DRIP IRRIGATION SCHEDULING OF CITRUS ORCHARD IN TUNISIA

PILOTAGE DE L'IRRIGATION LOCALISEE DES AGRUMES EN TUNISIE

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ABSTRACT

Drip irrigation scheduling of Clementine mandarin grove (planted since 1978) was carried out at citrus orchard located at Cap Bon on the Mediterranean coast of Tunisia, with layered soil (sandy on sandy clay loam). The irrigation scheduling program was monitored using a simple method based on soil water status among the prospected rooting zone (soil water balance and potential) coupled with crop water requirements determination, during three years, from 2005 to 2007.

From the obtained results, the following conclusions would be drawn:

- Prospecting showed that Clementine root system was located by 65% in the top soil surface layer and the remaining part is located in the subsequent layer with a particular root concentration (25%) within the layer's transition zone. No roots have been observed growing deeper than 1.00 m.
- Soil moisture characterization is useful to identify the water retention and to establish the frequency of soil watering,
- Soil water potential associated to soil moisture measurement represents a suitable way to estimate water deficit and irrigation scheduling,
- Irrigation triggering should be conducted in two phases. During the "flowering-June physiological fruit drop" period (February - June) the irrigation should be triggered when the 0.25 m deep tensiometer reading reaches 10 x 10^{-3} MPa (0.1 bar) while during the period of "fruit growth-ripening" (July-October) the tension would be 15 x 10^{-3} MPa (0.15 bar). These critical levels of soil water tensions could be recommended in order to establish an irrigation scheduling of citrus cultivated on low water retention sandy soils
- The following three dimensional regression model could describe the seasonal soil moisture distribution, within the root zone under drip irrigation:

$$\mathbf{Z = 0.054 + 0.873\ 10^{-3}\ x - 0.23\ 10^{-5}\ x^2 - 0.00163\ y + 0.258\ 10^{-4}\ y^2 - 0.83\ 10^{-6}\ x\ y}$$
$$\mathbf{(r^2=0.82^{**})}$$

θ: Soil moisture content (m^3m^{-3}), x: Root zone thickness (cm) and . y: time (day of the year).

The obtained results, has given in hand materials for the dissemination of the tested methodological approach. When used properly, it can enhance the irrigator's chances of success.

Keywords**:** Drip Irrigation scheduling; citrus; soil water status; crop water requirements.

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RESUMÉ ET CONCLUSIONS

La région agrumicole du Cap Bon de Tunisie est caractérisée par un drainage climatique mensuel (P-ETP) pratiquement négatif sur toute l'année, il n'est positif qu'exceptionnellement et le déficit hydrique s'accentue d'avantage durant la saison estivale, par conséquent la mise en valeur agrumicole intensive n'est possible qu'à travers la pratique de l'irrigation. Ainsi, une expérimentation portant sur le pilotage des irrigations a été réalisée durant 3 ans (2005-2007) dans un verger agrumicole au Nord de la Tunisie (Région El Gobba-Cap Bon). Le verger est composé d'arbres matures de Clémentiniers greffés sur bigaradier, plantés en 1978 à des écartements de 6 m× 4 m soit une densité de 417 arbres par hectare. Il est équipé d'un réseau d'irrigation localisée constitué de conduites principales, secondaires et tertiaires en polyéthylène et les lignes de plantation sont dotées d'une double rampe placée sous frondaison de part et d'autre des arbres. Les goutteurs sont du type intégré autorégulant, équidistants de 33 cm et débitant 2 l h^{-1} chacun, ainsi, chaque arbre dispose d'un débit horaire de 48 litres.

Le profil des sols de la parcelle expérimentale est caractérisé par l'individualisation de deux matériaux lithologiques bien distincts et d'épaisseurs inégales, qui se superposent dans le paysage : des horizons sub-superficiels à texture grossière évoluant sur des horizons de texture moyenne à fine.

Pour accomplir une gestion efficace de l'alimentation hydrique des arbres ce travail s'est articulé sur la combinaison à la fois de quelques outils de suivi et d'évaluation :

1) Une étude in situ du système radiculaire des arbres de Clémentinier permettant de caractériser la morphologie et la structure de la charpente radiculaire ainsi la densité de répartition dans le profil du sol. Les racines des arbres, à structure hiérarchisée, sont concentrées à plus de 65% dans les horizons sub-superficiels (0-0.60m), le reste qui représente 35% a envahis les horizons de profondeur avec une concentration préférentielle dans une zone dite de transition (25%).
2) Une évaluation quantitative de la rétention en eau du sol du site expérimental moyennant l'établissement des courbes caractéristiques d'humidité, appelées courbes de pF, et cela a été établis à partir des valeurs expérimentales de la rétention d'eau, selon le modèle $\theta(h)$ de van Genuchten (1978, 1980).
3) Des déterminations préliminaires des besoins en eau des arbres moyennant les données climatiques du site expérimental montrant que la demande annuelle en eau des arbres de Clémentinier, estimée dans le contexte environnemental de l'expérimentation, oscille entre 752.4 et 770.3 mm
4) La lecture journalière des données tensiométriques sous frondaison des arbres au niveau de quatre profondeurs dans la zone radiculaire (0.25, 0.5, 0.75 et 1.0 m), a permis le suivi du bulbe d'humectation et donc l'évaluation des processus l'humidification et d'épuisement des réserves hydriques du sol. Les tensions de l'eau à 0.25 m de profondeur du sol ont servi comme indicateur permettant le déclenchement des irrigations.
5) Enfin, le suivi de l'évolution des teneurs en eau volumiques (décadaires à bimensuelles) ont permis d'abord l'ajustement et la validation du programme de pilotage d'irrigation et également de visualiser la distribution saisonnière et spatiale de l'humidité le long du profil du sol et donc de schématiser le processus d'humectation-épuisement de la zone radiculaire des arbres de Clémentinier.

Cette approche méthodologique, bien qu'elle reste en grande partie spécifique au contexte pédoclimatique du site, a le mérite d'évaluer l'efficacité des apports d'eau d'irrigation sur la base d'une meilleure compréhension de la dynamique de l'eau dans le sol de la zone radiculaire des arbres dans son envergure tridimensionnel : teneur en eau rapportée à la capacité potentielle du réservoir sol, sa variabilité spatiale et temporelle en rapport avec la demande hydrique, spécifique à chaque étape du cycle phénologique des arbres. Ainsi, les résultats ont fait ressortir les conclusions suivantes:

a) La caractérisation de la morphologie et la structure du système radiculaire ainsi que sa densité de répartition dans le profil du sol est d'une grande importance pour accomplir une gestion efficiente de l'eau et des fertilisants.
b) L'établissement des courbes caractéristiques d'humidité des différents horizons du sol sous frondaison des arbres permet d'évaluer in situ la capacité de rétention en eau du sol et donc d'édifier des ajustements du front d'humectation.
c) La matrice des potentiels de l'eau du sol obtenue moyennant les lectures tensiomètriques, couplée au bilan hydrique issu des teneurs en eau du sol ont permis d'évaluer le déficit hydrique, paramètre primordial pour la programmation des irrigations.
d) Pour le déclenchement des irrigations, deux niveaux critiques de tension de l'eau du sol ont été fixés. Une tension équivalente à 10×10^{-3} MPa (0,1bar), a été appliquée durant la période de "démarrage de la vague de croissance printanière jusqu'à la chute physiologique de juin" (mars - juin). Par contre, durant la phase "post chute physiologique de juin et jusqu'au début de maturité des fruits", la tension critique de l'eau du sol peut grimper pour atteindre 15×10^{-3} MPa (0,15 bar). Ces niveaux jugés optimums pourraient être recommandés pour la programmation de l'irrigation des vergers de Citrus évoluant sur des sols d'apports sableux à faible capacité de rétention en eau.
e) La distribution saisonnière et spatiale de l'humidité du sol à travers les différents horizons de la zone radiculaire des arbres, se traduisant par les processus d'humectation et d'épuisement du sol, a été décrite par une relation tridimensionnelle ayant pour équation :

$$\mathbf{Z = 0.054 + 0.873\ 10^{-3}\, x - 0.23\ 10^{-5}\, x^2 - 0.00163\, y + 0.258\ 10^{-4}\, y^2 - 0.83\ 10^{-6}\, x\, y}$$

$$\mathbf{(r^2=0.82^{**})}$$

Avec θ : teneur volumique en eau du sol (m^3m^{-3}), x: épaisseurs des horizons du sol de la zone radiculaire des arbres (cm) et y: le temps (jours de l'année).

Les résultas obtenus contribuent à la compréhension de la dynamique de l'eau du sol de la zone radiculaire des arbres, qui traduit l'interaction entre les apports d'eau et les prélèvements par les arbres durant le cycle de croissance et de développement du Clémentinier dans le contexte pédoclimatique régionale semi aride Méditerranéen. Ainsi, l'approche présentée, pourrait être vulgarisée puisqu'elle aurait comme impact d'augmenter les chances de succès des producteurs agrumicole.

1. INTRODUCTION

Irrigation scheduling is a useful tool to provide crop water requirements, to avoid plant moisture stress and to improve irrigation water management. When used properly and wisely, it indicates the right amount of water to supply to cropland at the right time and in the right place. Consequently, it saves water, energy, labor, and fertilizer, and in many cases improves crop yields and product quality.

Irrigation scheduling methods are based namely on crop water requirement estimation using meteorological data treatments (Allen et al, 1998), soil water measurements, monitoring plant stress by leaf water potential and canopy temperature measurements providing information about plant water status reliably to the water need, trunk tree diameter and sap flow determinations (Brouwer et al., 1989; Harisson, 2005; Velez et al., 2007). Computer models that are being developed and continuously updated, allowed a precise irrigation scheduling and automation Never less, because of the cost and the required computer and agriculture scientific background, their use are already restricted to Research and Academic Institutions. In comparison to investment in irrigation equipment, the irrigation scheduling tools would be relatively inexpensive.

The commonly used and the less costing methods are based on calculating or measurement of crop water requirements, soil water monitoring by mean tensiometer measurement and/or soil water balance (Tam, 2006; Fares et al., 2007). Several devices are available for measuring soil moisture in order to monitor water stock variation according to a referred soil water holding capacity. Tensiometers are soil water measuring devices which monitor soil water tension and are sensitive to soil moisture change.

Tensiometer acts like a mechanical root. It is equipped with a gauge or reading unit that continuously registers how hard the root must work to extract water from soil. Tensiometer measurement (reading) can be related to the soil moisture content and irrigation decision is made according to specific crop critical soil water depletion. Two kinds of tensiometers are already available. One is sealed, water-filled tube equipped with vacuum gauge and the second is doted by electrical functioning system and measurements are obtained by using a reading unit. This tensiometer generation act as sensor and allowed their connection to agro meteorological plant or to be used solely by mean wire-less technology. Then, it allows automation of irrigation scheduling.

Citrus are among the crops, which require optimal soil moisture content and are vulnerable to water deficit as well as saturated root zone (Castell et al., 1987; Hammami, 2010). In addition, optimal soil moisture is an important component to monitor citrus trees fertilization (Hammami et al., 2009; Hammami, 2010; Hammami & Mellouli, 2011). Drip irrigation is the most used system on the citrus orchard in Tunisia, and although that it is confirmed to be a water conservative technique and as mean to increase in farm water and nutrients use efficiency, a gaps remain in the monitoring such system on citrus orchard (Cheneni et al., 2000) that would require wise and scientific irrigation scheduling, in order to establish optimal available moisture soil content and to enhance crop, soil and water productivities.

The most used methods in Tunisia to monitor irrigation of citrus orchards are based on the estimation of the evapotranspiration (Nasr et al., 2001; Nasr, 2002), which it consists on water removal by plant (transpiration) and water loss due to evaporation (Allen et al., 1998) and also by mean soil tension and water content devices. Thus, this paper presents results of irrigation scheduling program that was monitored, by using a simple method based on soil water status coupled with crop water requirements determination, during three years (2005-2007), in Clementine mandarin citrus orchard in Tunisia.

2. PHYSICAL EXPERIMENTAL SITE CHARACTERIZATION

The experiment was carried out at citrus orchard located at Cap Bon around 60 km NE of Tunis, on the Mediterranean coast of Tunisia (long.:10° 35' 23" E and lat.: 36° 36' 50" N). The soil is layered sandy (0-60 cm) on sandy clay loam (60-120 cm), according to USDA textural soil classification (Table 1).

The difference between moisture contents of Field Capacity and Wilting Point indicates the Total Available Soil Water (TAW) and Field Capacity gives information on water holding capacity of the soil. Such information's were used in order to avoid deep percolation and water stress as well. The soil water at Field Capacity is low on the top sandy layer (0-0.60 m) because its structural configuration and its high content on sand while on the subsequent horizon (0.60-1.20 m), water retention is relatively high due to its fine fraction content ("clay + silt"). Consequently, care should be allocated to irrigation scheduling according to the layers juxtaposition (Table 1).

Table 1. Physical soil proprieties of the experimental site
(Propriétés Physiques du sol du site expérimental)

Depth	Soil components			(*)θ_{fc}	(**)θ_{wp}	TAW	Bulk Density
	Clay	Silt	Sand				
(cm)		(%)		(m^{-3} m^{-3})		(mm)	(Mg m^{-3})
0-30	5	8	87	0.156	0.063	27.9	1.54
30-60	4	9	87	0.138	0.042	28.8	1.53
60-90	35	20	45	0.225	0.145	24.0	1.43
90-120	27	13	60	0.266	0.145	36.3	1.32

(*)θ_{fc}: soil water content at field capacity, **(**)**θ_{wp}:soil water content at wilting point
TAW: Total Available soil Water

Soil water retention curve, called pF curves, describes the relationship between soil water content (θ) and the related soil water tension or soil matrix water potential (h). Soil water retention characterization was established by using three replicates of soil samples for each layer and for different tensions, ranging from saturation until the wilting point. The curves were fitted (figure 1) according to *θ(h)* model (van Genuchten, 1978) by mean iteration of Marquardt (1963) .

$$\theta = \theta_r + (\theta_s - \theta_r)\ [1/1+ (ah)^n]^{\ m}$$

Were θ_r et θ_s are respectively the residual and saturated moisture contents α, *m* et *n* are adjustment parameters with m=1-1/n (van Genuchten, 1980). The obtained value of the adjustment parameters are indicated on table 2

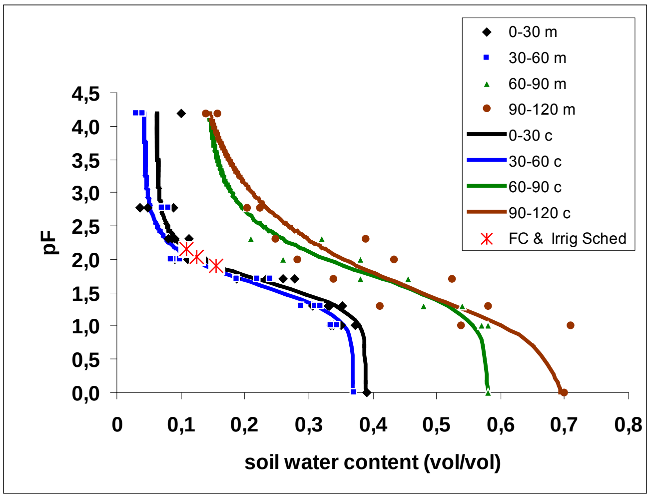

Figure 1. Measured (m) and calculated (c) θ(h) curves, according to *van Genuchten (1978 & 1980)* model. Symbols (*) indicate moisture contents successively at Field Capacity, at the two critical depletion for irrigation scheduling. (Courbes θ(h) mesurées (m) et calculées (c), selon le modèle de le modèle de van Genuchten (1978 & 1980). Les symboles (*) indiquent les teneurs en eau successivement à la capacité au champ et aux deux seuils de déclenchement de l'irrigation)

Table 2. Adjustment parameters of the relation θ(h) according to van Genuchten (1978 & 1980) model (Valeurs des paramètres d'ajustement de la relation θ(h) selon le modèle de van Genuchten (1978 & 1980)).

Depth (m)	θ_r (m^3/m^3)	θ_s (m^3/m^3)	α (cm^{-1})	(n)	(m)	R^2
0.0 – 0.30	0.080	0.390	0.03072	2.3252	0.5699	0.949
0.30 – 0.60	0.040	0.370	0.03425	2.1657	0.5382	0.967
0.60 – 0.90	0.058	0.580	0.0963	1.6979	0.4110	0.925
0.90 – 1.20	0.110	0.700	0.0339	1.3804	0.2756	0.813

3. TREE ROOT SYSTEM

It's evident that knowing where roots are located and their concentrations on the soil layers increases the production system efficiency when cultural practices are wisely applied under-tree area such as irrigation and fertilization (Bauer et al., 2003). Studies of root system distribution among tree growing area have not included Clementine Mandarin Cultivar rootstock at the citrus production zone of Tunisia. Then, the root distribution at the experimental site was studied on soil profiles by mean 8 prospecting locations spaced by 0.25 m, on 2 m radium from the tree. Soil and roots samples have been taken every 0.30 m layer until 1.20 m depth.

Prospecting showed that Clementine root system was located by 65% in the top soil surface layer (0-0.60 m) and the remaining part is located in the subsequent layer (0.60-1.20 m) with a particular root concentration (25%) within the layer's transition zone. No roots have been observed growing deeper than 1.00 m. In most prospected sites, the essential roots system was located on the first 0.90 m. The upper layer seems to be favorable to citrus root growth development due to the coarse textural characteristics of the soil material associated to the historical continuous watering. The root concentration observed in the transition layer could be attributed to soil stratification effect and to the fact of textural coarse layer on fine did hamper water capillary rise (Mellouli et al., 2000). However, roots observed on boundary zone, can be attributed perhaps to that the subsurface layer would be quickly water depleted during the historical irrigation scheduling, and roots tended to reach stored water in the down layer characterized by good water holding capacity (Table 1). Bauer et al. (2003) observed also shallow root distribution of citrus trees at Florida and rooting depth is limited of the A horizon.

1.EXPERIMENTAL DESIGN

The experiment was carried out on orchard of "Clementine mandarin" mature trees grafted on "Sour orange rootstocks" (70% canopy cover) planted in 1978 spaced 6.0 m × 4.0 m apart, giving 416 trees per ha. Because optimal soil moisture is an important component to monitor citrus fertilization, this work was conducted conjointly, in the same plots, with the fertilization and nutrition program experiment of Hammami et al. (2009); Hammami (2010) and Hammami & Mellouli (2011). The plots were drip irrigated by two lines of emitters using 24 auto compensating emitters set 0.33 m from each other. Each emitter had 2 l h^{-1} flow rate. It resulted that every tree received during irrigation 0.048 m^3 h^{-1}.

Irrigation scheduling was based on tensiometers readings, soil moisture content measurements and crop water requirement estimation. Four tensiometers were planted in each of four representative locations of the experimental site at 0.25; 0.50; 0.75 and 1.0 m depths inside humidification bulb, with the deeper immediately under the emitter. Four Neutron probe access tubes were also installed in two radial directions under the tree canopy, with 1 m distance and exploring the soil profile along 1.20 m depth (Figures 2).

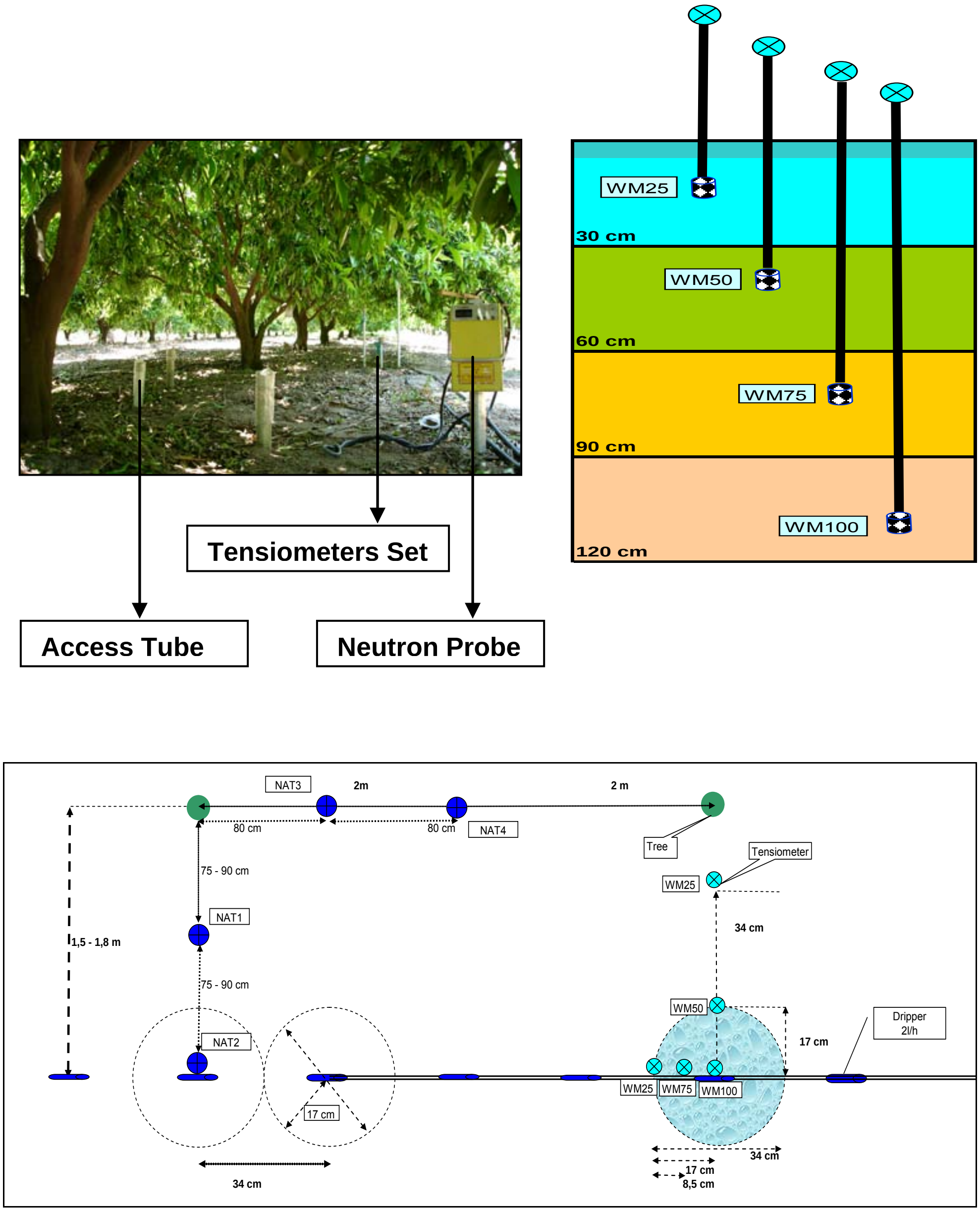

Figure 2. Experimental design water status monitoring. “WM” : Water Mark Tensiometer & “NAT” : Moisture Neutron Probe Access Tube (Protocole expérimental pour les mesures humidimétriques. “WM” : Tensimètre Water Mark & “NAT” : Tubes d’accès de la sonde à neutron)

2. IRRIGATION SCHEDULING

5.1. Crop water requirements calculation

Given the agro meteorological data of the experiment area, crop evapotranspiration rates (ETc) was calculated, in real time, by mean FAO method using the crop coefficient and reference evapotraspiration (Allen et al., 1998). The obtained ETc values, were used in order to decide precisely the amounts of irrigation supplies.

5.2. Tensiometer readings

Tensiometer readings were carried out daily. All tensiometers were used to evaluate daily water status among the soil profile before and after irrigation (Figure 2). The deeper tensiometer, located at 1 m depth, gave information to avoid water percolation and was useful to adjust irrigation water supplies. The 0.25 m depth tensiometer was basically used to identify soil water depletion level and as warming tool to start the irrigation.

The soil water status was maintained at field capacity by mean irrigation when total available water (TAW) depletion reaches a critical level resulting on water stress of the Clementine tree. The depletion critical level corresponds to the readily available soil water (RAW) in the root zone that can be depleted before moisture stress, with "RAW = p × TAW", p is a depletion fraction depending on the crop species (Allen et al., 1998).

Tow critical soil available depletion levels were adopted in order to decide the irrigation moment and its duration according to the soil water balance and the crop water requirements. The first one, equivalent to 25 to 33% depletion of TAW, should be used during flowering fruit set phase (Koo, 1969) and the second one is related to depletion reaching 50 to 67% which has to be applied during the remaining period of the growing season (Smajstrala et al 1985; Pearsons, 1989; Fares and Alva, 2000), but the commonly advised for citrus is already 50% (Allen et al., 1998). According to these ranges of allowed TAW depletion, the critical fractions adopted in our experiment site, were respectively 33% and 50%. Consequently, according to the moisture characterisation "pF curves" (Figure 1) and the tensiometer calibration measurements, the watering of trees was conducted in two phases. During the "flowering-June physiological fruit drop" period (February - June) the irrigation was triggered when the 0.25 m tensiometer reading reaches 10 x 10^{-3} MPa (0.1 bar) while during the period of "fruit growth-ripening" (July-October) the tension adopted was equal to 15 x 10^{-3} MPa (0.15 bar).

5.3. Soil water content monitoring

Soil water content was measured every 10 days to two weeks using neutron probe, during the three years of experimentation. The moisture content was monitored at 10 cm intervals down to 1.15 m starting at 15 cm depth. Neutron probe was calibrated by soil moisture content gravimetrically determination and instantaneous neutron probe readings. Obtained water content profiles were used to calibrate tensiometers readings and to validate the amounts of irrigation supplies.

6. RESULTS AND DISCUSSIONS

Crop water requirements calculation generated daily irrigation during the high water demand. Frequency was extended to 2 and 3 days depending on agro meteorological conditions, water tree demand and physical soil characteristic described above.

Regarding the Clementine trees canopy cover (70%) and the applied chemical weed control, the ETc was calculated using FAO Penman-Monteih methods with crop coefficients of 0.7 from November to March and equal to 0.65 during the remaining physiological cycle (Allen et al., 1998). Results (Table 3) show that annual water requirements are estimated by around 760 mm, which have to be satisfied by irrigation taking in count the efficient rainfall. The table 3 indicates also the period of high water demand where irrigation was daily conducted.

Table 3. Cumulated monthly and annually Crop Evapotranspiration ETc (mm) calculated according to FAO Penman- Monteith equation (Allen et al., 1998) for Clementine orchard with controlled weeds during 2005-2007. (Evapotranspiration mensuelle et annuelle ETc (mm) des clémentiniers calculées par l'équation FAO Penman- Monteith (Allen et al., 1998) pour un verger d'agrumes sans couverture du sol, durant 2005-2007).

Month / Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
2005	21.7	29.4	52.1	62.4	94.7	105.3	118.9	102.8	66.3	50.4	31.5	23.9	**759.3**
2006	21.7	29.4	54.3	74.1	94.7	107.3	114.9	104.8	72.2	50.4	29.4	17.4	**770.3**
2007	23.9	33.3	52.1	64.4	94.7	103.4	116.9	102.8	74.1	44.3	23.1	19.5	**752.4**
Mean	22,4	30,7	52,8	67,0	94,7	105,3	116,9	103,5	70,9	48,4	28,0	20,3	760,7
Standad Deviation	1,3	2,3	1,3	6,3	0,0	2,0	2,0	1,2	4,1	3,5	4,4	3,3	9,0

During the three consecutives experimentation years (2005, 2006 and 2007), the cumulated in field received water (Rainfall + Irrigation) was respectively 11543, 11170 and 10020 m^3 ha^{-1} (1154, 1170, 1002 mm per year) where around 50% supplied by irrigation, regarding that water needs did not coinciding with the significant rainfall events periods (Figure 3).

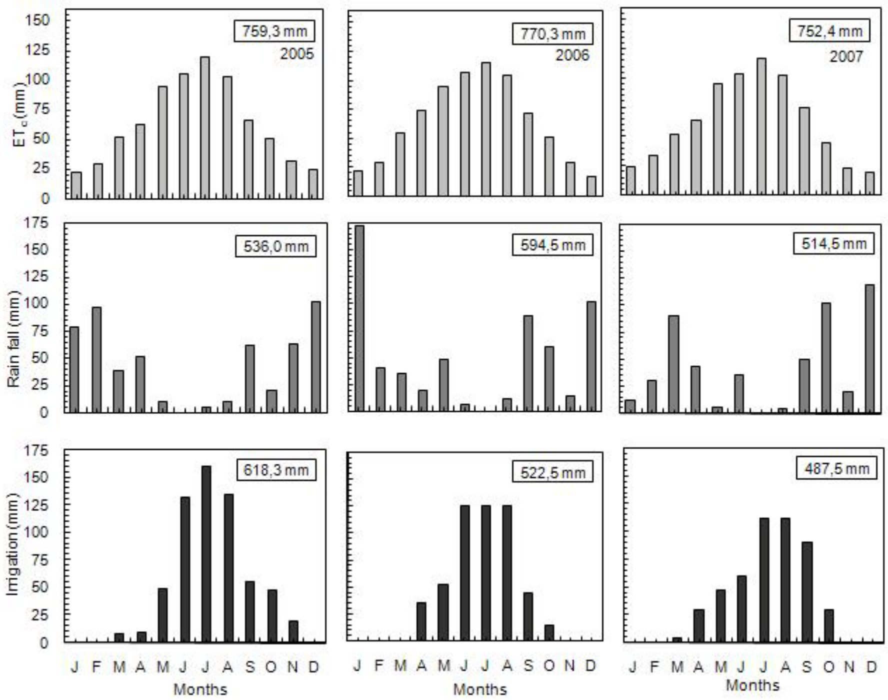

Figure 3. Evapotranspiration, rainfall, and irrigation data 2005-2007. Number in boxes indicates the annual cumulated amounts; **(*)** : Exceptional rainfall event (88 mm) occurred on 24/01/2006. (Evapotranspiration, précipitation et apport d'eau d'irrigation (2005-2007). Chiffre encadré indique les quantités cumulées ; **(*)** : Pluie exceptionnelle de 88 mm le 24/01/2006.)

Referring to the mean rainfall of the experiment region, exceeding rainfall was registered, equivalent to 9.4%, 21.2% and 5.0% respectively for 2005, 2006 and 2007. Never less, excess occurred during low water requirements of the trees. Wintry and autumnal rainfall favored a high soil water contents on the deeper clayed layer, resulting from intense percolation from the upper coarse layer. During summer period, the low precipitation amounts coincided with the high irrigation demand.

Irrigation scheduling was monitored by the 25 cm tensiometer readings, namely at 10 $x10^{-3}$ MPa (0.1 bar) during February through June and $15x10^{-3}$ MPa (0.15 bar) for the period of July to October. The amount of water supply was decided according to the estimated water requirements and soil water status indicated by the tensiometers sets. A validation of the quantified irrigation amounts was done using soil water stock among 1 m depth measured by neutron probe. Correction was made, when required, in order to deal with soil-moisture deficit which is the difference between the available water that soil can hold (Field Capacity) and the actual available water in the tree-root zone. Thus, root zone soil profile was maintained at field capacity and percolation and nutrients leaching were minimized. The tension evolution (Figure 4) confirms the maintaining of soil field capacity and demonstrates the best way achieved in the irrigation scheduling.

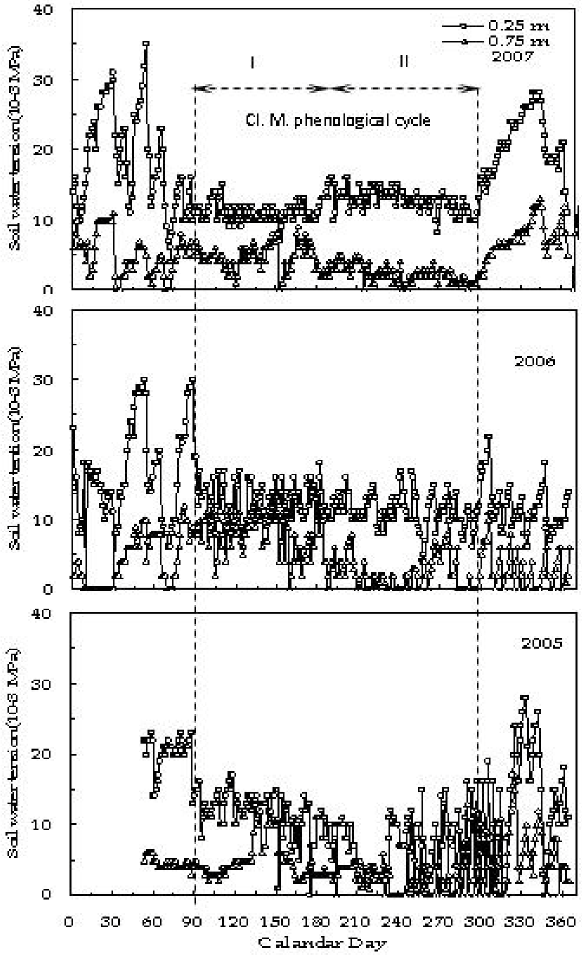

Figure 4. Daily soil water tension in the root zone at 0.25 and 0.75m depth during the phonological Clementine Mandarin cycle of 2005-2007. (I) Flowering - June physiology fruit drop phase, (II) Fruit growth - fruit maturity (Tensions journalières de l'eau du sol de la zone radiculaire à 0.25 m et 0.75 m de profondeur durant le cycle phénologique du Clémentinier pour 2005-2007. (I) : Floraison - chute physiologique de juin ; (II) : Grossissement du fruit - maturité et récolte)

On the basis of the data of the soil water content at different depths (0-1 m), during 2007 cropping season, regression model was used to correlate the soil water content (Z) to the soil depth (x) and time of cropping season (y).This tri dimensional representation (Figure 5) allowed identifying the humidification and uptakes dynamics in tree root zone and described the spatial and temporal soil moisture distribution, under drip irrigated Clementine mandarin tree canopy.

$$\mathbf{Z = 0.054 + 0.873\ 10^{-3}\ x - 0.23\ 10^{-5}\ x^2 - 0.00163\ y + 0.258\ 10^{-4}\ y^2 - 0.83\ 10^{-6}\ x\ y}$$

$$\mathbf{(r^2=0.82^{**})}$$

θ: Soil moisture content (m^3m^{-3}), x: Root zone thickness (cm) and . y: time (day of the year).

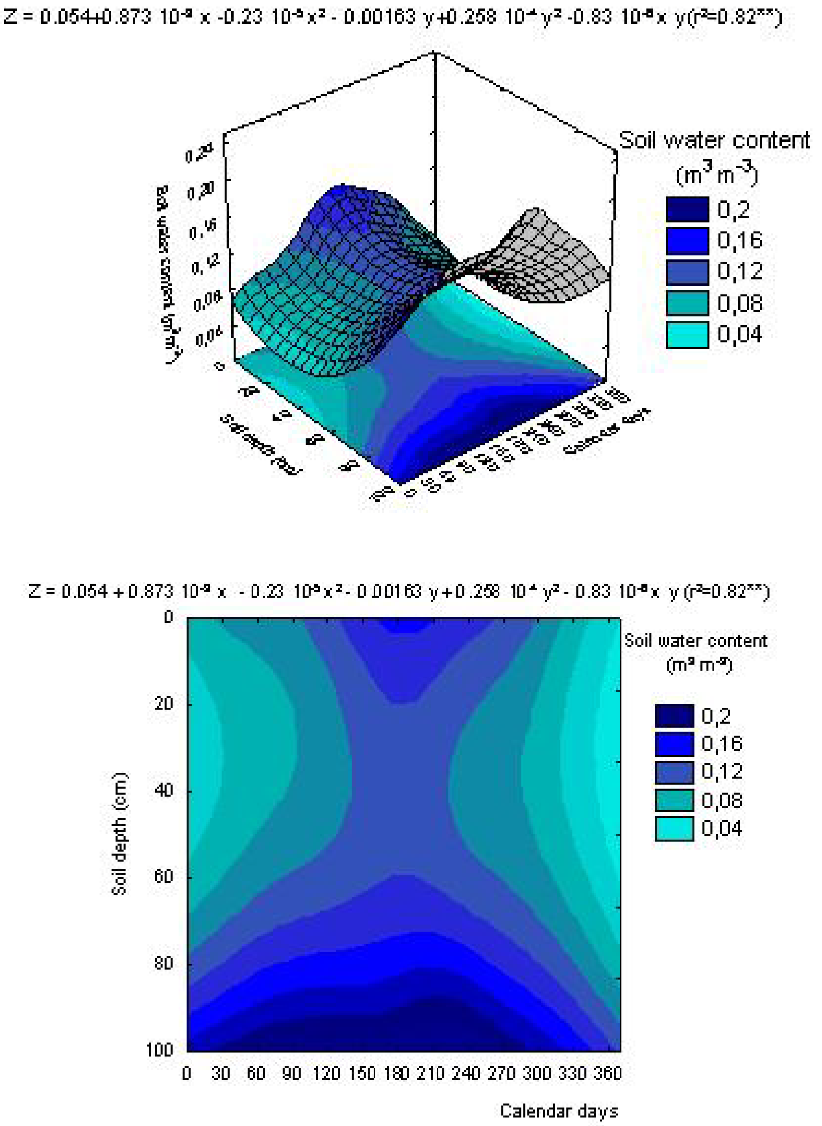

Figure 5. Tri dimensional and orthogonal projection of the mean soil water content variation at Clementine rooting zone during 2007. (Représentation graphique tridimensionnelle et projection orthogonale de la variation de la teneur volumique moyenne en eau du sol de la zone radiculaire du clémentinier durant 2007)

Figure 5 showed namely:

- Irrigation infiltration allowed firstly the field capacity on the top coarse soil layers having low water holding capacity, and then the infiltration process continues to supply the subsequent fine textured layers, characterized by good water retention. The rooting zone was maintained at field capacity and during the irrigation event, watering of the second layer was monitored by the control of the percolation from the boundary depth (0,60 m) in order to avoid perched water table, which is no tolerated by citrus roots. Thus, the results show that the management was target on establishment of humidification process suitable to deal with the water requirements and to avoid nutrients leaching from the rooting zone.
- The moisture content on the second fine textured layer was higher than observed on the coarse textured top soil layer. This is evident regarding the specific holding capacity of each material. According to the most active shallow rooting system, the water uptake from (0.60-1,00 m) horizon was low in comparison with the water consumption registered on the top soil (0-0.60 m). Never less, most water uptakes were limited effectively on the first 90 cm of the soil profile
- Although that the soil was maintained at field capacity among the root zone, the water uptake was quicker on the sandy top soil layer than in the depth. This is attributed particularly to the stratification of the soil and to the shallow high rooted system as described above.

7. CONCLUSIONS AND RECOMMENDATIONS

No doubt that Citrus are among the crops, which require optimal soil moisture content and are vulnerable to water deficit as well as saturated root zone. Although that drip irrigation system is confirmed to be a water conservative technique and as mean to increase in farm water and nutrients use efficiency, a gaps remain in the monitoring such system on citrus orchard that would require wise and scientific irrigation scheduling, in order to establish optimal available moisture soil content and to enhance water and fertilisers use efficiencies as well as crop and soil productivities.

The conducted experiment program of irrigation scheduling was monitored, by using simple method based on soil water status coupled with crop water requirements determination, during three years in citrus orchard in Tunisia. From the obtained results, following conclusions could be drawn:

- Prospecting showed that Clementine root system was located by 65% on the first sub surface layer (0-0.60 m) and the remaining part is located in the subsequent layer (0.60-1.20 m) with a particular root concentration (25%) within the layers transition zone. No roots have been observed growing deeper than 1 m. In most prospecting sites, the essential roots system was located on the first 0.90 m.
- Soil moisture characterization is useful to identify the water retention and to establish the frequency of soil watering,
- Soil water potential associated to soil moisture measurement and eventually to crop water requirements estimation represent a suitable way to estimate water deficit and conducting properly irrigation scheduling,
- In the case of the sandy soil, irrigation triggering should be when the 0.25 m deep tensiometer reading reaches 10×10^{-3} MPa (0.1 bar) during the “flowering-June physiological fruit drop” stage (Marsh to June), while during the period of “fruit growth-ripening” (June-October) the tension would be 15×10^{-3} MPa (0.15 bar). These water pressure levels, which maintained soil water content in the active root zone at field capacity during especially the critical physiological citrus tree stages, could be recommended in order to establish an irrigation scheduling of citrus cultivated on low water retention coarse textured soils under Mediterranean climatic conditions.

The obtained results, has given in hand materials for the dissemination of the tested methodological approach. When used properly, it can enhance the irrigator's chances of success.

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