ABSTRACT

Studies were conducted at Maseno University, Kenya from July 2003 to March 2005 to investigate the effect of four container sizes; V\textsubscript{1} (1.7 litres), V\textsubscript{2} (2.7 litres), V\textsubscript{3} (3.9 litres), V\textsubscript{4} (4.7 litres) and three irrigation frequency levels namely W\textsubscript{1} (irrigating every day), W\textsubscript{2} (irrigation every 2 days, W\textsubscript{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\textsubscript{2} assimilation rate, substomatal CO\textsubscript{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.

Keywords: avocado, irrigation, morphology, physiology, stomatal conductance, assimilation, container.

1. 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 eunymyous Eounymymus japonica (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\textsubscript{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. Other reports have indicated that root restriction retards plant metabolism by reducing hormone synthesis in the root system (Peterson et al, 1991b).

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\textsubscript{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\textsubscript{2} assimilation rate, transpiration rate, substomatal CO\textsubscript{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 CO₂ assimilation rate, transpiration rate, substomatal CO₂ 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.

2. MATERIALS AND METHODS

2.1. 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 metres above sea level and at a longitude of 34°and 36° East and latitude of 0°. The soils comprise a complex of somewhat excessively drained, shallow, stony and rocky soils of varying colour, consistency and texture (dystric 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, respectively. The pH of the soil ranges between 4.5 and 5.4 (Netondo, 1999). The soils have a water holding capacity of 40 percent. The area receives a fairly well distributed annual rainfall of 1853mm. The studies were conducted in a plastic greenhouse measuring 20m by 10m and a longitude of 34° and 36° East and latitude of 0°. The soils have a water holding capacity of 40 percent. The area receives a fairly well distributed annual rainfall of 1853mm. The studies were conducted in a plastic greenhouse measuring 20m by 10m and 30m 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%.

2.2. Preparation of experimental materials and methods

Overripe avocado (Persea americana) var Fuerte fruits were collected from a market in Kisumu city, 20km 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 cinamomoni), the seeds were extracted on January 21st, 2003 and then immersed in hot water at 49 to 50°C for 30 minutes before planting (Hartman et al., 2001).

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 0800hours and 1800 hours using watering cans. After germination, the seedlings were left in the nursery beds for three months then transplanted into four different container sizes of (V₁) 1.7litres, (V₂) 2.7litres, (V₃) 3.9litres, (V₄) 4.7litres according to the treatments. After transplanting, standard practices of weaving, 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 (1.7litres), V₂ (2.7litres), V₃ (3.9litres), V₄ (4.7litres) and 3 irrigation frequencies: W₁ (irrigating everyday), W₂ (irrigating every 2 days) and W₃ (irrigating every 3 days). The treatments were replicated four times.

2.3. 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 CO₂ assimilation rate, transpiration rate, stomatal conductance, substomatal CO₂ concentration and soil respiration.

2.3.1. 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 10cm from the base of the stem every four weeks at a resolution of 1cm to 100cm.

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 hours 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.

2.3.2. Physiological parameters

Soil respiration was determined on the plastic pots after removing the plants at a soil depth of 5cm using a portable respiration system type SRS (PP Systems, Hitchin, U. K.) 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, U. K.) was used. The stem was connected to a cuvette with a Parkinson leaf chamber whose area was 2cm². The intact leaf lamina was sealed in the leaf chamber and all the major veins were avoided. The boundary layer resistance was 0.2m²S⁻¹ while the flow rate was maintained at 200mls/minute. The IRGA equipment determined simultaneously net CO₂ assimilation rate, substomatal CO₂ 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 (L. S. D.) using the Statistical Analysis (S. A. S.) package.

3. RESULTS

Irrigation frequency significantly (P≤ 0.05) increased canopy heights of avocado seedlings. There were taller canopies at more frequent irrigation intervals (W₁) than less frequent ones (W₂ and W₃) (Table-1, Figure-1). There were also taller canopies in larger containers (V₄, V₅) than smaller ones (V₂ and V₃). In contrast, stem diameter was only increased by irrigation frequency but not container size (Table-1, Figure-1). 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 (W₁) intervals than less frequent ones (W₂, W₃). Similar trends were obtained with container sizes where larger container sizes (V₄, V₅) had lower fresh weights than smaller ones (V₂, V₁) (Table-2). The interaction between container size and irrigation frequency was significant (P≤ 0.05) and there were far heavier fresh weights under more frequent irrigation (W₁) and in larger containers (V₄, V₅) than smaller containers (V₂, V₁). Shoot dry weights had similar trends and both container size and irrigation frequency increased them (Table-3, Figure-2). 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 magnitudes of these increases were more at higher irrigation frequencies and larger containers showing an interaction between container size and irrigation frequency (Table-3, Figure-2).

Plant height was only significantly (P ≤ 0.05) increased by container size from the first second and fourth and seventh month after transplanting. In contrast irrigation frequency significantly (P≤ 0.05) increased plant heights at all sampling dates. Plant heights were taller in larger containers than smaller ones from the second to fourth month after transplanting. Similarly, more frequent irrigation intervals (W₁) had taller plants than less frequent ones (W₂ and W₃), at all the sampling dates (Table-4, Figure-3).

Container size did not significantly (P ≤ 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, Figure-3). Conversely, irrigation frequency increased it at all sampling dates (Table-5, Figure-3).

The physiological parameters were generally significantly (P ≤ 0.05) affected by container size and irrigation frequency. Container size significantly (P≤ 0.05) increased the CO₂ assimilation rate in months 2 and 3 after transplanting (Figure-5). Stomatal conductance was similarly increased by container size month 2 and 3 after transplanting (Table-6, Figure-5). In larger container sizes there were higher CO₂ assimilation rates and stomatal conductance (Figures 5 and 6) and vice versa. However, transpiration rate was only increased in month 2 after transplanting (Figure-7). In contrast, substomatal CO₂ concentration was unaffected by container size and irrigation frequency. There were significantly (P ≤ 0.05) higher values of stomatal conductance, net CO₂ assimilation rate and transpiration rates in larger containers than smaller ones during the months in which it affected them. In contrast, irrigation frequency increased CO₂ assimilation rate, stomatal 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 (W₂, W₃) than larger ones under more frequent irrigation intervals. Soil respiration was significantly (P ≤ 0.05) increased by container size and irrigation frequency and as the two factors increased soil respiration also increased and vice versa (Table-6, Figure-8).
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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Container size (L)</th>
<th>Irrigation frequency</th>
<th>Canopy height (cm)</th>
<th>Stem diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1 (1.7litres)</td>
<td>W1</td>
<td>25.2</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W2</td>
<td>22.2</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W3</td>
<td>17.0</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>V2 (2.7litres)</td>
<td>W1</td>
<td>25.7</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W2</td>
<td>24.6</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W3</td>
<td>23.1</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>V3 (3.9litres)</td>
<td>W1</td>
<td>49.6</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W2</td>
<td>43.6</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W3</td>
<td>41.1</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>V4 (4.7litres)</td>
<td>W1</td>
<td>59.9</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W2</td>
<td>41.2</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W3</td>
<td>35</td>
<td>0.9</td>
<td></td>
</tr>
</tbody>
</table>

Statistical parameter
- L. S. D\(^2\) between irrigation frequency means 16.7 19.7
- L. S. D\(^2\) between container sizes 14.4 15.1
- L. S. D\(^2\) between container size X Irrigation frequency 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 X Irrigation frequency: Significant  Not significant

1. W1, every day; W2, every 2 day; W3, every 3 days
2. L. S. D. at P≤ 0.05
3. F test at P≤ 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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Container size (L)</th>
<th>Irrigation frequency</th>
<th>Shoot fresh weight (g)</th>
<th>Root fresh weight (g)</th>
<th>Whole plant fresh weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1 (1.7litres)</td>
<td>W1</td>
<td>38.6</td>
<td>29.6</td>
<td>74.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W2</td>
<td>37.1</td>
<td>27.3</td>
<td>65.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W3</td>
<td>35.5</td>
<td>20.6</td>
<td>62.2</td>
<td></td>
</tr>
<tr>
<td>V2 (2.7litres)</td>
<td>W1</td>
<td>36.8</td>
<td>41.2</td>
<td>120.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W2</td>
<td>32.4</td>
<td>39.3</td>
<td>89.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W3</td>
<td>30.6</td>
<td>36.6</td>
<td>72.1</td>
<td></td>
</tr>
<tr>
<td>V3 (3.9litres)</td>
<td>W1</td>
<td>43</td>
<td>120.2</td>
<td>78.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W2</td>
<td>42</td>
<td>115.1</td>
<td>130.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W3</td>
<td>40</td>
<td>110.2</td>
<td>120.6</td>
<td></td>
</tr>
<tr>
<td>V4 (4.7litres)</td>
<td>W1</td>
<td>120.6</td>
<td>124.6</td>
<td>240.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W2</td>
<td>90.6</td>
<td>107.2</td>
<td>220.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W3</td>
<td>60.8</td>
<td>116.1</td>
<td>210.1</td>
<td></td>
</tr>
</tbody>
</table>

Statistical parameter
- L. S. D\(^2\) between irrigation frequency means 11.6 25.5 32.6
- L. S. D\(^2\) between container sizes 15.4 19.6 33.4
- L. S. D\(^2\) between container size X Irrigation frequency 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 X Irrigation frequency: Significant  Significant  Significant

1. W1, every day; W2, every 2 day; W3, every 3 days
2. L. S. D. at P≤ 0.05
3. F test at P≤ 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 \((P. \text{americana})\) rootstock seedlings grown at Maseno, Kenya.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Container size (L)</th>
<th>Irrigation Frequency(^1)</th>
<th>Shoot dry weight (g)</th>
<th>Root dry weight (g)</th>
<th>Whole plant dry weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_1) (1.7litres)</td>
<td>(W_1)</td>
<td>27.3</td>
<td>20.6</td>
<td>76.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(W_2)</td>
<td>5.2</td>
<td>18.9</td>
<td>24.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(W_3)</td>
<td>4.5</td>
<td>18.3</td>
<td>21.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(W_4)</td>
<td>32.6</td>
<td>36.3</td>
<td>41.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(W_5)</td>
<td>18.2</td>
<td>26.9</td>
<td>40.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(W_6)</td>
<td>15.5</td>
<td>20.4</td>
<td>41.5</td>
<td></td>
</tr>
<tr>
<td>(V_2) (2.7litres)</td>
<td>(W_1)</td>
<td>90.7</td>
<td>66.2</td>
<td>120.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(W_2)</td>
<td>40.2</td>
<td>56.5</td>
<td>110.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(W_3)</td>
<td>40.0</td>
<td>42.4</td>
<td>100.1</td>
<td></td>
</tr>
<tr>
<td>(V_3) (3.9litres)</td>
<td>(W_1)</td>
<td>65.6</td>
<td>130.1</td>
<td>120.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(W_2)</td>
<td>55.2</td>
<td>120.6</td>
<td>122.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(W_3)</td>
<td>52.1</td>
<td>140.3</td>
<td>140.2</td>
<td></td>
</tr>
</tbody>
</table>

Statistical parameter
- L. S. D\(^2\) between irrigation frequency means 11.2
- L. S. D\(^2\) between container sizes 12.6
- L. S. D\(^2\) between container size X Irrigation frequency 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 X Irrigation frequency
- Significant
- Significant
- Significant

\(W_1\), every day; \(W_2\), every 2 day; \(W_3\), every 3 days

1. L. S. D at \(P \leq 0.05\)
2. F test at \(P \leq 0.05\)
3. NS = Not Significant at \(P \leq 0.05\)

Table-4. Effect of different container sizes and irrigation frequency on plant height (cm) of avocado \((P. \text{americana})\) rootstock seedlings grown at Maseno, Kenya.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Container size (L)</th>
<th>Irrigation frequency(^1)</th>
<th>Months after transplanting</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_1) (1.7litres)</td>
<td>(W_1)</td>
<td>57.4</td>
<td>65.6</td>
</tr>
<tr>
<td></td>
<td>(W_2)</td>
<td>42.6</td>
<td>46.2</td>
</tr>
<tr>
<td></td>
<td>(W_3)</td>
<td>40.2</td>
<td>37.1</td>
</tr>
<tr>
<td>(V_2) (2.7litres)</td>
<td>(W_1)</td>
<td>57</td>
<td>65.3</td>
</tr>
<tr>
<td></td>
<td>(W_2)</td>
<td>35.9</td>
<td>45.2</td>
</tr>
<tr>
<td></td>
<td>(W_3)</td>
<td>38.6</td>
<td>42.6</td>
</tr>
<tr>
<td>(V_3) (3.9litres)</td>
<td>(W_1)</td>
<td>72.6</td>
<td>75.1</td>
</tr>
<tr>
<td></td>
<td>(W_2)</td>
<td>47</td>
<td>56.2</td>
</tr>
<tr>
<td></td>
<td>(W_3)</td>
<td>37.4</td>
<td>42.3</td>
</tr>
<tr>
<td>(V_4) (4.7litres)</td>
<td>(W_1)</td>
<td>42.3</td>
<td>54.6</td>
</tr>
<tr>
<td></td>
<td>(W_2)</td>
<td>46.2</td>
<td>49.4</td>
</tr>
<tr>
<td></td>
<td>(W_3)</td>
<td>42.9</td>
<td>43.2</td>
</tr>
</tbody>
</table>

Statistical parameter
- L. S. D\(^2\) between irrigation frequency means 10.0
- L. S. D\(^2\) between container sizes 15.7
- L. S. D\(^2\) between container size X Irrigation frequency 16.2

Significance of F tests\(^3\) for irrigation
- Signif.
- NS
- NS
- NS
- Signif.
- Signif.
- Signif.

Significance of F tests\(^3\) for container size
- Signif.
- Signif.
- Signif.
- Signif.
- Signif.
- Signif.

Significance of F tests\(^3\) for container size X Irrigation frequency
- Not Significant
- Not Significant
- Not Significant
- Not Significant
- Not Significant
- Not Significant

\(W_1\), every day; \(W_2\), every 2 day; \(W_3\), every 3 days

1. \(W_1\), every day; \(W_2\), every 2 day; \(W_3\), every 3 days
2. L. S. D at \(P \leq 0.05\)
3. F test at \(P \leq 0.05\)
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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Container size (L)</th>
<th>Irrigation frequency</th>
<th>Months after transplanting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>V₁ (1.7litres)</td>
<td>W₁</td>
<td>18.2</td>
<td>23.7</td>
</tr>
<tr>
<td></td>
<td>W₂</td>
<td>16.5</td>
<td>17.2</td>
</tr>
<tr>
<td></td>
<td>W₃</td>
<td>14.6</td>
<td>15.4</td>
</tr>
<tr>
<td>V₂ (2.7litres)</td>
<td>W₁</td>
<td>25.5</td>
<td>21.7</td>
</tr>
<tr>
<td></td>
<td>W₂</td>
<td>22.3</td>
<td>14.8</td>
</tr>
<tr>
<td></td>
<td>W₃</td>
<td>20.1</td>
<td>16.3</td>
</tr>
<tr>
<td>V₃ (3.9litres)</td>
<td>W₁</td>
<td>26.5</td>
<td>29.3</td>
</tr>
<tr>
<td></td>
<td>W₂</td>
<td>24.1</td>
<td>27.4</td>
</tr>
<tr>
<td></td>
<td>W₃</td>
<td>23.2</td>
<td>26.2</td>
</tr>
<tr>
<td>V₄ (4.7litres)</td>
<td>W₁</td>
<td>25.3</td>
<td>39.3</td>
</tr>
<tr>
<td></td>
<td>W₂</td>
<td>24.5</td>
<td>26.3</td>
</tr>
<tr>
<td></td>
<td>W₃</td>
<td>23.4</td>
<td>24.3</td>
</tr>
</tbody>
</table>

Statistical parameter

| L. S. D² between irrigation frequency means | 32.2 | 34.9 | 39.2 | 21.4 | 25.4 | 29.9 |
| L. S. D² between container sizes means | 20.9 | 22.4 | 29.6 | 33.3 | 23.1 | 27.7 |
| L. S. D² between container size X Irrigation frequency | 7.3 | 9.9 | 11.1 | 15.5 | 11.6 | 12.4 |

Significance of F tests³ for irrigation


Significance of F tests³ for container size

| Signifi. | Signifi. | Signifi. | NS | NS | NS |

Significance of F tests³ for container size X frequency

| Signifi. | Signifi. | Signifi. | NS | NS | NS |

¹ W₁, every day; W₂, every 2 day; W₃, every 3 days

² L. S. D. at P < 0.05

³ F test at P < 0.05

⁴ 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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Container size (L)</th>
<th>Irrigation Frequency</th>
<th>CO₂ Assimilation rate</th>
<th>Stomatal Conductance</th>
<th>Transpiration rate</th>
<th>Soil respirat.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Months 2</td>
<td>Months 3</td>
<td>Months 2</td>
<td>Months 3</td>
</tr>
<tr>
<td>V₁ (1.7litres)</td>
<td>W₁</td>
<td>1.0</td>
<td>0.59</td>
<td>16.9</td>
<td>6.7</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>W₂</td>
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<td>0.35</td>
</tr>
<tr>
<td></td>
<td>W₃</td>
<td>0.99</td>
<td>0.2</td>
<td>11.6</td>
<td>6.1</td>
<td>0.35</td>
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<tr>
<td>V₂ (2.7litres)</td>
<td>W₁</td>
<td>1.29</td>
<td>1.62</td>
<td>17.9</td>
<td>9.1</td>
<td>0.58</td>
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<tr>
<td></td>
<td>W₂</td>
<td>1.1</td>
<td>1.3</td>
<td>15.2</td>
<td>7.3</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>W₃</td>
<td>1.0</td>
<td>1.1</td>
<td>4.3</td>
<td>6.4</td>
<td>0.30</td>
</tr>
<tr>
<td>V₃ (3.9litres)</td>
<td>W₁</td>
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<td>2.9</td>
<td>19.9</td>
<td>13.3</td>
<td>0.91</td>
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<tr>
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<td>7.2</td>
<td>16.4</td>
<td>11.4</td>
<td>0.88</td>
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<td>22.1</td>
<td>20.4</td>
<td>14.5</td>
<td>0.71</td>
</tr>
<tr>
<td>V₄ (4.7litres)</td>
<td>W₁</td>
<td>3.0</td>
<td>26.6</td>
<td>25.2</td>
<td>19.7</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td>W₂</td>
<td>4.2</td>
<td>30.2</td>
<td>30</td>
<td>25.5</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>W₃</td>
<td>5.3</td>
<td>32</td>
<td>34.1</td>
<td>31.1</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Statistical parameter

| L. S. D² between irrigation frequency means | 1.1 | 0.5 | 2.2 | 3.4 | 3.1 | 2.3 |
| L. S. D² between container sizes | 2.1 | 3.2 | 1.5 | 2.2 | 4.1 | 3.0 |
| L. S. D² between container size X Irrigation frequency | 2.4 | 1.7 | 1.7 | 2.6 | 3.4 | 1.3 |

Significance of F tests³ for irrigation


Significance of F tests³ for container size

| Signifi. | Signifi. | Signifi. | NS | NS | NS |

Significance of F tests³ for container


¹ W₁, every day; W₂, every 2 day; W₃, every 3 days
L. S. D. at $P \leq 0.05$

F test at $P \leq 0.05$

(a) Units of CO$_2$ assimilation rate are umol m$^{-2}$ s$^{-1}$ (mg CO$_2$ m$^{-2}$ s$^{-1}$)

(b) Units of stomatal conductance are umol m$^{-2}$ s$^{-1}$

(c) Units for soil respiration are umol m$^{-2}$ s$^{-1}$

**Figure-1.** Effect of container size and irrigation frequency on the canopy height and stem diameter of Avocado (*Persia americana*) rootstock seedlings grown at Maseno, Kenya.

**Figure-2.** Effect of container size and irrigation frequency on the shoot and root fresh and dry weights of Avocado (*Persia americana*) rootstock seedlings grown at Maseno, Kenya.
Figure-3. Effect of container size and irrigation frequency on the number of leaves of Avocado (*Persea americana*) rootstock seedlings grown at Maseno, Kenya.

MAP = Months after planting

Figure-4. Effect of container size and irrigation frequency on the plant height of Avocado (*Persea americana*) rootstock seedlings grown at Maseno, Kenya.

MAP = Months after planting.
**Figure-5.** Effect of container size and irrigation frequency on the CO$_2$ assimilation rates of Avocado (*Persia americana*) rootstock seedlings grown at Maseno, Kenya.

**Figure-6.** Effect of container size and irrigation frequency on the stomatal conductance of Avocado (*Persia americana*) rootstock seedlings grown at Maseno, Kenya.
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 favorable 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; Peterson et al., 1991). Furthermore, larger containers apparently provided for more nutrient uptake, increased hormone synthesis and root metabolism (Peterson and Krizeki, 1992; Peterson et al., 1991). Further studies are recommended to measure these parameters to confirm these statements. Under such favorable 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 and Luaha, 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
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 CO₂ concentration. Further, it only
significantly affected stomatal conductance and CO₂
assimilation rates during months 2 and 3 after
transplanting and transpiration rate during month 2 after
transplanting. The effect on CO₂ 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 CO₂ assimilation rates.

Another important factor which may have a
profound effect on CO₂ assimilation rate in plants is the
substomatal CO₂ concentration which, in the present study
was not affected by container size. Therefore, the
increases in CO₂ assimilation rate during the two months,
without a corresponding decline in substomatal CO₂
concentration could be due to non-stomatal effects on the
photosynthetic processes, possibly an increase in the
mesophyll resistance (Connic et al, 1989). A reduction in
substomatal CO₂ concentration can be detrimental to the
photosynthetic process especially in the presence of the
rubisco enzyme. For many species substomatal CO₂
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
CO₂ concentration in the present study. Other workers
have also reported increase of CO₂ assimilation rates,
transpiration rates and stomatal conductance from
increased irrigation frequency (Luaha, 2005).

Soil respiration was significantly (P < 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 X irrigation frequency interaction. The
conditions in the larger containers such as increased soil
volume, nutrient uptake, hormone synthesis as discussed
else where in this paper 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.

**CONCLUSIONS**

It can be concluded that:

Container size significantly increases plant growth when it
is increased from 1.7 litres to 3.9 litres through its effect
on morphological parameters. Irrigation frequency of (W₁,
irrigating everyday) increases morphological and
physiological parameters more than irrigating less
frequently (W₂ and W₃). Canopy height, stem diameter,
transpiration rate and substomatal CO₂ 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.

REFERENCES


