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Water–yield relations and optimal irrigation strategy for tomato crop grown in Mediterranean climatic conditions

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Abstract:
Background*: In Tunisia, as in all arid and semi-arid zones, water scarcity is one of the main factors limiting agricultural production. Faced with the need to preserve water resources and increase agricultural production due to an ever-growing population, it becomes imperative to focus on the productivity of irrigated crops.However, there are still some gaps with respect to crop water use efficiency and productivity. In this work, the inter relationship between crop yield, water consumption and water use efficiency were determined for field grown tomato crop grown under Mediterranean climatic conditions.The established relationships were usedto search for an irrigation management approach aimed at maximizing the productivity of field grownTomato Crop.*
Materials and Methods*: The study is mainly based on* long-term *simulations using the cropwat model. The simulations are performed assuming a long term weather database and representative soil types of the study area, chosen on the basis of their available soil water in the root zone (TAW). The CROPWAT model was used to estimate crop yield, water consumption and water use efficiency of field grown tomato crop as a function of water supply and pedoclimatic variability.*
Results*: The results obtained showed that crop yield tends to stabilize globally for water inputs above 400 mm. However, an increase in water use above an average of 3000 m3/ha may be associated with a reduction in crop water use efficiency. Thus, under conditions of limited water resources, optimal total water supply is about 3000 m3/ha. In fact, beyond this value, an increase in water consumption by the plant is met with a very small increase in yield.Moreover, results highlighted the role of variability induced by of available soil water in the root zone on crop water use efficiency of field grown tomato. Indeed, for the same level of water supply, soils with high water holding capacity provide the highest WUE values compared to other soil types.*
Conclusion:*The analysis suggested that, under limited water resource conditions, full supplemental irrigation should be replaced with a level of deficit irrigation that should maximize water use efficiency.Indeed, water regime corresponding to maximum WUE does not correspond to maximum grain yield.*
Key Word*:irrigation, yield, water use efficiency, tomato crop, crop model.*

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I. Introduction

Several southern Mediterranean countries are in a situation of serious water stress [1], [2] mainly due to a high demand for water from the agricultural sector. In Tunisia, in addition to the fact that irrigated agriculture consumes more water than other production sectors, water management in irrigated areas is far from optimal [3], [4]. Faced with the need to increase agricultural production due to a still growing population and the need to preserve water resources, concerns about water use efficiency have increased in Tunisia. These concerns have been addressed through the modernization of irrigation systems, the reformulation of water pricing and the promotion of water saving techniques at farm level [5]. However, despite these efforts to save water, several studies [6], [5], [7], [8] have shown that there is still possiblities for improvement in the water productivity of irrigated crops. Despite the existence of other factors, crop water management appears to be a key parameter responsible for a wide variation in water efficiency of a given crop [9]. Thus, the search for a water management strategy adapted to local soil and climate conditions is essential to improve crop water use efficiency, particularly in regions with limited water resources [10], [11]. In this context, the evaluation and design of new crop management practices through simulation is part of a complementary approach to experimentation [12], [13]. In fact, crop models have become essential tools in research studies concerning the enhancement of agricultural productivity and optimizing irrigation water management [14], [15]. Crop simulation models allow testing a wide range of crop management options in contrasting soil and climate conditions [16].

This work focuses on the analysis of water use efficiency of the durum tomato crop grown in Mediterranean climatic conditions as a function of water supply and soil water retention properties. The objective is to contribute to the search for irrigation strategies for improving water use efficiency of durum wheat. This work is based on the application of a crop model to search for an irrigation management approach aimed at maximizing the productivity of Tomato Crop grown in Mediterranean climatic conditions depending on soil properties.

II. Material And Methods

Study area

The OuedRmel irrigation scheme (35°55' N-10°25' E) is located in the Northeastern part of Tunisia (Fig. 1). The scheme, supplied by the OuedRmel dam, covers an irrigated area of about 4770 ha. It is mainly supplied with water from the OuedR'mel dam. The dominant crops are olive trees cereals and vegetable crops.

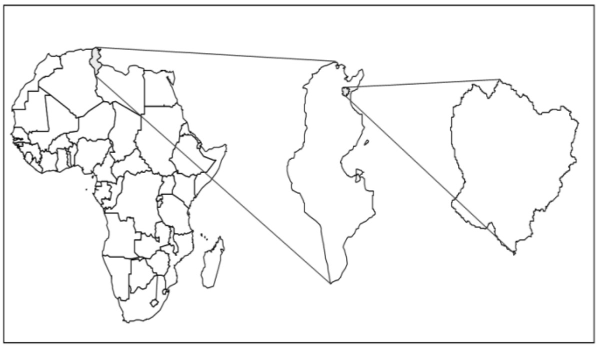

Figure 1.Location of the study area

According to long-term weather data (1986-2006) summarized in Table 1, maximum monthly temperatures range between 16 and 31ºC and minimum monthly temperature vary from 7 to 21ºC. Mean relative humidity varies from 65% to 74% and monthly rainfall ranges between 4 and 48 mm. According to Emberger's classification, the study area is located in the lower semi-arid bioclimatic stage with mild winters, and its proximity to the sea confers on it a Mediterranean-type climate.

Table 1. Mean climatic data (1986- 2006) in the study area (meteorological station of OuedSouhil

	Temperature (°C)		Precipitation (mm)	Relative Humidity (%)	Wind speed (m.s^{-1})
	Tmax	Tmin			
January	15.69	7.24	41.43	76.16	1.49
February	16.32	7.04	29.18	72.98	1.72
March	18.28	8.79	28.83	71.52	1.82
April	20.30	10.49	26.37	71.13	1.70
May	23.64	13.92	23.09	69.67	1.78
June	28.49	17.44	11.53	65.25	1.66
July	31.15	20.05	4.86	65.60	1.68
August	32.08	21.25	10.13	67.51	1.61
September	28.84	19.87	42.52	73.21	1.50
October	25.38	16.85	37.09	74.73	1.37
November	20.27	12.01	48.10	73.93	1.49
December	17.03	8.36	40.97	75.32	1.41

According to the rainfall data, the average annual rainfall is 344 mm. Rainfall distribution varies from year to year and the rainfall regime seems to follow a dry and a wet cycle. The monthly rainfall distribution shows a rainy period from October to March and a dry period from April to September. In fact, a large part of the rainfall comes from rain storms of which a large part falls in autumn. According to historical climate data (1986-2006), the average annual temperature is about 18.3 °C, with the lowest recorded temperatures in January and the highest in August

Crop model and water productivity indexes

In order to take into account the variability of water supply and pedoclimatic conditions, the work methodology was based on the application of a crop model. Thus, the CROPWAT model version 8.0 [17] was applied to study the response of tomato crop to various irrigation scenarios according to the pedoclimatic conditions of the irrigated district of Bouficha. irrigation scheduling was simulated by Cropwat model based on an automatic option based on water depletion level of the readily available water in the root zone (RAW). Thus, five irrigation scenarios have been selected for which the depletion of the RAW varies from 100% to 200%. The scenarios assume automatic irrigation to field capacity. Thus, the I100 scenario assumes automatic irrigation whenever 100% of the RAW is depleted by crop evapotranspiration. Whereas scenarios I120, I130, I140, I150 consider irrigation whenever respectively 120%, 130%, 140%, and 150% of the RAW is depleted by evapotranspiration. In addition, the model was run with historical daily average climatic data for the study area recorded over a 20-year period (1986-2006). Climatic data included maximum and minimum air temperatures, global radiation, wind speed and daily precipitation. Furthermore, the effects of the simulated irrigation scenarios were studied for different soil types selected on the basis of their total available water in the rootzone (TAW) defined as the difference between the soil moisture content at field capacity θcc and that at permanent wilting point θpfp multiplied by the root system depth [18]. Thus, nine soils were selected: three soils (S1, S2 and S3) with a TAW greater than 160 mm, three intermediate soils (S4, S5 and S6) with TAW between 100 and 160 mm and three soils (S7, S and S9) with TAW less than 100 mm. According to [19], the soils selected have contrasting characteristics in terms of useful reserve.

Tablz 2. Main soilscharacteristics

Soil		clay (%)	Sand (%)	Limon (%)	θ_{cc} (%)	θ_{pfp}(%)	TAW (mm)
TAW1	S7	18	78	4	27	15	80
	S8	16	80	4	11	4	55
	S9	18	57	25	27	15	92
TAW2	S4	15	5	82	29	15	155
	S5	32	34	34	53	36	144
	S6	15	70	14	29	15	140
TAW3	S1	29	36	35	53	36	181
	S2	24	12	65	38	19	188
	S3	49	17	32	57	37	190

In Cropwat model, the crop is characterized by the duration of its development phenological stages, the crop coefficient and the yield response factor (Ky) reflecting the sensitivity of the crop to water stress. In fact, the model estimates the yield in relation to the relative deficit of crop evapotranspiration according to [18]:

$$\left(1-\frac{Y_a}{Y_m}\right)=k_y\left(1-\frac{ETa}{ETM}\right)$$

Where :

- Y_a : actual crop yield (tonne/an)
- Y_m : maximum crop yield (tonne/ an)
- k_y : yield response factor
- ETa : actual evapotranspiration
- ETM : maximum evapotranspiration

Thus, prior to the use of the CROPWAT model, the durations of the development stages were adjusted so that they corresponded to the physiological characteristics of the crop grown under the conditions of the study area. Thus, for the seasonal tomato crop, the planting date was set at April 5 in accordance with the planting date generally chosen by the farmers in the Bouficha area. In addition, the durations of the different phases of crop development were adjusted based on the results obtained by [20] following experiments carried out on tomato cultivation in Tunisia. While the values of (Ky) were set in accordance with the values observed for Mediterranean climatic conditions [18].

Table3.Adjusted model parameters

Parameter	Initial value	Adjusted value
initial phase (days)	30	25
development phase (days)	40	30
mid-season phase (days)	45	35
late phase (days)	30	30

Moeover, crop water productivity was assessed through two water use efficiency indexes. First, crop water use efficiency (WUEc) was estimated to assess the efficiency of the process by which water is consumed by the plant to produce biomass. It is generally defined as the ratio of yield to the amount of water consumed by the crop generally assimilated to seasonal crop evapotranspiration [21]. Thus, WUEcwas defined as follows:

$$WUEc = \frac{Ya}{ETa}$$

where :
ETa : actual crop evapotranspiration
Y : actual crop yield
However, the determination of optimal irrigation strategies should be based on a water efficiency index which allows estimating the valorization of the seasonal volume of water supplied to the crop (irrigation and rainfall) in terms of crop production [22], [23].. Thus, applied water use efficiency (WUEip) was definedas follows [24]:

$$WUEip = \frac{Ya}{Vi + P}$$

where :
P: precipitation
Vi: seasonal amount of irrigation water used by the crop

III. Results and discussion

Yield relation with total applied water

Figure 2 shows the variation in yield as a function of water supplied to the crop according to TAW. This relationship is described graphically by a second degree polynomial function which is similar to that obtained by[25]. Overall, it can be noted that yield increases with increasing the amount of water provided to the crop linearly for amounts up to 400 mm. However, yield tends to stabilize if the total water supply provided by irrigation and rainfall exceeds 400 mm. This result is in agreement with those reported for other crops such as wheat [26] and potato [27]. In fact, high amounts of water are not highly valued by the crop due to water losses by runoff and percolation.

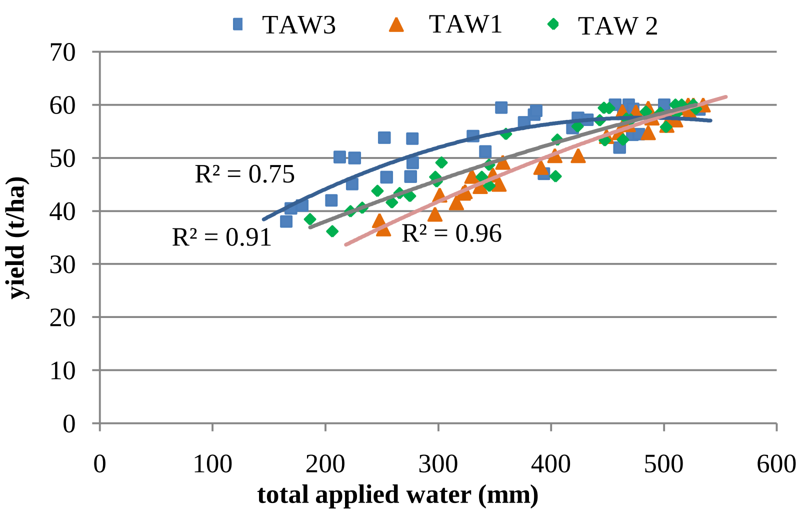

Figure 2. Relationship between yield and the total applied water to the crop as a function of TAW

Moreover, for the same water supply, soils with high TAW (RU3) have higher yields than soils with low TAW (RU1). For example, if the water supply is 350 mm, the yield reaches 55 t/ha in RU3 soils, while it does not exceed 43 t/ha in low RU soils. Yield reduction in low-UK soils may be the result of losses through deep percolation of water and leached nitrogen [28]. In fact, soils with low TAW favour water losses by runoff and percolation, especially if a high volume of water is applied. Whereas soils with high useful reserves make better use of water inputs thanks to their storage capacity, which limits water losses by deep percolation

Evapotranspiration-yield relationship

The relationship between relative yield reduction and relative evapotranspiration deficit (figure 3) allows analysis of the effect of water restriction on yield.According to Figure 11, if crop evapotranspiration reaches about 60% of maximum evapotranspiration, the decrease in yield would be 40%. This value is lower than that obtained by [20] who indicated that the tomato crop yield could be reduced by 50% if the crop evapotranspiration reaches 60% of its maximum value. On the other hand, according to results obtained by [20], Tomato is more sensitive to water deficit than wheat. On the other hand, it can be noted that if crop evapotranspiration is maximal (REE/ETM ratio = 1), yield reduction is almost none. Indeed, in the Cropwat model, yield reduction is only attributed to the reduction in crop water consumption.

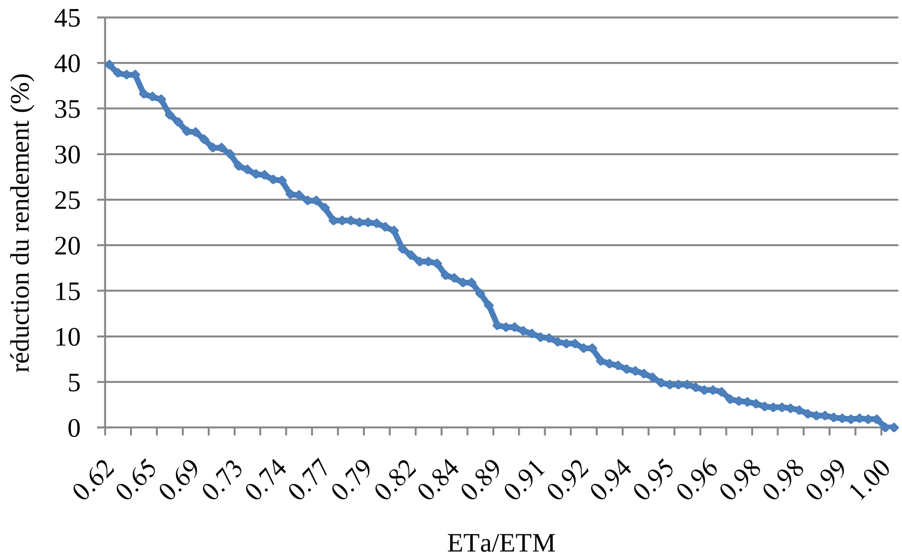

Figure 3.Relationship between relative yield reduction *and* relative evapotranspiration deficit

Evapotranspiration-water supply relationship

Figure 2 shows the variation of evapotranspiration as a function of total applied water was established according to TAW (Figure 4) based on the results of simulations. According to figure 4, the relationship between crop evapotranspiration and water consumption is graphically represented by a second-order polynomial function for the three soil types.

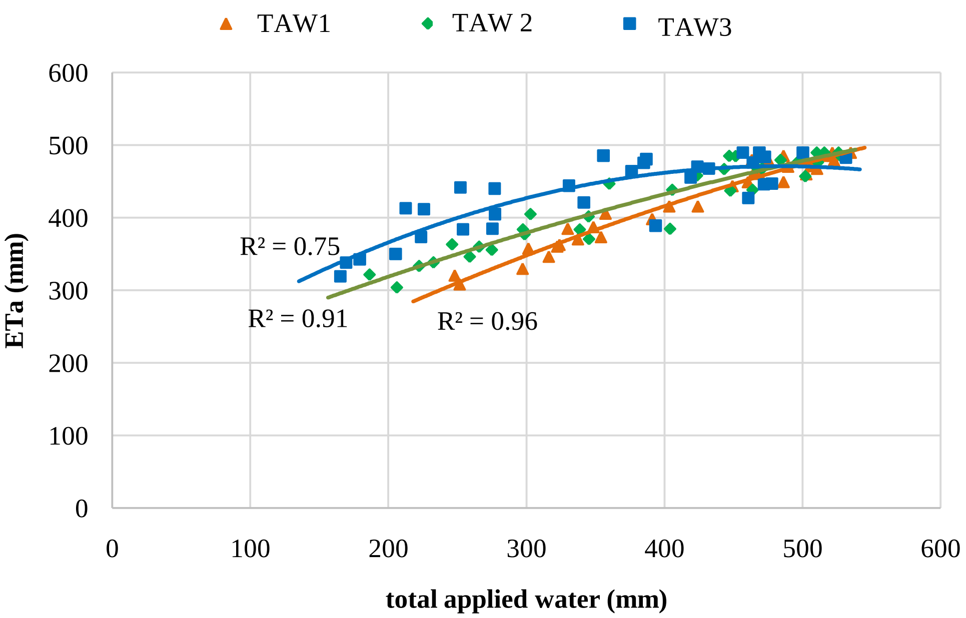

Figure 4. Relationship between crop evapotranspiration and the total applied water to the crop as a function of TAW

It could be noticed that the ETC increases with the amount of water supplied to the crop. However, it tends to stabilize at a value of about 470 mm for water volumes higher than approximately 500 mm. In fact, when there are no other limiting factors, ETC is influenced mainly by crop-related water conditions. In fact, high water applications provide favourable conditions for maximum crop evapotranspiration [30]. However, ETC remains limited by a threshold value that is a function of the physiological characteristics of the plant and the considered cultivar [18]. When comparing the results obtained among soil types, it can be seen that, for the same water quantity, crop evapotranspiration is higher in soils with a high useful reserve. For example, for a water supply of 300 mm, the REE reaches 450 mm in soils with a high useful reserve, while it does not exceed 350 mm in soils with a low useful reserve. In fact, soils with a high useful reserve allow more favorable conditions for crop evapotranspiration.

Variation in water use efficiency as a function of yield and water consumption

Figure 5 illustrates the relationship between crop water use efficieny and the total applied water as a function of TAW. Overall, it can be seen that the water use efficiency of the WUE crop increases with the amount of water supplied to the crop linearly for water amounts up to about 400 mm. It tends to stabilize for amounts above 400 mm.

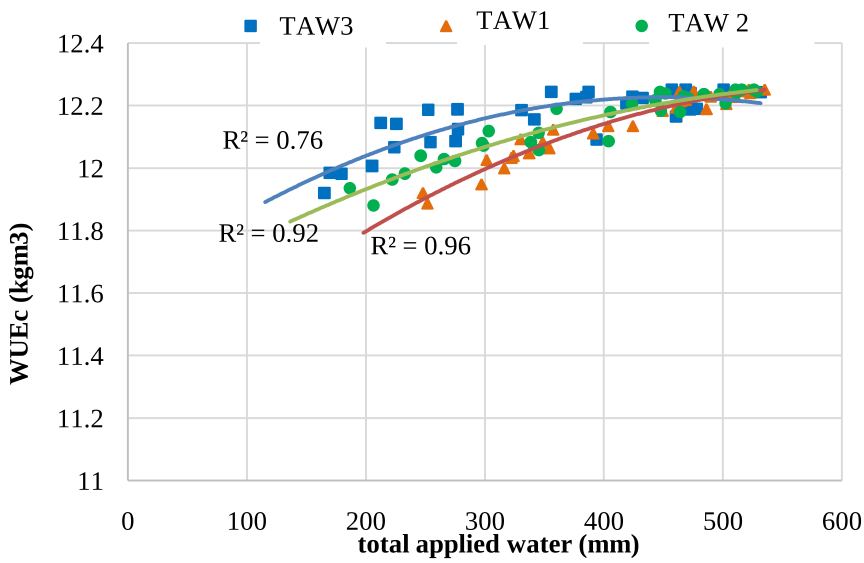

Figure 5. Relationship between crop water use efficiency and the total applied water to the crop as a function of TAW

It should be noted that the variation in WUE with water use is small in comparison to the variation in yield with water consumption. In fact, WUEc shows little variation with environmental factors [31].

In addition, the results show that relatively high values of crop water use efficiency are recorded in soils with high soil reserves. Although the variation is small, the results show that, for the same water supply, soils with high useful reserve provide the highest WUE values compared to other soil types. However, the difference between soil types decreases with increasing water levels. For water amounts greater than 450 mm, the crop water use efficiency becomes similar between the three soil types.Furthermore, the relationship between the water use efficiency of tomato crop and its yield is graphically described by a second degree polynomial function (Figure 7).

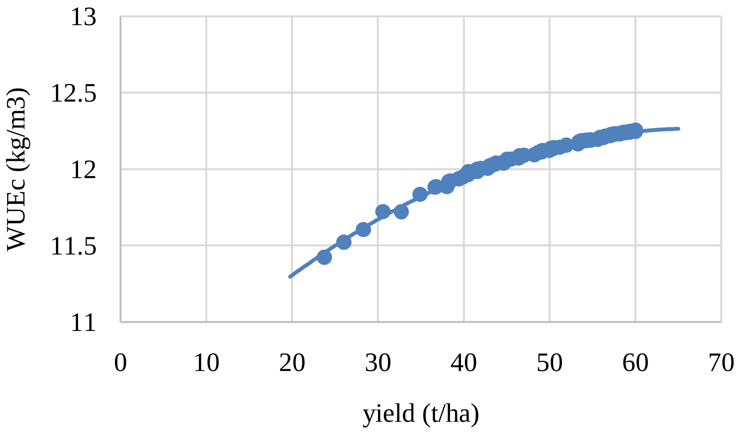

Figure 7.relationship between yield and crop water use efficiency of tomato crop

The relationship was similar to that obtained for several crops [32], [33], [34]. Overall, it can be observed that water use efficiency increases linearly with yield up to values of about 40 t/ha. However, efficiency tends to stabilize at a value of about 12.2 kg/m3 for yields above about 60 t/ha. Thus, high yields are not necessarily associated with an increase in water use efficiency.

Figure 8 shows the variation in WUEip water use efficiency and yield as a function of crop water use. In the figure, a distinction is made between the amount of water required to achieve maximum yield and the amount of water delivered to ensure maximum WUEip water use efficiency. In fact, it can be seen that maximum yield is achieved with water supplies above 400 mm, while WUEip decreases at water supplies above 300 mm.

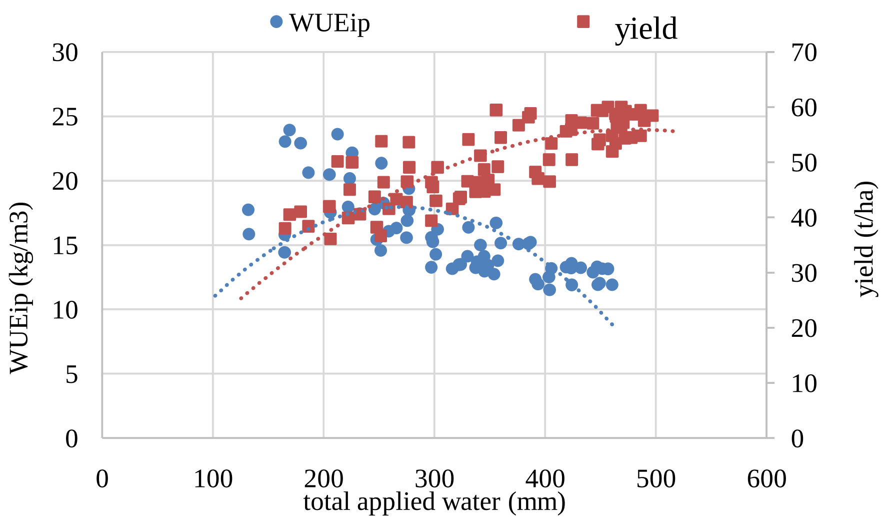

Figure 8. Variation of yield and total applied water use efficiency of tomato crop as a function of total applied water

In fact, an increase in water supplied to the crop provides favorable conditions for crop evapotranspiration [30]and thus for yield development, but may lead to higher losses by runoff and deep percolation [35] and thus to reduced efficiency. Thus, high water supply can only result in improved efficiency if it is associated with a proportionately greater increase in transpiration than water losses by runoff and infiltration [29]. Thus, to maximize water use efficiency under conditions of limited water resources, it is recommended that an irrigation scenario should be planned so that the cumulative water supplied by irrigation and rainfall does not exceed 300 mm.

IV. Conclusion

The study highlighted the possibilities of increasing water use efficiency of tomato crop by optimizing water management. In fact, the water regime associated with maximum yield may not correspond to maximum water use efficiency.Thus, under conditions of limited water resources, the optimal total water supply corresponding to maximum water use efficiency is about 300 mm. highest values of yield and crop water use efficiencyare recorded in soils with high TAW characterized by better water storage capacity and less frequent water stress. Moreover, research perspective is to study the combined effects of water regime together with fertilization regime on water use efficiency of tomato.

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