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EFFICIENCY OF DRIP IRRIGATION SYSTEM FOR «PAULOWNIA» TREES IN THE AAKKAR COASTAL PLAIN OF LEBANON

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ABSTRACT: The term «irrigation efficiency» is an important indicator for the evaluation of rational use of water in agriculture which is a main consumer of water in Lebanon that is soon going to suffer from water shortage. The current research includes the study of a pioneer crop that has an economical and environmental potential: it is the fast-growing «Paulownia» tree associated with citrus and cultivated on a parcel equipped with a drip irrigation system. The detailed review of this parcel consists of soil, crop and hydraulic study. The ratio of the required calculated net crop water compared to the consumptive gross volume of water used for the crops shows the average level of the irrigation efficiency on the parcel which eventually requires improvement. Consequently, the analysis aims to identify the reasons behind this level of efficiency and to recommend the adoption of certain techniques and feasible measures for improvement.
Key words: fast growth Paulownia tree, drip irrigation efficiency, crop water requirements.

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INTRODUCTION

The need of water which is a main element for survival of all living beings, is gradually increasing, because on the one hand, the demand of the population is constantly growing and modern lifestyle promotes excessive consumption of water, and on the other hand, the decrease in water availability due to pollution is affecting the natural water resources. This requires a global intervention to rationalize the use of the mobilized water, especially in agriculture which is a major water consumer.

Characterized by a short and cold winter and a long and hot dry season, the climate of Lebanon imposes the supply of irrigation water to farmlands during dry season. Irrigation is considered the lifeline of agriculture whose main role is to improve the productivity of agricultural surfaces, increase farmers' incomes, and stabilize the rural society of the country. From the 248,000 hectares of utilized agricultural area (S.A.U) that form roughly ¼ of the total area of Lebanon, only 104,000 hectares are irrigated that is 42% of the S.A.U.[1]. Among the different consumption purposes of the available water, irrigated agriculture ranks first (64.8%), followed by domestic use (30%), and industry use (5.2%) [2].

Several scenarios and attempts to draw up a national balance of resources and needs were presented in various bibliographies. The various balance sheet terms differ slightly from one reference to another. Based on several statistics, a study was proposed by the Ministry of Environment, the World Bank and the American University of Beirut (AUB), where it was stated that Lebanon should expect a shortage of water starting in 2012 (fig.1).

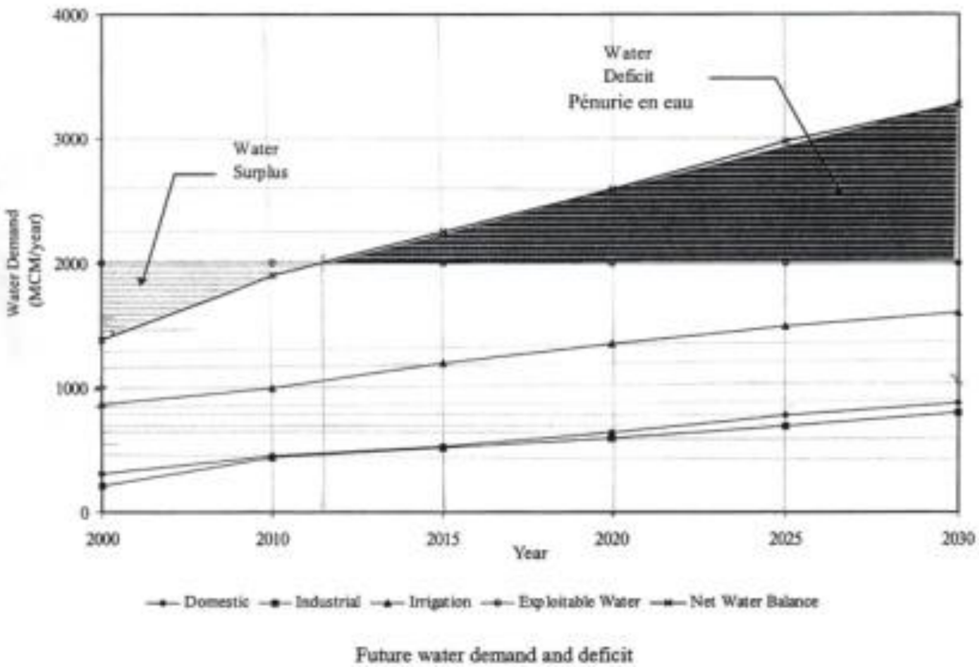

Figure 1: The eventual water shortage in Lebanon (MimEnv/ AUB / WB, 2001) [3]

Certainly, optimizing irrigation can be achieved by the correct adoption of new on-farm irrigation techniques such as localized systems (drip, micro sprinkler ...) whose efficiency could reach 95%, instead of the adoption of traditional surface methods whose efficiency is often less than 50%. Despite this, it would be necessary to improve the on-farm irrigation management by the application of water volume based on calculation of crop water requirements (quantity of water needed) and by finding the right time for watering (when to irrigate).

The efficiency of the on-farm irrigation is defined as the ratio of the volume of delivered water to the input of the operation and used by evapotranspiration for a given crop (net water requirements), minus losses by runoff and percolation. The efficiency of the application is the result of two main factors: (i) adequate frequency and irrigation dosage compared to the crop water requirements (ii) water application uniformity.

In other words, efficiency is the ratio of the gross volume given to a cultivated soil on the calculated net crop water requirements. Irrigators often tend to provide excessive doses especially when they lack experience, which decrease the rate of irrigation efficiency and cause unwanted water loss. The objectives are to (i) contribute to water savings as water is becoming a threat to the entire Lebanese population; (ii) highlight the importance of water in agriculture which is a sector that implicates irrigation planners to optimize irrigation and (iii) show the benefits of shifting from traditional surface irrigation towards more efficient irrigation techniques such as drip irrigation.

MATERIAL AND METHODS

The experimental site

The study was conducted during the 2009 growing season in a typical associated citrus + paulownia orchard situated in the northern coastal plain of Aakar, Lebanon. The selected site has an altitude of 38 m above the sea level, 34° 38'N and 36° 04'E. Weather is typically sub-humid Mediterranean characterized by a hot and dry summer extending from May through September and a cold and rainy winter with well-marked strong winds. Average annual rain is of 840 mm (Climatic Atlas of Lebanon 1977). About 95% of the precipitation fall between November and March and the rest in April-May. Long term rain averages recorded at Abdeh station of the Lebanese agricultural Research Institute (LARI) show no rain between June and August. High temperatures during summer period induce high rates of potential evapotranspiration.

Laboratory analyses of soil samples taken from the experimental site at 0-40 cm depth of the soil profile showed 17.3% sand, 32.0% silt, 48.9% clay and 1.8% organic matter. The soil texture is clay-silt.

The experimental orchard is 5.61 ha (535 m long × 105 m wide) cultivated with paulownia trees (cv. Valencia) and is situated within a farm the one total area is 125 ha. Paulownia trees are planted at 6 m x 3 m dimensions and are alternated with citrus trees planted at the dimensions (Fig 2). The contours of the orchards are planted with pomegranate trees serving as wind breaks.

Paulownia was introduced in Lebanon for the first time in 1997.This tree can be considered as a new cash crop in Lebanon for timber production which often imported at rising prices. Rough calculations of profitability were encouraging for some farmers who are able to conduct long-term investments. The expected average annual profit is 6000 US dollars per hectare (for 6 m × 3 m) planting dimension the number of paulownia trees in one hectare is 555 trees). Grown for one year in a nursery, seedlings of paulownia were transplanted into the plot in alternation with 8-year old citrus trees. Due to the exceeding height of paulownia trees, alternate trees such as citrus do not suffer any relevant growth problem because they receive enough solar radiation.
In the study area, water for irrigation is distributed to the farm through open channel collective distribution network, which gain their sources from the nearby "Estouane" river. In addition, some farms in the area use groundwater as the main source for irrigation. Groundwater is exploited through wells equipped with submersible electrical pumps. Most of the farms use traditional furrow irrigation system.

Irrigation system

The experimental orchard (5.61 ha) is divided into 4 blocks, 1.4 ha each. The orchard is equipped with a localized drip irrigation system, which consists of the following components:

a. Lateral pipes with drippers

Each row of trees is provided with a polyethylene lateral pipe of 25 mm Ø (diameter) that has incorporated drippers (emitters) which permit for water to flow directly to each tree in a localized routine.

Two types of drippers are used: "Azud" of (12 ℓ/h) flow and "arab-drip" of (4 ℓ/h). Emitters are fixed as the following (Table 2):

- For the 8 years old orange tree: 5 drippers of (12 ℓ/h) are fixed, making a total flow rate of 60 ℓ/h/tree.
- For a new "Paulownia" tree: 4 drippers of (12 ℓ/h) are fixed, making a total flow rate of 48 ℓ/h/tree.
- For pomegranate tree: 4 drippers of (4ℓ/h) are fixed, making a total flow rate of 16ℓ/h/tree.

b. Sub-main pipes

Drippers incorporated in laterals pipes are fed from a sub-main pipe of polyethylene of 75 mm diameter.

c. Main pipe

The sub-main pipes are fed by the main line supplying water from the head unit until the block. Its diameter is 125 mm and its length is 500 m. The main pipe also is equipped with 4 gate valves, 125 mm in diameter, installed at the upstream of each of the existing 4 blocks.

d. Control head unit

It consists of:

- A flow meter to read and record the volume of irrigation water in (m^3) delivered to the orchard;
- A 125 mm disc filter whose role is to trap the solid particles found in the water in order to prevent clogging problems in the drippers;
- A fertilizer mixer to inject fertilizer into the irrigation system;
- A hydro-cyclone filter to remove heavy solid particles (sand) found in the pumped ground water;
- Pressure gauges for direct indication of the operating pressure in the irrigation system;
- A submersible pump for pumping groundwater from a depth of (Δh = - 60 m) approximately, through an electric generator consuming fuel.

By using the volumetric meter, the measured volume of water pumped into the drip system was 57 m^3/h for irrigating a block of 1.4 ha, thus corresponding to an irrigation module of 40 m^3/h/ha. For Paulownia trees whose flow dripper holds 42% (Table 1), the volume provided will be 16.8 m^3/h. As a result, for irrigation duration of 1 to 3 hours the dose of water supplied would be from 16.8 to 50.4 m^3.

Calculation of irrigation requirements of paulownia trees

Crop water requirements of paulownia trees were calculates using the FAO approach based on CROPWAT software and its associated CLIMWAT database [4,5]. CROPWAT is software to carry out standard calculations for reference evapotranspiration, crop water requirements, and crop irrigation requirements, and more specifically the design and management of irrigation schemes [4,5].

The program uses monthly climatic data (temperature, relative humidity, wind speed, sunshine hours), for the calculation of reference evapotranspiration. To do all its work the software needs another program which is the CLIMWAT to gives the climate and rain data of the nearest station of our orchard. In our case, the nearest appointed weather station by CLIMWAT was Abde station of the Lebanese Agricultural Research Institute (LARI). Potential evapotranspiration (ETo) in CROPWAT is calculated using the Penman-Monteith equation using daily inputs of minimum and maximum air temperature, minimum and maximum relative humidity, wind speed at 2 m height and solar radiation. Effective rain in CLIMWAT database is calculated at the basis of 65% of total rain using the USDA S.C. method.

The calculations of irrigation requirements encompass five steps (Table 2):

Step 1: Calculation of daily potential evapotranspiration (ETo in mm/day) by CROPWAT. Daily ETo is then converted to mm per month by multiplying the daily ETo rates by the number of days;

Step 2: Monthly crop water requirements (ETc) are calculated as the product of ETo (mm/month) and the corresponding crop coefficient (Kc). Values of Kc at single growth stages of paulownia were obtained from the Chinese Academy ofForestry Staff and the Canadian International Research Center (1986);

Step 3: Effective rain ($Rain_{eff}$, in mm) is obtain from rain database in CLIMWAT as:

$$Rain_{eff} = Rain \times 0.65 \qquad (1)$$

Step 4: Net Irrigation Requirements (NIR, in mm) are calculated as the difference between crop water requirements (ETc) and effective rain ($Rain_{eff}$);

Step 5: Gross Irrigation Requirements (GIR, in mm) are calculated as the ratio of NIR to the efficiency of on-farm irrigation system (E_u, in%). E_u is the product of the efficiency of the irrigation system (E_{is}, %) and distribution uniformity (DU, in %):

$$GIR\ (mm) = \frac{NIR\ (mm)}{Eu\ (\%)} \qquad (2)$$

In our case, the theoretical efficiency of the drip irrigation system (E_{is}) was considered 0.9 (90% efficient) and the uniformity of distribution of water flow through the drippers also was 0.9 (90% uniformity), so that measured E_u was equal to 0.81 (81%).

RESULTS AND DISCUSSIONS

Calculations of net and gross irrigation requirements of paulownia trees

Table 2 illustrates the results of the 5-step procedure described in the material and methods for the calculation of net and gross irrigation requirements of paulownia trees. At first, the calculations of potential evapotranspiration (ETo) made with CROPWAT gave an average daily rate of 3.85 mm (row 2) and an average daily rate of crop evapotranspiration (ETc) of 2.0 mm (row 4). The summation of monthly ETc values yields 733.4 mm (row 5). This value represents crop water requirements of paulownia trees all over the year. Data in row 6 are those of effective rain provided by CLIMWAT database for Abdeh meteorological station as 65% of monthly rain. After that, irrigation requirements at monthly basis are calculated as the difference between crop water requirements in row 5 and effective rain in row 7. These calculations are illustrated in row 8. * When values of $Rain_{eff}$ are higher than ETc, then negative values are not summed up as seasonal net irrigation requirements. Table 1 shows that seasonal net irrigation requirements of paulownia trees from April through October are 564 mm. At a final stage, seasonal net irrigation requirements are converted to gross irrigation requirements by dividing by the efficiency of the on-farm irrigation system (E_u) and the obtained value is 696 mm. Figure 2 provides an illustration of the evolution of net seasonal irrigation requirements of paulownia from April through, along with the corresponding crop coefficient (Kc).

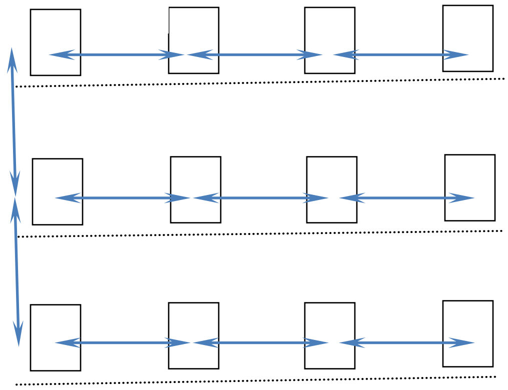

Figure 2: Distribution of paulownia (P) and their associated Valencia citrus trees (C) in the study plot

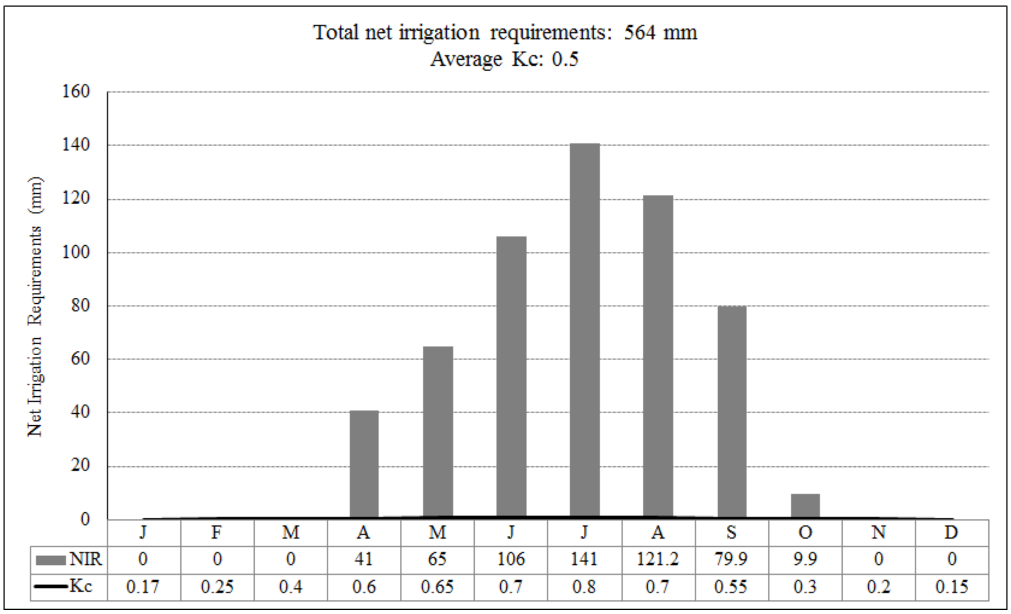

Figure 3: Evolution of net irrigation requirements and crop coefficients (Kc) of Paulownia trees

Table 1: Volume of water provided for each crop (dripper of 12 ℓ/h an 4 ℓ/h)

		Crop			Total
	Unit	Oranges	Paulownia	Pomegranate	
Number of drippers of (4 ℓ/h) / tree			4		
Number of drippers of (12 ℓ/h) / tree		5	4		
Flow rate (ℓ/h) / tree		(4 x 12)= 60 ℓ/h	(4 x 12) = 48 ℓ/h	(4 x 4) = 16 ℓ/h	124 ℓ/h
Number of trees		2 250	2 200	800	
Total dose per trees species	(m3/h)	2250 x 60 = 135	2200 x 48 = 105.6	800 x 16 = 12.8	253.4
% of the water flow given per tree specie	%	54	42	4	
Total water volume given per season (1 May - 18 September) (counter)	m3	13 350	11 865	990	24 718

Table 2: Calculations of net and gross irrigation requirements of Paulownia tress in Aakar coastal area (Lebanon)

			Months												Total
		Unit	J	F	M	A	M	Jn	Jl	A	S	O	N	D	
1	Number of days	Days	31	28	31	30	31	30	31	31	30	31	30	31	
2	Eto	mm/day	2.1	2.5	3.0	3.6	4.0	5.1	5.7	5.6	5.2	4.0	3.1	2.3	
3	Kc	unitless	0.17	0.25	0.4	0.6	0.65	0.7	0.8	0.7	0.55	0.3	0.2	0.15	
4	Etc = Eto x Kc	mm/day	0.36	0.63	1.2	2.16	2.6	3.57	4.56	3.92	2.86	1.2	0.62	0.35	
5	Paulownia water requirement Etc	mm/month	11.1	17.5	37.2	64.8	80.6	107	141	121	86	37	18	1	
6	Rain (R)	mm/month	206	127	100	36	23	1	0.5	0.5	9	42	109	186	
7	Effective Rain (R x 65%)	mm/month	134	82.5	65	23.4	15	0.6	0.3	0.3	5.85	27.	71	121	
8	Net Irrigation Requirement NIR = (Etc – EffRain)	mm/month	-123	-65	-28	+41	+65	+106	+141	+121	+80	+10	-52	-110	
9	Seasonal Net Irrigation Requirement	mm/month				41	65	106	141	121	80	10			564
10	Measured On-farm irrigation system (Eu =	%													
11	Gross Irrigation Requirement (GIR)	mm/month				51	80	131	171	150	99	12			694
12	Drip GIR (30% coverage)	mm/month													208

* When $Rain_{eff}$>ETc values are negative and are not summed up as seasonal net irrigation requirements

Table 3: Calculated and effective net seasonal irrigation requirements of paulownia under the climatic conditions of coastal Akkar plain

	Irrigation method	Area (ha)	m^3/season
Calculated net irrigation requirements	Surface furrow	1.0	5640.0
	Surface furrow	5.61	27104.0
	Localized drip system	5.61	9492.2
	Localized drip system	5.61	10382.0

Determination of irrigation efficiency

For the 5.61 ha experimental orchard, the calculated net irrigation requirements of 564 mm make a total of 31640.4 m^3, or 5640 m^3 per ha. It is worthwhile to mention that irrigation stopped in September 18th because rain was recorded after that date and there was no need for irrigation as there was enough moisture in the soil. As a result, total pumped water for irrigation into the 5.61 fa experimental orchard was 27104 m^3 as recorded by the flow meter of the head unit.

In other words, seasonal net irrigation requirements of Paulownia trees under the climatic conditions of the coastal Akkar plain is 5640 m3/ha and total net irrigation requirementsfor the whole 5.61 ha experimental orchard are 31640.4 m3. For the installed drip irrigation system, where the irrigated area does not exceed 30% of the total planted area, real net irrigation requirements would be 31640.4×0.3, say 9492.2 m3. This value will be used for the estimation of irrigation efficiency.

On the other hand, the recoded supplied irrigation volume throughout the irrigation season into the 5.61 ha experimental orchard is 24718 m^3, taken into account as mentioned above that irrigation was withheld on 18th September. Given that the flow rate of drippersrepresents 42% of total irrigation supply volume, this results in an equivalent value of 10382 m^3.

As such irrigation efficiency can be obtained as the ratio of calculated net irrigation volume to effective applied gross water volume:

$$\frac{\text{Calculated net irrigation volume}}{\text{Effective applied gross water volume}} = \frac{9492.2 \text{ m3}}{10\ 382 \text{ m3}} x\ 100 = 91.4\%$$

The results of the irrigation efficiency show that paulownia growth is improved when irrigation is better scheduled. Many studies, namely García-Morote et al [6], LIano-Stelo et al. [7]. Indeed, these authors demonstrated that biomass production of paulownia trees improved when irrigation efficiency was increased. They also demonstrated that higher dose of irrigation led to higher biomass production, but water availability remains the main factor controlling biomass growth and production of paulownia. These studies showed that the recommended method of watering paulownia is drip irrigation, with constant flow of watering along with high aptitude to fertigation to ensure a rapid growth regime.

CONCLUSIONS

Given the importance of irrigation management in agriculture to achieve good efficiency of water use by crops and trees to minimize production costs and reduce stresses on the environment, it would be of benefit to paulownia farmersand growers to adopt a series of good practices that aim at better estimating irrigation requirements at a given growth stage. In addition, drip irrigation has been shown to be an efficient system for irrigation paulownia trees under semi-arid conditions. Drip irrigation has the advantage to supply sufficient nutrients for paulownia growth at the higher level of soil moisture.

The results of this research clearly show the difference between the theoretical calculations of water requirements and the volume of water brought to the land by farmers. It is obvious that this difference is considerable water loss.This is the general aspect of water use in agriculture. This pushes agronomists to play a special role in the irrigation management in order to face the problem of near water scarcity in the country and contribute in its improvement.

By using the FAO approach, irrigation requirements of paulownia trees were in the range of 560-570 mm during the whole irrigation season from April through October, with high irrigation requirements during the period of July-August. This corresponds to the net irrigation requirements, which in other terms are the difference crop water requirements and effective rainfall. This finding helps irrigation planners and deciders to account for the needed irrigation requirements of paulownia trees before taking any step toward establishing new orchards. On the other hand, drip irrigation has been shown to act efficiently in irrigated paulownia orchards. With an irrigation efficiency at on-farm level ranging from 80% to 85%, gross irrigation requirements pf paulownia were found to be close to 700 mm, or some 7000 m3 for each irrigated hectare.

We concluded that in semi-arid Mediterranean regions, such the Northern Akkar Pain of Lebanon, drip irrigation can be an effective approach for water saving and environmental protection. On the other hand, with its rapid growth and huge biomass production, paulownia is recognized to play a key role in maintaining ecologicalbalance and improving the rural livelihood in the semi-arid areas of Lebanon, and can serve as an effective strategy to carbon storage and mitigation of global climate change.

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