The impact of "continuous" deficit irrigation on carrot crop development in the Saïs plain, Morocco

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Abstract. In the Maghreb, as in many arid and semi-arid zones, water resources are vulnerable to climatic variations, for which reason various scientific studies are being conducted in an attempt to face these changes while maintaining the yield potential of crops. The aim of the following paper is to evaluate the impact of continuous deficit irrigation (CDI) on the carrot (Daucus Carota L.) crop. A complete randomized block design (CRBD) involving five treatments and four repetitions was adopted for this experimental design. The studied treatments are: T1(125% ETc), T2(100% ETc), T3(85% ETc), T4 (75% ETc) and T5 (66% ETc). Vegetative, biochemical, and yield parameters were measured to identify carrot response and provide optimal water management for deficit irrigation on carrot. Irrigation at 125% ETc achieved the highest yield (59 tons/ha). However, in terms of yield, treatment (T1) was not significantly different from (T2) nor (T3). Meanwhile, the 66% ETc water deficit treatment (T5) showed remarkable decreases in yield. This means that even when providing more water it does not increase the yield meaning that the plant does not use the given water but instead, it is lost and on the other hand a 15% water deficit did not significantly impact the yield.

Keywords: Carrot, continuous deficit irrigation, water dose.

Introduction

It is considered that the Mediterranean region is highly exposed to climate change. As part of this region, Morocco is highly exposed to the damaging effects of climate change. It has recently reached a situation of water scarcity and stress with an annual water supply per person of about 700 m³, which is below the critical value of 1000 m³/capita. This value is expected to drop to 500 m³/capita by 2025 (INRA Meknes, 2017). The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014) stated that the stress on water resources is expected to increase due to climate change, in addition to future population growth and urbanization.

Given this context, efforts to develop the irrigated agricultural sector are expected to be oriented toward improving water productivity at the field scale. It is no longer possible to manage water solely according to economic profitability rules, but rather it must be considered as a vital asset to be rationalized and preserved. The deficit irrigation technique, which prioritizes obtaining optimal crop water productivity over maximum yields (Lawal A.M 2021), seems like a viable strategy to improve the sustainability of Morocco's irrigated agriculture. It is a strategy by which net yields are optimized by reducing the quantity of water used in irrigation applied in a crop under mild water stress. The resulting yield decrease can be considered small relative to the water savings achieved.

Prior to starting a deficit irrigation program, it's essential to understand how crops respond to water stress at particular growth stages or throughout the season (Kirda, 2022). Varieties with high yielding crops are generally vulnerable to water stress, while low yielding varieties are not. For instance, while traditional varieties can

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tolerate deficit irrigation, new maize varieties cannot. The most suitable crops for this irrigation method are those that are drought tolerant and have a shorter growing season, as advised by Stewart and Musick in 1982.

The carrot (Daucus carota L.) is a widely grown vegetable crop in arid and semi-arid regions. In Morocco, this crop occupies a crucial place among vegetable crops and plays a very important economic role. It was estimated to cover a total area of more than 24,000 ha in 2020, distributed across the country and all year round, with an average yield of 32.38 tons/Ha (FAOSTAT, 2022).

1. **Material and methods**

1.1. Experimental site and protocol

The 0.3 hectare experimental plot at the National School of Agriculture in Meknes served as the study site. It is located in the Territorial Commune of Sidi Slimane Moul El Kifane, Fez-Meknes region (Long= -5.47502075 °, Lat= 33.84278345 °, Altitude= 624.12 m). The plot has been a fallow for several years. The experiment concerns the monitoring of the behavior of the carrot hybrid JERADA RZ under deficit irrigation. Sowing was accomplished in paired rows on the planting beds using a precision pneumatic seeder on April 24 at a depth of 1 cm. Each elementary plot (110 m²) is composed of 6 planting beds spaced 30 cm apart and each bed contains 6 planting lines.

A full randomized block design (CRBD) with four repetitions and five water regimens is the experimental design (figure 1) that was used. It is important to mention that all treatments received 100% irrigation from the transplanting to the one leaf stage. The treatments are:

- Control treatment:
  - Treatment T2: Comfort irrigation with a dose of 100% ETc during the whole cycle;
- Heavy irrigation:
  - Treatment T1: Luxury irrigation with a dose of 125% ETc from the one-leaf stage;
- Deficient irrigation:
  - Treatment T3: CDI applying 85% ETc from the one-leaf stage until the end of the cycle;
  - Treatment T4: CDI applying 75% ETc from the one-leaf stage until the end of the cycle;
  - Treatment T5: CDI applying 66% ETc from the one-leaf stage until the end of the cycle.

![Figure 1: A schematic representation of the experimental layout](image)

A drip irrigation system was used to provide localized irrigation to the experimental plot. There are three straightforward polyethylene ramps with integrated drippers in each treatment, evenly spaced at 30 cm on the ramp and delivering 1 l/hour. The ramps are spaced at a distance of 0.4 m from each other.

Since the focus of this study was water supply, the crop was grown without regard to other constraints (labor, density, fertilization, weeding, etc.).

1.2. Measurements and data recording

Measurements were carried out on morphological, physiological and biochemical parameters of the aerial and underground parts. Throughout the trial period, they were performed every 15 days on 72 randomly selected participants, removing 3 plants from each elementary parcel (20 parcels total).
1.2.1. Growth parameters

The growth and development parameters observed and measured include the number of leaves and the vegetative height as well as the root length and crown diameter.

1.2.2. Biochemical analysis:

Proline, as a marker of resistance to abiotic constraints (including water stress), was analysed in the laboratory based on the procedure outlined by Bates et al. (1973). Using a digital refractometer, the soluble solids concentration (°Brix) was also determined.

1.2.3. Yield Parameters

During the yield estimation, the number of plants /m² was monitored for the 20 experimental units. Once it was time to harvest, each plant's upper half was removed off, and each plant's wet weight was recorded. To calculate the fresh and dry plant weight, they were all placed in an oven set at 60°C for two days. After harvesting the quadrats, the total and root yield were determined for each treatment for the 4 blocks to cover the fruit yield of the whole parcel.

1.3. Data analysis

The Excel spreadsheet was used to execute the statistical analysis of the parameters of study, as well as to calculate the data means and conceptualize the diagrams. The statistical software SPSS (version 20) was used for the analysis. In order to evaluate the statistical statements, the data were first verified for normality and uniformity of variance. From that, the data were examined at a 5% probability level using the Student-Newman-Keuls (SNK) multiple comparison test and a 1-way analysis of variance (ANOVA).

2. Results and discussion

2.1. How water stress affects yield parameters

Descriptive data analysis of the total yield of carrots shows that this parameter is strongly influenced by the water regime applied. The highest overall yield per hectare was recorded among the treatment T1 (125%) which was 59.595 T/ha, while the lowest was in treatment T5 (66%) which was 32.417 T/ha (figure 2).

![Figure 2: Total yield in T/ha under different water regimes.](image_url)

The irrigation rate had a highly significant impact on the ultimate total yield, according to the analysis of variance. These results showed that the over-irrigated treatment with 125%Etc and the control treatment 100%ETc are not statistically different even if there is a slight difference in total yield. From another side, the reduction of 15% of water (treatment T3(85%)) shows no statistical difference from the comfort irrigation 100% ETc. This could assist in decreasing the amount of water used while improving the efficiency of water use with a slight
reduction in total yield. However, with 75%Etc and 66% ETc deficit irrigation, the difference become remarkable leading to a drop in the total yield.

These results provide evidence that even if farmers were to add more water in the aim of increasing the yield, this would not be the case. Indeed, the yield increases but by such a small amount compared to the amount of water added that this increase is not significant. Therefore, the added water is in reality only lost either by percolation or by evaporation, and therefore the plant does not take advantage of it.

In the other case of a 15% deficit, indeed the yield declined by 8T/ha but in comparison with the 100%ETc control treatment the difference was not significant. Thus, in periods of drought or lack of water, a water deficit can be tolerated without drastically affecting the yield. However, once the deficit exceeded 25% and reached 33% the yield almost dropped by half.

In a study conducted by Carvalho et al 2016, it was reported that irrigation at 120% ETc, which is higher than the amount of water needed for crops, did not result in a rise in crop productivity, which is similar to our study. In addition, he reported that irrigation at 72% ETc or 43% ETc resulted in a decrease in yield that was significant. Also a study that was conducted the previous year on the same plot on potato crop showed that water savings of roughly 77 mm were achieved while keeping a good yield when a 25% water limitation was applied as opposed to 100% comfort irrigation. (El Bergui et al 2019).

2.2. Water stress’s effect on agronomic water use efficiency

Table 1 below represent the impact of various irrigation regimes on water productivity, called also agronomic water use efficiency. Note that the water productivity (Kg/m³) = Production / Quantity of water used):

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Root yield (kg/ha)</th>
<th>Water used (m3/ha)</th>
<th>Water saving compared to control (m3/ha)</th>
<th>Water productivity (kg/m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 (125%)</td>
<td>39269</td>
<td>4497</td>
<td>-</td>
<td>8.73</td>
</tr>
<tr>
<td>T2 (100%)</td>
<td>34732</td>
<td>3663</td>
<td>-</td>
<td>9.48</td>
</tr>
<tr>
<td>T3 (85%)</td>
<td>30775</td>
<td>3130</td>
<td>533</td>
<td>9.83</td>
</tr>
<tr>
<td>T4 (75%)</td>
<td>25861</td>
<td>2805</td>
<td>858</td>
<td>9.22</td>
</tr>
<tr>
<td>T5 (66%)</td>
<td>21625</td>
<td>2480</td>
<td>1182</td>
<td>8.72</td>
</tr>
</tbody>
</table>

The results obtained regarding water productivity show that the highest value was recorded among the T3 treatment (85%) which was 9.83 kg/m³, while the lowest ones were found in the T1 (125%) and T5 (66%) treatments which were 8.73 T/ha and 8.72 T/ha respectively.

Based on the existing research literature, Nagaz et al. (2017) showed that the highest water use efficiency values are those of the 60% ETc treatment. While Léllis et al. (2017) reported that the maximum water use efficiencies for carrots were obtained with 80% ETc irrigation.

It may be stated that deficit irrigation with a 85% ETc threshold that generates the highest water use efficiency is considered the best strategy to value water while saving it and increasing productivity. However, a 34% restriction in crop water requirements leads to a decrease in water use efficiency, which significantly affects root yield. The same for the over-irrigation treatment with an addition of 25% of the crop’s water requirement leads to the lowest water productivity. The adoption of such a deficit irrigation strategy should be considered mainly in the context of water scarcity and also considering the price of water.

Conclusion

Given the rising environmental challenges (climate change and water scarcity) as well as the increasing production costs, the issue of adapting to the water shortage has become crucial. Furthermore, the energy used for pumping water must be taken into consideration, as it is one of the most expensive expenses of the farm, which must be managed with accurate irrigation scheduling. In this study, the deficit irrigation (DI) approach was evaluated in order to assess the ideal irrigation conditions and parameters for carrot to optimize and stabilize yields under water-limited conditions. In fact, this study assessed the effect of sustainable deficit irrigation with five water regimes 125%, 85%, 75% and 66% Etc on the carrot crop.

This current trial has shown that the carrot yield is affected by the applied irrigation rate for on both total and root yield. The significant effect of irrigation regime on yield was mainly due to the number of roots and their average weight per treatment: on one hand, there was no significant difference between the treatments irrigated at 125%
and 100% daily ETc that recorded the highest total yields (59T/ha and 56T/ha respectively) which makes the 25% of added water not justified statistically. On the other hand, a reduction of 15%ETc had no significant effect on total yield compared to the control treatment, however higher deficit irrigation affected significantly the yield.

For agronomic water use efficiency, the highest value was recorded by plants under deficit irrigation with 85% ETc achieving, 9.83Kg for each cubic meter of irrigation water. Whereas, plants over-irrigated with 125%ETc recorded the lowest water use efficiency (8.73Kg/m3), which mean that the deficit irrigation approach leads to produce more carrots with less used water and thus consume less energy for irrigation. And so, according to these results, deficit irrigation approach with a 15% reduction of crop evapotranspiration could be considered as the best strategy to promote mainly in the context of water scarcity, high cost of energy and climate change.

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