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WATER REQUIREMENTS OF INDIVIDUAL OLIVE TREES IN RELATION TO CANOPY AND ROOT DEVELOPMENT

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SUMMARY – Olive trees are traditionally planted with different densities, depending on local rainfall amounts and distribution. Presently, supplemental irrigation of this species is gaining popularity because it has been demonstrated that the supply of little amounts of water can improve growth and increase yield. However while water requirements of intensive plantations are relatively well known, there is little information on how to manage semi intensive orchards. This paper concerns the development of a methodology for calculating irrigation amounts per tree using data on ETo and effective rainfall. The approach was applied to a semi intensive young orchard in the region of Tunis. Climatic data and measurements of tree growth were used to investigate consumptive use of trees during the first six years of development. Results show relationships between effective rainfall, irrigation water supply and canopy size. A generalized model for young orchard is therefore proposed.

Key words : olive tree, irrigation, growth, model, evapotranspiration

RESUME – *L'olivier est traditionnellement cultivé avec différentes densités de plantation en fonction des quantités de pluie et de leur distribution. L'irrigation complémentaire de cette culture est actuellement de plus en plus pratiquée car il a été démontré que des faibles quantités d'eau d'irrigation peuvent améliorer la croissance et la production. Cependant, si pour les plantations intensives adultes, les besoins en eau sont relativement bien connues, les données relatives à la conduite des plantations semi-intensives sont peu nombreuses. Ce papier concerne le développement d'une méthodologie de calcul des besoins en irrigation par arbre en utilisant l'ETo et la pluie efficace. L'approche a été appliquée à un verger semi-intensif de jeunes oliviers dans la région de Tunis. Les données climatiques et les mesures de la croissance de l'arbre ont été utilisées pour investiguer la consommation des arbres durant les six premières années de leur développement. Les résultats montrent l'existence de relations entre la pluie efficace, les apports d'eau par irrigation et le développement de l'arbre. Un modèle de calcul pour les jeunes vergers est proposé.*

Mots clés : *olivier, irrigation, croissance, modèle, evapotranspiration*

INTRODUCTION

In Tunisia important olive plantations growing under arid conditions, have been maintained productive since the Roman era thanks to appropriate management of rainfall water. The traditional techniques of *Meskats,* which make use of runoff water is widely practiced in the coastal region of Sousse and is particularly adapted to the undulating area receiving annually about 350 mm of rainfall (Ben Mechlia and Ouessar, 2004).

In flat areas, e.g. the region of Sfax, with annual rainfall of about 200 mm and deep sandy soils, the strategy is totally different : olive trees are planted at a very low density in order to increase water availability. Under such situations, only 5% of the total area is covered by vegetation whereas the volume colonized by the root system is very important. Lateral extension allow single trees to extract water and nutrients from an area of about 500 m² and root depth can reach as much as 3 m.

The robustness of the root system of olive trees and its high potential to adapt to various rainfall and soil situations allowed the development of large plantations over a wide range of semi-arid environments. Distance between trees is used to increase water availability. It increases from 10 m in northern Tunisia where rainfall exceeds 400 mm to 24 m in the southern part where average rainfall is around 200 mm.

Work on rooting systems of olive trees started in Tunisia during the 1940's and concerned adult plantations of the Chemlali variety (Yankovictch and Berthelot, 1947 ; Vernet et Mousset, 1963). Under rainfed condition, root growth depends on soil texture. In clay-textured soils, root systems develop superficially following the soil slits and show tortuous ramifications. In sandy soils, the number of roots is larger by about 30%, vertical extension is more important and ramifications are observed in the layer 0-40 cm (Ben Rouina et al., 1997). Recent studies reported relationships between the soil water content and root development.

Under irrigation, the root system develops in the wetted area and even beyond (Palease and al., 2000) and vertical distribution covers the first 70 cm with maximum concentration in the 40-60 cm layer (Bongi and Palliotti, 1994). Palease and al. (2000) reported high correlation between the root system and the above-ground development in the absence of competition with other organs for carbohydrates. Root growth may be reduced in young olive trees during the active vegetative growth period as a result of competition between the different organs of the tree. A more vigorous canopy development results in a larger root density.

Low water availability reduces canopy and root growth, and may alter the roots-canopy ratio (Dichio and al., 2002). Prolonged water shortages may even increase mortality of fine roots of olive trees which represent the main absorbing surface.

Presently, irrigation of olive trees is gaining popularity with the development of new semi-intensive orchards and there is a real challenge to develop irrigation practices adapted to conditions of changing rooting systems. Traditionally, the water balance equation is used to estimate irrigation requirements in order to maintain soil moisture in the entire field above a critical value. Procedure and coefficients to calculate water requirements are given for a large number of crops in the FAO bulletin 56 (Allen et al., 1998). However, for olive trees, values are given for high density adult trees plantations with 40-60% ground coverage by canopy and height of 3 to 5 meters.

The lack of precise information about crop coefficients to be used for low planting densities and for young trees leads to substantial errors in the estimates of evapotranspiration because the partitioning between transpiration and soil evaporation changes tremendously.

Assessment of the effective rainfall is another challenge for estimating irrigation requirements. As root systems of young trees cover only a small proportion of the area between rows, only the fraction of rainfall mobilized for transpiration should be taken into account in the water balance equation.

This paper discusses methods of determining irrigation requirements and how water supply could be linked to the development of canopy and root systems of the trees during the critical first years of cultivation when ground cover and root system are incomplete. The approach is applied to irrigation of a semi-intensive young orchard in Mornag near Tunis. The experimental work was carried out to investigate consumptive use of olive trees canopy growth and root development during the first six years after planting.

IRRIGATION REQUIREMENT OF OLIVE TREES

Annual precipitation in the main olive growing areas is highly variable and sequences of successive dry years with important deviation from mean are frequent (*Table 1*). Application of small amounts of irrigation is used by many farmers in order to mitigate the effect of rainfall deficit. Supplemental irrigation during the dry periods is used either to stabilize production or to avoid permanent damage to the tree. Ben Rouina et al., (1997) reported that for the region of Sfax, supplying 2.5 m^3 of water during the dry season could help maintain some vegetative growth of adult olive trees.

Table 1. Long term average and annual rainfall in the main olive growing areas in Tunisia during 1998-2002.

	1997/1998	1998/1999	1999/2000	2000/2001	2001/2002	Long term Average
Mornag	376	440	410	327	345	450
Sousse	189	382	160	214	222	320
Kairouan	121	306	119	232	202	300
Sfax	130	320	169	103	183	200

The FAO single crop coefficient method (Allen 1998) is a practical tool to estimate crop evapotranspiration (ET_c). The equation established for full covering crops is given by (Eq. 1)

$$ET_c \text{ (mm)} = ET_o \text{ (mm)} * K_c \qquad (1)$$

where ET_o is the reference evapotranspiration (mm) calculated by the Penman-Monteith method and K_c is the crop coefficient.

The use of this method for trees is limited to high density full covering orchards for which average Kc values are given in the FAO 56 paper. For olive trees a value of 0.65-0.7 is recommended for adult plantations with a percentage of soil covered by canopy greater than 60%. Some authors reported monthly Kc values that reflect seasonal variation of physiological activity (Fernandez and Moreno, 1999)

For low planting densities, a reduction factor (Kr) was suggested to correct for incomplete cover (COI, 1997; Fernandez and Moreno, 1999). Value of Kr goes from 1 to 0.7 as ground cover goes from 60% to 30%.

Analytic equation was also proposed by Allen et al (1998) for a corrected crop coefficient using effective height and canopy ground coverage (eq. 2).

$$K_c = K_{c\min} + (K_{cfull} - K_{c\min}) \min\left(1, 2f_c, (f_{ceff})^{\left(\frac{1}{1+h}\right)}\right) \qquad (2)$$

where K_{cmin} is bare soil coefficient (0.2), K_{cfull} is crop coefficient corresponding to full cover (0.65), h is the effective height of the tree and f_{ceff} and f_c are respectively effective fraction of soil covered by the canopy and observed from nadir.

However, during the first years after planting, both transpiration and soil evaporation are affected by the volume of canopy. Specific values of crop coefficient should be adopted in order to reflect increasing LAI and canopy cover. For young trees of Arbequino cultivar planted at 7x3.5 m, Testi at al (2004) reported Kc values of respectively 0.19, 0.24 and 0.34 for trees aged one, two and three years.

Before full development of the root system, only a fraction of rainfall water is accessible to trees. Water balance equation should consider the area concerned by tree transpiration i.e where roots are active (S_{root}).

For young trees it is probably more convenient to consider evapotranspiration (ET), rainfall (P) and irrigation (I) in terms of volume of water/tree instead of mm. S_{root} is assumed to be circular and to increase following a logistic-shaped curve. Water balance for young tree concerns only this surface.

Considering that irrigation water (I*, m^3) is supplied by localized system or in small basins around the trunk, only a small surface is wetted and affected by soil evaporation and transpiration. Irrigation water is therefore assumed to be fully accessible to the root system of the tree.

Effective rainfall for a single tree (P*) is taken as the volume of rainfall water available to the root system which could be approximated by (eq. 3).

$$P^* (m^3) = P (m). S_{root} (m^2) \quad (3)$$

where P is rainfall considered here as total rainfall.

Finally the evapotranspiration volume of an individual tree (ET*) can be estimated from the root area of the tree (eq. 4).

$$ET^* (m^3) = K_c . ETo (m). S_{root} (m^2) \quad (4)$$

A field work has been carried out to explore the usefulness of these concepts.

EXPERIMENTAL SETTING

Experimentation has been carried out during the period 1998-2003 at the experimental station of the National Institute of Agronomy-INAT, located at Mornag, 15 km south of Tunis (Tunisia). The region is characterized by an average rainfall of 450 mm and reference evapotranspiration of 1200 mm.

Olive plants were installed over 1.6 hectare, on a textured clay soil (32% Clay, 53% loam and 15% Sand) characterized by high bulk density (1.7 g cm^{-3}). Trees of the Meski, Chetoui, Manzanille and Picholine cultivars were arranged at 6m x 6m spacing i.e. with planting density of 278 trees / ha.

Climatic factors required by the Penman Monteith equation (Allen at al, 1998) are collected at INAT weather station while rainfall is measured at the experimental site in Mornag.

Canopy and root system were monitored during the six years after plantation. Maximum canopy diameter is taken as a growth indicator and measured twice a year in February and September on 48 trees. Root distribution is determined annually by the trench method (Böhm, 1979) on a different tree of the Chetoui cultivar. Observations were made on the lateral faces of a 1x1 m cubic hole located 40 cm from the trunk. For each face, five horizons with 20 cm depth were considered and roots number and diameters were measured. The volume explored by the root system was therefore mapped and linked to the canopy development.

IRRIGATION MANAGEMENT

During the experimentation period 1998-2003, irrigation was applied by different irrigation systems starting with small basins, and in 2002 drip system was installed. However, with all systems, a strategy consisting in replenishing soil profile in the root zone was used in order to cope with the frequent failures in the distribution network. Time interval between irrigation varied from 20 to 50 days. The first irrigation date varied from March to May depending on rainfall received during the winter season and the last in august or september. Watering conditions and irrigation practices for the whole period are given in *Table 2*.

After plantation, irrigation was applied with small amounts but high frequency in order to ensure good installation of the cuttings. A number of four irrigations was adopted the following years. During dry years, irrigation started on March to stimulate vegetative growth.

Table 2. Irrigation management of the experimental olive orchard during the first six years of cultivation, Mornag-Tunisia.

	1998	1999	2000	2001	2002	2003
First irrigation	March	May	April	April	March	May
Last irrigation	August	September	September	September	August	September
Irrigation system	Basin	Basin	Furrow	Furrow	Drip	Drip
Dose (m^3 $tree^{-1}$)	0.12	0.18	0.22	0.44	0.7-1.7	0.3-1.0
Number of irrigations	7	4	4	4	4	7
I* (m^3 $tree^{-1}$)	0.84	0.72	0.88	1.76	4.98	5.41

ROOT GROWTH AND DISTRIBUTION

Root development was analyzed each year using the trench method (Böhm, 1979) on trees from Chetoui cultivar. The number and diameter of roots emerging on each face of the trench were measured and mapped.

Starting the second year after planting, roots grew rapidly in lateral and vertical directions. More than 70% of the roots are located in the first 60 cm of the soil. As reported by Bongi and Palliotti (1994), the root system was found to be mainly confined to the top meter of soil. The largest diameter evolved from 2 mm the first year to a maximum of 32 mm the fourth year and their color changed from white to yellow. Large roots are observed beyond the first 30 cm. They develop horizontally with numerous fine roots which represent the main absorbing surface. Lateral root growth is estimated using the maximum root length for each soil layer and assuming central symmetry to the trunk

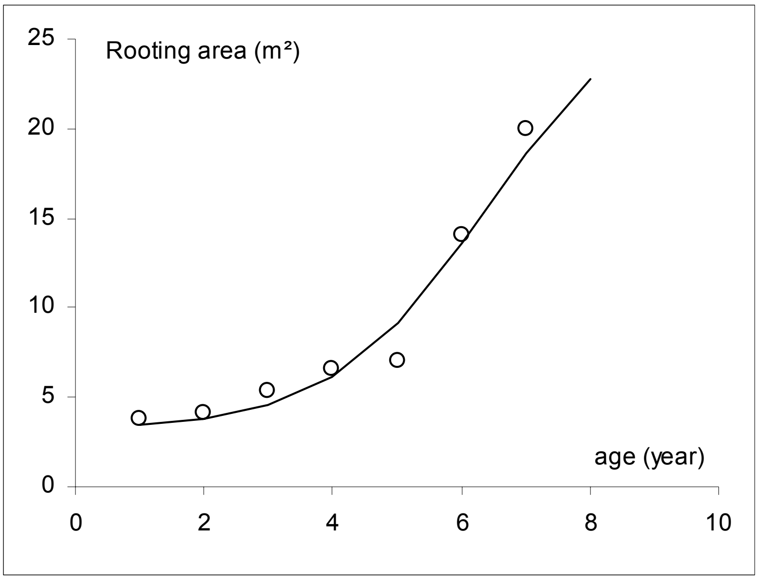

Fig. 1. Rooting area of young olive trees aging 1 to 7 years.

Root surface increased slowly the first year, but more rapidly the following years. The soil volume explored by roots increased during the first four years by about 1 m^3 each year. Obtained values may be considered too low when compared to other findings. Fernandez et al. (1992), Dichio et al., (2002) reported for 3 years old “Coratina” irrigated olive trees cultivated in south Italy on loamy soil a value of 8.6 m^3 per plant. For non irrigated trees, receiving 670 mm rainfall annually, the soil volume explored by roots is 5.1 m^3. Our plants reached only 3.7 m^3 probably because they are planted on hard clay soil which may limit root development.

CANOPY DEVELOPMENT

Canopy diameter was measured for the four varieties on 12 trees per variety, and three times a year : one in September and twice in February, before and after pruning.

Substantial growth is observed beetween April and September with variable rates. Canopy diameter increase between successive prunings over the four years ranged from 0.5 to 1.25 m with significant differences among varieties.

Applied water didn't seem to be limiting to vegetative growth since good development of trees was observed during the years of experimentation.

Canopy diameter increased rapidly to reach an average value of 2.2 m four years after planting. For the same period, lateral extension of roots reached a distance of 1.45 m from the trunk exceeding canopy limit. These results are in concordance with those reported by Bongi and Palliotti (1994).

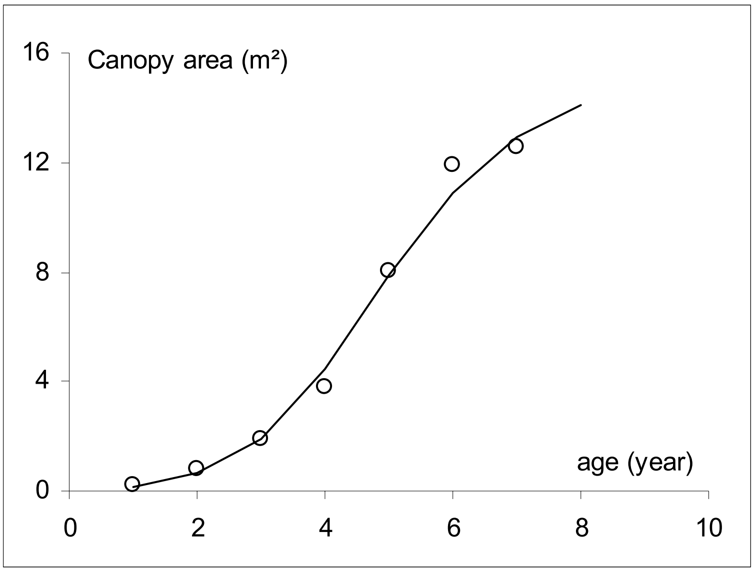

Fig. 2. Average canopy projection area of young olive trees, Mornag-Tunisia

MODELING CANOPY AND ROOT EXTENSION

Canopy cover and root extension are essential for irrigation requirement estimation as they determine evapotranspiration and water availablity for the root system. However while canopy cover measurements are considered as easy, surface covered by the root system is much more difficult to carry out.

Root extension as well as canopy increase seems to coincide with a logistic growth curve as given by eq. (5).

$$L(t)=Lo+\frac{Lx-Lo}{1+\exp(\alpha(t-\beta))} \qquad (5)$$

where t is the number of years from planting, *Lo, Lx* dimension of interest respectively at planting and at maximum growth, α, β are adjustment parameters.

Low values of root / leaf ratio seem to influence the production level of the olive trees as a result of vigorous canopy development and high carbohydrates availability. While high values of root / canopy ratio may indicate a greater availability of water per unit of leaf area and may be used as indicator of tree adaptation to water shortage as indicated by Dichio and al., (2002) who reported ratios of 0.34 for three-years old irrigated olive trees and 0.50 for the non-irrigated ones.

IRRIGATION SUPPLY AS RELATED TO CANOPY AND ROOT DEVELOPMENT

In order to link the water supplied to trees to the evaporative demand, a supply ratio (K_{supply}) that takes into account only the tree-related quantities as defined by eq. (6).

$$K_{supply} = (P^* + I^*) / ET^* \quad (6)$$

This ratio could be considered as a crop coefficient for young trees when reference evapotranspiration, rainfall and irrigation amounts are computed according to equation 3 and 4 and expressed in m^3/tree. Adoption of such ratio allows estimation of irrigation requirements for different rainfall and evapotranspiration regimes.

A trial and error procedure along with the above mentioned conceptual framework were used to conduct irrigation. In our experiment, the adopted frequency and the delivered quantities (*Table 2*) seem to be adequate for young olive trees. It allowed a normal vegetative growth and good development of the tree as mentioned before. Amounts of water supply ratios are given in figure (3).

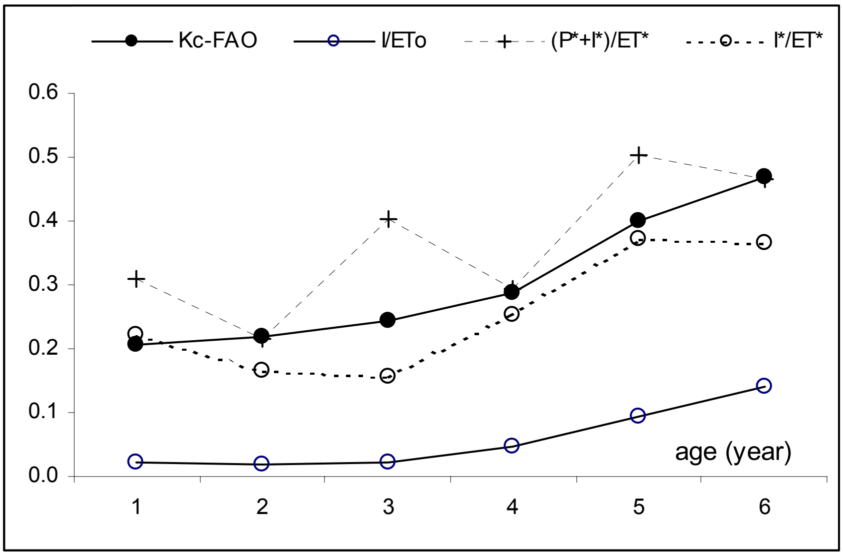

Fig. 3. Variation of Kc-FAO, irrigation supply (I/ETo), volumetric total supply (P*+I*/ET*) and volumetric irrigation supply (I*/ET*) ratios calculated for the period April-August over the first six years of olive trees cultivation, 1998-2003, Mornag-Tunisia.

Results show that the ratio of applied irrigation, (I, mm) to reference evapotranspiration (ETo, mm), during the dry season from april to august, was very low. It increased from 0.02 to 0.14 when trees grew from one to six years. When using the volume method, for calculation the irrigation and precipitation falling on the area covered by roots, K_{supply} comes very close to the Kc-FAO. Estimation of effective precipitation remains however a big challenge for using the proposed method.

Our progress in the future will be measured by our capacity to integrate knowledge on water supply, evaporative demand and the soil volume explored by the root system for different locations and planting densities.

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