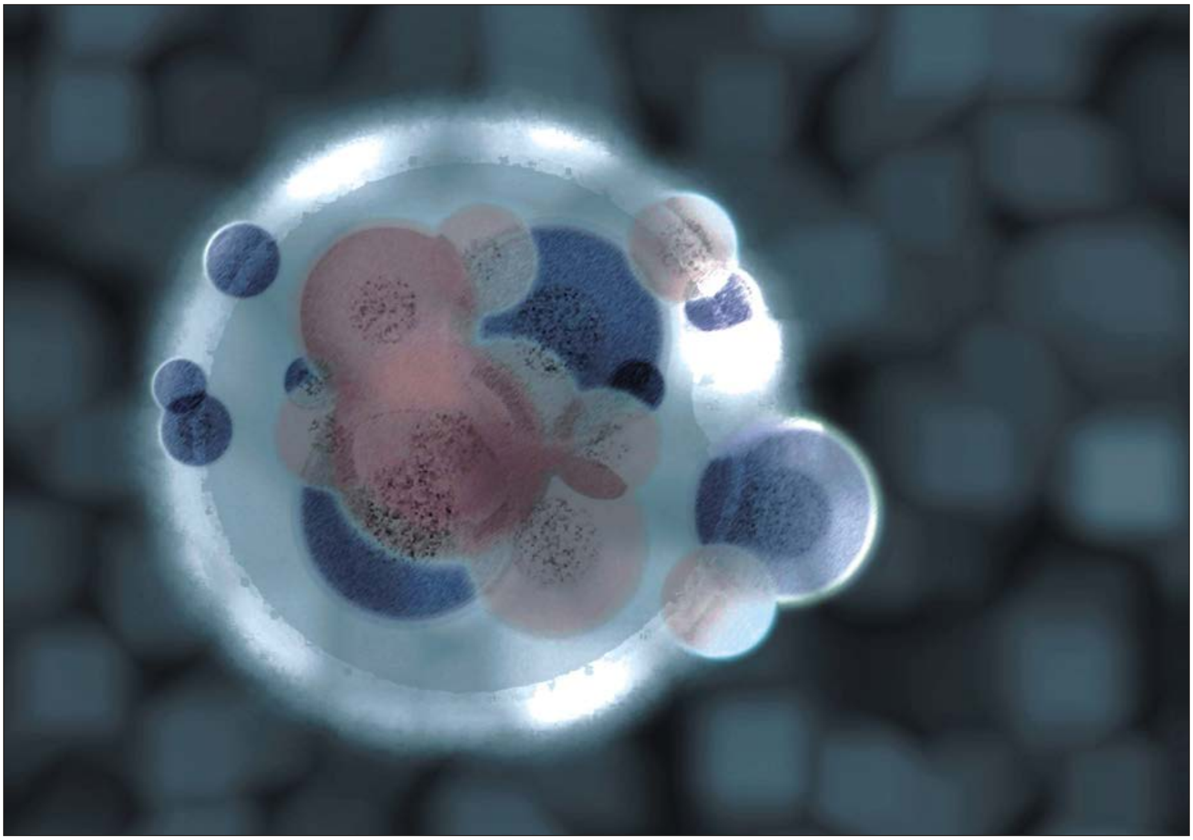

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Morphological and Physiological Parameters of Avocado (*Persea americana*) Rootstock Seedlings as Affected by Different Container Sizes and Different Levels of Irrigation Frequency

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Abstract: Studies were conducted at Maseno University, Kenya from July 2003 to March 2005 to investigate the effect of four container sizes; V_1 (1.7 L), V_2 (2.7 L), V_3 (3.9 L), V_4 (4.7 L) and three irrigation frequency levels namely W_1 (irrigating every day), W_2 (irrigation every 2 days, W_3 (irrigation every 3 days in a polythene-covered greenhouse on the morphological and physiological parameters of Avocado (*P. americana*) rootstock seedlings. The experimental design was completely randomized replicated four times. Morphological and physiological parameters were determined using standard methods and they were number of leaves, plant height, stem diameter, shoot and root dry and fresh weights, whole plant dry and fresh weight, CO_2 assimilation rate substomatal CO_2 concentration, soil respiration, transpiration rate and stomatal conductance Both irrigation frequency and container size significantly increased these parameters and the interaction between them was either significant or not depending on the parameter.

Key words: Irrigation, morphological, physiological, stomatal conductance, assimilation, container size

INTRODUCTION

The avocado (*P. americana*) is one of the tropical fruits grown in Kenya for local consumption and export. Kenya is one of the major countries producing avocado in Africa. The area under avocado is increasing in Kenya but there are not enough avocado seedlings to satisfy the local demand for them. The productivity of the Kenyan fruit tree nurseries is low because they do not use the correct nursery practices for fruit tree nursery production such as appropriate planting pot sizes.

Commercial nursery producers are usually faced with two options during tree seedling production. The first option is upcanning in this process, young seedlings are planted into smaller containers and later repotted. The process is labour intensive. However, the plant canopy shades the size-appropriate container and reduces heat in the growth medium and crop failure (Beeson, 1991). The second option, used in Kenya is the use of one container size until the first seedling is ready for planting.

Increased container size increases canopy growth; Keever and Cobb (1987). In pears (*Pyrus calleryana*), peach (*Carya illinoensis*), Japanese eounymous *Eounymymus japanica* Thumb) and other plant species, respectively. Conversely, growing seedlings in small containers cause root restriction, which in turn reduces canopy growth; (Tschaplinski and Blake, 1995), plant growth expressed as shoot length, fresh weight, dry weight accumulation and leaf area (Vizzotto *et al*., 1993). Small containers allow less expansion and caliper development of plants, reduce the number of secondary shoots and total length of all shoots (Alvarez and Caula, 1993), reduce CO_2 assimilation rate and leaf conductance (Rieger and Marra, 1993), reduce leaf nutrient levels, except N (Rieger and Marra, 1993) and reduce dry weights of roots, stems, leaves and fruit (Bar-Tal and Pressman, 1996). Root restriction reduces dry matter production but it does not cause nutrient deficiency (Peterson and Krizeki, 1992) However, Bar Tal *et al.* (1995) reported that root restriction reduces both dry matter production and K concentrations, including roots.

Still, there has been no study conducted on the effect of different degrees of root confinement reflected in different container sizes on the growth of young avocado (*P. americana*) rootstock seedlings, which is predominantly raised by the Kenyan fruit nurseries.

There are two main problems facing the avocado tree seedling nursery production in Kenya namely use of inappropriate nursery container sizes and irrigation regimes. This has caused low production of seedlings. Further, the following methodologies will be carried out as an improvement of the previous studies on this area, namely non-destructive determination of the morphological parameters, determination of physiological parameters such as substomatal CO_2 and soil respiration, use of local substrate but not commercially prepared substrates which are used by nursery owners in Kenya because of their cost and availability and use of a porometer which can simultaneously determine all the gas exchange parameters.

The hypotheses of the study were that infrequent irrigation reduces growth of avocado seedlings, and use of smaller containers reduce the growth of avocado seedlings. The objectives were to investigate the effect of different container sizes on CO_2 assimilation rate, transpiration rate, substomatal CO_2 concentration and stomatal conductance of avocado rootstock seedlings, to investigate the effect of different container sizes on plant height., stem diameter, shoot and root dry weights, whole plant dry weight and number of leaves, to investigate effect of different irrigation frequencies on CO_2 assimilation rate, transpiration rate, substomatal CO_2 concentration and stomatal conductance of avocado rootstock seedlings, plant height, canopy height, stem diameter, shoot and root dry weights, whole plant dry weight and number of leaves.

MATERIALS AND METHODS

Location of research site: The study was conducted at the Maseno University, nurseries in Maseno, Kenya. The nurseries are located at an altitude of 1515 m above sea level and at a longitude of 34 and 36° East and a latitude of 0°. The soils comprise a complex of somewhat excessively drained, shallow, stony and rocky soils of varying colour, consistence and texture (dystric regosols with ferralic cambisols, lithic phase and rock outcrops. The soils are acidic with high extractable Ca and K contents. Soil organic carbon and phosphorus content are 1.8% and 4 mg kg^{-1}, respectively. The pH of the soil ranges between 4.5 and 5.4 (Netondo, 1999). The soils have a water holding capacity of 40%. The area receives a fairly well distributed annual rainfall of 1853 mm. The studies were conducted in a plastic green house measuring 20×10 m in length and width and 30 m in height. The maximum and minimum temperatures in the structure were 26±4 and 35±5°C, respectively with a relative humidity of 60±5%.

Preparation of experimental materials and methods: Overripe avocado (*Persea americana*) var Fuerte fruits were collected from a market in Kisumu City, 20 km away on January 20th, 2003 and transported to Maseno University and stored overnight in a refrigerator at 5°C. To eliminate infection from avocado rot (*Phytophthora cinamomi*), the seeds were extracted on January 21st, 2003 and then immersed in hot water at 49 to 50°C for 30 min before planting.

The seeds were then sown in well prepared nursery beds dug to fine tilth to which was added Farm Yard manure and Diammonium Phosphate fertilizer (i.e., inorganic fertilizer). The bed was watered daily at 08:00 and 18:00 h using watering cans. After germination, the seedlings were left in the nursery beds for three months then transplanted into four different container sizes of (V_1) 1.7 L, (V_2) 2. 7 L, (V_3) 3.9 L, (V_4) 4.7 L according to the treatments. After transplanting, standard practices of weeding, irrigation, fertilization and pest and disease control were followed (Rice *et al*., 1987).

The experiment was set up in a Completely Randomized Design (CRD) comprising 4 treatments of container size namely, V1(1.7 L), V2 (2.7 L), V3 (3.9 L), V4 (4.7 L) and 3 irrigation frequencies: W_1 (irrigating everyday, W_2 (irrigating every 2 days) and W_3 (irrigating every 3 days). The treatments were replicated four times.

Measurements of parameters: This was carried out for a period of 9 months, after which the seedlings were ready for grafting. The studies were conducted between July 2003 and May 2004. Both morphological and physiological parameters were determined. The morphological parameters determined were number of leaves, plant height, stem diameter, shoot and root dry weights and whole plant dry weights. The physiological parameters determined were CO_2 assimilation rate, transpiration rate, stomatal conductance, substomatal CO_2 concentration and soil respiration.

Morphological parameters: Plant height was measured from the base of the stem to the shoot apex using a metre ruler every 4 weeks. All the fully expanded leaves, on each of the mango rootstock seedlings were counted and recorded every four weeks to determine the number of leaves. The diameter of each seedling was measured by a veneer caliper at a distance of 10 cm from the base of the stem every four weeks at a resolution of 1 to 100 cm.

Determination of the plant dry weight involved destructive measurements. The plants were carefully uprooted after loosening the soil and rinsed under tap water. Care was taken to ensure that all the root masses sticking to the soil were removed by soaking the roots in water and sieving out all the root segments. The plants were sorted out into shoots, roots and leaves, dried in an oven at 70°C for 48 h and then weighed. The weight was obtained by using an electronic weighing balance (Denver Instrument Model XL-3100). The measurements were carried out at the expiry of the experiment.

Physiological parameters: Soil respiration was determined on the plastic pots after removing the plants at a soil depth of 5 cm using a portable respiration system type SRS (PP Systems, Hitchin, UK) with no soil temperature probe. It reflected the degree of microbial activity.

Gas exchange measurements were taken on the most recent, fully expanded and well-exposed healthy leaves under bright sunlight. Leaves measured were in position 2 to 5, leaf position being the most recently emerged leaf. An open Infrared gas analyzer (IRGA) Porometer model (CIRAS) (PP systems, Stortfied, Hitchin, Herts, UK) was used. The stem was connected to a cuvette with a Parkinson leaf chamber whose area was 2 cm^2. The intact leaf lamina was sealed in the leaf chamber and all the major veins were avoided. The boundary layer resistance was 0.2 $m^{-2}sec^{-1}$ while the flow rate was maintained at 200 mL min^{-1}. The IRGA equipment determined simultaneously net CO_2 assimilation rate, substomatal CO_2 concentration, stomatal conductance and transpiration rate. The data was stored in the data logger in the equipment and analyzed statistically. Measurements were taken on attached leaves and three readings were taken from each leaf for all the four replications and two leaves were taken per plant. Data obtained was subjected to Analysis of variance (ANOVA) and means separation done by Least significant Differences (LSD) using the Statistical Analysis (SAS) Package.

RESULTS

Irrigation frequency significantly ($p \leq 0.05$) increased canopy heights of avocado seedlings. There were taller canopies at more frequent irrigation intervals (W_1) than less frequent ones (W_2) and (W_3) (Table 1). There were also taller canopies in larger containers (V_4, V_3) than smaller ones (V_2 and V_1). In contrast, stem diameter was only increased by irrigation frequency but not container size. The interaction between container size and irrigation frequency was significant for canopy height but not stem diameter. There were heavier shoot and root fresh weights at more frequent irrigation (W_1) intervals than less frequent ones (W_2, W_3). Similar trends were obtained with container sizes where larger container sizes (V_4, V_3) had lower fresh weights than smaller ones (V_2, V_1) (Table 2). The interaction between container size and irrigation frequency was significant ($p \leq 0.05$) and there were far heavier fresh weights under more frequent irrigation (W_1) and in larger containers (V_4, V_3) than smaller containers (V_2, V_1). Shoot dry weights had similar trends and both container size and irrigation frequency increased them (Table 3). Root dry weight and whole plant dry weight were similarly increased by container size and irrigation frequency. There were heavier root and whole plant dry weights as container size and irrigation frequency increased. The magnitude of these increases were more at higher irrigation frequencies and larger containers showing an interaction between container size and irrigation frequency (Table 3).

Plant height was only significantly ($p \leq 0.05$) increased by container size from the first second and fourth and seventh month after transplanting. In contrast irrigation frequency significantly ($p \leq 0.05$) increased plant heights at all sampling dates. Plant heights were taller in larger containers than smaller ones from the second to fourth

Table 1: Effect of container size and irrigation frequency on the canopy height and stem diameter of avocado (*P. americana*) rootstock seedlings grown at Maseno, Kenya

Treatments	Irrigation frequency[1]	Canopy height (cm)	Stem diameter (cm)
Container size (L)			
V_1 (1.7 L)	W_1	25.2	0.7
	W_2	22.2	0.7
	W_3	17.0	0.6
V_2 (2.7 L)	W_1	25.7	1.0
	W_2	24.6	0.9
	W_3	23.1	0.8
V_3 (3.9 L)	W_1	49.6	1.1
	W_2	43.6	0.6
	W_3	41.1	0.7
V_4 (4.7 L)	W_1	59.9	1.3
	W_2	41.2	1.1
	W_3	35.0	0.9
Statistical parameter			
LSD[2] between irrigation frequency means		16.7	19.7
LSD[2] between container sizes		14.4	15.1
LSD[2] between container size×Irrigation		10.1	17.3
Significance of F tests[3] for irrigation		Significant	Not significant
Significance of F tests[3] for container size		Significant	Significant
Significance of F tests[3] for container size ×Irrigation frequency		Significant	Not significant

[1]W_1, Every day; W_2, Every 2 day; W_3, Every 3 days, [2]LSD at $p \leq 0.05$, [3]F-test at $p \leq 0.05$

Table 2: Effect of different container sizes and irrigation frequency on the shoot fresh weight, root fresh weight and whole plant fresh weight of avocado (*P. americana*) rootstock seedlings grown at Maseno Kenya

Treatments	Irrigation frequency	Shoot fresh weight (g)	Root fresh weight (g)	Whole plant fresh weight (g)
Container size (L)				
V_1 (1.7 L)	W_1	38.6	29.6	74.7
	W_2	37.1	27.3	65.5
	W_3	35.5	20.6	62.2
V_2 (2.7 L)	W_1	36.8	41.2	120.6
	W_2	32.4	39.3	89.6
	W_3	30.6	36.6	72.1
V_3 (3.9 L)	W_1	43.0	120.2	78.6
	W_2	42.0	115.1	130.5
	W_3	40.0	110.2	120.6
V_4 (4.7 L)	W_1	120.6	124.6	240.2
	W_2	90.6	107.2	220.6
	W_3	60.8	116.1	210.1
Statistical parameter				
LSD[2] between irrigation frequency means		11.6	25.5	32.6
LSD[2] between container sizes		15.4	19.6	33.4
LSD[2] between container size×Irrigation		20.9	26.2	39.9
Significance of F tests[3] for irrigation		Significant	Significant	Significant
Significance of F tests[3] for container size		Significant	Significant	Significant
Significance of F tests[3] for container size ×Irrigation frequency		Significant	Significant	Significant

[1]W_1, Every day; W_2, Every 2 day; W_3, Every 3 days, [2]LSD at $p \le 0.05$, [3]F-test at $p \le 0.05$

Table 3: Effect of different container sizes and irrigation frequency on the shoot dry weight, root dry weight and whole plant dry weight of avocado (*P. americana*) rootstock seedlings grown at Maseno, Kenya

Treatments	Irrigation frequency[1]	Shoot dry weight (g)	Root dry weight (g)	Whole plant dry weight (g)
Container size (L)				
V_1 (1.7 L)	W_1	27.3	20.6	76.9
	W_2	5.2	18.9	24.9
	W_3	4.5	18.3	21.2
V_2 (2.7 L)	W_1	32.6	36.3	41.5
	W_2	18.2	26.9	40.6
	W_3	15.5	20.4	41.5
V_3 (3.9 L)	W_1	90.7	66.2	120.6
	W_2	40.2	56.5	110.2
	W_3	40.0	42.4	100.1
V_4 (4.7 L)	W_1	65.6	130.1	120.5
	W_2	55.2	120.6	122.5
	W_3	52.1	100.3	140.2
Statistical parameter				
LSD[2] between irrigation frequency means		11.2		
LSD[2] between container sizes		12.6		
LSD[2] between container size×Irrigation		14.3		
Significance of F-tests[3] for irrigation		Significant	Significant	Significant
Significance of F-tests[3] for container size		Significant	Significant	Significant
Significance of F-tests[3] for container size × Irrigation frequency		Significant	Significant	Significant

[1]W_1, Every day; W_2, Every 2 day;: W_3, Every 3 days, [2]LSD at $p \le 0.05$,[3]F-test at $p \le 0.05$

month after transplanting. Similarly, more frequent irrigation intervals (W_1) had taller plants than less frequent ones (W_2 and W), at all the sampling dates (Table 4).

Container size did not significantly ($p \le 0.05$) affect the number of leaves from months 3 to month 6 after transplanting but increased it month 1 and month 2 after transplanting (Table 5) Conversely, irrigation frequency increased it at all sampling dates (Table 5).

The physiological parameters were generally significantly ($p \le 0.05$) affected by container size and irrigation frequency. Container size significantly ($p \le 0.05$) increased the CO_2 assimilation rate in months 2 and 3 after transplanting. Stomatal conductance was similarly increased by container size month 2 and 3 after transplanting (Table 6). In larger container sizes there were higher CO_2 assimilation rates and stomatal conductance and vice versa. However, transpiration rate was only increased in month 2 after transplanting. In contrast, substomatal CO_2 concentration was unaffected by container size and irrigation frequency. There were significantly ($p \le 0.05$) higher values of stomatal conductance, net CO_2 assimilation rate and transpiration rates in larger containers than smaller ones during the months in which it affected them. In contrast, irrigation frequency increased CO_2 assimilation rate, stomatal

Table 4: Effect of different container sizes and irrigation frequency on plant height (cm) of avocado (*P. americana*) rootstock seedlings grown at Maseno, Kenya

		Months after transplanting						
Treatments	Irrigation frequency[1]	1	2	3	4	5	6	7
Container size (L)								
V_1 (1.7 L)	W_1	57.4	65.6	72.2	75.3	76.4	80.0	85.0
	W_2	42.6	46.2	54.1	64.2	66.2	72.3	75.0
	W_3	40.2	37.1	42.3	56.6	58.1	64.2	67.2
V_2 (2.7 L)	W_1	57.0	65.3	69.7	75.5	78.4	79.4	66.3
	W_2	35.9	45.2	53.4	54.2	56.2	60.1	62.4
	W_3	38.6	42.6	47.2	49.1	54.3	67.3	63.3
V_3 (3.9 L)	W_1	72.6	75.1	79.2	80.5	82.3	84.4	86.1
	W_2	47.0	56.2	62.2	65.3	70.3	72.4	76.2
	W_3	37.4	42.3	45.1	46.6	56.7	66.4	66.2
V_4 (4.7 L)	W_1	42.3	54.6	57.3	60.2	63.1	65.8	67.4
	W_2	46.2	49.4	52.2	54.0	56.0	58.0	59.0
	W_3	42.9	43.2	54.1	53.0	51.0	54.0	55.0
Statistical parameter								
LSD[2] between irrigation frequency means		10.0	12.6	17.7	19.8	20.2	22.0	17.2
LSD[2] between container sizes		15.7	22.2	25.5	35.5	19.7	22.6	17.9
LSD[2] between container size × Irrigation frequency		16.2	21.4	26.6	29.8	32.4	15.2	11.3
Significance of F-tests[3] for irrigation		Significant	NS	NS	NS	Significant	Significant	Significant
Significance of F-tests[3] for container size		Significant	Significant	Significant	Significant	Significant	Significant	
Significance of F-tests[3] for container		n Significant	NS	NS	NS	Significant	Significant	

[1]W_1, Every day; W_2, Every 2 day; W_3, Every 3 days, [2]LSD at $p \le 0.05$, [3]F-test at $p \le 0.05$, NS = Not Significant at $p \le 0.05$

Table 5: Effect of different container sizes and irrigation frequency on the number of leaves of avocado (*P. americana*) rootstock seedlings grown at Maseno, Kenya

		Months after transplanting					
Treatment	Irrigation frequency[1]	1	2	3	4	5	6
Container size (L)							
V_1 (1.7 L)	W_1	18.2	23.7	24.7	37.4	46.0	51.2
	W_2	16.5	17.2	17.2	25.3	37.3	44.6
	W_3	14.6	15.4	15.3	19.2	30.2	35.5
V_2 (2.7 L)	W_1	25.5	21.7	38.5	44.2	50.4	57.4
	W_2	22.3	14.8	35.5	37.4	32.6	36.3
	W_3	20.1	16.3	32.1	34.3	35.1	40.4
V_3 (3.9 L)	W_1	26.5	29.3	49.0	58.0	66.0	68.0
	W_2	24.1	27.4	44.1	55.1	59.2	65.4
	W_3	23.2	26.2	42.6	40.1	46.3	42.2
V_4 (4.7 L)	W_1	25.3	39.3	59.6	66.2	77.2	79.1
	W_2	24.5	26.3	52.0	53.6	60.2	60.9
	W_3	23.4	24.3	41.0	37.3	49.1	49.6
Statistical parameter							
LSD[2] between irrigation frequency means		32.2	34.9	39.2	21.4	25.4	29.9
LSD[2] between container sizes means		20.9	22.4	29.6	33.3	23.1	27.7
LSD[2] between container size × Irrigation frequency		7.3	9.9	11.1	15.5	11.6	12.4
Significance of F-tests[3] for irrigation		Significant	Significant	Significant	Significant	Significant	Significant
Significance of F-tests[3] for container size		Significant	Significant	Significant	NS	NS	NS
Significance of F-tests[3] for container size X frequency		Significant	NS	Significant	NS	NS	NS

[1]W_1, Every day; W_2, Every 2 day; W_3, Every 3 days, [2]LSD at $p \le 0.05$, [3]F-test at $p \le 0.05$, NS = Not Significant

Table 6: Effect of different container sizes and irrigation frequency on the physiological parameters of avocado (*P. americana*) rootstock seedlings grown at Maseno, Kenya

		Assimilation rate[4]		Stomatal conductance[4]		Transpiration rate[4]	
Treatments	Irrigation CO_2 frequency[1]	Months 2	Months 3	Months 2	Months 3	Months 2	Soil respirat.[4]
Container volume (L)							
V_1 (1.7 L)	W_1	1.00	0.59	16.9	6.7	0.41	3.2
	W_2	1.23	0.31	13.4	6.2	0.40	3.0
	W_3	0.99	0.20	11.6	6.1	0.35	2.8
V_2 (2.7 L)	W_1	1.29	1.62	17.9	9.1	0.58	4.5
	W_2	1.10	1.30	15.2	7.3	0.35	5.3
	W_3	1.00	1.10	4.3	6.4	0.30	5.1
V_3 (3.9 L)	W_1	2.40	2.90	19.9	13.3	0.91	4.7
	W_2	2.60	7.20	16.4	11.4	0.88	2.6
	W_3	2.50	22.10	20.4	14.5	0.71	8.0
V_4 (4.7 L)	W_1	3.00	26.60	25.2	19.7	0.91	10.1
	W_2	4.20	30.20	30.0	25.5	1.30	12.6
	W_3	5.30	32.00	34.1	31.1	1.50	13.4

Table 6: Continued

Statistical parameter						
LSD[2] between irrigation frequency means	1.1	0.5	2.2	3.4	3.1	2.3
LSD[2] between container sizes	2.1	3.2	1.5	2.2	4.1	3.0
LSD[2] between container size × Irrigation	2.4	1.7	1.7	2.6	3.4	1.3
Significance of F-tests[3] for irrigation	Significant	Significant	Significant	Significant	Significant	Significant
Significance of F-tests[3] for container size	Significant	Significant	Significant	Significant	Significant	Significant
Significance of F-tests[3] for container	Significant	Significant	Significant	Significant	Significant	Significant

[1]W_1, Every day; W_2, Every 2 day; W_3, Every 3 days, [2]LSD at $p \leq 0.05$, [3]F-test at $p \leq 0.05$,
[4](a) Units of CO_2 assimilation rate are umolm^{-2} sec^{-1} (mgCO$_2$m^{-2} sec^{-1})
(b)Units of stomatal conductance are umolm^{-2} sec^{-1}, (c) Units for soil respiration are umolm^{-2}sec^{-1}

conductance, transpiration rate at all the sampling dates. The interaction between the two factors was also significant for these gas exchange parameters at all the sampling dates (Table 6) and the values were far smaller in smaller containers and in less frequent irrigation (W_2, W_3) than larger ones under more frequent irrigation intervals. Soil respiration was significantly ($p \leq 0.05$) increased by container size and irrigation frequency and as the two factors increased soil respiration also increased and vice versa (Table 6).

DISCUSSION

Height of canopy, fresh and dry weights of shoot, root and whole plant were increased by container size. Plant height was not consistently increased by container size and this explains why canopy height was not significantly affected by container size in the present study i.e., the latter was not determined monthly while plant height was measured at the expiry of the experiment in previous studies These increases show that larger containers have a more favourable growth environment for the avocado rootstock seedlings caused by less root restriction which resulted in increased growth rates (Vizzotto *et al*., 1993; Peterson and Krizeki, 1992). Furthermore, larger containers apparently provided for more nutrient uptake, increased hormone synthesis and root metabolism (Peterson and Krizeki, 1992). Further studies are recommended to measure these parameters to confirm these statements. Under such favourable environments existing in large containers there was increased development of primary shoots and total length of the shoots producing taller plants (Alvarez and Caula, 1993). Although container size increased final canopy height it did not consistently increase plant height. Therefore in a follow up study canopy heights should also be determined monthly and not only at the end of the experiment because it is affected by plant heights. In an earlier study on citrus, (*C. sinensis*) rootstock seedlings (Ouma, 2005) container size increased both plant height and height of canopy but in that study the experimental conditions were very different. The number of leaves, of avocado seedlings in the present study was not also consistently increased by container size. This also differs with the results of my previous study on another plant species, (*Citrus sinensis*) (Ouma, 2005). But in that study the final leaf count was determined but not monthly leaf counts as in the present study.

Apart from plant height and number of leaves, the results of the present study agree with (Ouma, 2005; Vizzotto *et al*., 1993). However, container size did not affect the stem diameter in this study disagreeing with the findings of (Ouma, 2005; Vizzotto *et al*., 1993). This is may have been due to the different plant species and different experimental conditions. Irrigation frequency increased plant height, height of canopy, fresh and dry weights of shoots and roots, stem, diameter, number of leaves, fresh and dry weights of whole plants. This is in agreement with Ouma (2005) working on young citrus (*C. sinensis*) rootstock seedlings which are different from avocado and it is apparently due to the participation of water in the early growth processes of cell division and cell enlargement, metabolic activities and as a medium of nutrient uptake (Ouma, 2005; Luvaha, 2005). Water from frequent irrigation regimes seems to have had a more pronounced effect on the growth parameters in larger containers than small containers less frequent irrigations under small containers was apparently very stressful and seriously limiting to plant growth. Under larger containers more water added may have enhanced nutrient uptake and growth processes many-fold. In Kenya where the nursery industry is increasing in prominence and complexity this study is important because the issue of container size is often neglected resulting in disastrous consequences in reduced nursery productivity particularly with respect to the nursery production of avocado rootstocks. However, container size did not affect the stem diameter in this study and this disagrees with Ouma (2005) and Vizzotto *et al*. (1993). This may have been due to the different plant species which have different growth requirements, patterns and adaptabilities.

Irrigation frequency increased plant height, height of canopy, fresh and dry weights of shoots and roots, stem diameter, number of leaves and whole plant dry weights.

This is in agreement with Ouma (2005) working on citrus (*C. sinensis*) rootstock seedlings and it is apparently due to participation of water in the early growth processes of cell division and cell enlargement, metabolic activities and as a medium of nutrient uptake, water from frequent irrigation seems to have had a more pronounced effect on the growth parameters in larger containers but less frequent irrigations under small containers was apparently very stressful.

Physiological parameters: Container size neither affected transpiration rate nor substomatal CO_2 concentration. Further, it only significantly affected stomatal conductance and CO_2 assimilation rates during months 2 and 3 after transplanting and transpiration rate during month 2 after transplanting. The effect on CO_2 assimilation rate for the two months is apparently due to its effect on stomatal conductance over the same period. The small effect on stomatal conductance may be attributed to the fact that the stomatal conductance is strongly affected by growth conditions and changes with leaf age characteristically maximum stomatal conductance does not attain a peak value until several days after leaf emergence (Jones, 1992). The plants in the present study were still too young to have noticeable leaf conductance hence, also the small effect on CO_2 assimilation rates.

Another important factor which may have a profound effect on CO_2 assimilation rate in plants is the substomatal CO_2 concentration which, in the present study was not affected by container size. Therefore, the increases in CO_2 assimilation rate during the two months, without a corresponding decline in substomatal CO_2 concentration could be due to non-stomatal effects on the photosynthetic processes, possibly an increase in the mesophyll resistance (Cornic *et al.*, 1989). A reduction in substomatal CO_2 concentration can be detrimental to the photosynthetic process especially in the presence of the rubisco enzyme. For many species substomatal CO_2 concentration tends to remain constant over a range of environmental conditions (Pearcy, 1981). This may explain the lack of effect of container size on substomatal CO_2 concentration in the present study. Other workers have also reported increase of CO_2 assimilation rates, transpiration rates and stomatal conductance from increased irrigation frequency (Luvaha, 2005).

Soil respiration was significantly ($p \leq 0.05$) increased by container volume and as the volume increased there was a consistent increase of soil respiration and this was apparently less enhanced in small containers and less frequent irrigations showing a significant container size × irrigation frequency interaction. The conditions in the larger containers such as increased soil volume, nutrient uptake, hormone synthesis as discussed else where in this study all appeared to increase soil microbial activities thus increasing soil respiration. These conditions were more enhanced under frequent irrigations. The increase of soil respiration under more frequent irrigation can be attributed to that fact that water enhances nutrient uptake and metabolic activities such as protein or enzyme synthesis which enhance microbial activities hence soil respiration.

CONCLUSION

It can be concluded that Container size significantly increases plant growth when it is increased from 1.7 to 3.9 L through its effect on morphological parameters. Irrigation frequency of (W_1, irrigating everyday) increases morphological and physiological parameters more than irrigating less frequently (W_2 and W_3). Canopy height, stem diameter, transpiration rate and substomatal CO_2 concentration are not significantly affected by container size and irrigation frequency. Both container size and irrigation frequency affect plant growth through their effects on morphological and physiological parameters.

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