Water productivity of *Origanum syriacum* under different irrigation and nitrogen treatments using an automated irrigation system

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Abstract

Limited water supplies in semi-arid and arid regions are limiting crop production and profitability. Lebanese Oregano (*Origanum syriacum*) is a perennial herb of the Lamiaceae (mint) family that has high commercial and medicinal potential, with little known about its water requirements. A four-replicate split-plot field study was conducted during 2013–2014 in the Beqaa Valley in Lebanon to determine the yield response of *Origanum syriacum* to different levels of drip irrigation and evapotranspiration (ET_c), and to document its growth parameters and soil water use. Four irrigation treatments were automatically set by applying 60%, 80%, 100% and 120% of Hargreaves ET as calculated by a commercial irrigation controller and weather station. Flowmeters were used on the four treatments and the irrigation amounts were measured. Results show that total fresh and dry yield as well as dry leaf yield significantly decreased with decreasing %ET. The highest ET treatment gave the highest fresh and dry yield and dry leaf yield but the lowest dry/fresh yield ratio. The 60% ET was significantly lower than all other treatments. No significant difference was found among the 60% and the 80% ET treatments. Water use efficiency increased significantly as irrigation decreased. Water productivities were highest (0.97 kg/m^3) for the lowest irrigation treatment (vs. 0.70 kg/m^3 for the highest irrigation treatment).
Keywords: water productivity, origanum, irrigation, nitrogen, semi-arid.

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1 Introduction

Irrigation water in the Middle East remains the most important factor threatening food security in the region [1]. Too often it competes with domestic, municipal, and industrial uses for water. In arid and semi-arid environments characterized by low rainfall and high potential evaporation, irrigation is a must for profitable agricultural production. Decreased rainfall in the last decade coupled with an increasing irrigation demand had led to a decline in springs and groundwater levels as well as well yields and river flows, affecting agricultural production and farmers' livelihoods [2]. There is a high potential for water savings in agriculture, namely appropriate green water management. One way to improve economic return per unit of water applied is through a reduction in the applied irrigation water in periods of the growing season in which the yield is not affected. Another approach would be to use crops with high water productivity and return value. A third option would be to use drought tolerant crops [3].

Studying yield response to irrigation, especially over several years, is crucial for developing economic studies of cropping rotations, irrigation water management, and water productivity. Crops have different yield responses to irrigation, and this has been and will continue to be studied thoroughly for many crops under different conditions, given the advances in irrigation techniques and management [4–8]. Irrigation studies on some plants like medicinal and landscape plants and herbs are not as diverse. *Origanum syriacum* (*O. syriacum*) is well known for its essential oils (namely carvacrol), and for its use in salads as fresh produce, and in pastries as ground dried leaves (usually mixed with sesame, sumac, and olive oil) [9].

O. syriacum is a native-to-Orient aromatic perennial herb of the Lamiaceae family. It is considered as one of the most important essential oils producing crop, mainly the carvacrol type [10]. Its oils are known for their antiseptic [11], nematicidal [12], anti-fungal [13], and insecticidal [14]. The crop has a high potential in use as a food-preservative [10], anti-snails [15], anti-mites and anti-aphids [16]. It is used as a spice in many Mediterranean and Mexican cuisines. Due to its high demand, it became a protected species in Lebanon as it is over-exploited. Commercial planting can be promising as it could satisfy the market demand and improve the natural occurrence of the plant.

The objective of this research is to determine the growth response as well as fresh and dry yield response of *O. syriacum* to 1) different irrigation regimes in an attempt to determine its water requirements; and 2) different nitrogen treatments. Water productivity of *O. syriacum* in kg of dry yield/m^3 of applied water is also determined.

2 Materials and methods

2.1 Location and soils

This research was conducted at the American University of Beirut's Agricultural Research and Education Centre (AREC) located in the centre of the Beqaa Valley of Lebanon (coordinates 33°55' latitude and 36°04' longitude, 995 m ASL). Mean annual rainfall in the area is 528 mm (57 years of data), with a standard deviation of 165 mm. The climate is classified as semi-arid, with an average annual pan-evaporation of 2 meters, 70% of which occurs between April and September. The soil of the experimental plot was shallow gravelly clay (Calcaric Cambisols) having a pH of 7.89, an EC of 0.004 dS/m, CaCO3 of 32.5% and an organic matter content of 2.48%. The water holding capacity at 33 kPa was 42%, and that at 5 bars was 32.7%. The important available plant nutrients (mg/kg of soil) in the Ap horizon (0–15 cm) at the time of planting were: Nitrogen, 12; P, 20; and K, 530.

The experiment consisted of four irrigation treatments (based on different percentages of Hargreaves ET: I1=60%, I2=80%, I3=100% and I4=120%), and four nitrogen treatments (N1=0, N2=75, N3=150 and N4=225 kg/ha) arranged in a randomized split-plot design with four replicates. Irrigation treatments were applied at the whole plot level while nitrogen treatments were applied at the sub-plot level. Each whole plot had three lines of the crop spaced 0.4 meters apart, with 1 m path between whole plots. Each subplot consisted of 4 plants per line, with a total of 12 plants per sub-plot. Urea (46.5% N) was selected as the applied fertilizer. The required amounts were divided into 3 applications applied at a monthly interval starting.

Cultural practices were the same for all treatments and include an application of 40 kg/ha di-potassium hydrogen phosphate. A non-irrigation treatment was not included because planting occurred late in spring were soil moisture does not sustain new plants. The irrigation variable was achieved by applying a percentage of Hargreaves ET during each irrigation event rather than decreasing the irrigation frequency across treatments, which was not feasible using the automated system that automatically calculates the timing based on the set percentages.

2.2 Irrigation protocol

Soil moisture of all plots was raised to field capacity right after planting. Water within the experimental site was provided by a fully automated irrigation system consisting of a reservoir with two pumps, a main network, one controller, weather station, flow sensor, flow meters, four 1” solenoid valves each corresponding to a different irrigation treatment, and a secondary irrigation network downstream the solenoid valves. Drip irrigation was used with in-line emitters spaced at 0.4 m with 4 lph per emitter per plant. The irrigation water was well water from underlying marl limestone aquifer of good quality with total dissolved solids of 320 mg/l. Well water was pumped into a supply pool from which water was diverted into a regulating reservoir. An automatic pump was installed at the reservoir and the pump is operated automatically by a commercial controller within which the irrigation treatments were programmed. Each irrigation treatment was controlled using a 32 mm solenoid valve wired to and connected to the corresponding whole-plot in every replicate.

2.3 Automated irrigation control system components

The automated control system consisted of: an ET-Based controller, a 3G communication Aircard, a wireless weather station, and a flow sensor. The controller is a 4-station base model which command, by the mean of low-voltage wiring, the opening and closing of series of 24V solenoid valves. The network card was installed with a 3G subscriber identification module (SIM) card thus enabling the controller to be connected to the network for internet access. The weather station is simply a temperature sensor and a rain sensor. It was installed in the middle of the experimental field and wirelessly connected to 3G Aircard. Daily high and low temperatures were monitored throughout the experimental period, turning the controller into an ET-Based water management system.

The flow sensor was directly connected to the network card. The flow sensor aims at providing an alarm for pipe leakages and/or low flow event. Total water flow for each treatment was measured with a flowmeter installed after each solenoid valve. All plots were tilled once with a mouldboard, disked and levelled one week prior to transplanting. Two month-old decapitated seedlings were transplanted on May 27th, 2014. The tips of the plants were removed to break apical dominance and induce shoot development.

2.4 Chronology of experiment

Nitrogen treatments were split into three applications, starting on July 18th (along with the irrigation treatments), August 2nd and August 23rd. Shoot height was recorded 40 days after the beginning of the first nitrogen application. Urea (46% N) was used and the necessary amounts/application were dissolved in water and manually applied to each plant in the subplot.

Irrigations were scheduled 3 times a week, with the controller determining the irrigation times automatically. The irrigation system is an ET based water management system. The weather station installed in the experimental field monitors the daily high and low temperatures. ET rates are calculated based on Hargreaves equation for reference evapotranspiration rate as in eq. (1) [17].

$$ET_0 = 0.0023 \times (T_{mean} + 17.8) \times (T_{max} - T_{min})^{0.5} \times R_a \qquad (1)$$

where, ET_0 is the reference evapotranspiration rate; T_{max} (°C) is the maximum daily air temperature; T_{min} (°C) is the minimum daily air temperature; R_a (MJ $m^{-2}d^{-1}$) is the extra-terrestrial solar radiation.

The controller prompts the user to enter the latitude for solar radiation calculations. At each irrigation interval, the reservoir pump is activated by an order given by the controller. The irrigation system was operating at a constant pressure of 1.2 bars, and the average emitter discharge rate was measured to be 4.56 l/hr, equivalent to 50 mm/hr that was set within the auto-adjust mode of the controller (based on the in-field wetted perimeter observation and assuming a system efficiency of 85% [18]. The average measured wetted area following 20 minutes irrigation was around 30 cm. The controller accepts user-defined application rates as well as those corresponding to the manufacturer’s standard sprinkle systems. The user can also adjust the rates among different zones (in this case irrigation treatments) as percentage of required depth. The set irrigation depths will be converted to zone run times within the controller that will operate the pump and solenoids accordingly.

No ground water contribution to crop water use was possible (depth to groundwater is greater than 50 m).No effective rainfall occurred between the planting and the first harvest. During the second harvest, effective rainfall was taken into account for computing the water productivity from irrigation water. Water use efficiency (WUE), was expressed as the ratio of dry matter yield to that of the water use i.e. kg /ha/mm.

The test plots were harvested twice, on September 13th and November 17th**.** The measured yield parameters were for the two harvests are: the fresh weight of above-ground biomass, the dry weight, and the dry leaf weight for the first cut, for the middle row of plants in each of the 64 subplots.

Statistical analysis was performed using JMP 10 – Copyright 2012 SAS Institute Inc. software package. The whole plot effects, the random effects and the effects of irrigation, nitrogen, and irrigation nitrogen interactions were analysed. Least significant differences at an alpha of 0.05 were calculated using the all pairs Tukey–Kramer HSD (honestly significant difference) test [19, 20]. This test is an exact alpha-level test if the sample sizes are the same, and conservative if the sample sizes are different [21]. The test protects the significance tests of all combinations of pairs, and the HSD intervals become greater than the Student's t pairwise LSDs. All harvested plants were oven-dried at 65°C for 72 h in order to measure dry matter. Average plant height for the middle row plants/subplot is reported. Following the first cut, no growth parameters were collected. Above ground biomass (fresh and dry, all cuts) and dry leaf weight (first cut) for all plants within the subplots is analysed.

3 Results and discussion

3.1 Effect on crop growth

Shoot height of all plants was measured at the date of the application of the first nitrogen treatment (Day 0 of the experiment), and one month following the beginning of the treatments. Shoot height of I4 (120% ET) was significantly higher than I1 (60% ET). No significant differences were found within the alternate irrigation treatments, or among nitrogen treatments. Shoot number was not affected by either irrigation or nitrogen treatments (averaging 10 shoots/plant over the experiment period and until the first cut).

3.2 Effect of irrigation on crop yield

The yield collected on September 13th (1st cut) and November 17th (2nd cut) was significantly affected by irrigation levels. The above ground biomass, both fresh and dry, increased significantly with increasing irrigation applications. The yield in the second harvest was approximately 25 to 40% higher than the first one. This may be due to the development of an efficient root system and to the rainfall event (40 mm) that occurred during the month prior to the second cut. Similar results were obtained by Al-Kiyyam *et al.* [22] on total fresh yield of *O. syriacum*. The effect of different irrigation strategies on total dry aboveground biomass is shown in table 1. Comparing between irrigation levels at 60% ET and at 80% ET, or at 80% ET and 100% ET, there is no significant difference. The high irrigation treatment was significantly different from all alternatives and produced the highest yield (4.67 t/ha of dry above ground biomass was produced applying 120% ET, 40% higher than applying 60% ET).

Table 1: Effect of different irrigation treatments on total dry aboveground biomass (t/ha) for first and second harvest and total yield (levels not connected by same letter are significantly different using Tukey–Cramer HSD, p=0.05).

Irrigation treatment (% of ET)	Dry aboveground biomass First harvest (t/ha)	Dry aboveground biomass Second harvest (t/ha)	Total dry aboveground biomass(t/ha)
120%	1.89[a]	2.73[a]	4.67[a]
100%	1.67[ab]	2.07[b]	3.74[b]
80%	1.44[bc]	1.88[bc]	3.32[bc]
60%	1.17[c]	1.60[c]	2.77[c]

3.3 Effect of nitrogen application on crop yield

No effect of nitrogen treatments was noted on the fresh yield of both cuts or the dry yield of the first cut. Table 2 shows the effect of nitrogen treatments on the dry yield of the second cut. This deferred response is believed to be due to the presence of sufficient nitrogen level in the soil before fertilization. The analysis shows no significant difference between applying high nitrogen treatment (225 kg/ha) and the no nitrogen treatment (0 kg/ha). Yield was significantly higher with the highest nitrogen treatment but only using the student-t test.

Table 2: Effect of different nitrogen treatments on total dry aboveground biomass (t/ha) for the second harvest (levels not connected by same letter are significantly different using the Tukey–Kramer HSD test; * indicates significantly different than all other treatments using the Student-t test, p = 0.05).

Nitrogen (kg/ha)	Dry Aboveground biomass (t/ha) Second Harvest
N4 (225)	2.42[a*]
N3 (150)	1.93[b]
N2 (75)	1.88[b]
N1 (0)	2.05[ab]

Figure 1 shows the response surface of the total above ground dry biomass to irrigation and nitrogen treatments. The response was created by allowing the nitrogen and irrigation treatments to be continuous variables within the statistical analysis. The response is a convex surface which has two peaks, at low and high nitrogen levels (0 and 225 kg/ha). The dry yield reach its maximum (5.78 t/ha) in the combination of the highest nitrogen treatment (225 kg/ha) with the highest irrigation level (120% ET).

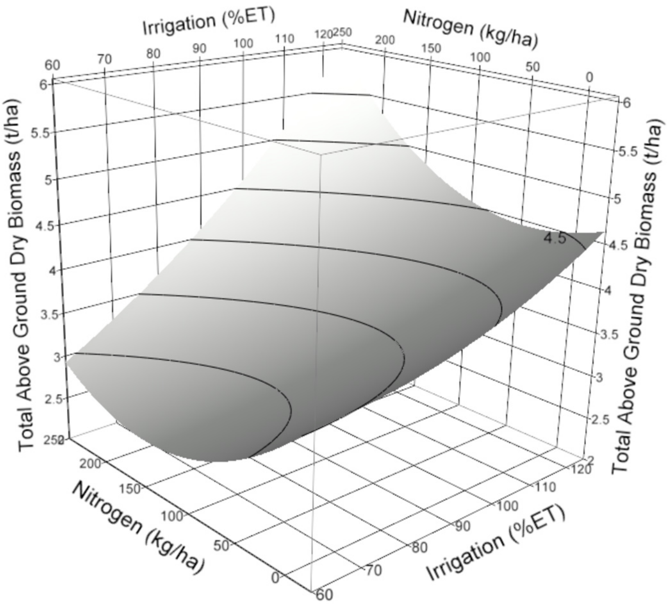

Figure 1: Response surface of total above ground dry biomass to irrigation and nitrogen treatments.

Table 3 shows the effect of different irrigation and nitrogen treatments on total dry aboveground biomass (t/ha) for total yield. The production in plots where 120% ET was applied is significantly higher than applying 60% ET, regardless of the level of nitrogen. There is no significant difference between nitrogen treatments or among 60% ET irrigation level and 80% ET.

3.4 Water productivity

Water productivity (Table 4) linearly decreased (Figure 2) with increasing irrigation application. A peak was not reached, indicating the need for a higher and lower irrigation application to determine the full range of the water productivity values. A polynomial fit was also possible for this graph with a slightly improved R-squared (0.995 vs. 0.992 in the linear fit). Increased water productivity with drier irrigation regimes indicates that the crop is utilizing applied water more efficiently, although the total dry yield is lowest.

Table 3: Interaction effect of different irrigation and nitrogen treatments on total dry aboveground biomass (t/ha) for total yield, (levels not connected by same letter are significantly different).

Irrigation (% ET)	Urea Nitrogen (kg N/ha)			
	0	75	150	225
60%	3.21[cde]	2.68[de]	2.49[e]	2.72[de]
80%	3.58[bcde]	3.37[cde]	3.03[cde]	3.29[cde]
100%	3.17[cde]	3.85[bcde]	3.88[bcde]	4.06[bcd]
120%	4.92[ab]	3.73[bcde]	4.24[abc]	5.78[a]

Table 4: Water productivity of *O. syriacum* (kg/m^3) as influenced by different irrigation treatments.

Irrigation (% ET)	Measured applied water (mm) June–November	Effective precipitation (mm)	Productivity of applied water (kg/m^3)
120%	585	80	0.70
100	433	80	0.81
I2	340	80	0.88
I1	253	80	0.97

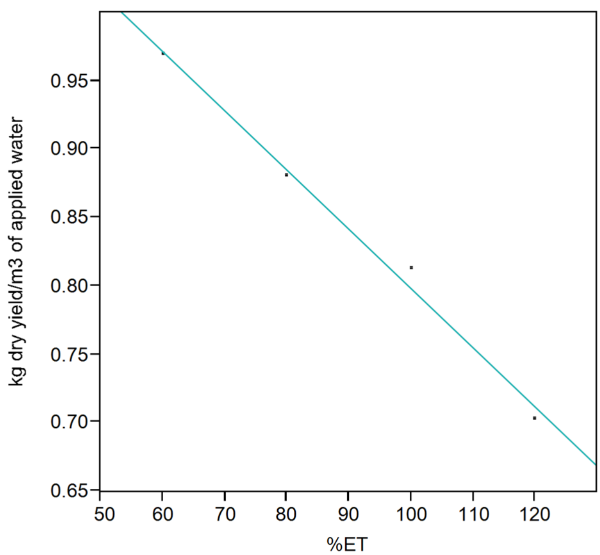

Figure 2: Water productivity of *O. syriacum* as a function of % Hargreaves ET applied water (Intercept = 1.23, Slope = -0.00433, R-Square = 0.992).

4 Conclusions

A one-season experiment has been performed on *O. syriacum* to determine its response to irrigation and nitrogen treatments in a semi-arid environment under calcareous clay soils. The experiment was conducted using an automated smart irrigation system delivering water according to Hargreaves ET using a simple weather station wirelessly connected to a controller. Results show that the set-up is helpful in conducting similar experiments due to ease of control and accuracy of delivered water. Yield response of the crop to irrigation was determined and found to be significantly affected by lowest irrigation treatments. Response of dry yield to nitrogen treatments was not realized until the second cut late in the season. Water productivity of the crop was highest in the lowest irrigation treatment. It is recommended that the full irrigation treatment of 120% ET to be applied unless the water savings using the lowest irrigation treatment are justified. Nitrogen fertilizer application should be delayed until second and third cuts in order to allow for existing soil nitrogen be utilized.

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