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Soil moisture monitoring and plant stress measurement of young citrus orchard

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ABSTRACT

Capacitance probes were tested in a young citrus orchard for irrigation water saving; Cumulative water received by the plot reached 334 mm and 398 mm for the first and second year period respectively (irrigation + useful rain). Irrigations were made in 521 interventions when the lowest dose of 1.05 mm was used and in 210 interventions when the highest dose of 2.6 mm was applied. Capacitance probes were giving values statistically different compared to the gravimetric method, but with, however, a meaningful interrelationship; A good correlation was then obtained between real values and reading from capacitance probes, a value of 16% showed by the C-probe is equivalent to 22%. The parameters of growth, trunk diameter microvariations probes (LVDT) and components of yield are well correlated with Soil moisture and Vapor Pressure Deficit (VPD). Treatment 1 (T1) was better in cold period (December, January and February), while Treatment 4 (T4) was more efficient from flowering (March) and developed deep roots (more than 50 cm). Leaf water potential and LVDT showed the sensitivity of T1 towards climate changes during high evaporative demand days. Analysis of soil moisture data showed that the field capacity was maintained at not more than 30 cm soil depth for T1, which developed very superficial roots (45% at only 10cm). The number of roots was significantly different between treatments, T4 was distinguished by a greater concentration of roots (8843), compared to T1 (4104). After 27 months from plantation, the Yield showed a performance of 46 T/ha recorded for the dose of 2.1 mm, when the fruit size was 70% of Size 1-3; water saving was about 50% and valuated at 105 l/kg produced.

Keywords: Water saving, Capacitance probe, FDR, LVDT sensor, Citrus, Irrigation.

INTRODUCTION

Souss Massa is a region with arid-to-semi arid climate, the pressure into ground water and the level of water uptake for agriculture is very high (521Mm^3 per year), However, irrigation waters are almost exclusively pumped from the water table which is being depleted by 2 to 3 meter per year [1]. The climate is very arid with rainfall of about 150-200 mm/year concentrated in winter and ETo of 1800 mm/year with more than 7 mm/day in the Summer, average winter temperatures can reach as low as 5-7°C whereas average summer temperatures can be as high as 32-36°C [2-3]

Adding the effect of the foreseen climate change, the available water volumes are expected to shrink by 10-15% of the actual volumes in 2020 due to the falling groundwater levels and the reduction of the storage capacity of dammed lakes by siltation [4]

The citrus sector in the Souss region occupies about 33 000 ha which represents about 40% of the whole citrus plantings in Morocco, and employing quasi permanent irrigation with very limited water resources. This has led to the use of low volume irrigation systems (i.e.; drip, microsprinklers etc.) by more than 80% of the citrus orchards [5]. All efforts of public agencies and the private sector are geared towards generalizing the use of drip irrigation to protect these resources by optimizing water use and minimizing non-point source pollution of groundwater.

Moreover, studies made in 2007-2009 showed that the technical level of orchard managers is very low with the domination of empirical methods of irrigation management and fertigation in citrus orchards. In fact, the region is way behind in terms of implementing scientifically based irrigation management and adequate methods of water daily supply. This is mainly due to the lack of scientific information and adequate instruments for quantifying the doses and deciding the frequency of irrigation [5]. Growers generally assess crop response visually to decide when to irrigate. Such visual observations frequently correspond to levels of water stress that may affect tree growth and/or production adversely. To sustain agriculture, it is particularly important to optimize crop yields by minimizing inputs, mainly water and nutrient application; Irrigation management based measures of plant and soil water status need to be adopted in intensive horticulture of Souss Massa region, where there is strong competition for scarce water supplies. The measurement of plant water status could represent a promising technique for precise irrigation scheduling because of its dynamic nature, which is directly related with climatic and soil conditions, as well as with crop productivity [6-8].

Many approaches to improve water management have been developed [9], some of which involve the use of sensors to monitor continuously either the soil water content [10] or the plant water status [11]; Stem water potential is a reliable plant-based water status indicator for irrigation scheduling in fruit trees [12-15]. However, its measurement is cumbersome procedure and requires frequent trips to the Weld and a significant input of labor.

Recording the Maximum Daily Shrinkage (MDS) of the trunk has been proposed in several studies as a tool for continuous estimates of plant water status [16-18], Citrus tree irrigation scheduling can be based on MDS, avoiding the appearance of any plant water stress situation without affecting yield or fruit quality [19]; however, plant water status integrates the effect of the soil water available to the plant and the climatic conditions; this complicates the use of absolute values obtained from plant-based water stress indicators for irrigation scheduling as proposed by some authors [20].

The Watermark [21] is a relatively low-cost soil moisture sensor, which is easy to use and install and can function consistently over a range of soil water tension from 10 kPa to 200 kPa [22] , which make it not very suitable tool in those cases where irrigation practices maintain a low soil tension [23-24]. Moreover, the Watermark does not respond properly to rapid drying or partial rewetting of the soil, showing hysteretic behavior [25], and calibration appears to be unique for each individual sensor [26-28].

Capacitance probes are an alternative to tensiometers for continuous monitoring of soil moisture content within and below the rooting zone and it facilitate optimal irrigation scheduling aimed at minimizing both the effects of water stress on the plants, and also the leaching of water below the root zone, which can have adverse environmental effects [29-30]. However, when used for measurement of soil water content, capacitance probes can be influenced by soil type [31-33], Bulk density [34] and soil salinity [35], it would therefore require individual calibrations for each soil under moderate soil salinity conditions [36], Nevertheless, the relationship developed between soil water content measured by tensiometers and the one measured by the FDR probe must be determined before these sensors can be used effectively in irrigation scheduling and management [37].

This work aims to develop strategies to improve irrigation water use efficiency based on soil-plant-atmosphere measured parameters, using fixed dose and a variable frequency as a water supply technique. Irrigation monitoring was studied in a 'Nules' Clementine grafted on Citrus macrophylla in the Experimental Farm of the Hassan II Institute of Agronomy and Veterinary Science. A complete block design experiment (with 6 blocks) was undertaken using 4 treatments based on an 'f' value representing the percentage of water used from the soil water reserve at which the irrigation is applied. Four doses were thus defined: 1.05, 1.6, 2.1 and 2.6 mm/application corresponding to an 'f' factor of 10%, 15%, 20% and 25%. Measurements concerned parameters of the soil-plant-atmosphere continuum: ETo were calculated based on complete weather station installed in the same experimental plot; Soil moisture was measured through two depths capacitance probes (C-probe), as well as the soil water tension, LVDT sensors installed at trunk level and leaf water potential monitoring helped to evaluate the stress state of trees.

The objectives of the use of these equipments are:
1. Test of modern instruments for measuring parameters in the soil-plant-atmosphere continuum, particularly for the interpretation of recorded data;
2. Determine the reliability of the probes used and their performances, by comparing modern instruments [FDR (Frequency Domain Reflectometry) and LVDT (linear variable differential transformer) probes] with conventional methods (such as gravimetry) ;
3. Quantify the response of a young citrus orchard to different irrigation regimes defined as four "dose x frequency" combinations and its contribution to the best irrigation practices.
4. Determination of plant water use efficiency, using slightly stressing water regimes often known as regulated deficit irrigation (RDI) strategy for water saving.

Results presented in this report are a contribution aiming at using modern instruments for improving irrigation management in a young citrus orchard located in the area of Agadir. Various combinations of water "dose × frequency" of supply were tested without stressing the trees.

MATERIALS AND METHODS

The experimental plot has an area of 2500 m² (50 m wide and 50 m large). The trees are of the 'Nules' variety grafted onto *Citrus macrophylla* rootstock. Planting density is: 1.5 m between trees and 4 m between rows (*i.e.*; 1600 trees/ha). The plot is equipped with various instruments used for applied research and drip irrigation system. Each tree row has a single polyethylene pipe with integrated self compensating drippers that are placed at 75 cm from one to another on the pipe and their flow is about 2.3 l/hour at a pressure varying within the range of 1 to 4 bars. Each tree has 2 drippers. The soil is loamy with 17% clay, 48% silt and 35% sand. When water is applied, there is a continuous humid soil band due to the uniform spacing between drippers combined with the texture of the soil.

The factor studied is the quality of irrigations (dose and frequency of applications). All of the other production practices (fertilization, protection against pests and diseases, weed control etc.) are optimal and were similar for the whole experimental plot. Immediately after planting the trees, water was systematically applied. Water supply was less than 1.5 mm per day. During this period, the total of water applied was 128.4 mm; after that, differential water regimes were applied. A given water regime is based on precise knowledge of the net maximum dose (NMD, in mm/day), defined as follows Feyen et al., 1984:

$$\mathbf{NMD = f \times (HFC - HPWP) \times Da \times Z \times PSH}$$

where: HFC is the soil moisture at field capacity; HPWP is the soil moisture at the permanent wilting point; (HFC – HPWP) represents the useful soil water reserve and its value is 15 % w/w; Da is soil Bulk density (the value 1.4 will be used); Z is root depth (equals to 0.4 m); and PHS is the percentage of effectively humidified soil (estimated to be 17.5). The four water regimes corresponding to the four treatments studied are defined in terms of the “f” coefficient. This coefficient signifies the threshold level of the useful water reserve at which irrigation is applied. Four values were tested: f = 10%; f = 15%; f = 20% and f = 25%. The four treatments are presented in Table 1.

Table 1 Details of the irrigation regimes (combination: dose x frequency)

Irrigation regimes (treatments)	f (in %)	Net maximal dose (in mm)	Corresponding duration of irrigation
1	10	1.05	1h 21 mn
2	15	1.6	2h 00 mn
3	20	2.1	2h 43 mn
4	25	2.6	3h 22 mn

In practice, application of these treatments was done according to the concept of « a fixed dose applied during the whole experimental period and varying the number of times this dose was split (named frequency here)» ; in reality, the value of reference evepotranspiration (ETo) given by the weather station according to the Penman-Montheith [38], is used to calculate crop evapotranspiration (ETc), by introducing the crop coefficient Kc :

$$\mathbf{ETc\ (mm/day) = Kc \times ETo\ (mm/day)} \qquad \mathbf{(2)}$$

The daily value for ETc is compared to the calculated dose (Table 1). If the ETc value is equal to or greater than the predefined dose, this water dose is applied; if the value is lower than the calculated value, it is cumulated with that of the following day until the predefined net maximal dose is reached. In this way, for the same total final dose, the water regime associated to the 1.05 mm net maximal dose will require the highest number of water applications whereas the régime defined with a fixed water dose of 2.6 mm will require the least number of water applications. The other 2 water regimes are in between. At the end of the experimental period (*i.e.*; approximately 6 months in our case), all of the trees in the experimental plot will have received the same amount of water. The only difference between one regime and another is the way the water was applied. The four treatment thus defined (combinations dose × frequency) were applied to the trees in a random manner but using a complete bloc design with 6 blocs (= replications). The plot contains 24 experimental units. Each elementary parcel is made of 10 trees.

Measurements and observations

Characterization of soil water retention using Richards apparatus: soil sampling was done in the first 50 cm profile and samples were taken at intervals of 10 cm of depth. Metal cylinders of 4.2 cm in diameter and 4 cm in depth were used for *in situ* samplings.

Characterization of the root profile in the soil: it allows architectural visualization of the roots in the soil, in relation to the relative distance to the drippers and to the tree trunk. A square-shaped screen (1 m in each side) composed of elementary openings of 10 cm x 10 cm is placed against the vertical wall of the profile; roots located in each opening were counted after their classification according to their diameter (Ø < 1 mm ; 1≤ Ø < 3 mm ; Ø ≥ 3 mm).

Vegetative growth: several parameters were observed (trunk diameter, spring growth development, number of leaves per shoot, internode length). Shoot growth measurements were made on 3 shoots per tree using 3 trees per experimental unit and 6 replications (blocs) (*i.e.*; 54 measurements per treatment). These measurements were done at monthly intervals. The MINITAB computer software was used for statistical analysis.

Two LVDT probes (Solartron DF 2.5 from England) were installed on 2 representative trees of the 2 most extreme treatments (*i.e.*; f = 10 % and f = 25 %) to measure daily trunk microvariations.

Soil volumetric water content: four FDR probes (C-probes from Australia) are used to monitor soil water changes at 25 and 50 cm depths. Concomitantly with this automatic method, Watermark tensiometers (Irrometer from USA) were installed at 25 and 50 cm depths, to determine the water status in the soil. These instruments were installed at 20 cm from the water pipe, at half way between the 2 drippers, and at 30 cm from the trunk of the tree.

Soil samples were used to determine correlations with the data obtained using FDR probes. For this purpose, sampling was performed at 15 day intervals. A single sample is the mixture of 6 samplings done at the same depth for each one of the four treatments.

RESULTS AND DISCUSSION

Results presented here are those obtained during the two first years after plantation.

Climate characterization during the experimental period

Global solar radiation had a continuous increasing trend from January to June. Solar energy supply is about 600 to 800 w/m² during the month of January and about 1000 w/m² in June. Air evaporative demand is estimated from the reference evapotranspiration (ETo). Fig. 1; Thus, Year 2009 was clearly hotter than 2010, ETo showed extreme values until 7 mm/day on April 2009, when hot and dry winds from the desert blow over the region, however those values didn't reach 3 mm/day for the same period. Furthermore, average temperatures are around 10 °C in January and above 25 °C in June. This temperature range is favourable for citrus growth and development. Conversely, periods of dry and hot winds are significantly not good for citrus, particularly if they coincide with flowering or with the early stages of fruit growth. This is not the case yet for the very young experimental orchard we are using.

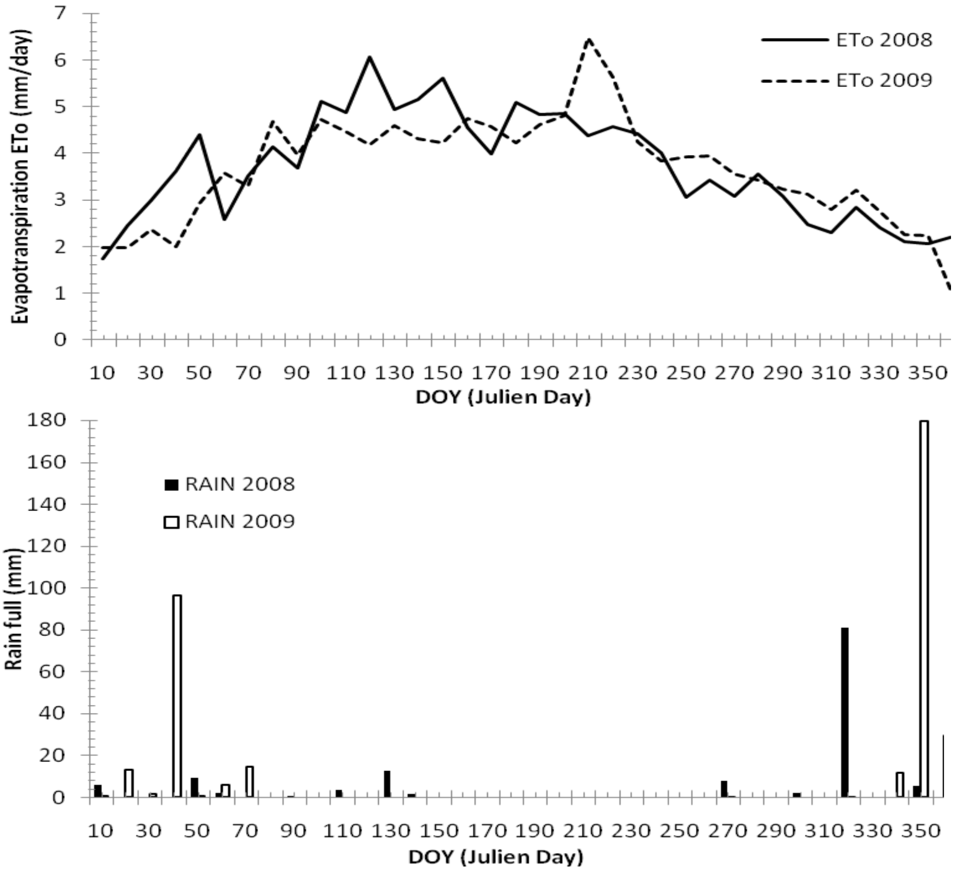


Fig. 1 Time course of reference Evapotranspiration (ETo) and of Rain full during the period of study; each value is an average of 10 successive days.

Water retention curve or pF curve

Values in Fig. are relative to different soil depths. The trends are identical. The observed differences are due to the difference in soil granulometric composition from one soil horizon to the other. This causes a certain variation in bulk soil density and, consequently, variations in soil microporosity. The 40-50 cm soil horizon is slightly deficient in terms of water retention, probably due to conditions of soil compaction at this depth.

In all cases, the average curve binding soil water pressure potential with soil volumetric water content has a polynomial form: y = 0.067x2 – 2.915x + 45.230

After adjusting the results obtained experimentally with information from the literature [39-40-41], we have chosen soil moisture at field capacity (HFC of 30 %) and soil moisture at permanent wilting point (HPWP of 15 %). Available soil moisture is determined as the difference between the water content at field capacity and permanent wilting point (Sodek et al. 1990) [41].

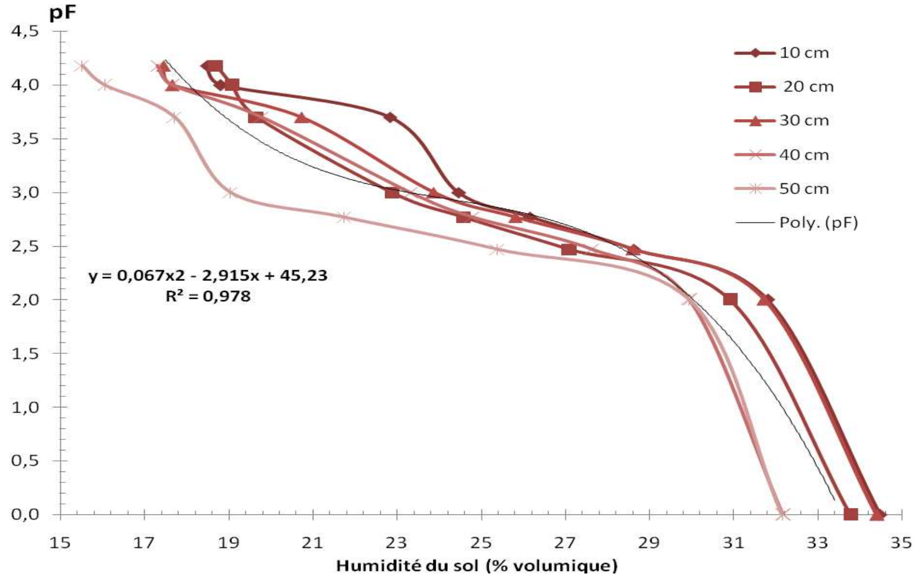


Fig. 2 Water retention curves (pF curves) for the experimental orchard

Water supply scheduling

The Table summarizes the calendar of water applications between June 2009 and May 2010. As was mentioned above, it wasn't a question of restricting amounts of water applied but a question of qualitative management using variable frequencies of water applications. The results show that our young orchard has received a water quantity equivalent to 334 mm and 398mm per the year of 2009 and 2010 respectively, which is slightly lower than the amount reported by I. García-Tejero and al for 100% ETc [42]. The high dose of 2.6 mm/application required 210 irrigation cycles whereas the lowest dose of 1.05 mm/application required 521 interventions during the two years period.

Table 2 Water height applied during 2009 and 2010 to the young 'Nules' orchard

Year	Rain day	Rain full	Useful rain		Number of water applications				Total of irrigation water	Total of water received by the orchard (mm)	
		Mm	mm	%	T1	T2	T3	T4	mm	Total	Useful
2009	13	133	37	28	283	185	141	114	297	430	334
2010	38	355	149	42	238	155	119	96	249	604	398

Soil moisture monitoring using tensiometers

Examination of the changes in soil water tension (Fig.) indicate much contrasted trends between the very extreme water regimes (T1 and T4). Firstly, during the month of February, the 2 curves for water tension in the soil are very close to each other for the two soil depths studied (25 and 50 cm). There was excess of water even at the very shallow soil profile. The reason was the application of a high crop coefficient (Kc = 0.4) extracted from the FAO publication [43]. We then used a lower Kc value starting March the first; from this date onward, Kc was 0.3 which was more compatible with the vegetative soil cover which was approximately 13 %. Fluctuations were more noticeable for the shallow soil horizon (0-25 cm) compared to deeper horizons (25 to 50 cm). Application of small doses but at high frequencies (Fig.) gave rise to a soil water tension of 10 to 15 cbars; application of higher doses but at lower frequency gave rise to a water tension of about 10 cbars. The soil tensions in deeper profiles are less than 20 cbars in both cases. It is noteworthy that humidity at field capacity is close to 30 cbars. From these data, it therefore appears that there is still room for additional water saving, this method gives a relatively good estimate of the crop water requirements [44].

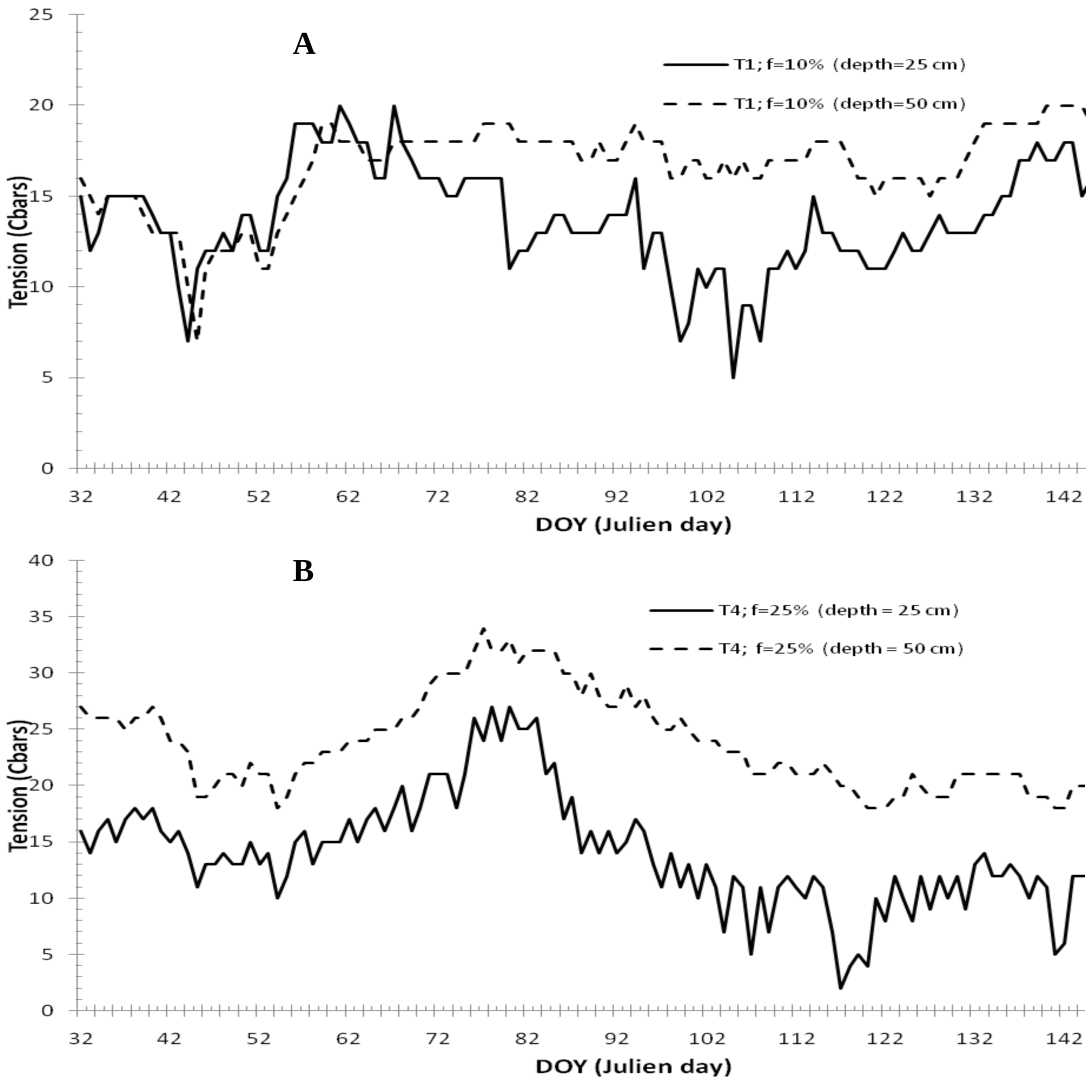


Fig. 3 Daily timecourse of soil water tension in T1 (very frequent applications; 1.05 mm/application ; f = 10 %) and T4 (less frequent supply of 2.6 mm/application; f = 25 %), for each of the two soil depths : 25 cm (continuous line) and 50 cm (dashed line).

Soil moisture monitoring using capacitance probes

Data from FDR probes gave the trend shown in Fig. for soil volumetric water content. It is noteworthy that, at times, there were interruptions in the recording due to either problem of telemetry transmission or to intrinsic problems in the probe's electronics, or to the site where the detector was placed. In all cases, FDR probe showed decreasing amounts of water in the soil, at 50 cm depth, following the change in Kc on day 60. This trend was also observed in the records of the soil water tension (Fig.). Supplying small doses (Fig.) but at low frequency gave plotted curves that are very close for the two soil horizons (25 and 50 cm depths). This observation does not apply to Treatment 4 in which there was high doses but applied less frequently.

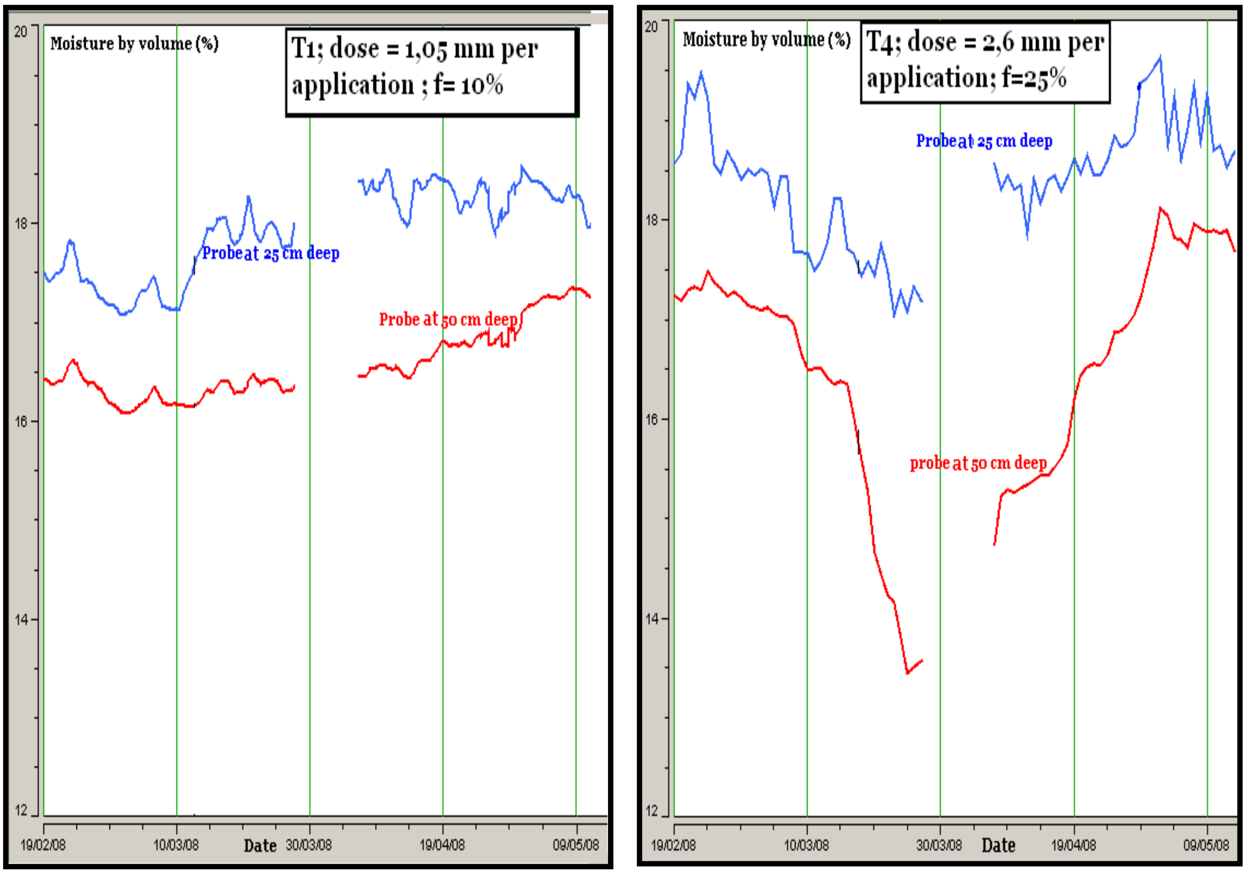


Fig. 4 Changes in the soil volumetric water content, measured using FDR probe in T1 (very frequent applications of 1.05 mm/application ; f = 10 %), and T4 (less frequent applications of 2.6 mm/application; f = 25 %) for each of the two soil depths : 25 cm and 50 cm.

A major remark concerns recorded absolute values of soil water. The range in values (16 to 18 % in the case of T1 and 18 to 20 % in the case of T4) is not compatible with the remarkable values of soil water retention obtained in the laboratory (HFC = 30 % and HPWP =15 %). As an illustration, a FDR value of 16 % would be synonymous to a very low humidity in the soil, a situation which was ruled out by the tensiometric values. Calibration curves are therefore necessary under experimental conditions. To elucidate this problem, a calibration curve was obtained (Fig.). It indicates a linear relationship between, on the one hand, soil volumetric content obtained by gravimetry, and, on the other hand, the one obtained using FDR. From these data, a value of 16 % obtained by FDR probe is equivalent to about 22 % in the reality.

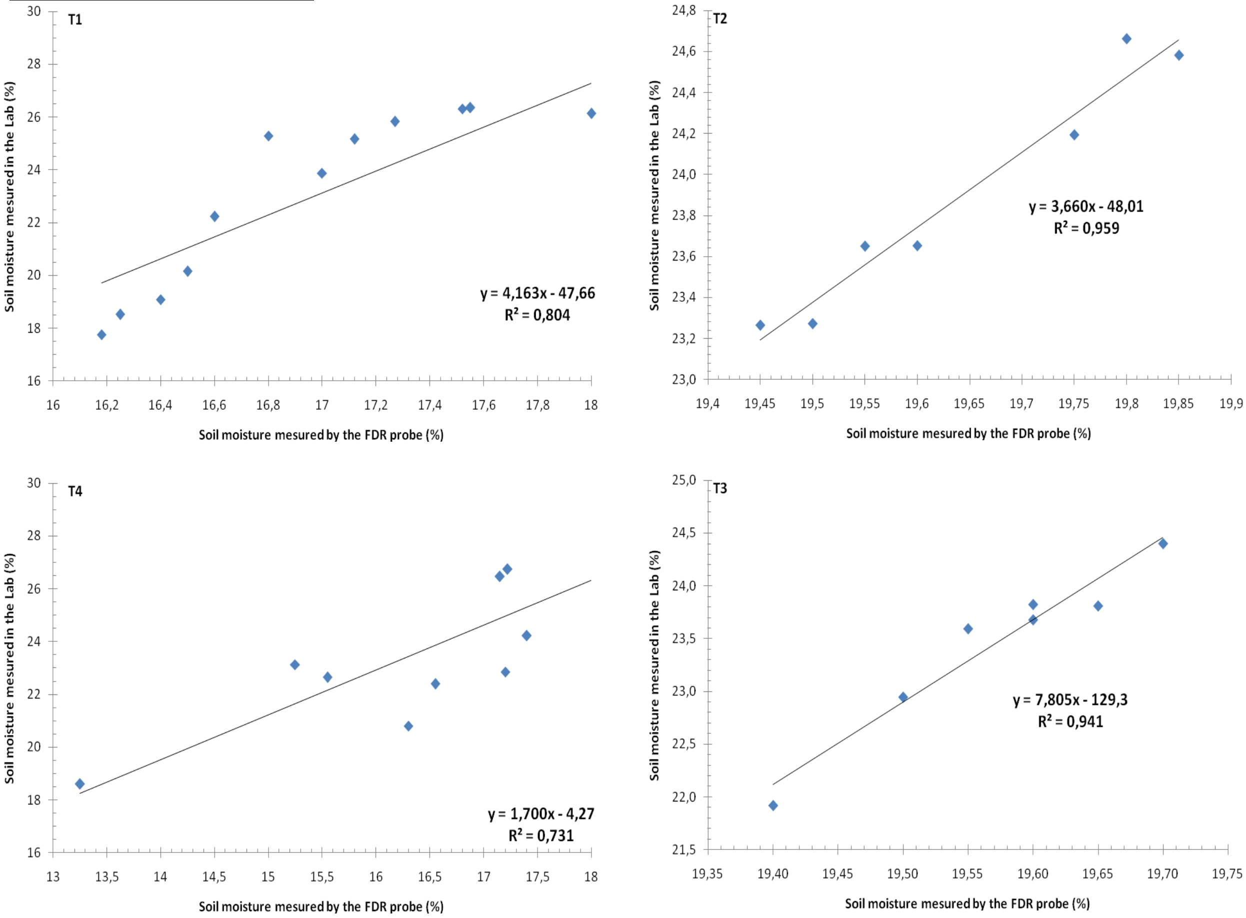
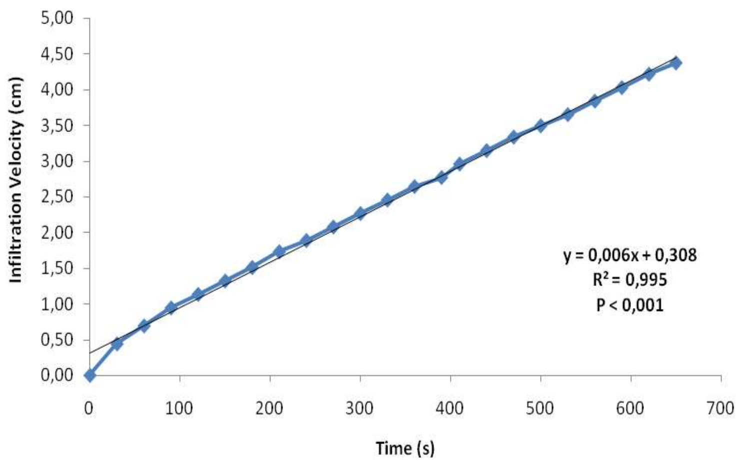


Fig. 5 Correlation between Soil volumetric water content (%) obtained by the laboratory gravimetric method (Y) and that obtained in the field using FDR probe (X).

It was also possible, to quantify the water infiltration velocity into the soil (Fig.): we notice that irrigation water needs 1h30min to reach 30 cm depth and 3h to infiltrate until 60cm. It means that the time between two irrigations must be between 1h30 and 3 hours which is in concordance with recommendations from Eran Segal and al [45] .

Fig. 6: Water infiltration velocity into the soil (cm per second).

Vegetative growth



A comparison between measurements from LVDT showed no significant effect of the irrigation regimes on growth of the trees (Fig.) with a slight advantage for T4 (high dose but less frequency). Those results are conforming to those found by other authors [46-52]. Regime T1 was better during the cold period, and T4 was able to continue a strong growth during the warm period. It is noteworthy that trunk diameter went from 10 to 50 mm in the two years study.

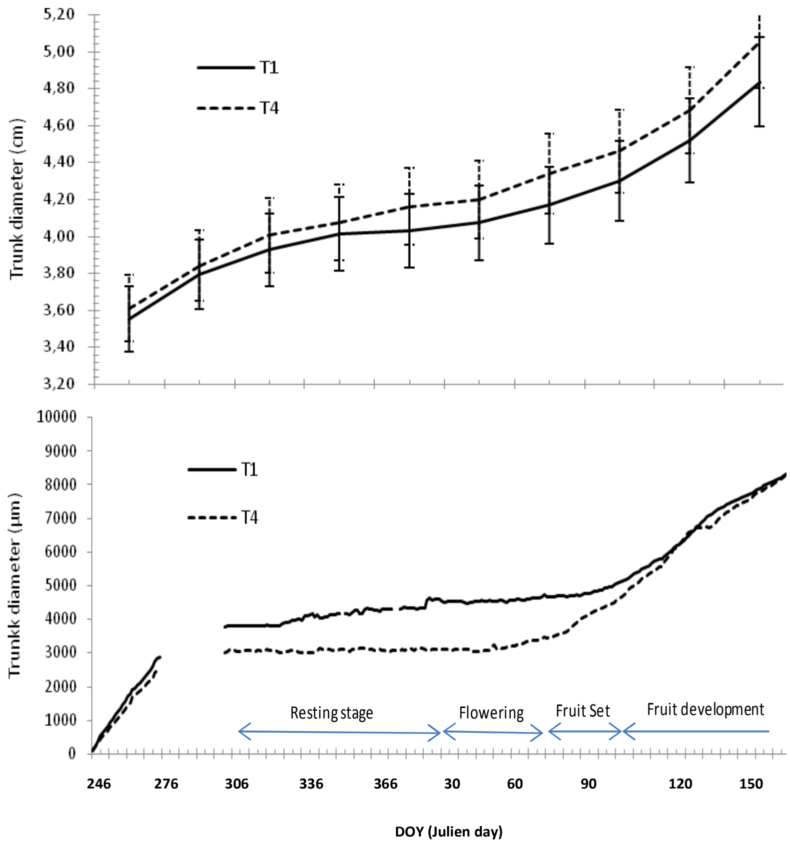


Fig. 7 Effect of water regimes on Daily growth rate (DGR) of the trunk diameter for T1 and T4 (each value is a mean of 72 observations in µm/day).

The difference in water applications resulted in micro-variations at the tree trunk growth (Fig.). Therefore, water regime with low dose and high frequency of applications (T1) gave fluctuations much greater than those obtained for water regime with higher dose but low frequency of supply (T4).

The examination of Fig. indicates two major observations:

- The daily gain in growth (about 50µm/day), associated with mild temperatures for growth during the months of January and February is highly remarkable for Treatment 1; this trend was reversed with the high temperatures of April and May when the daily growth was close to zero or even negative with very high range of contractions;
- Excess water observed until the end of February (i.e.; when crop coefficient Kc was 0.4) and which was amplified by high doses in Treatment 4 indicates that gain in growth was almost null.

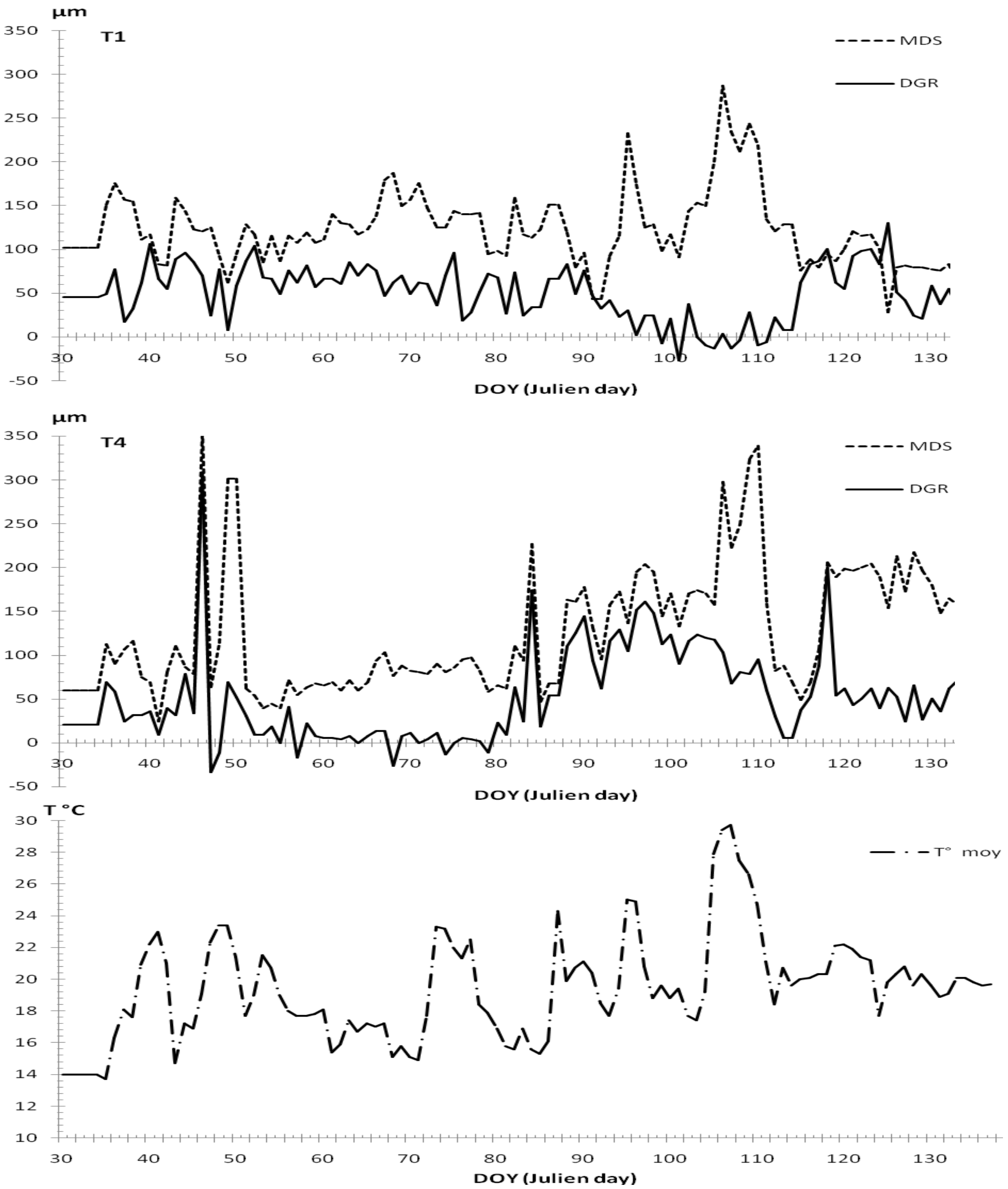


Fig. 8 Evolution of Maximum Daily Shrinkage (MDS) of the plant trunk and Daily Growth Rate (DGR) (using LVDT sensor), for Treatment 1 (dose = 1.05 mm/application and f = 10 %) and Treatment 4 (dose = 2.6 mm/application and f = 25 %) compared to the temperature average during 2009.

The analysis of Fig. shows a difference between treatments in terms of trunk behavior; indeed, the regime in combination with low doses and a high frequency (T1) results in greater fluctuations compared to T4, in the same day.

Except for the period from late April or early May when the T4 recorded greater fluctuations compared to T1, this was due to a decrease in soil moisture because of the crop coefficient applied at this time (Kc=0.3), we then realized that this value was not enough to satisfy plant water requirements at the beginning of fruit growth.

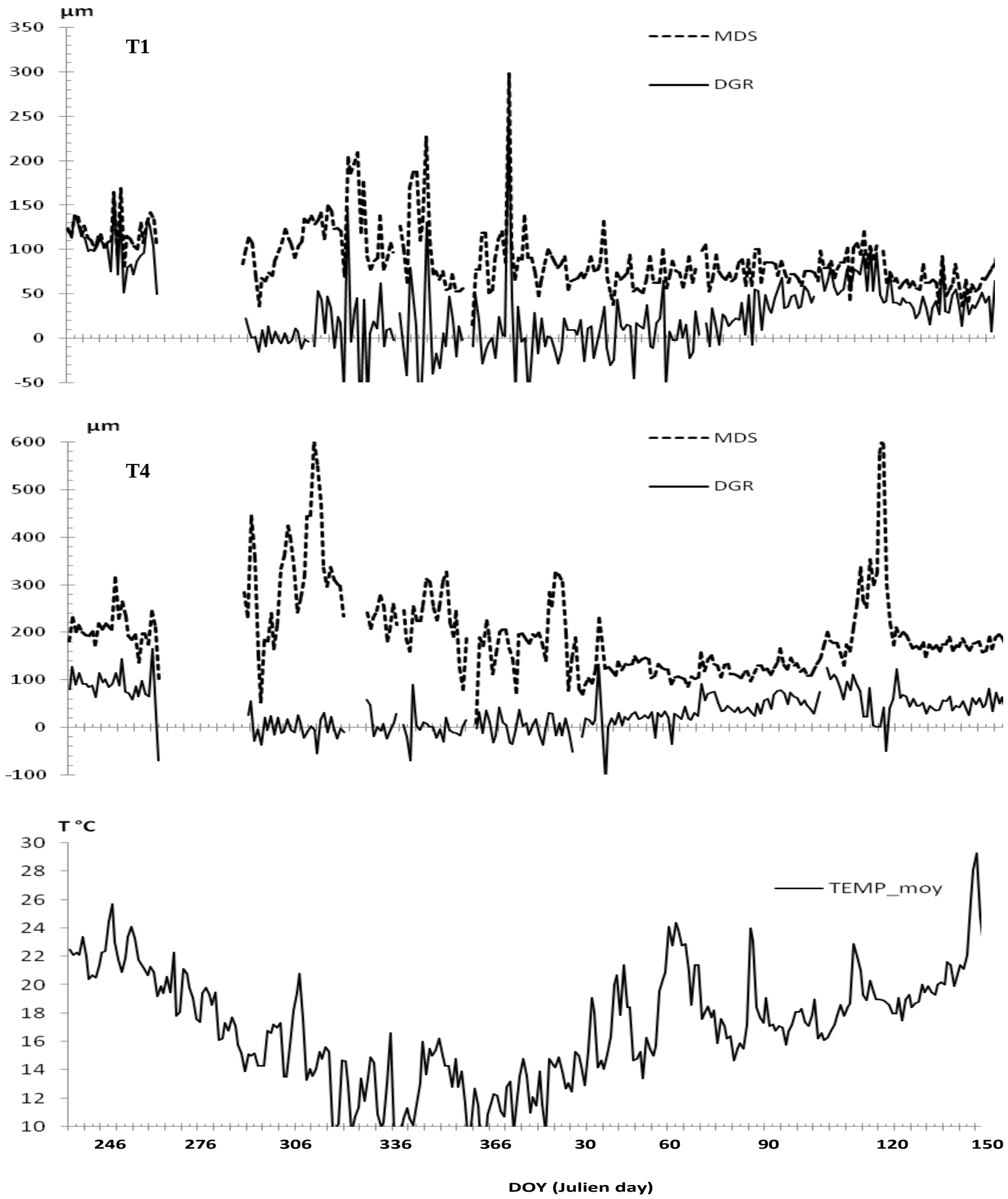


Fig. 9 Maximum Daily Shrinkage (MDS) of the plant trunk and Daily Growth Rate (DGR) (using LVDT sensor), for Treatment 1 (dose = 1.05 mm/application and f = 10 %) and Treatment 4 (dose = 2.6 mm/application and f = 25 %) compared to the temperature average during 2010.

The analysis of trends showed at Fig. **Error! Reference source not found.**leads to the following:

- During late November and early December, the DGR of the two treatments was null. In contrast during late December and early February, the DGR was higher for treatment 1 (with very high MDS) thanks to relatively mild temperatures.

- Lack of water observed in late April to early May (before we increased the crop coefficient from 0.3 to 0.4) was expressed at the treatment 4 by large MDS and a DGR almost null, especially because of significant increases in temperature (average temperature exceeding 24 °C).

It appears that the micro-variations of the circumference of the trunk are closely linked to climatic factors, and the availability of water in the soil [53]; Fig. shows that the MDS is greater when the temperature is higher, so the DGR is reduced, which was reported by the work [54-55]; However, recent results have shown that other factors may also affect the MDS such as development stage [56], fruit load [57], tree size and root system [58].

It appears that the micro-variations in trunk circumference are highly related to climatic factors. Fig. proves that the extent of contraction is much greater with increased temperatures; consequently, the gain in growth is reduced.

To study the relationship that might exist between dendrometric data and climate parameters we have chosen the day 115 which had extreme climatic conditions worsened by a very hot and dry wind blowing from the East:

- Temperature range : 16,3 - 41,0 °C
- Relative humidity range : 9 - 50 %
- Global solar radiation = 2704,32 J/cm²/day
- ETo sum : 7,5 mm/day

Under these tough conditions, trunk micro-variations of our young trees are correlated, on the one hand, with temperature (Fig. 11), air relative humidity, and on the other hand, with ETo (Fig. 12). These variations are observed in the case of Treatment 1 (low dose and high frequency of water application). A very strong correlation was obtained with these two climate parameters.

Young trees react very strongly to climate change.

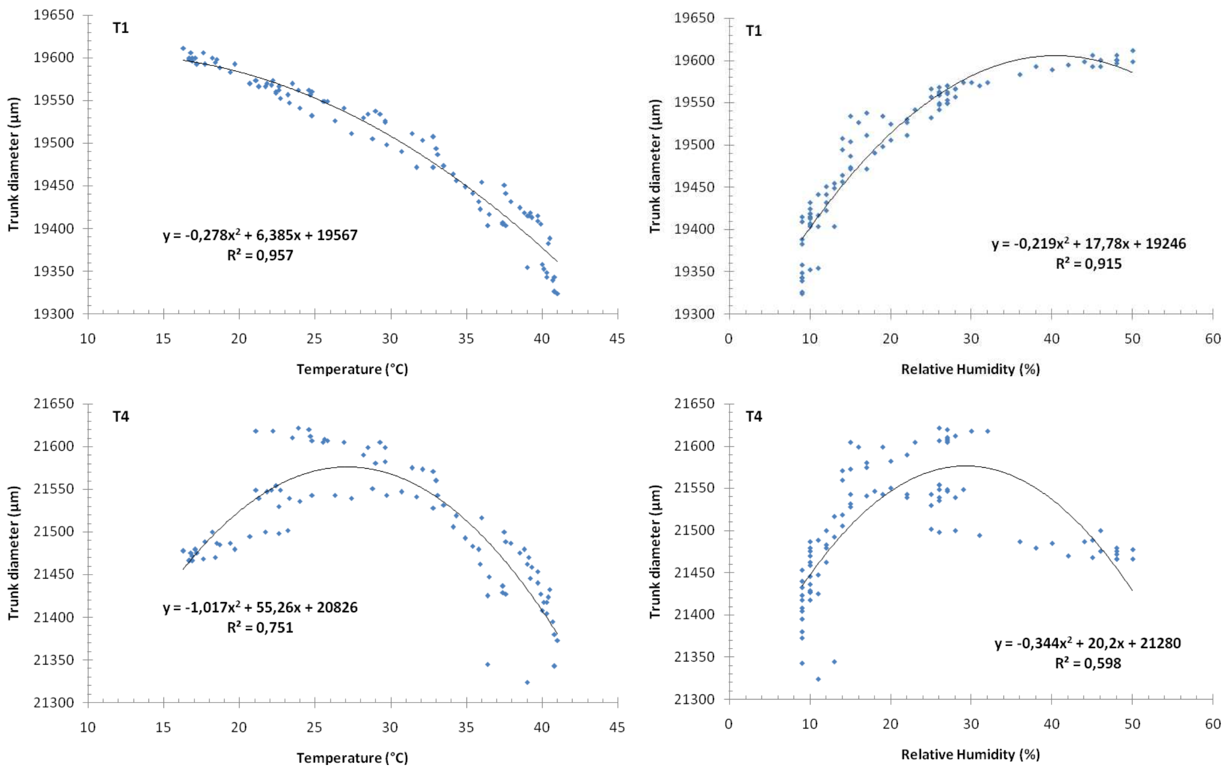


Fig. 10 Correlation between trunk diameter measured using LVDT sensor, in relation to changes in temperature and relative humidity, for Treatment 1 (dose = 1.05 mm/application and f = 10 %).

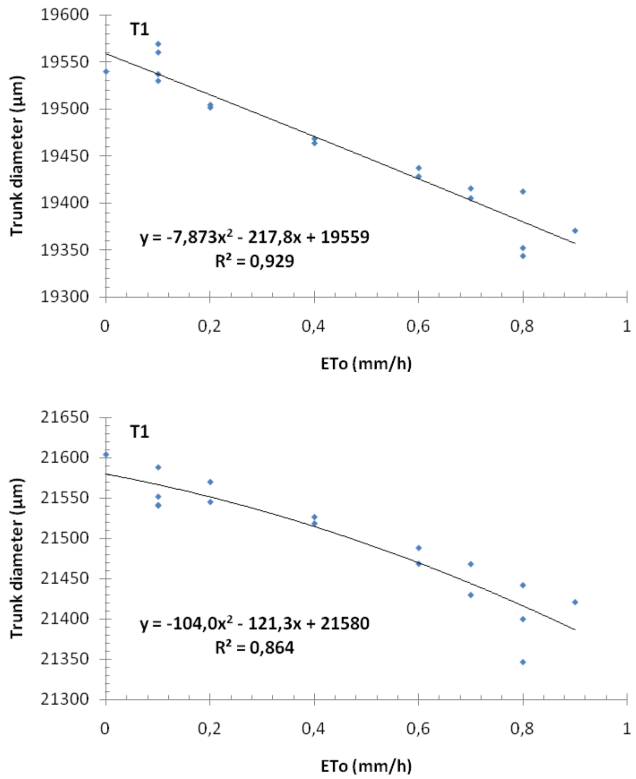


Fig. 11 Correlation between trunk diameter measured using LVDT sensor, in relation to reference Evapotranspiration per hour (ETo), for Treatment 1 (dose = 1.05 mm/application and f = 10 %).

Root profiles

In this report, we are only presenting results for the root hairs responsible for water uptake (diameter < 1 mm). The greatest root concentration of the feeder roots is located at less than 40-50 cm depth. For these young trees, the 0-10 cm soil horizon contains zero roots. About 79 % of these roots are localized between 20 and 50 cm of soil depth. In addition, a good horizontal distribution of these roots is observed, which proves that soil humid bulbs overlap under the emitters which is also in relation with the loamy nature of the soil. In fact, maximum number of roots (13%) is found at mid-way between the drippers indicating that this is the appropriate zone where FDR probes and tensiometers should be installed.

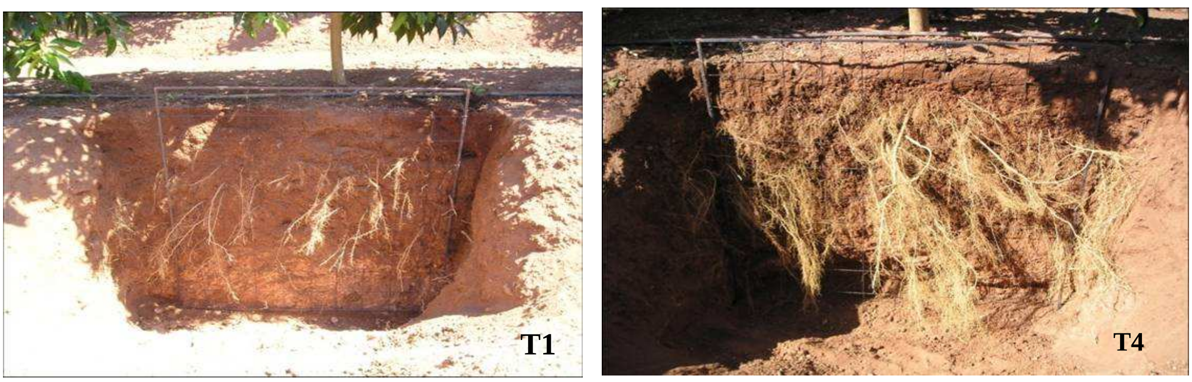


Fig. 12 Photos of root sections at the end of the experiment for Treatment 1 and treatment 4.

The analysis of the Table 3 brings to say that trees from the treatment 1 (high frequency and low doses) develop a very superficial active roots (over 72% of roots in the 0-40 cm horizon and 15% in the 40-50 cm horizon) due to water regime which brings a superficial soil humidity. Moreover, the total number of roots is relatively low compared to other treatments especially treatment 4 (low frequency with high doses) which developed roots much larger and well distributed until 80 cm depth (4102 for T1 and 8843 for T4) (table 4).

Table 3 Root counts in a soil profile (Ø <1mm) made at 20 cm from tree trunk and just underneath the irrigation pipeline for treatment 1; the placement of the 2 drippers coincides with horizontal distances

depth (cm)	Horizontal distribution										Counts	%
	0-10	10-20	20-30(*)	30-40	40-50	50-60	60-70	70-80	80-90(*)	90-100		
0-10	0	0	0	0	0	0	0	0	0	0	**0**	
10-20	14	60	36	86	140	50	56	70	60	49	**621**	**15%**
20-30	60	80	100	100	210	200	180	90	70	26	**1116**	**28%**
30-40	30	80	120	111	80	80	80	80	80	100	**841**	**21%**
40-50	12	90	70	35	80	80	50	45	45	109	**616**	**15%**
50-60	80	56	40	58	50	42	47	19	22	80	**494**	**12%**
60-70	8	12	40	28	40	44	24	30	20	30	**276**	**6%**
70-80	6	3	10	10	12	12	7	0	7	12	**79**	**2%**
80-90	0	0	0	13	10	8	20	0	0	8	**59**	**2%**
90-100	0	0	0	0	0	0	0	0	0	0	**0**	**0%**
Total	**210**	**381**	**416**	**441**	**622**	**516**	**464**	**334**	**304**	**414**	**4102**	**100%**
%	**5%**	**9%**	**10%**	**11%**	**15%**	**13%**	**12%**	**8%**	**7%**	**10%**	**100%**	-

(*): Approximate placement of the 2 emitters.

Table 4 Root counts in a soil profile (Ø <1mm) made at 20 cm from tree trunk and just underneath the irrigation pipeline for treatment 4; the placement of the 2 drippers coincides with horizontal distances

depth (cm)	Horizontal distribution										Counts	%
	0-10	10-20	20-30(*)	30-40	40-50	50-60	60-70	70-80	80-90(*)	90-100		
0-10	0	0	0	0	0	0	0	0	0	0	**0**	**0%**
10-20	10	30	50	160	200	250	180	100	70	20	**1070**	**12%**
20-30	150	120	150	200	390	300	250	180	200	80	**2020**	**23%**
30-40	70	200	150	80	260	200	250	160	100	60	**1530**	**17%**
40-50	80	100	150	160	180	150	180	160	120	50	**1330**	**16%**
50-60	90	160	130	180	170	180	160	100	90	68	**1328**	**15%**
60-70	20	60	70	150	35	40	160	80	30	25	**670**	**7%**
70-80	20	30	65	100	80	90	100	20	60	2	**567**	**6%**
80-90	20	35	16	60	30	15	70	8	15	0	**269**	**3%**
90-100	7	13	9	5	0	0	3	10	12	0	**59**	**1%**
Total	**467**	**748**	**790**	**1095**	**1345**	**1225**	**1353**	**818**	**697**	**305**	**8843**	**100%**
%	**5%**	**8%**	**9%**	**14%**	**15%**	**14%**	**15%**	**9%**	**8%**	**3%**	**100%**	-

(*): Approximate placement of the 2 emitters.

CONCLUSION

Optimization of water supply to citrus trees is no longer a necessity but a prerequisite for sustainability of agriculture in the Souss-Massa region. During experiment, irrigation was applied based on ETo from Penman-Montheith formula which is widely used as it integrates different climatic parameters to characterize the evaporative demand of the local climate. According to this method, cumulated annual ETo is approximately 1800 mm. In addition, systematic use of crop coefficients published by FAO [**Error! Bookmark not defined.**] can lead to results with an average degree of precision. It was then necessary to revise these values and

apply values that are adequate with local conditions and, in particular, with the very limited soil cover brought by the young citrus trees of the experiment. The final objective of this work was to define the theoretical value of the maximum irrigation dose beyond which there is a risk of water percolation into deep soil horizons.
On an annual total water of 398 mm received by the plot, a water height of 249 mm was applied per year. This quantity required 238 interventions using doses 1.05 mm/application for Treatment 1 and only 96 interventions for treatment 4 in which doses of 2.6 mm/irrigation were used.

Treatment 1 was highly performing under cold weather (i.e.; during January and February) but showed limitations under high temperature conditions. This observation let us think more about use of irrigation regimes that would combine low doses and relatively great doses along the year, in relation with environmental conditions.

Results from monitoring the moisture status of the soil indicated that the 0-50 cm profile was regularly wetted. Soil water tension was favorable to tree growth. Soil water content was close to field capacity. FDR probe allowed an automatic, continuous and easy monitoring of soil water. Interpretation of the recorded data requires certain precautions. Calibration curves confirmed this observation.

Finally, Growth parameters showed no differences between treatments; it appears that the micro-variations in tree trunk circumference are very susceptible to variations in climatic parameters, in particular, temperature and relative humidity. The LVDT detectors can serve to characterize the water status of the trees.

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