Drip vs. Mini-sprinkler Irrigation System on Leaf Water Potential and Various Vegetative Attributes of Annona squamosa under Lebanese Conditions

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ABSTRACT

Recently, the introduction of tropical crops in Lebanon represented a challenge for farmers and researchers. Constraints to the adaptation of such crops, to climatic and soil conditions were found. In this study, an orchard of Annona trees (Sq/Ch combination) was irrigated by mini-sprinkler system and drip system, and compared to a control (not irrigated) over two consecutive years (year 4 and year 5 of the project). Compared to the control, plant height and leaf number were improved the most in year 5 by drip irrigation. Leaf water potential that peaked in the summer season in control plants (-1.8 MPa) was the lowest in plants irrigated by drip system (-1.3 MPa). No significant difference was observed between treatments in the number of lateral shoots. TDM of plant parts was improved by drip irrigation in both experimental years by 81 g (year 4) and by 258 g (year 5). LMF was significantly enhanced in year 5 by the mini-sprinkler system. RMF was the highest in trees irrigated by drip irrigation (0.265 g/g) and the lowest in the control (0.227 g/g). SMF was the highest in control trees in both experimental years. It seems that drip system presented an optimal method for the irrigation of annona.
well as improving fertilizer use and management, resulting in higher yields and better fruit quality (de Q. Pinto et al., 2005). Water application is optimal in the early morning or late afternoon (Younes, 2016). Also, during the dry season, irrigation of Annonas should be withheld for 8 to 10 weeks to ensure dormancy and flower bud initiation. Therefore, the aim is to ensure the trees do not become stressed through the lack of water during the flowering and fruiting period (SCUC, 2006).

In recent years, farmers in Lebanon have been trying to fight the redundancy and over saturation of their crops in the Lebanese market by introducing tropical and subtropical crops such as the Annona. However, its adaptation to the climatic conditions of Lebanon is still largely understudied. Based on that, a study was conducted starting from 2013 to assess the adaptation of Annona plants to the climatic conditions of Lebanon, including that of applying various irrigation regimes such as the drip irrigation and mini-sprinkler irrigation. The study was divided into two phases. The first phases concluded that the cultivar having \textit{A. squamosa} as a scion and \textit{A. cherimola} as a rootstock was the most promising when planted in a red soil (loamy clay soil) and supplied with iron. Therefore, the experiment continued in the fourth and fifth year (phase 2) and investigated the effect of the 3 irrigations regimes. The aim of this study is to assess the efficiency of two irrigation systems: drip irrigation and mini-sprinkler irrigation compared to the control (no irrigation) by measuring several plant growth indicators.

**MATERIALS AND METHODS**

**Experimental Site**

The project was carried out for 5 years, started in 2013 and ended in 2018. The experiment was located in an orchard of Beblyeh, South of Lebanon, which is a region situated at 150 masl, with an altitude of 245 m in average, a latitude of 33.213582, and a longitude of 35.269648. During the experiment, climatic and environmental conditions of the area were recorded and the data were obtained from the Directorate General of Civil Aviation, the Department of Meteorology. The meteorological station is located in Qasmieh, which is very close to Beblyeh. The study area has a relative humidity of 70%, rainfall of 900 mm, and a temperature between 25 ± 5°C during the summer season and 10 ± 5°C during the winter season.

**Treatments and Calculations**

Based on the findings in phase 1 of the project which extended over 3 years, phase 2 continued with sugar apple plants which were obtained through cleft grafting of \textit{A. squamosa} scion on \textit{A. cherimoya} rootstock for the next two following years. These were planted in a red soil, or a sandy loamy one (Naim, El-Sebaaly, Sajyan, & Sassine, 2018), which has a low salinity, a pH of 8.01, and a low organic matter and nitrogen content. But, since Annonas prefer soils that are rich in organic matter (de Q. Pinto et al., 2005), the soil was supplied with organic manure (goat manure). Finally, also due to the findings of phase 1, the soil was supplied with iron fertilization to produce the most optimal growth conditions for Annona plants. In the orchard, the trees were planted with a distance of 4 m amongst themselves and 4.5 m between each row. The experiment was conducted over two consecutive years. Three irrigation systems were tested on these plants: control (no irrigation), drip-irrigation system, and mini-sprinkler system. Irrigation started from February to October, with an efficiency of 85% for the mini-sprinkler system and 95% for the drip irrigation system. The frequency of irrigation in each system was set based on these following procedure.

For the control, irrigation was only applied during iron fertigation (note here that 25 g/plant iron fertigation was applied in the other two irrigation systems as well, from May to September). For the mini-sprinklers: two emitters were used for irrigation of each plant with a flux of 40 l/hour by each emitter from February to October. For the drip system: four emitters were used for the irrigation of each plant a flux of 4 l/hour by each emitter from February to October.

Calculations were done using CROPWAT computer program, which models crop-specific water requirement based on the Penman–Monteith equation (Allen, Pereira, Raes, & Smith, 1998). Crop coefficients (Kc) were adjusted on 0.63, 0.65 and 0.5 at flowering, fruit set and growth, respectively (Rodriguez Pleguezuelo, Durán Zuazo, Francia Martínez, Muriel Fernández, & Tarifa, 2011).

The experiment was arranged in a randomized complete block design (RCBD) including three treatments (control, mini-sprinkler and drip-irrigation systems) and three replications per treatment.
Vegetative Traits
Plant height was measured on field during the flowering period. Plant height was measured from grafting point to the plant where brown staining color was evident and was caused by the effect of soil contact. The trunk diameter was measured at the widest point of the main stem after separating the main stem from the root system. The number of lateral shoots was counted. Leaf number (through visual counting) was recorded once per month starting from April to September.

Leaf Water Potential
Leaf water potential was measured using a pressure chamber (Model 615 pressure chamber PMS Instrument Company / USA). Leaves were sampled randomly at each time, covered with polyethylene bags to prevent water loss, and placed in the cavity of the pressure chamber. The observations were taken in both experimental years during mid-May, June and July. Readings were carried out starting at 4 am until 8 pm with an interval of 4 hours between consecutive measurements.

Plant Part Ratios and Weights
Each experimental year, 9 plants were removed from each treatment using a bulldozer. An accurate digital balance was used to weigh each bag containing samples of leaves. At this period, the fresh and dry weights of the leaves were measured after oven-drying at 100°C until obtaining of a constant weight. The following parameters were also measured:

Total Dry Mass (TDM) (g) = Dry mass of leaves (g) + dry mass of shoots (g) + dry mass of roots (g)
Leaf Mass Fraction (LMF) (g/g) = \( \frac{\text{Leaf dry mass}}{\text{Dry mass of total plant}} \)

Root Mass Fraction (RMF) (g/g) = \( \frac{\text{Root dry mass}}{\text{Dry mass of total plant}} \)
Stem Mass Fraction (SMF) (g/g) = \( \frac{\text{Stem dry mass}}{\text{Dry mass of total plant}} \)
Specific Leaf Area (SLA) (m²/kg) = \( \frac{\text{Leaf area}}{\text{Leaf dry mass}} \)
Shoot/Root (S/R) ratio (g/g) = \( \frac{(\text{Leaf + stem dry mass})}{\text{Root dry mass}} \)

Statistical Analysis
Data was analyzed using SPSS (Statistical Package for Social Sciences) software version 25®. Means were compared by Duncan’s multiple range tests at P ≤ 0.05. Repeated Measures Anova was performed on leaf number using Statistica software version 12®. Schematic representation of graphs was done using Microsoft Excel.

RESULTS AND DISCUSSION
Vegetative Growth
The data in Table 1 shows that plant height was not significantly enhanced by any irrigation system in year 4. However, in year 5 drip irrigation mostly enhanced this indicator (341.47 cm) followed by mini-sprinkler (320.14 cm) compared to the control (298.7 cm). Trunk diameter was only enhanced in year 4 similarly by drip and mini-sprinkler irrigation compared to the control. The number of lateral shoots in both years was not influenced by the irrigation systems. The number of lateral shoots in the plants irrigated by mini-sprinklers and drip irrigation was higher than that of the control, but the values were not statistically significant.

Leaf number, that was measured several times, was enhanced by both irrigation systems starting from the month of May (Fig. 1); this indicator peaked in plants irrigated by drip-irrigation. This effect was similarly observed in both experimental years.

| Table 1. Plant height, trunk diameter and number of lateral shoots of Annona trees in years 4 and 5 |
|---------------------------------|-----------------|-----------------|-----------------|
| **Year 4**                      | **Plant height (cm)** | **Trunk diameter (cm)** | **Number of lateral shoots** |
| Control                         | 279.500ab       | 7.200a          | 16.800a         |
| Mini-sprinkler                 | 275.200a        | 7.500b          | 17.500a         |
| Drip irrigation                | 281.600b        | 7.500b          | 17.200a         |
| **Year 5**                      |                  |                 |                 |
| Control                         | 298.697a        | 7.640a          | 17.900a         |
| Mini-sprinkler                 | 320.143b        | 7.837a          | 18.500a         |
| Drip irrigation                | 341.477c        | 7.830a          | 19.000a         |
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Fig. 1. Number of leaves of Annona tress on different irrigation system at year 4 and 5

Fig. 2. Leaf water potential in year 4
Leaf water potential that is represented in Fig. 2 and Fig. 3 peaked in all treatments at 12:00 pm, mainly during July. When comparing between treatments (Fig. 2) it was observed that despite the sampling month, the lowest water potential in plants was observed on drip system. For instance, at 12:00 pm/June, the lowest leaf water potential was found in drip-irrigated plants (-1.1 MPa), followed by mini-sprinkler (-1.2 MPa). The highest leaf water potential was observed at control plants (-1.6 MPa).

Similar pattern was observed in this year on the remaining two months at which the leaf water potential was measured (regardless of the time of day at which it was measured). The stimulatory effect was the same in year 5 as presented on Fig. 3.

**Plant Part Ratios and Weights**

TDM, LMF, RMF and SMF were similarly affected by the irrigation systems (Table 2) as previously observed on vegetative indicators (Table 2).

**Table 2.** TDM, LMF, RMF, and SMF in years 4 and 5

| Treatments     | TDM (g)    | LMF (g/g) | RMF (g/g) | SMF (g/g) |
|----------------|------------|-----------|-----------|-----------|
| Year 4         |            |           |           |           |
| Control        | 605.800a   | 0.143a    | 0.251a    | 0.606b    |
| Mini-sprinkler | 659.600b   | 0.162b    | 0.263b    | 0.575a    |
| Drip irrigation| 686.700c   | 0.166c    | 0.262b    | 0.572a    |
| Year 5         |            |           |           |           |
| Control        | 871.043a   | 0.156a    | 0.227a    | 0.617c    |
| Mini-sprinkler | 991.820b   | 0.171c    | 0.255b    | 0.574b    |
| Drip irrigation| 1128.687c  | 0.165b    | 0.265c    | 0.570a    |

Remarks: Values in the same column followed by different letters, differ significantly by DMRT (α ≤ 5%); TDM: Total Dry Mass, LMF: Leaf Mass Fraction, RMF: Root Mass Fraction, SMF: Stem Mass Fraction.

**Leaf Water Potential**

Leaf water potential that is represented in Fig. 2 and Fig. 3 peaked in all treatments at 12:00 pm, mainly during July. When comparing between treatments (Fig. 2) it was observed that despite the sampling month, the lowest water potential in plants was observed on drip system. For instance, at 12:00 pm/June, the lowest leaf water potential was found in drip-irrigated plants (-1.1 MPa), followed by mini-sprinkler (-1.2 MPa). The highest leaf water potential was observed at control plants (-1.6 MPa).
1), mainly at year 5. On the contrary, SMF in the control was higher than other treatments. In year 5, Annona trees irrigated by the drip system had the highest TDM (1128.687 g) and RMF (0.265 g/g), followed by mini-sprinkler (991.82 g and 0.255 g/g, respectively) and control (871.043 g and 0.227 g/g, respectively). LMF was mostly enhanced by mini-sprinkler irrigation (0.17 g/g). Finally, SMF of control plants (0.617 g/g) was the highest compared to the remaining treatments. In both years, the leaf fresh and dry weights were highest in plants irrigated by the drip irrigation, followed by those irrigated by the mini-sprinkler and control (Fig. 4). On the contrary, SLA in Fig. 5 peaked in control plants and was the lowest in drip irrigated plants. For instance, in year 5 it was 0.09 m²/kg for the control, 0.075 m²/kg for the mini-sprinkler, and 0.07 m²/kg for the drip irrigation. The shoot/root ratio was similarly affected by the irrigation treatments (Fig. 6). For instance, in year 5, the shoot/root ratio was 3.41 g/g in the control, 2.91 g/g for the mini-sprinkler and 2.78 g/g for the drip-irrigation.

In the current study, non-irrigated Annona plants adapted to the climatic and soil conditions on the orchard. This is consistent with the findings of Egydio Brandão & Santos (2016) and Kowitcharoen et al. (2018) which specified that A. squamosa is a drought tolerant plant. Trunk diameter and number of lateral shoots did not differ between irrigated and non-irrigated plants, eliminating the potential of a possible link between irrigation and the vigor of growth of these two parameters. In the same context, SMF in control plants was higher than that in the irrigated plants. Hence, the absence of irrigation induced the proliferation of stem parts on the expense of other parts; the RMF and LMF were higher in irrigated plants. As a result, the leaf water potential of control plants was the highest due to the absence of irrigation.

When comparing between both systems, drip irrigation almost maximized all studied traits. This simulative effect is related to many factors including the establishment of a vigorous rooting system and a reduction of lead water potential. Both aforementioned factors are directly related to an improved water flux inside the plant system. According to Júnior, Bandaranayake, Parsons, & Evangelista (2012) and Li, Tan, Wang, Cao, & Yang (2019), root distribution is highly affected by irrigation systems and water availability. Similar findings were reported by El-Beltagi, Sassine, Hammoud, & Sebaaly (2019) stating that under drought conditions, irrigation systems positively affect the growth of Annona plants. This is related to the difference of efficiency of water delivery between both of these two irrigation systems. This is an evident from the findings of Jägermeyr et al. (2015) which concluded that drip irrigation is more efficient due to the fact that its water emission is restricted to a smaller wetted soil volume. Its efficiency decreases the amount of water loss through effectively decreasing the amount of leaching and evapotranspiration, compared to other irrigation systems. This results in a higher income per water unit (FAO, 2007; Ouda, Zohry, & Noreldin, 2020).
The adoption of the drip water system minimized water stress, which is revealed by lowering the leaf water potential. In fact, this indicator is reliable in measuring water balance inside the plants (Ratzmann, Zakharova, & Tietjen, 2019). The increase of leaf water potential in the control plants is directly related to the soil water content and consequently the water movement inside the plant. According to many authors, water stress is coupled with an increase in abscisic acid (ABA) biosynthesis in the roots at first and later on in the shoots, causing stomatal closure and reduction in leaf dimensions (Hu, Cao, Ge, & Li, 2016; Saradadevi, Palta, & Siddique, 2017). This was reflected in the current study by a reduction in the leaf fresh and dry weights. On the contrary, with the application drip water irrigation, the accumulation of water and the resulting translocation of nutrients such as iron were reflected in an increased fresh and dry weight of leaves, compared to the control.

**CONCLUSION**

The adoption of drip irrigation allowed the plant to establish a balance between its roots and...
above ground parts. Future research is to study the best time interval between the consecutive irrigations that is the most suitable for the field conditions.

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