THE EFFECT OF SOIL VOLUME ON CANOPY AND ROOTS GROWTH OF

*Opuntia ficus-indica*

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DOCTORATE IN AGRICULTURAL SCIENCES, FORESTRY AND ENVIRONMENTAL
XXIX CYCLE
Introduction

- The reduction of the soil volume implies:
  - physiological and morphological changes of the roots system and the allover plant growth (Aphalo and Rikala, 2003)
  - modification of the functional balance between roots and shoots (Tonutti and Giulivo, 1990)
  - controlling shoot growth in plant but without producing signs of nutrient deficiency (Rieger and Marra, 1994)
  - changes in transportation and carbohydrates metabolism (Ray and Sinclair, 1998; Ronchi et al. 2006)
- Nevertheless, plant response to soil volume might be species specific
Introduction

• *Opuntia ficus-indica* (L) Mill) is propagated by cuttings planted in the field. The use of containers to produce propagation can insure and increase the orchard uniformity. However, the container size may affect the plant growth and development (Inglese and Pace, 2000).

• Moreover, *O. ficus-indica* is more than often grown either in the arid and semi-arid areas or under intensive orchard plantation. In both cases the root are experiencing reduced soil volume due of shallow soils or the high plants density.

• Thus, the knowledge of the effect of the root restriction on *O. ficus-indica* roots and canopy behavior is required to explore the potential of this species where soil volume is limited.
Objective

This study investigated the effect of soil volume restriction on below and above ground growth of Opuntia ficus-indica through understanding the limit imposed by root restriction via different soil volumes.
THE EFFECT OF SOIL VOLUME ON ROOT SYSTEM AND GROWTH

THE EFFECT OF SOIL VOLUME ON CANOPY GROWTH AND ROOT / CANOPY RATIO

THE EFFECT OF SOIL VOLUME ON *Opuntia ficus-indica* ROOTS TURNOVER
TOPIC 1: THE EFFECT OF SOIL VOLUME ON ROOT SYSTEM AND GROWTH

Materials and Methods

One-year-old *Opuntia ficus-indica* cladodes of the cultivar “Gialla” were cut and dried for two weeks in the shade.

Five different sizes of pots: 50, 33, 18, 9 and 5 Liters

These pots filled with dry fine, sandy loam soil field capacity was 35%; wilting point 20% (g/g); pH: 6.8; organic matter: 80 g kg\(^{-1}\) and total Nitrogen: 10 g kg\(^{-1}\)
TOPIC 1: THE EFFECT OF SOIL VOLUME ON ROOT SYSTEM AND GROWTH

Materials and Methods

• May 2014, cladodes were planted in pots with half of their length in the soil

• Plants were watered regularly to maintain soil water content and to avoid any visible sign of water stress.

• Four different sampling dates were used (6, 12, 18 and 24 months).

• For each sampling date, three replicates (pots) were planted

• The experimental design was a completely randomized design in possible combinations of the two factors, soil volume and date of the sampling, with three replications.
TOPIC 1: THE EFFECT OF SOIL VOLUME ON ROOT SYSTEM AND GROWTH

Materials and Methods

• Roots of each plant were divided visually into three groups depending on its diameter: fine roots less ≤ 2 mm, Medium roots (2-5 mm) large roots > 5 mm.

• The roots of each group were measured with a ruler to a precision of 1 mm.

• Roots surface area was measured using VegMeasure software®
TOPIC 1: THE EFFECT OF SOIL VOLUME ON ROOT SYSTEM AND GROWTH

Materials and Methods

Hardware

Digital Photography

Software

Image Processing
The total surface area of yellow roots from the image classification was calculated by summing the total area occupied by pixels classified as roots surface area. These values were multiplied by \( \pi \) (approximately \( 3.14 \)).
TOPIC 1: THE EFFECT OF SOIL VOLUME ON ROOT SYSTEM AND GROWTH

Materials and Methods

- Root volumes were calculated from surface area and root length by assuming that roots are cylindrical.
- three random subsamples from each group/ pot. Samples were weighed and dried at 75 °C for 72 h and the dry weight for each group was calculated.
- Root density: the total root volume/soil volume (cm³ L⁻¹)
- Root length density per soil unit (RLD): the total root length/soil volume (cm L⁻¹)
TOPIC 1: THE EFFECT OF SOIL VOLUME ON ROOT SYSTEM AND GROWTH

Results

The graph illustrates the total root length (cm) over different soil volumes and months. It shows that the total root length increases with time and soil volume.

- **50 Liters**
- **33 Liters**
- **18 Liters**
- **9 Liters**
- **5 Liters**

The data suggests that larger soil volumes lead to longer root systems, especially noticeable after 18 months.
TOPIC 1: THE EFFECT OF SOIL VOLUME ON ROOT SYSTEM AND GROWTH

Results

![Graph showing the effect of soil volume on root system and growth over 24 months. The x-axis represents months (6, 12, 18, 24), and the y-axis represents total root surface area (cm²). The graph compares different soil volumes (50, 33, 18, 9, and 5 liters). The data shows an increase in root surface area with increased soil volume, especially after 18 months.](image-url)

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TOPIC 1: THE EFFECT OF SOIL VOLUME ON ROOT SYSTEM AND GROWTH

Results

![Graph showing the effect of soil volume on root system and growth. The x-axis represents months (6, 12, 18, 24), and the y-axis represents total root dry mass (g). The graph includes different soil volumes (50 Liters, 33 Liters, 18 Liters, 9 Liters, 5 Liters) at different time points.](image-url)
TOPIC 1: THE EFFECT OF SOIL VOLUME ON ROOT SYSTEM AND GROWTH

Results

![Large root surface area (cm²) vs. Months]

- 50 Liters
- 33 Liters
- 18 Liters
- 9 Liters
- 5 Liters
Results

![Graph showing the effect of soil volume on root system and growth.](image-url)

**TOPIC 1: THE EFFECT OF SOIL VOLUME ON ROOT SYSTEM AND GROWTH**
TOPIC 1: THE EFFECT OF SOIL VOLUME ON ROOT SYSTEM AND GROWTH

Results

![Bar chart showing the effect of soil volume on root system and growth](chart.png)

- Fine root surface area (cm²)
- Months: 6, 12, 18, 24
- Soil volumes: 50 Liters, 33 Liters, 18 Liters, 9 Liters, 5 Liters
RESULTS

Root length density (RLD) (cm/L)

- 50 Liters
- 33 Liters
- 18 Liters
- 9 Liters
- 5 Liters

The graph shows the effect of soil volume on root system and growth. As the soil volume decreases, the root length density increases.
TOPIC 1: THE EFFECT OF SOIL VOLUME ON ROOT SYSTEM AND GROWTH

Results

![Graph showing the effect of soil volume on root system and growth over months. The x-axis represents months (6, 12, 18, 24), and the y-axis represents root density (cm$^3$ L$^{-1}$). The graph compares 50 liters, 33 liters, 18 liters, 9 liters, and 5 liters of soil volume. The bars indicate the root density at each soil volume across different months.](image-url)
Conclusion

• The total root length, surface area, dry mass, volume as well as the surface area of the large roots were inhibited by the soil volume restriction. While there was increase in fine roots growth in the soil volume unit which means plant develops more fine roots when soil/nutrient sources are not available.

• The effect of soil restriction on roots seems to be minor or moderate at the early stages of the plant growth but increases later.

• The more finer root system per soil volume of *O. ficus- indica* seems to be a kind adaptive strategy in order to enable the plants to increase the possibility of exploring new nutritive resources.
TOPIC 2: THE EFFECT OF SOIL VOLUME ON CANOPY GROWTH AND ROOT GROWTH/CANOPY TH RATIO

Materials and Methods

Cladodes of each plant in each pots were counted and numbered according to its age. Cladodes were clustered into three groups: mother cladodes, first generation cladodes and second generation cladodes. The total number of the cladodes in each group was recorded.

The cladodes thickness was measured in mm with a vernier caliper
TOPIC 2: THE EFFECT OF SOIL VOLUME ON CANOPY GROWTH AND ROOT GROWTH/CANOPY GROWTH RATIO

Materials and Methods

The width and length of each cladode were measured; these values were used to estimate the area of the cladode using the formula

\[ X = \frac{W}{2} \times \frac{L}{2} \times \pi \]

The fresh weight of each cladode was taken, three subsamples of each cladodes were cut weighed and dried in a forced-draft oven at 75 °C for 72 h to estimate the dry weight.

The root: shoot ratio was calculated (Dry weight for roots/dry weight for canopy)
TOPIC 2: THE EFFECT OF SOIL VOLUME ON CANOPY GROWTH AND ROOT / CANOPY GROWTH RATIO

Results

![Graph showing the number of the second generation cladodes over months for different soil volumes. The graph compares 50 Liters, 33 Liters, 18 Liters, 9 Liters, and 5 Liters. The number of cladodes increases with time for all volumes, with the highest number of cladodes observed in 24 months for 50 Liters and 18 Liters.](image-url)
Results

![Bar chart showing the effect of soil volume on canopy growth and root/canopy growth ratio over different months. The x-axis represents months (6, 12, 18, 24), and the y-axis represents the total number of cladodes. Different soil volumes (50, 33, 18, 9, and 5 liters) are compared.](Image)
Results

TOPIC 2: THE EFFECT OF SOIL VOLUME ON CANOPY GROWTH AND ROOT / CANOPY GROWTH RATIO

![Graph showing the effect of soil volume on canopy growth and root/canopy growth ratio.](image-url)
TOPIC 2: THE EFFECT OF SOIL VOLUME ON CANOPY GROWTH AND ROOT / CANOPY GROWTH RATIO

Results

![Graph showing the effect of soil volume on canopy growth and root/canopy growth ratio](image-url)
Conclusion

• The soil volume restriction can affect the roots and canopy growth of *Opuntia ficus-indica* leading to reduction in canopy growth and canopy dry matter accumulation

• This reduction was associated to a lower cladode number

• The root: canopy dry mass ratio increased with the soil volume increase

• Plants under small soli volume tended to have stable root: canopy ratio overtime
Materials and Methods

% of Carbon derived from *Opuntia ficus-indica* (OFI) root turnover (OFI-C contribution)

\[
\text{New carbon derived from OFI (Ncd)} = \frac{\delta^{13} C_{OFI} - \delta^{13} C_{old}}{\delta^{13} C_{biomass\ OFI} - \delta^{13} C_{old}}
\]

The \(\delta^{13}C\) measured using an EA-IRMS (elemental analyser isotope ratio mass spectrometer Carlo Erba Na 1500, model Isoprime (2006), Manchester, UK.)
TOPIC 3: *Opuntia ficus-indica* ROOTS TURNOVER

**Materials and Methods**

**Old Carbon derived (Ocd) = 1 – Ncd**

\[
\text{Root turnover} \% = \frac{\text{New C derived} \times \text{SOC}}{\text{Root weight} \times \text{C}_{\text{root}}} \times 100
\]

- The C content in the bulk soil for each pot (g)
- The concentration of C in the root biomass (g kg\(^{-1}\))
- Root dry weight (g) in each pot
TOPIC 3: *Opuntia ficus-indica* ROOTS TURNOVER

Results

<table>
<thead>
<tr>
<th>Months</th>
<th>50 Liters</th>
<th>33 Liters</th>
<th>18 Liters</th>
<th>9 Liters</th>
<th>5 Liters</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>-26.0</td>
<td>-25.5</td>
<td>-25.0</td>
<td>-24.5</td>
<td>-24.0</td>
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<tr>
<td>18</td>
<td>-24.5</td>
<td>-24.0</td>
<td>-23.5</td>
<td>-23.0</td>
<td>-22.5</td>
</tr>
<tr>
<td>24</td>
<td>-22.5</td>
<td>-22.0</td>
<td>-21.5</td>
<td>-21.0</td>
<td>-20.5</td>
</tr>
</tbody>
</table>

Carbon isotopic signature $\delta^{13}C$ (‰)
TOPIC 3: *Opuntia ficus-indica* ROOTS TURNOVER

**Results**

![Graph showing carbon derived by roots for different volumes of water: 50 Liters, 33 Liters, 18 Liters, 9 Liters, 5 Liters. The graph shows the carbon content in g C kg\(^{-1}\) soil.](image-url)
TOPIC 3: *Opuntia ficus-indica* ROOTS TURNOVER

Results

<table>
<thead>
<tr>
<th>Root turnover (%)</th>
<th>50 Liters</th>
<th>33 Liters</th>
<th>18 Liters</th>
<th>9 Liters</th>
<th>5 Liters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>
Conclusion

• The restricted soil volume enhanced the C stock

• Plants placed in the smallest soil volume (5 Liters) stopped producing new second cladodes after the first sampling date as all the investments were put into the roots growth resulting in the highest percentage of the roots turnover

• These results confirmed the importance of the *Opuntia ficus-indica* as a potential plant that can survive under low soil volume with ability to balance its growth under the harsh environments

• *Opuntia ficus- indica* provide reasonable organic carbon amount that improve the quality of the soil leading to healthy ecosystems