Productivity and water saving of ‘Fortune’ plum under different water regimes

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Abstract. This study was conducted over four consecutive years (2015-2018) in the Sefrou region of Morocco, between Sais and the Middle Atlas Mountains. The goal of the study was to assess how plum trees respond to three different irrigation strategies: a normal supply of water (T2) to meet 100% of crop water needs; an irrigation deficit (T1) that provides only 75% of the water needs; and an additional water supply of 25% (T3) above the crop needs. The study found that deficient irrigation (T1) had no significant effect on plum yield or average fruit weight at harvest, but an excess water supply of 25% (T3) over the requirements (T2) resulted in higher yields and average fruit weight than the control. T3 also showed an increase in fruit size at harvest compared to the control, but not in T1 compared to T2. However, the excess water input for T3 did not justify the excess yield in terms of water use efficiency (WUE). On the other hand, T1 maintained the same level of production as the control while saving water, which resulted in a higher WUE compared to T2 and T3..
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1. Introduction

The hydrological context of water resources in Morocco is becoming increasingly worrisome due to globally recognized climate change and water scarcity. Morocco is located in an arid to semi-arid zone resulting in scarce and irregular rainfall [1]. The effects of climate change are a concern for water professionals in Morocco and all regions of the world [2, 3]. According to most forecasts, climate change will cause increasing aridity in Morocco in the coming decades [4, 5]. Furthermore, growing demand for water and increasing scarcity of the resource only add to these concerns.

On the other hand, agriculture is found to consume 85% of all the water used in the world [6] and 93% of Morocco's water [7]. Among the biggest consumers of irrigation water are fruit trees, which have developed considerably in recent years, the plum tree, for example, which is the focus of this study, has increased from 2100 ha to 13 950 ha in irrigated areas between 1980 and 2018 [8]. So, the sustainability of fruit tree production in the country cannot be taken for granted any longer. It's time to take immediate action to ensure that we can continue to reap the benefits of this industry in the long run. We must act now and make the necessary changes to guarantee a sustainable future for this vital sector.

A critical challenge for the upcoming decades is to increase food production while using less water. This can be achieved by improving water use efficiency through the application of appropriate irrigation strategies, including deficit irrigation. [9].

Thus, this paper examines and evaluates the response of plum (var. Fortune) to three amounts of irrigation on young plum trees, 75%, 100%, and 125% of the crop evapotranspiration during 4 years of trial (2015-2018).

2. Materials and methods

2.1. Experimental orchard

The study was conducted over four growing seasons (2015; 2016; 2017 and 2018) in an agricultural farm located in the atlas mountain "Louata" near the city of Séfrou-Morocco. The 'Fortune' trees were planted in 2010 in a north-south orientation, spaced 3m x 6m, and pruned into a Goblet form on the 'Myrobolan' rootstock. The soil was clay-silt with 38.8% clay, 38.3% silt, 22% sand, and 16% active limestone in the upper layer (0-40 cm) containing the effective root system. During the four experimentation years, the average air temperature (°C) in the region was approximately 17.6; 18.5; 18.6, and 16.1 °C for 2015, 2016; 2017, and 2018 respectively. Precipitation during the three production seasons was 459, 340, 287, and 429 mm, respectively, for 2015, 2016, 2017, and 2018 (Table 1). The amount of rainfall was considered while distributing irrigation water to each treatment. The experimental plots were equipped with a drip irrigation system that had two drip lines with integrated, self-regulating drippers. The drippers were evenly spaced 75 cm apart on the ramp and delivered 3.6 l/hour. Each tree is supplied by 8 drippers distributed over two ramps, giving an hourly rainfall of 1.6 mm/hour.

Table 1 . Total precipitation and average temperature for the years 2015, 2016, 2017, and 2018.

Year	Total precipitation in (mm/year)	Average temperature in (°C/year)
2015	459	17,6
2016	340	18,5
2017	287	18,6
2018	429	16,1

2.2. Irrigation treatments

The daily net irrigation amount is calculated using a water balance formula that compares crop water requirements to the water supply from natural sources.

$$GWR = ((Kc * ETo)/IE*UC) - Er \qquad (1)$$

with *GWR*: Gross Irrigation Water Requirement (mm); *Kc*: Cultivation coefficient for plum proposed in FAO Bulletin 56 [10] (Kc_{in} = 0.8 during flowering, cell division and hardening of the stone; Kc_{mid} = 1.3 at fruit swelling and Kc_{end} = 0.85 during ripening); *Er:* Effective rainfall (mm), also called useful rainfall, is calculated by subtracting the losses due to runoff or deep percolation (70%) from the total rainfall; The irrigation efficiency (*IE*) was quite high at 0.9 since the irrigation network was relatively new. The term *UC* refers to the uniformity coefficient which was equal to 90% in our study; and *ET0* is the daily reference evapotranspiration, expressed in (mm/day) and calculated by the Penman Monteith formula *(2)* using the climatic data received from a meteorological station located on the same site.

$$ET0 = (0{,}408(Rn-G) + (900/T).\gamma.u2.\ \delta e) / (\Delta + \gamma(1+0{,}34u2)) \qquad (2)$$

ET0 = Potential evapotranspiration, Water volume evapotranspired (mm day−1)
Δ = Rate of change of saturation specific humidity with air temperature. (Pa K−1)
Rn = Net irradiance (MJ m−2 day−1), the external source of energy flux
G = Ground heat flux (MJ m−2 day−1), usually equivalent to zero on a day
T = Air temperature at 2m (K)
u2 = Wind speed at 2m height (m/s)
δe = vapor pressure deficit (kPa)
γ = Psychrometric constant (γ ≈ 66 Pa K−1)

Irrigation treatments were as follows: an irrigated treatment T1 with a deficit amount, receiving 75% of the crop's water needs throughout the cycle; an irrigated control T2 receiving 100% of the crop's evapotranspiration and T3 receiving an over-irrigation of 25% of the crop's needs and therefore 125% ETc. Aside from the irrigation levels mentioned earlier, the trees received identical agricultural practices including pest control, pruning, and fertilization...

2.3. Experimental design

In this study, a randomized complete block design was utilized, consisting of four block replicates, each including all three treatments. Each treatment group was composed of five trees within the same block. Among them, three trees with the same trunk diameter were selected to monitor various parameters, while the remaining two were used as guard trees.

2.4. Climatic conditions

A fairly remarkable difference appears between the four years of the experiment, putting the first year of the trial in first place in terms of rainfall with an annual total of 459 mm, of which 37% during fruit development. In a second place, 2018 appears with 429 mm during the whole year and 208 mm during the cell division of the fruit. 2016 takes the third class with a total of 340 mm for the year and 182 mm during the first phases of fruit growth. And finally, 2017 records 287 mm, 81% of which is in the dormant phase of the tree (Figure 1). In terms of average temperature, it could be noted that during the 4 trial years, this parameter followed the same trend, with a remarkable difference during the pit hardening phase until harvest between 2017 and 2018, up to a 7 °C difference.

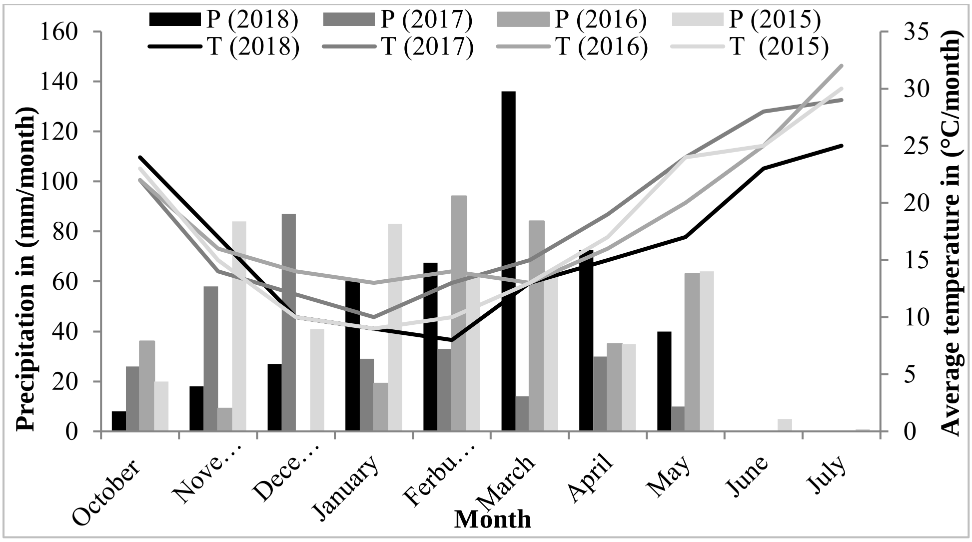

Fig. 1. Average temperature and total precipitation per month for the years 2015 (■), 2016 (■), 2017 (■) and 2018 (■).

2.5. Measured parameters

2.5.1. Production parameters

After the thinning operation, we counted the total number of fruits per tree. Yield per tree was determined by weighing the yield at harvest across all passes and an extrapolation of yield per hectare was subsequently calculated. Average fruit weight was calculated after.

2.5.2. Water Use Efficiency

Agronomic efficiency of water use, also known as water productivity, is a significant indicator that helps to determine the economic profitability of each treatment in relation to the amount of water used. This parameter has been calculated for every treatment, enabling a comparison of all treatments in terms of agronomic efficiency.

The formula for calculating water use efficiency:

$$WUE = y / ET \qquad (3)$$

Where: *WUE* = Water Use Efficiency; *y* = Crop Yield (Kg) ; and *ET* = Evapotranspiration or water applied (m^3).

2.6. Data processing

The data obtained from the experiment was analyzed using SPSS and Microsoft Office Excel. The analysis included descriptive statistics such as means, standard deviation, and coefficients of variation, as well as analysis of variance. If significant differences between treatments were found, the means were compared at a 5% threshold using the Student Newman and Keuls (SNK) test.

3. Results & discussion

3.1. Yield and its components

Based on the yields presented in (Table 2), it is important to note that with the exception of the first year of the trial (2015) which experienced hail, the following three years (2016, 2017 & 2018) showed almost the same yield response to the tested irrigation regimes. In detail, there was no significant difference between the three treatments T1 (75%), T2 (100%) and T3 (125%) in terms of yield response in 2015. On the other hand, and for the years 2016, 2017 and 2018, T3 (125%) still leads the yield obtained with 53.35; 42.73 and 61.08 (t/ha) respectively for 2016, 2017 and 2018. Secondly, T2 (100%) was able to record yields of 44.77; 37.23 and 57.63 (t/ha) for 2016, 2017 and 2018 respectively. Finally, the deficit treatment T1 (75%) recorded the lowest yields with 42.07, 37.20 and 54.47 (t/ha). It should also be noted that the difference in yield between the T3 treatment (125%) and the T2 control (100%) was significant, while the difference in yield between the T2 control (100%) and the T1 deficit treatment (75%) did not appear to be significant.

Table 2 Effect of irrigation treatments on the yield and fruit weight of 'Fortune' plum across four years (2015-2018). The data provided represent means ± standard deviation, with different letters indicating significant differences as per the SNK test at P ≤ 0.05. You can find a detailed description of the treatments used in Section 2.2.

Seasons	Treatments	Parameters	
		Yield in ($t.ha^{-1}$)	Fruit weight in (g/fruit)
2015	T1	20,00 ± 18,41 a	82,77 ± 16,61 a
	T2	26,30 ± 18,95 a	77,59 ± 18,48 a
	T3	19,90 ± 21,57 a	94,49 ± 14,79 a
2016	T1	42,07 ± 6,61 b	51,05 ± 8,91 a
	T2	44,77 ± 7,61 b	50,83 ± 10,39 a
	T3	53,35 ± 16,42 a	55,48 ± 14,32 a
2017	T1	37,20 ± 9,75 b	83,28 ± 16,45 b
	T2	37,23 ± 8,73 b	86,86 ± 18,35 b
	T3	42,73 ± 6,91 a	107,71 ± 14,42 a
2018	T1	54,47 ± 6,41 b	122,03 ± 6,39 b
	T2	57,63 ± 6,54 b	130,05 ± 7,35 b
	T3	61,08 ± 8,03 a	140,10 ± 5,40 a

Based on the above, it can be said that a 25% restriction of water requirements compared to 100% evapotranspiration demand allows a 25% saving in the quantities supplied without penalizing yields. On the other hand, a 25% increase in water supply leads to a decrease in water savings, but a significant increase in yield.

The difference between the 2015 results on the one hand and those of 2016; 2017 and 2018 on the other hand can be linked to the climatic conditions of the year 2015 and more precisely to rainfall. Indeed, among the four years of the trial, 2015 recorded the highest total rainfall, with 459 mm during the whole year and 170 mm during the fruit growth phases. Therefore, as water was not a limiting factor for any of the treatments in 2015, the difference in yield did not occur between them.

It should be noted that there is not enough research on plum irrigation strategies, specifically sustainable deficit irrigation (SDI) and over-irrigation. The application of moderate SDI on young trees in the short term has been found to increase water use efficiency without affecting tree performance, which is consistent with our findings. However, when young trees are subjected to long-term water restriction (seven consecutive seasons), it does not affect yield but leads to smaller trees. This ultimately caused a 29% decrease in yield in the eighth season when the previously deficit-irrigated trees were fully watered [11].

3.2. Water productivity (WUE)

The water use efficiency values for the plum yields achieved under the different treatments (T1, T2, and T3) are shown in the figure below.

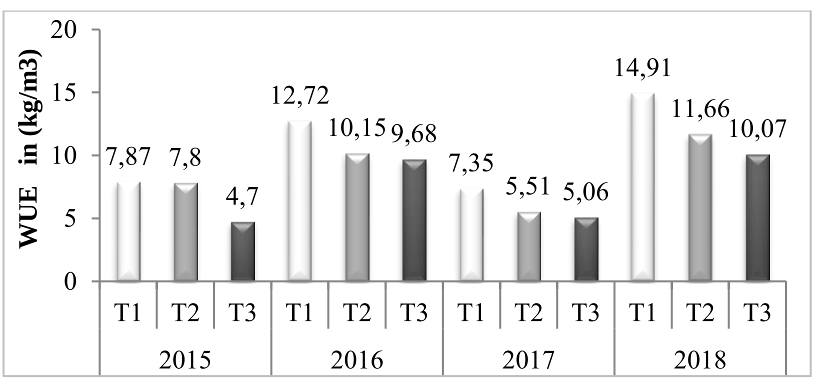

Fig. 2. Water use efficiency (WUE) of T1 (■), T2 (■) & T3 (■) for the years 2015-2018.

The results show that for all the years of the trial, the highest water use efficiency is observed with the deficit treatment T1 (75% ETc), with 7.87; 12.72; 7.35 and 14.91(kg/m3) respectively for 2015, 2016, 2017 and 2018. The control treatment T2 followed T1 in terms of water use efficiency with deviations of the order of 0.07; 2.57; 1.84 and 3.25 (kg/m3) less than T1 for 2015, 2016, 2017 and 2018 respectively, while the treatment T3 (125%) ranked last in terms of water productivity.

These observed differences in water use efficiency (WUE) between treatments are mainly due to water savings achieved with deficit irrigation. It should therefore be borne in mind that the increase in water inputs compared to the needs with 25%, although it allowed an increase in yields compared to the control, led to a considerable decrease in water productivity. In other words, the surplus of yield achieved by T3 compared to the control does not justify the surplus of irrigation water provided. On the other hand, it can be seen that the treatment T1, allows water savings of around 25% compared to T2 without penalizing the yield. It was able to have better water productivity compared to T2 and T3.

We can conclude that for the 'Fortune' plum cultivar in Mediterranean climates, it is more efficient to reduce water usage by 25% compared to the crop's needs, rather than increasing it by 25%. This finding is supported by several studies [12, 13, 14, 15, 16] which have shown that limiting water supply throughout the growth cycle or during certain stages results in increased water productivity.

4. Conclusion

To summarize, the crop yield, size, and average fruit weight were found to be improved under T3 irrigation treatment (125%) as compared to T2, but this led to a decrease in water use efficiency in comparison to the control. Conversely, T1 treatment (75%) showed the same level of production, fruit size, and weight as the control. This treatment also provided water savings without any adverse effect on yield, leading to good water use efficiency. In contrast, the over-irrigated treatment resulted in higher yield than the control, but with lower water use efficiency.

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