Afr. J. Biotechnol.* **5**, 1249-1253.

Morton, J. (1987) Passion fruit. In: J. F. Morton (Ed.). *Fruits of Warm Climates*, pp. 320–328. Miami, Florida, USA.

Nakasone, H. Y. and R. E. Paull (1998) Tropical fruits: Crop Production Science in Horticulture Series. CAB International, Wallingford.

Osmond, C. B. (1994) What is photo-inhibition? Some insights from comparisons of shade and sun plants. In: *Photo-inhibition of Photosynthesis: From Molecular Mechanisms to the Fields*. N. Baker and J. Bowyer (Eds.), pp. 1-24. Oxford, BIOS Scientific.

Osmond, C. B., K. Winter and S. B. Powles. (1980) Adaptive significance of carbon dioxide cycling during photosynthesis in water-stressed plants. In: *Adaptation of Plants to Water and High Temperature Stress*. N. C. Turner, P. J. Kramer, (Eds.), pp. 139-154. New York, John Wiley and Sons.

Parry, A.D., A. Griffiths and R. Horgan (1992) Abscisic acid biosynthesis in roots: The effects of water stress in wild type and abscissic acid deficient mutant (notabilis) plants of *Lycopersicon esculentum Mill. Planta* **187**, 192-197.

Sousa, F. D. V., J. A. Frizzone and M. V. Folegatti (2005) Water use efficiency of the yellow passion fruit under different irrigation levels and potassium doses. *Rev. Bras. Eng. Agríc. Ambient* **9**, 302-306.

Torsten, U., U. Bettina and J. M. MacDougal (2004) Passion flowers of the world. Timber Press, Portland. Cambridge.