Project No. 023120

IRRIQUAL

Sustainable orchard irrigation for improving fruit quality and safety

Specific Targeted Research or Innovation Project
Food Quality and Safety

FINAL ACTIVITY REPORT

Period covered: 01/07/2006 – 31/12/2009 Date of preparation:15/02/2010

Start date of Project: 1st – July – 2006 Duration: 42 months

Project coordinator name: Juan José Alarcón
Project coordinator organisation name: Consejo Superior de Investigaciones Científicas

PUBLISHABLE EXECUTIVE SUMMARY

SUMMARY

European countries, especially in the Mediterranean area, need to encourage more sustainable agriculture practices, reducing inputs (e.g., water, fertilisers), and minimising any negative impact on fruit safety and quality. One of the most promising ways to improve the sustainability of irrigated agrosystems is to develop and optimise the orchard water management, adjusting water application for improved crop quality and assuring crop safety. In this sense, the topic of interest of IRRIQUAL project deals with the valuation of new irrigation practices (including water doses implementation, water quality use and fertigation management). The research methodology will be based on a combination of experiments, field surveys and modelling tools aimed at predicting the impact of a given irrigation practice on the relevant inputs (water, fertilizers) and outputs (yield, quality, safety) of four Mediterranean fruit trees species (Peach, Olive, Almond, Citrus). Previously to the establishment of such practices, a better knowledge of the effects of different irrigation strategies on crop physiological response, crop quality and crop safety are required. The resulting recommendations on irrigation design and practices will be transferred to farmers by the elaboration of Irrigation Best Management Practices for each target crop and location. The resulting data and know-how will be transferred also to the irrigation industries by the development of new irrigation technology (including hardware and software components for an automated irrigation equipment), and the optimisation of the irrigation water disinfection using ultrasound technology.

CONTRACTORS INVOLVED:

1. Participant 1 (Coordinator) CSIC (Madrid, Spain)
2. Participant 2 (Contractor) UPCT (Cartagena, Spain)
3. Participant 3 (Contractor) FECOAM (Murcia, Spain)
4. Participant 4 (Contractor) ABACOTECH (Cartagena, Spain)
5. Participant 5 (Contractor) CONTARIEGO (Murcia, Spain)
6. Participant 6 (Contractor) INRA (Avignon, France)
7. Participant 7 (Contractor) UTH (Volos, Greece)
8. Pariticpant 8 (Contractor) UNIFG (Foggia, Italy)
9. Pariticpant 9 (Contractor) WU (Wadeningen, Holland)
10. Participant 10 (Contractor) LARI (Beirut, Lebanon)
11. Participant 11 (Contractor) LRA (Beirut, Lebanon)
12. Participant 12 (Contractor) IAV (Agadir, Morocco)
13. Participant13(Contractor) SAPIAMA(Agadir, Morocco)

COORDINATOR: Juan José Alarcón (jalarcon@cebas.csic.es). Dept. Riego (CEBAS-CSIC). Campus Universitario de Espinardo, 30100, Murcia, Spain

PROJECT WEB SITE: www.irriqual.com; www.irriqual.eu

WORK PERFORMED AND RESULTS OBTAINED:

From the start of the IRRIQUAL (July 2006), different partners modified the irrigation equipment and implemented most of the instrumentation needed for the realization of the experimental protocols and field surveys .

1. A battery of experiments has been evaluated in order to know the physiological and agronomic response of different fruit trees to deficit irrigation and the value of the information delivered by plant-based indicators for optimizing the scheduling of irrigation.
2. The study of different irrigation strategies effects on quality and safety attributes of citrus, peach, almond and olives crops at harvest ad after storage was done at different regions.
3. Specific experimentations were carried out enabling simultaneous measurements of the soil moisture dynamics and root system in connection with different irrigation strategies.
4. Yield and fruit quality, photosynthesis and radiations data were recorded in different assays in order to develop a bio-tecnological model at the tree level.
5. It was studied the disinfection of irrigation water, using alternative technology based on the application of ultrasounds, by means of which the levels of algae and bacteria in irrigation reservoirs are reduced. The development of one prototype for water disinfection has been developed.
6. A telemetry system was installed in several fruit trees orchards to monitor in continuous the water status of the soil-plant continuum under different irrigation scheduling treatments. One automatic irrigation controller based in the evolution of trunk diameter fluctuactions and soil water content has been developed.
7. The collection and tabulation of actual irrigation practices was carried out in different localizations. This data have been used for the development of Best management practices.
8. Several dissemination activities (peer reviewed paper, oral presentations, training and demonstration courses, etc) have been done by different partners.
9. The evaluation of the socio-economic impact of irrigation strategies, in terms of farmer's profitability, has been considered.

Crop physiology

Fruit trees have showed to be highly responsive to irrigation, and to be more efficient in terms of yield per unit of supplied water when deficit irrigation strategies are applied. The other key objective related to this topic has been to identify the most adequate plant water stress indicators that could be used for improving deficit irrigation management and plant water use efficiency. The most important assays in this topic are described below:

a) Use of stem water potential for scheduling regulated deficit irrigation in peach trees.

- The results confirm the possibility to reduce the irrigation water by at least 30% applying RDI during phenological stages less sensitive to water deficit without negatively affecting peach growth and yield. However, long term evaluation of RDI in further years is necessary to consider the possible carryover effect on yield and fruit quality from year to year with respect to plants irrigated according to their water requirement.

b) Influence of irrigation level and recycled water reuse on water relations, leaf mineral composition, yield and fruit quality of mandarin trees.

- The effects of different types of water were not evident on the seasonal evolution of soil water content. In soil salinity, the use of RDI and reclaimed wastewater produced a salt accumulation more marked from 30 cm to the emitter.

- A reduction of stem water potential was observed in the regulated deficit irrigation treatments. The stomata conductance and the assimilation rate were reduced during the water deficit period when reclaimed wastewater was used.

- Total yield was not significantly affected by the different water quality and RDI treatments, but the reclaimed wastewater and RDI treatment, produced less kg per tree than the others. Peel thickness, weight (g/fruit) and juice volume, were affected by reclaimed wastewater irrigation.

- The regulated deficit irrigation increased the water use efficiency in the mandarin trees. These field results provide additional evidence that long-term effects must be studied when using reclaimed wastewater in fruit trees.

c) Chemical and microbiological study of using reclaimed wastewater for irrigation of lemon trees.

- The possibility to mixed reclaimed wastewater with well water is a good solution to avoid the problems associated with wastewater use in agriculture. The extent of mixing will be determined by the quality of the two sources of water.

- The high salinity, Cl and B concentration were the main restrictions associated with treated wastewater used in our experiments. Although leaf toxicity levels were not observed, salt accumulation can be a decisive problem for citrus crops, particularly after long-term use.

- In our conditions, the wastewater did not constitute an appreciable nutrient source for the soil.

- The microbial quality of the irrigation water did not influence the microbial quality of lemon fruits. Thus, the use of reclaimed wastewater as irrigation water for lemon trees did not represent a microbial risk for lemon fruits.

d) Effects of regulated deficit irrigation on physiology and fruit quality in apricot trees.

- Apricot tree is an appropriate species to apply RDI thanks to the clear separation between their vegetative and reproductive growths and its ability to recover the fruit diameter reduction suffered during RDI application.

- Furthermore, some qualitative characteristics such as the level of soluble solids, fruit taste and the colour of the fruit are enhanced.
- These two reasons, together with irrigation water savings of at least 30%, emphasize the RDI strategies as a possible solution in areas with water shortage.

e) Installation of an experimental citrus plot at the IAV campus in Agadir (implementation of good irrigation practices involving the relationships soil-plant-climate).

- The low dose of water irrigation treatment (1.05 mm/application) brought about a limited root development to within 50 cm depth, whereas the 2.6 mm/application gave a greater root development at this soil depth. This greater dose (2.6 mm/application) had a positive impact on tolerance of trees to the extremely hot temperatures of the end of July 2009.
- The LVDT probe that measures tree trunk micro-variations has shown the continuous growth of trees and demonstrated the limits of the low doses in conditions of high heat in the summer

f) Installation of an experimental citrus orchard in Lebanon (comparison of regulated deficit irrigation with local irrigation schedule).

- The RDI treatments saved 60% of the water used for irrigation, since 1500 m^3 of water were applied in the local treatment, while 600 m^3 of water were applied in the RDI treatament, this shows that farmers are consuming big water irrigation volumes based on their traditional knowledge. Here we could touch the benefit from new irrigation scheduling methods.

Fruit quality and safety on citrus and stonefruits

- The contribution of different partners in this topic have been to characterize, just after harvest and after storage, the basic attributes of yield , quality and safety of peach and citrus trees grown under different irrigation strategies. The most important approaches in this topic are described below:

a) Effects of regulated deficit irrigation on peach quality before harvest.

- Based on the non destructive measurements of flesh color by the pigment analyzer, RDI peaches were less mature fruits than Control ones. The pigment analyzer indexes were similar in the blush and non-blush area.
- The Pigment Analyzer was an objective measurement to determine changes in the flesh color of RDI peaches.
- RDI peaches showed higher size, weight and SSC than Control fruits although were less mature at harvest than Control fruits based on the firmness and flesh color.

b) Effects of regulated deficit irrigation on peach quality after storage at different temperatures.

- RDI peaches showed higher size, weight and SSC than Control fruits. This could be due to moderate Deficit Irrigation strategy during the stage II which caused a slight stress but afterwards, the fruit was able to recover, reaching the size of the Control fruits or even higher.

- RDI caused fruit peel stress lowering the content of vitamin C and carotenoids, while increasing the phenolic content, mainly proanthocyanidins.
- The quality of the RDI peaches can be maintained at low temperatures but high temperature promoted deterioration and fungal decay. The marketing successes for RDI peaches must results from a combination of cultivars with a positive influence of RDI strategies and improvements in fruit handling and distribution.
- RDI fruits showed less storage potential because of high decay probably because of micro cracks formed in bigger fruits.

c) Effects of regulated deficit irrigation and water irrigation quality on the safety attributes of mandarin and grapefruit at harvest.

- Different water qualities and different irrigation strategies did not affect the quality parameters such as weight, SSC, pH, TA, firmness.
    - However, irrigation with water from a tertiary wastewater treatment plant influenced the sensory quality of mandarins because reduced the overall visual qualityas well as the juiciness and flavour while promote the presence of white membrane.
    - The use of wastewater also reduced the mandarin production, probably due to the high salinity content of this type of water.
- The different water qualities did not affect the microbial quality and safety of mandarins.
- The nitrate content of mandarins was very low and independent of the content of fertilizers in the irrigation water.
- Grapefruits treated with water from a tertiary wastewater treatment plant showed higher weight and size and also higher juice production. This could be probably due to the high content in organic material of this type of water.
- In general, the irrigation with different water qualities and different irrigation strategies (Fully irrigated and RDI) did not affect the rest of the quality parameters such as maturity index and vitamin C content in grapefruits.

d) Effects of regulated deficit irrigation on the quality attributes of mandarins growing in Agadir conditions.

- Quality parameters of mandarins such as weight, size, peel thickness, juice production, pH, ºBrix, maturity index, vitamin C and phenolic acid contents were not affected by irrigation strategies (irrigation doses) applied at different locations in Morocco.

e) Effects of regulated deficit irrigation treatments during fruit growth III phase on quality attributes of peach.

- A moderate RDI treatment during fruit growth stage III seems to be a good mean to improve water saving and agronomic performance without any negative impact on fruit quality.

- A severe RDI treatment (17 to 25% of ET0) despite an improvement in WUE, strongly reduced yield performance but also the gustative (sugar acid ratio) and nutritional quality (fruit ascorbate content), so it should not be recommended.

- The present data on fruit quality confirm that management of RDI during peach growth stage III offers an efficient way to control water supply and water loss with limited impact on fruit quality. Moreover, they gave thresholds (water deprivation indicator expressed as $\%ET_0$), that should not be exceeded in order to keep optimal fruit yield and quality.

f) Effects of irrigation management practices on quality of peaches and nectarines in Greece.

- Loadel peaches from deficit irrigated trees seemed to have improved fruit quality compared to fruit from well watered trees. On the other hand, deficit irrigation in Fortuna peaches probably delayed ripening and if left for longer on the tree, they could develop better quality than fruit from well watered trees.

- Reflective mulch seemed to improve Loadel peach fruit quality mainly due to earlier ripening. Fortuna peach fruit quality did not clearly benefit from reflective mulch as this cultivar's leaf functioning was found to be negatively affected from the reflective mulch.

- In Royal Glory peaches and Caldesi 200 nectarines, fruit from the lower shaded part of the tree had inferior skin color and inferior quality (and nutritional) compared to fruit from the upper part of the tree with ample available light. In both cultivars measured in Velestino, fruit growth was not affected by deficit irrigation or reflective mulch application compared to control (well irrigated treated trees).

g) Study the effects of regulated deficit irrigation on quality and safety attributes and polyphenols of citrus growing in Lebanon.

- In the citrus orchard, the fruit's firmness decreased progressively since June due to fruit ripening, whereas in the nectarine orchard the fruits kept their firmness till late September. No significant differences were observed between treatments.

- In nectarine orchard, the fruits of all the treatments contained significant amounts of aerobic mesophilic bacteria, total coliforms, yeasts and moulds. However, the fecal coliforms were mostly reduced in the RDI treatment. In citrus orchard, none of the fruit samples had any fecal coliforms.

Fruit quality and safety on almond and olives

During the third year activities were carried activities related to different commodities (almonds and olives): Determination of quality at harvest and after storage of almond fruits;

Determination of olives quality at harvest, after storage, and on the oil after processing. The most important studies in this topic are described below:

a) Effects of irrigation treatment on quality attributes of almond at harvest.

- Despite the lower amount of water applied in PRD and RDI, both these water-deficit treatments did not affect kernel quality, since no differences were found in both the studied years in physical and chemical attributes compared to fully irrigated almond trees.
- Trees without irrigation had lower yield, and produced almonds with reduced dimensions and weight.
- Almonds growth in non irrigated plot also received the lowest evaluation for general appearance and showed a different peel color at harvest and during storage.

b) Effects of temperature and modality (shelled/unshelled) of storage on quality attributes of almond kernels during storage.

- The storage temperature had an effect only in 2008, with almonds stored at 0 °C showing lower variation in some color parameters than almonds stored at room temperature.
- Almonds stored in shell showed a different pattern in sucrose content during storage, and higher oil content at the end of storage, regardless of the storage temperature. Almonds stored in shell at room temperature had a lower antioxidant activity after 5 months of storage.

c) Effect of irrigation treatment on quality attributes of olives and olive oil at harvest.

- Deficit irrigation regime negatively influenced olive and olive oil yield, and although it did not negatively affect the quality indices used to classify olive oil by commercial grades, influenced other important parameters such as total polyphenols and tocopherols content at harvest and during storage.
    - Oil from deficit olives showed a minor content of α-tocopherol and a different fatty acid composition, with minor oleic acid content, that in a general way did not affect unsaturated/saturated ratio, while a lower MUFA/PUFA ratio was found for this treatment, indicating less undesiderable changes in fatty acid composition.

d) Effect of irrigation treatment on quality of olive oil after processing.

- Reduced water supply resulted in an increase in oil content, and lead to some improvement in oil quality, as indicated by a lower acidity and higher stability. Moreover oil from deficit treated olives showed a better nutritional value, and with a higher polyphenol content. Since no difference in yield was observed between control and deficit treatments, results could indicate the potential use of deficit irrigation regime.

e) Effects of saline water on quality on olives at harvest and on the oil after processing.

- Salt irrigation did not show evident effects on oil color, quality indices, nutritional characteristics, fatty acid composition and sensorial attributes. Salt stress treatment significantly affected only water content of olives at harvest, which was significantly lower in salt treated fruits, while no differences were found in dimensional characteristics and density measurements, in respiration rate, firmness and color score evaluation.

- Results of experiments carried out in 2007 and 2008 did not show a clear effect of the salt irrigation treatment on quality of olives and olive oil, so further investigation is needed in order to obtain a better knowledge of the long-term effects on salty water to the plant.

f) Irrigation treatments and fruit characteristics of the "Manzanilla" olive fruits for table consumption and oil quality.

- Production increased with irrigation; however yield reduction in the RDC treatment was small, despite of these trees receiving 50% of ETc only.
- Irrigation decreased oil stability and polyphenol contents. However, all treatments showed similar contents in oleic acid. Pigment contents decreased with irrigation. This is related to what we have already said for the maturity index: contrary to what it was expected, irrigation increased the maturity index.

g) Determination of the microbials on almonds and olives exposed to different irrigation treatment at harvest and during storage.

- Almonds exposed to different irrigation treatments did not show any difference in terms of microbial load (yeast, moulds and total mesophilic bacteria). Any presence of coliforms was detected.
- No differences due to the irrigation treatment were observed on microbial load on olive fruits subjected to different irrigation quantity. No coliform units were found for any treatment.

h) Determination of the nitrite and nitrate content on almonds and olives exposed to different irrigation treatments.

- Nitrites were below the detection limit of 0.02 mg/L for all treated almonds, while nitrates did not show differences among treatment, ranging from 8 to 10 mg/kg of sample.
- Nitrites were below the detection limit of 0.02 mg/L for both treated olives, while nitrates did not show differences between treatments, ranging from 4.5 to 4.8 mg/kg of sample.

Soil water balance model

The main objective on this workpackage was the characterization and modelling of the effects of different irrigation strategies on soil moisture dynamics, root architecture growth and plant functioning. In this framework, four sub-tasks have been simultaneously carried out:

a) Root growth: temporal and spatial variation: Two main experiments have been established. The first one took place in orchard conditions to study the dynamic of root growth and the second one in greenhouse, in pots, to estimate the architecture of fine roots in growth in a more homogenous soil.

b) Soil water content: temporal and spatial varitions: Different irrigations treatments were applied (Control, Regulated Deficit Irrigation and Null irrigation), and the soil water content was measured at different location (depth, distance to the dripper) to characterise (i) the time and spatial distribution of soil moisture around a dripper, (ii) the water balance and uptake by the plant.

c) Modelling soil water transfer and uptake: Two approaches have been conjointly developed. Firstly, an already available soil water model using analytic resolution of the soil water transfer, solving the Richards' equation over the whole soil volume (HYDRUS 2-D), was used in order to simulate the moisture distribution and its dynamics under drip irrigation (UPCT partner). A specific soil water model was developed (INRA partners) dividing the soil volume in different compartments, with different properties regarding the soil water availability and the root density.

d) Towards new monitoring of plant parameters for irrigation management: In this topic, we sought for new ways of monitoring plant's parameters linked to water status or uptake that could possibly be used for monitoring / irrigation purposes. The main focus was on the use of electrical resistivity of soil or plant: Stem electrical resistivity for stem water potential determination and the test of an electrical method for estimation of mean root length and absorbing surface area.

Crop quality model

This workpackage deals with the improvement and adaptation of a tree/orchard model that accounts for the effects of irrigation strategies and cultural practices on fruit yield and quality. The work completed is described as follow:

a) Model adjustments and improvements from the previous version of tree model. One of the most important adaptations undertaken in the model was the new way of calculating the carbon transfers. Furthermore, a new algorithm concerning light interception by the tree was implemented in the model.

b) Simulations and testing the model: In order to observe the behaviour of the model, simulations and analyses were carried out on two different peach tree varieties already implemented in the model: an early-maturing cultivar (Alexandra) and a late-maturing cultivar (Suncrest).

c) Development of a transpiration submodel for the linkage of QualiTree to the soil water uptake model: In order to undertake an integration of the soil water uptake model developed and the virtual tree model, and furthermore to take into account the variation of the water availability within the crown, it is necessary to estimate the actual tree transpiration and the stem water potential distribution within the canopy.

Fruit quality model

One of the aims of IRRIQUAL project is to assess quality attributes of fruits that have been subjected to different irrigation treatments and types. Here, the effect of different types of irrigation water is studied on quality attributes of fruit such as firmness, colour and water loss. The hypothesis is that treated waste water has no effect on these quality attributes. This hypothesis has been tested, not only on the measured data, but also on parameters statistically estimated by non-linear regression using models on water loss, firmness and colour. The test of these models has been done in specific experiments carried out in different locations:

a) Effects of different irrigation treatments on fruit quality of grapefruits growing in Murcia (Spain). Data analysed by CEBAS-CSIC (2007-2008).

- The tertiary water treatment for the 2007 dataset showed more mature fruit for some quality attributes, but not skin colour. For the 2008 dataset this is clearly also the case for the skin colour when full irrigation (like in 2007) is applied. However, when RDI is applied the trend seems to reverse, less mature fruit in terms of skin colour for the tertiary treatment. Hypothesis might be that skin colour maturity depends on the availability of water with a low EC when RDI is used and vice versa. So, when tertiary water, having a relatively high EC, is used in a non-RDI irrigated orchard riper fruits are encountered.
- The weight effect for the tertiary water/control grapefruits is not well understood. The tertiary water treatment contains a higher EC that would normally limit cell elongation during phase I and II but might enhance the number of cells. Elongation might be optimal in case of full irrigation in comparison to the RDI treatment, resulting in large fruit. It is unclear why the RDI fruit of the water transfer are bigger than those of the control. Perhaps the RDI treatment might influence the bio-allocation due to less shoot growth during phase I and II towards the fruits.
- The sugar/acid content indicates again that grapefruits from the tertiary water treatment are generally a bit more mature (less sugar and less acid but a slightly higher sugar/acid ratio) than those of the water transfer treatment.

b) Effects of different irrigation treatments on fruit quality of peaches growing in Murcia (Spain). Data analysed by CEBAS-CSIC (2008-2009).

- Control fruit are more mature in terms of skin colour and firmness, but less mature in terms of flesh colour. This might indicate that RDI treated peach orchards can be harvested a few days later.
- Health promoting compounds show non-significant differences between irrigation treatments.
- RDI peaches have about a 15% higher weight than those of the control fruit while water loss is lower. Combined with the higher brix (SSC) content of RDI fruit this treatment can be recommended from a quality point of view.

c) Effects of different irrigation treatments on fruit quality of almonds growing in Cartagena (Spain). Data analysed by University of Foggia (2008).

- RDI fruit loses less water than other irrigation, has a slightly (not significant) higher initial rupture force and higher final rupture force than for e.g. FI almonds. It has to be stressed though that differences between treatments are, although sometimes significant, quite small. There seems to be no reason not to recommend RDI or PRD from a quality point of view.

d) Effects of different irrigation treatments and reflective mulch on the quality of green olives growing in Anchialos (Greece). Data analysed by University of Foggia (2007-2008).

- Deficit (RDI), Ref and RD fruit seem to have different effects on maturity depending on the cultivar compared to control fruit. Nevertheless, most effects are not significant (skin colour, chilling injury) for the four irrigation treatments, except for firmness (Deficit fruit firmness for Chondrolia cultivar and RD fruit riper for the Konservolea Amfisis cultivar).

- Also no significant results are obtained for the gallic acid content, an indicator of the phenol content. This would indicate that, from a quality point of view, a RDI treatment can be recommended. With regard to the reflective much treatments (Ref and RD), they can also be recommended from a quality point of view.

On farm management model

In IRRIQUAL, the activities in this topic are divided into two sub-tasks:

a) In-situ valuation of the effects of different RDI practices, on water use efficiency, fruit quality and safety: During the first two years useful results were obtained. This type of activity was pursued in the 3rd year with the following activities:

- Validation of reference baselines for deficit irrigation management in almond orchards. It is possible to schedule deficit irrigation using the signal strength intensity based on trunk MDS. However, a correct scheduling requires: - careful check of the functioning of the LVDT sensors; - suitable analysis and interpretation of the signal intensity by a trained farmer or an expert (adviser)

- Regulated deficit irrigation in peach trees. Agronomic performances, fruit quality and thresholds values for midday stem water potential and trunk micrometric fluctuation: In spite of the noise around the micrometric trunk fluctuations, MDS is a continuously monitoring tool of tree responses to the climatic demands and water deprivation. It is thus a tool more useful and practical than midday stem potential measurements especially for the grower's for regulated deficit irrigation management. However, researches are still necessary to specify the factors explaining variability of MDS thresholds and also to propose simple and reliable tools for a better use by growers.

b) Simulation of the effects of RDI practices on orchard functioning using a orchard simulator: Activities in this subtask were iniciated from the second year when the availability of the tree interception model (Rayprun) was an important step. In this 3rd year, the important step was to deliver a fruit tree model that allows the coupling of the RayPrun radiation interception model to a C-balance model at the shoot scale (QualiTree).

Water disinfection prototype

A water disinfection prototype has been developed by CONTARIEGO (the main partner involved in this WP). The effectiveness of the irrigation water disinfection process using the ultrasounds treatment has been tested in different localitions. Four reservoirs were considered, differing in location, size, origin of the water and number of equipments installed.

The experiments carried out confirm that ultrasounds applied in real irrigation reservoirs reduce algal and bacterial levels. Given that we are dealing with water bodies exposed to air the term biological elimination cannot be used, since there will always be a residual level of algae. However, one can speak of control or reduction, which in the cases studied was around 80%, meaning that the method can be considered effective and suited to the task assigned – the provision of good quality irrigation water and the improvement of filtering systems.

The experiments pointed to the strong influence of the quality of the water received by the reservoirs. It was also seen that the surface area of the reservoirs affect the outcome of treatment. In both cases, such adverse affects can be offset by increasing the number of machines (1 machine/100 m). Final conclusions were two points: the treatment is considerate effective and it can be applied in any reservoir.

Irrigation scheduling automatism

A prototype real-time, interactive sensor arrangement for measuring soil moisture and trunk diameter fluctuation has been developed and tested for precisely and automatically scheduling irrigation in fruit trees.

Hardware

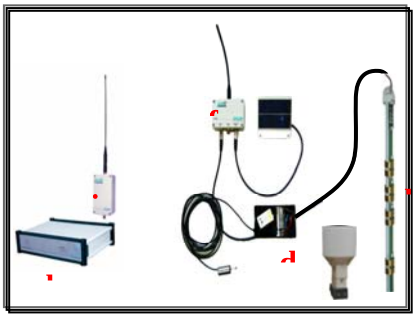

Photo 1: Components of the automatic Irrigation scheduling prototype. a) multisensor capacitance probe, b) capacitance sensor, c) LVDT sensor, d) special circuit, e) rain gauge, f) radio transmission unit RTU, g) solar panel, h) telemetry gateway, i) radio modem.

Software

The PC-algorithm uses a series of input variables and thresholds values to run properly and prevent undesired field troubles. The input variables are described as follow:

1- "Start_time": it is the daily time at which the PC-algorithm is executed. It is recommended to be executed daily after sunset.

2- L_MxTD and U_MxTD values: These are the lower and upper limits of the time interval through which the maximum trunk diameter or "MxTD" is reached. The MxTD occurs normally in the period between dawn and 3 hours after sun rise.
3- L_MnTD and U_MnTD values: These are the lower and upper limits of the time interval through which the minimum trunk diameter or "MnTD" is reached. The MnTD occurs normally in the period which extends from 1 hour before noontime till sunset time.
4- MDS_{i-obs} : It is the maximum daily shrinkage of the observed trees. It is calculated as the difference between MxTD and MnTD.
5- MDS_{i-ctr} : It is the maximum daily shrinkage of the control trees. It is calculated as the difference between MxTD and MnTD
6- SI_i: The signal intensity is computed as the ratio of the MDS_{i-obs} value of the observation tree to the MDS_{i-ctr} value of the control tree.
7- SI_threshold: It is the value of the signal intensity above which the plant is considered under water-stress conditions and irrigation should be triggered ON.
8- MAD value. It is the management allowable soil-water depletion above which any decision on additional water application driven by the plant water status should be carefully supervised.
9- Min_IrrigTime value. It is the minimum time of irrigation required for the wetting front to move through a wet soil from the surface down to the limit of the plant root zone.
10- Max_IrrigTime value. It is the maximum time of irrigation required for the wetting front to move through a dry soil from the surface down to the limit of the plant root zone.
11- Δ_SWC_{max} value: It is the zone .

Development of Best Irrigation Management Practices

The scope of this work was the development of irrigation and fertilization BMPs with the incorporation of the collected knowledge on present situation for irrigation and fertilization for each crop. The following guidelines were developed

The detailed irrigation BMPs which are meant to be used by persons involved in irrigation management with a certain knowledge background to be qualified for irrigation management (certain farmers, governmental and private stakeholders related to irrigation). General irrigation BMPs were developed for public dissemination with the purpose of pointing out the importance of proper management of irrigation as a cultural practice to properly use irrigation water and distribution systems Specific irrigation BMPs were developed for use by all involved stakeholders (farmers, monitoring personnel-scientists, local authorities, etc). These specific BMPs were developed for olive, peach and citrus. Specific fertilization BMPs were also developed for olive, peach and citrus to be used from all interested stakeholders.

Evaluation of Sustainability

The results of the research carried out in the different Regions point at the technical and economic superiority of regulated deficit irrigation strategies. The analysis of basic Technical-Economic indicators for the peach and citrus farms surveyed show a greater profitability of RDI strategies with respect to conventional strategies. In all cases, RDI strategies increase the productivity of water and, in some cases also the productivity of other farm inputs such as labour and fertilizers. Moreover, RDI strategies increase Total Factor Productivity.

WP 1: CHARACTERIZATION OF THE ORCHARDS

OBJECTIVES: To adapt and complement the experimental orchards and to implement the needed instrumentation in pilot farms, as required by the experimental surveys to be carried out in other WPs of the Irriqual project.

WORK PERFORMED:

From the start of the Irriqual project (July 2006), different partners modified the irrigation equipment and implemented most of the instrumentation needed for the realization of the experimental protocols and field surveys to be realized in the next two years.

Four main fruit tree species will be studied in this project: Peach, Almond, Olive and Citrus**.** All of them are representative of economically and socially important production systems of Mediterranean Countries, and are associated with the techniques of localized drip irrigation.

WP 2: EFFECTS OF REGULATED DEFICIT IRRIGATION ON CROP PHYSIOLOGY

OBJECTIVES: Acquisition of complementary knowledge on crop physiological response under different orchard irrigation, locations and species.

CONTRACTORS:

CSIC, UPCT, INRA, UTH, LRA, SAPIAMA.

WORK PERFORMED:

1) Use of stem water potential for scheduling regulated deficit irrigation in peach trees (CEBAS-CSIC).

Stem water potential was used in order to establish the regulated deficit irrigation in adult peach trees. The physiological and agronomical values obtained in regulated deficit irrigation were compared to control treatment with full irrigation. The results confirmed the possibility to reduce the irrigation water by at least 30% applying RDI during phenological stages less sensitive to water deficit without negatively affecting peach growth and yield. However, long term evaluation of RDI in further years is necessary to consider the possible carryover effect on yield and fruit quality from year to year with respect to plants irrigated according to their water requirement.

2) Influence of irrigation level and recycled water on water relations, leaf mineral composition, yield and fruit quality of mandarin trees (CEBAS-CSIC).

The soil water content was maintained at field capacity for all treatments from the beginning of the irrigation season till the start of deficit irrigation; since that date till the end of deficit irrigation the soil water content of the RDI treatments were depleted progressively by root water uptake while only 50% of the water lost by ETc were restored to the soil. The effects of different types of water were not evident on the seasonal evolution of soil water content. In soil salinity, the use of RDI and reclaimed wastewater produced a salt accumulation more marked from 30 cm to the emitter.

A reduction of stem water potential was observed in the regulated deficit irrigation treatments respect to the values observed in control plants, independently of the quality of water applied.The stomata conductance and the assimilation rate were reduced during the water deficit period when reclaimed wastewater was used.

Total yield was not significantly affected by the different water quality and RDI treatments, but the reclaimed wastewater and RDI treatment, produced less kg per tree than the others. Peel thickness, weight (g/fruit) and juice volume, were affected by reclaimed wastewater irrigation.

The regulated deficit irrigation increased the water use efficiency in the mandarin trees. These field results provide additional evidence that long-term effects must be studied when using reclaimed wastewater in fruit trees.

3) Chemical and microbiological study of using reclaimed wastewater for irrigation of lemon trees (CEBAS-CSIC)

The mix of reclaimed wastewater and well water used in Campotejar had a better agronomic and microbiological quality than Cartagena´s reclaimed wastewater. Therefore, the possibility to mixed reclaimed wastewater with well water is a good solution to avoid the problems associated with wastewater use in agriculture. The extent of mixing will be determined by the quality of the two sources of water. However it is also possible that changes in management practices (eg increased leaching to avoid long-term salt accumulation in the soil profile) could allow for a high fraction of reclaimed wastewater to be used for irrigation. The high salinity, Cl and B concentration were the main restrictions associated with treated wastewater used in our experiments. Although leaf toxicity levels were not observed, salt accumulation can be a decisive problem for citrus crops, particularly after long-term use. In both locations, the treated wastewater application did not increase the macronutrients and organic matter measured in the soil. In our conditions, the wastewater did not constitute an appreciable nutrient source for the soil. The crop yield was slightly lower in Cartagena than in Campotejar, showing that total crop production is reduced by the application of salts. This yield reduction was produced by a reduction of number of fruits per tree, because the quality of lemon fruits was increased by the use of the lowest quality wastewater after three years on treatment. In fact, in 2007, lemon fruits obtained from the Cartagena's field showed higher SSC and TA as well as higher weight than fruits obtained from the Campotejar's field. Nevertheless, fruit quality indexes of lemon fruits from both locations were in the normal range. On the other hand, the microbial quality of the irrigation water did not influence the microbial quality of lemon fruits. Thus, the use of reclaimed wastewater as irrigation water for lemon trees did not represent a microbial risk for lemon fruits.

4) Effects of regulated deficit irrigation on physiology and fruit quality in apricot trees (CEBAS-CSIC)

The results indicated that the apricot tree is an appropriate species to apply RDI thanks to the clear separation between their vegetative and reproductive growths and its ability to recover the fruit diameter reduction suffered during RDI application. Furthermore, some qualitative characteristics such as the level of soluble solids, fruit taste and the colour of the fruit are enhanced. These two reasons, together with irrigation water savings of at least 30%, emphasize the RDI strategies as a possible solution in areas with water shortage, like the south-eastern region of Spain.

5) Regulated deficit irrigation on olives, fres market peaches and canning peaches growing in Greece (UTH).

Three experimental farms were established in Greece:

- Anchialos, olives cvs Konservolea and Chondrolia Chalkidikis;
- Velestino, fresh market peaches cv Royal Glory and nectarine cv Caldesi 2000;
- Tyrnavos, canning peaches cvs Fortuna and Loadel.

Treatments for peaches: control (usual irrigation volume), deficit (one month before harvest and post harvest until September), reflective (Extenday mulch on the tree row from one month before harvest to September), combination reflective plus deficit.

Treatments for olives: as above except treatment initiation two months before harvest (mid July) and reflective treatments applied only to Konservolea olive trees.

In all the experiments, ETc was calculated weekly for each site with the weather stations installed. Soil moisture profile (only on the peach farms) and thermal dissipation probes were used periodically in each experimental farm. Stem water potential has been measured periodically. Fruit growth was followed over time. Measured or calculated in each site periodically before or after harvest and later away from harvest: Leaf chlorophyll, dry matter and specific leaf weight; Leaf chlorophyll fluorescence; Leaf photosynthetic parameters measured or calculated (Ps and transpiration rates, leaf temp, WUE, stomatal conductance, quantum yield).

Anhialos orchard: Konservolea leaf characteristics

Leaf dry matter (%) increased from July to Sept in all treatments and in both leaf ages. In July, leaves from RD had similar DM to control and lower than leaves from deficit. Leaves from deficit had similar DM to control and leaves from all treatments had lower

DM than leaves from R. In Sept, leaves from RD and from control had lower DM than leaves from D and R. This increase in DM for D leaves was due to a high value for old leaves DM in September. The new leaves had lower DM than old leaves only in July. In Sept, leaves from both ages had similar DM. Leaves of both ages from R had similar and high DM in July and Sept. Specific leaf weight did not change from July to September in all treatments and both leaf ages. There were no differences in SLW between all four treatments at both times and ages. New leaves had lower SLW than old leaves both times but mainly in July.

Leaves collected in July had lower chl a / chl b ratio than leaves collected in Sept in all treatments and both ages. There were no differences in chl a / chl b ratio between all four treatments at both times and leaf ages, except in Sept when leaves from C had higher chl a / chl b ratio than leaves from D. New leaves had higher chl a / chl b ratio than old leaves at both times.

Anhialos orchard: Chondrolia leaf characteristics

Leaves from Chondrolia olives in July had quite higher leaf % dry weight than in Sept in both treatments and both leaf ages. In July, leaves from control had higher leaf % dry weight than from deficit in both leaf ages. In September, leaves from both treatments had similar leaf % dry weight. New leaves had similar % dry weight to old leaves in both times.

Old leaves in July had higher specific leaf weight (SLW) than old leaves in September in both treatments. New leaves had similar SLW both times. Leaves from control and deficit had similar SLW at both times and both ages. New leaves had lower SLW than old leaves both times, but SLW values were especially high in July.

Leaves in July had lower total chl than leaves in Sept in both treatments (especially in control) and both ages. Leaves from control and deficit had similar total chl values at both times and ages. New and old leaves had similar total chl values at both times.
Leaves in July had lower chl a / chl b ratio than leaves in Sept in both treatments and both ages. Leaves from control and deficit had similar chl a / chl b ratio values at both times and ages. New leaves had higher chl a / chl b ratio than old leaves at both times.

The comparison between irrigation treatments differed for each measurement date. However, it was possible to conclude that, despite the treatment, high PAR resulted in high transpiration rate and stomatal conductance (but low CO_2 inside the leaf and ratio CO_2 inside the leaf over CO_2 out) without affecting Ps rate and, thus, resulting in low WUE and sometimes low QY.

Velestino orchard: peach cv Royal Glory leaf physiology and leaf characterictics

Leaves from control had the lowest leaf temperature. The highest leaf temperature was found in leaves from regulated deficit irrigation. All deficit irrigation treatments reduced leaf transpiration rate, leaf stomatal conductance, leaf photosynthesic rate and leaf water use efficinecy compared to control. Leaves from RD had also the lowest Fv/Fm values mainly compared to leaves from control.

Leaf dry weight (%) significantly increased in all treatments but especially in control and deficit treatments at date 3 compared to the values at the other three dates.

There were no differences in SLW between the treatments except in September when leaves from deficit had lower SLW than leaves from the other treatments. Shade leaves had lower SLW than sun-exposed leaves especially in leaves from deficit and at most times.

The ratio chl a / chl b decreased with time in all treatments, but with a different manner in each of them, and in both positions. Leaves from the reflective treatments had higher chl a / chl b ratio than leaves from the other treatments in May and June, while there were no differences between treatments in chl a / chl b ratio in July and September. Shade leaves had similar chl a / chl b ratio as sun-exposed leaves at all times and treatments.

Velestino orchard: Caldesi nectarine leaf physiology and leaf characteristics

Leaves from control had in most cases lower leaf temperature than the leaves of the rest of the treatments. Leaves from R and control treatments had higher transpiration rate than the leaves from deficit and from RD at all 3-day sets. Stomatal conductance changed with time exactly like transpiration rate above. The differences in stomatal conductance between treatments were similar as in transpiration rate but smaller. However, photosynthetic rate was significantly different between dates without any clear trend for each 3-day package. Leaves from control had generally almost all the dates higher values of water use efficieny (WUE) than leaves from the other treatments.

There was neither clear trend per 3-day package for Fv/Fm nor any difference between the three 3-day packages. Only minor differences found between treatments. Leaves from up had higher Fv/Fm values than leaves from the shade in most times and in all treatments.

Leaf dry weight gradually increased with time in all treatments and both positions. There was a trend at all times for the leaves from deficit to have higher dry weight than the leaves from other treatments. Shade leaves had lower dry weight than sun-exposed leaves in May and June and at all treatments.

Specific leaf weight slightly increased over June, partially decreased in July and increased again in September. This was true as a trend in all treatments and both positions. There were no differences in specific leaf weight between treatments at all times. Shade leaves had lower SLW than sun-exposed leaves at all times and treatments.

Tyrnavos, canning peaches cvs Fortuna leaf characteristics and physiology

Fortuna leaf dry matter content (%) increased gradually during the summer for all treatments and for both positions. The leaves from reflective treatments had higher leaf dry matter than leaves from control and from deficit. Fortuna specific leaf weight increased, decreased and increased again over the summer period in all treatments. The specific leaf weight of reflective treatments was higher than the leaves from control early July and late August, but had similar specific leaf weight late July. Leaves from deficit had similar specific leaf weight as leaves from control all through the summer. Sun leaves had higher specific leaf weight than shade leaves at control, deficit and RD and early in the summer only as differences diminished later on. Sun and shade leaves at reflective treatment had similar specific leaf weight over the summer.

Leaves from deficit always had similar CO2 concentration inside the parenchyma as leaves from control. Leaves from deficit had similar PAR as leaves from control almost all dates. Leaves from deficit had similar leaf temperature as leaves from control in many dates. Leaves from deficit had lower transpiration rate than leaves from control. Leaves from deficit had lower stomatal conductance than leaves from control in all dates. Leaves from deficit had lower Ps and WUE than leaves from control in all dates.

Tyrnavos, canning peaches cvs Loadel leaf characteristics and physiology

There were no differences in leaf dry matter between the leaves of control and deficit treatments at all times and both positions. There were no differences in specific leaf weight between the leaves of control and deficit treatments at all times and both positions.

Leaves from deficit had similar PAR as leaves from control but there were all trends in each date and large variability. Leaves from deficit had slightly higher leaf temperature than leaves from control. Leaves from deficit had slightly lower transpiration rate than leaves from control. Leaves from deficit had lower stomatal conductance than leaves from control. Leaves from deficit had lower Ps and WUE than leaves from control.

6) Regulated Deficit Irrigation in Morroco (IAV)

With the agreement of EU, the funds allocated to IAV Hassan II (IAV) in the IrriQual project were used at 60% for installation of an experimental citrus plot at the experimental farm of the IAV campus in Agadir. This plot has 2500 m² and was used for a program of applied research with the following objectives:

- Putting up a favorable location destined to research on water use on citrus ;
- Implement good irrigation practices using a scientific rational that involves the relationships soil-plant -climate ;
- Demonstrate water economies that can be realized when controlling dosis and frequencies of water applications;
- Evaluate efficiency of water use and its valorization for citrus culture;
- Constitute a demonstration unit destined to local producers with the aim optimal use of modern instruments for managing and monitoring irrigation such as compact meteorological stations, capacitive probes, LVDT probes, probes measuring sap flow etc.

The experimental plot was organized to receive 4 different treatments replicated 6 times using a randomized complete bloc design. The variety was ‘Nules’ Clementine grafted onto *Citrus macrophylla* rootstock. A high density planting was adopted (1.5 m between trees within rows x 4 m between rows) and made in June 2007. Work achieved was focalized around optimal irrigation management by studying 4 combinations dose x frequency. Remote control system was used to automatically follow and in real time, evolution of ETo (weather station), evolution of water in the soil (C-probes), micro variations in trunk diameter of trees (LVDT probes). In addition to these parameters, soil sampling using soil gauge and hand feel all help make the necessary crosschecks and establish correlations with the automatically recorded measurements.

The main results obtained can be summarized as follows:

- Severity of the climate was made clear and between-year variations were compared: 164 mm of rainfall in 2008 and only 126 mm in 2009, distributed on 33 rainy days in 2008 and 17 rainy days in 2009 ;

- The weather station was used to automatically calculate daily values of reference evapotranspiration (ETo), which were adjusted using a crop coefficient to satisfy the requirements of a young citrus orchard;

- The yearly balance of water supply reached less than 300 mm/year for an orchard of 2 years of age. This water quantity represents about 1/3 of the water requirements of an adult full bearing plantation in the Souss region (Agadir) ;

- A methodology of supply of water was applied according to the concept of « fixed dose and variable frequency», for piloting irrigation, using a simple technique that is easily adaptable and transposable to the growers ;

- Water regimes adopted (dose x frequency) allowed to insure a certain moisture comfort for the trees since growth of these trees was done in presence of a soil water tension comprised between 10 and 20 cbars for the upper soil horizon (0 to 30 cm deep) and 30 to 40 cbars for the more deep soil (30 to 50 cm) ;

- During the 2008-2009 season, supply of a fixed dose of 2.6 mm/application was accomplished in 96 operations, against 238 times for the fixed dose of 1.05 mm. This translated into a different water behavior in the various soil horizons and, thus, a qualitatively different root development in the soil profile;

- The low dose of 1.05 mm/application brought about a limited root development to within 50 cm depth, whereas the 2.6 mm/application gave a greater root development at this soil depth. This greater dose (2.6 mm/application) had a positive impact on tolerance of trees to the extremely hot temperatures of the end of July 2009;

- The LVDT probe that measures tree trunk micro-variations has shown the continuous growth of trees and demonstrated the limits of the low doses in conditions of high heat in the summer;

- The variety/rootstock combination used (‘Nules’ Clementine/*Citrus macrophylla*) has shown a great adaptation to the imposed water regimes. In fact, recorded growth rates for the 4 water regimes tested were statistically identical. This gave rise to yields of 26 to 28 kg of fruit/tree, meaning yields of 43 to 46 tons/ha for a tree density of 1660 trees/ha.

- Fruit size was in the proportions of 70% within commercial size classes of 1, 2 and 3 (large sizes). These results were judged as being exceptionally high since trees are only 2 years old. This is a challenge for the research which should continue to demonstrate the sustainable and direct relation between optimization of irrigation and yield performance;

- In terms of valorization of water by the trees, the experimentation demonstrated that each kilogram of Clementine needs 85 liters of water (3750000 liters per hectare /44300 kg par hectare), while in growers' orchards water use efficiency is much greater than 100 liters/kg of Clementine. The cubic meter of water used was valorized at 50 Moroccan Dirham/m^3, which constitutes a record at the regional scale.

7) Regulated deficit irrigation in Lebanon (LRA)

In Lebanon, the project mainly consists on studying the effect of different irrigation methods on the crop physiological response and on the fruit quality and safety. With a final objective to elaborate the best irrigation management model on **peach** and **citrus**. This model should allow stimulating realistically the behavior of the soil-tree system, thus the use of irrigation will be in a more sustainable and efficient way.

In December 2006, two pilot plots were selected to conduct the experiments. The first one in Maghdoucheh (South of Lebanon) over 2000 square meters of citrus (variety Sicilian grafted on sour orange, trees age: 20 years) and the second in Kherbet Qanafar (Bekaa valley) over 4000 square meters of peaches (nectarine "August Orebrad" grafted on GN-15 peach rootstock, tress age: 3 years). The applied treatments are as follow:

A - *Local:* It is the control and rely on the irrigation schedule followed by the farmers in the region.
B - *Regulated Deficit Irrigation* ***(RDI)****:* It consists of recovering 100% of the soil-water lost by ETc except during the second stage of fruit growth when only 50% of the lost-water is restored to the soil, this period goes from beginning of June till the end of August.
C - *Regulated Deficit Irrigation and Fertigation* ***(RDIF)****:* It is the same as the RDI treatment, with the addition of fertigation.
D - *Soil Plant Atmospheric monitoring* **(*SPAC*)**: Irrigation module according to Soil – Plant – Atmosphere Conditions. The decision on triggering the irrigation system ON/OFF was taken according to the daily signal intensity which is the ratio of the maximum trunk diameter to that of the control tree.

The RDI and SPAC treatment saved respectively 60% and 56% of the water used for irrigation, since in the local treatment, 1500 m^3 of water were applied, while in the RDI and SPAC treataments, 660 m^3 and 600 m^3 of water were applied respectively. This shows that farmers are consuming big water irrigation volumes based on their traditional knowledge. Here we could touch the benefit from new irrigation scheduling methods.

WP 3 and WP 4: EFFECTS OF RDI PRACTICES ON QUALITY AND SAFETY OF STONE FRUITS AND CITRUS

OBJECTIVES: Study the effects of different RDI strategies, nutrient supply by fertigation and irrigation water quality on the quality and safety of Stone fruits and citrus.

CONTRACTORS:

CSIC, INRA, UTH, LRA, SAPIAMA, WU.

WORK PERFORMED:

As variability of RDI effects on fruit quality may depend on the species tested, the degree of water stress imposed and specific site soil and climate conditions, several groups performed the study. Stone fruits and citrus were grown in different irrigation areas: Peaches in Murcia (Spain), Avignon (France), Saida-Tyre (Lebanon) and Volos (Greece), nectarines in Volos (Greece) while lemons, mandarins and grapefruits in Murcia (Spain) and mandarins in Agadir (Marocco) and Saida-Tyre (Lebanon). Fruit quality determinations were carried out by CSIC (peach and citrus) in Spain, INRA (peach) in France, UTH (peach) in Greece, SAPIAMA (citrus) in Morocco, LRA (citrus and peach) in Lebanon and WU (peach and citrus) in the Netherlands. The evaluation of the quality characteristics included a combination of sensory attributes, physicochemical characteristics as well as the determinations of the phytonutrients such as polyphenols, carotenoids and vitamin C. Microbial safety of stone fruits and citrus was evaluated by CSIC (Spain) at harvest and during storage. The number of samples involved in the three years study was appropriate to guarantee a sound statistical value of the obtained results.

RESULTS ACHIEVEMENT:

<u>1- Effects of different regulated deficit irrigation (RDI) during stage I and II on quality characteristics of peaches</u>

Maria I. Gil, Ana Allende, Macarena Moreno, Mercedes Almagro, Natalia Hernández, Laura Fernández, Alicia Marín, Francisco López-Gálvez, Juan Antonio Tudela.
CEBAS-CSIC, Campus de Espinardo, P.O. Box 164, 30100, Espinardo (Murcia), Spain.

Peaches (*Prunus persica* L.) are one of the most common and economically important fruit tree species of the Mediterranean area, where drought periods are frequent and irrigation water is a limiting factor for productivity. RDI is useful in these areas where low water availability is the primary parameter limiting production of fruit trees. In peaches, the majority of fruit growth occurs in the final 6-8 weeks before harvest when vegetative growth is almost complete. The use of RDI strategies during stage I and II of fruit growth is becoming a common practice in areas with low water availability. The aim of this study was to investigate the influence of RDI during stage I and II on the quality characteristics of peaches including the content of vitamin C, phenolics and carotenoids. Two irrigation strategies, fully irrigated (FI) and RDI, (25% of Etc stage I and stage II) were compared at two levels of thinning, commercial and half of the commercial crop load.

The results obtained demonstrated that severe RDI did not influence negatively the quality characteristics of peaches Flordastar when compared to FI fruits. Only FI of fruit at low crop load, caused a significant increase in fresh weight while SSC, TA and pH as well as the color of the peel and the flesh were not affected by the irrigation treatments and crop load. Peach firmness was also unaffected by water deficit. The peel was the tissue largely influenced by the RDI strategies. RDI strategy significantly decreased the content of vitamin C in the peel when comparing with FI at commercial crop load. However, at low crop load, no significant differences in the content of vitamin C between the peel of FI and RDI fruits were observed. In addition, the content of vitamin C in the flesh of early ripe peaches was not influenced by RDI. Phenolic content in the peel of RDI fruits was higher than that of FI. Thus, RDI significantly increased the content of anthocyanins, procyanindins and phenolic acids in the peel. Water stress implies an activation of the phenolic compounds biosynthesis in the peel of fruit suffering RDI. However, no differences were observed between the flesh of FI and RDI peaches. In addition, the influence of RDI on the carotenoid content was similar to that observed for vitamin C. Thus, at commercial crop load, the peel of RDI fruits showed lower content of carotenoids than the peel of FI peaches. However at low crop load, no significant differences were observed between the peel of FI and RDI fruits. When the flesh of peaches subjected to RDI strategies was studied, it was seen that the content of carotenoids in the flesh of FI fruits was always higher than that of RDI fruits, particularly at low crop load.

When moderate RDI strategies were evaluated on “Catherine” peaches it was observed that at harvest RDI fruits were less mature than FI fruits, showing higher chlorophyll content than those FI fruits. The content of vitamin C and carotenoids of RDI fruits was lower while the content of phenolics, mainly anthocyanins and procyanindins, was higher. It was shown that moderate RDI regimens improve fruit quality by increasing fruit size and weight, retained firmness, increased the content of soluble solids (SSC) when compared with FI fruits. RDI peaches were less mature with regard to skin color. One hypothesis could be that RDI normally limit cell elongation during phase I and II but might enhance the number of cells. Elongation might be optimal in case of FI in comparison to the RDI treatment. As there was no water stress during fruit development stage III, fruit quality was not altered at harvest, resulting in large fruit. This can explain why the RDI fruit were bigger than those of the control. Perhaps the RDI treatment might influence the bio-allocation due to less shoot growth during phase I and II towards the fruits. Therefore, moderate RDI strategies appear to have the effect to produce bigger but less mature fruits which were more susceptible to decay during storage at chilling and non chilling temperatures. Cold storage has been shown to slow dawn the senescence processes and retard decay development of stone fruits. However, chilling injury (CI) limits the storage life of peaches under low temperature. In fact, losses of peaches “Flordastar” occurred at low-temperature even when storing under controlled atmospheres because of the internal breakdown of the fruit flesh during storage. RDI fruit showed less storage potential because of high decay due to rot development during storage. Internal breakdown does not occur at 10ºC or above, but rapid ripening and senescence preclude holding these fruit at high temperatures. Therefore, to maintain high quality of RDI peaches the optimum maturity stage at harvest is critical as well as temperature management and controlled atmospheres storage.

Conclusions

Severe regulated deficit irrigation (RDI) of peaches cv Flordastar during stage I and II of fruit growth caused fruit peel stress lowering the content of vitamin C and carotenoids, while increasing the phenolic compounds mainly anthocyanins and procyanidins. Other quality aspects such as soluble solid content, titratable acidity and fruit skin color are not influence negatively in response to RDI. A limiting factor of the use of severe deficit irrigation techniques is the negative impact on the fruit size and therefore the combination with low crop load by thinning is recommended. However, moderate deficit does not necessary reduce fruit size and weight. On the contrary, mild deficit irrigation applied during stage I and II induces a slight increase in fruit size and weight if normal water supply is insured during the last stage of fruit growth. The last stage of peach growth prior to harvest is very critical and it seems that RDI reduces skin color and maintains fruit firmness which indicates a less ripeness stage of RDI fruits at harvest. Respiration rate and ethylene production does not vary with irrigation treatments. When water stress is applied during fruit development stages I and II, fruit quality during storage is similar to fully irrigated fruits but a limitation on the storability potential of RDI fruits is observed due to a higher susceptible to decay by rot development compared to control fruits. This study confirms the possibility to reduce irrigation water by applying moderate RDI during the early stages of fruit growth without negatively affecting crop yield and fruit quality at harvest but considering a reduction in the postharvest storage life.

References:

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2- Effects of different irrigation strategies on the quality and safety of citrus

Maria I. Gil, Ana Allende, Macarena Moreno, Mercedes Almagro, Natalia Hernández, Laura Fernández, Alicia Marín, Francisco López-Gálvez, Juan Antonio Tudela.
CEBAS-CSIC, Campus de Espinardo, P.O. Box 164, 30100, Espinardo (Murcia), Spain.

Mediterranean countries have experienced severe water supply and demand imbalances, with more frequent and longer lasting periods of drought (Aiello et al., 2007). Among various water conservation practices, the use of non-conventional water resources such as treated wastewater has been proposed (Mahasneh et al., 1989; Al-Lahlam et al., 2003). Wastewater reuse for agriculture represent a good alternative as it has the potential to meet growing water demands, conserve potable supplies, reduce disposal of pollution effluent into surface water bodies, allow lower treatment costs and enhance the economic benefits for growers due to reduced application rates for fertilizer (Jiménez-Cisneros, 1995; Paranychianakis et al., 2006; Aiello et al., 2007). Another way to optimize water resources is to employ regulated deficit irrigation (RDI) strategies, in which moderate water stress is applied during part of the seasonal cycle of plant development (Kriedemann and Goodwin, 2003). However, the quality and quantity of water used for irrigation might affect the quality and safety of the fruits. The present study evaluates the influence of water irrigation qualities and RDI strategies on the quality parameters and the content of bioactive constituents of mandarins and grapefruits.

2.1. Mandarins

In general, quality parameters of mandarins such as weight, size, external colour, juice production, soluble solids, pH, total acidity, firmness and peel thickness were not affected by the type of irrigation water quality and RDI strategies in mandarins. However, in the third evaluation period (harvest season November 2008) it was observed that mandarins subjected to RDI strategies and irrigated with water from the Tajo-Segura water transfer showed lower weight and size than the rest of the water treatments. This is accordance with previous results which demonstrated that RDI fruits usually showed shorter equatorial diameter but a higher total soluble solids content and titratable acidity than control fruits (Pérez-Pérez et al., 2008; Navarro et al., 2010).

Mandarins obtained from trees irrigated with the regular water showed a higher content of vitamin C when compared to rest of the mandarins. On the other hand, the phenolic content of mandarins was not influenced by the water quality but it was influenced by the RDI treatments when irrigated with regular water. Mandarins obtained from trees subjected to regular water and RDI strategies showed lower phenolic content than mandarins obtained from fully irrigated trees. A similar tendency was observed for mandarins obtained from trees irrigated with water from a wastewater treatment plant. However, these clear differences were not observed when irrigated with water from the Tajo-Segura water transfer.

The sensory quality of mandarins was evaluated to determine the impact of water qualities and RDI strategies on the sensory quality of fruits. It was observed that the overall visual quality, flavour and juiciness of the mandarins was affected by the irrigation treatments. In this case, the lowest scores were obtained for mandarins obtained from trees irrigated with water from a wastewater treatment plant. The adverse effects observed in the sensory quality of mandarins could be due to the high salinity of the water from the wastewater treatment plant. Additionally, the crop productivity was significantly reduced when irrigated with wastewater, which corroborates the negative effect of this type of water quality on the quality and production of mandarins after three years of irrigation with the same type of water.

The microbial quality of the water used to irrigate the mandarin threes showed significant differences depending of the water source. Thus, the water obtained from the Tajo-Segura water transfer showed the lowest microbiological quality. This type of water had the highest counts of total coliforms (2.3 log cfu g^{-1}), thermotolerant coliforms (1.2 log cfu g^{-1}), and *E. coli* (0.3 log cfu g^{-1}). On the other hand, the levels of

Listeria spp were below the limit of detection (<1 cfu mL^{-1}) in all water samples. It was observed that the use of RDI strategies did not affect the total coliform counts of soil irrigated with the different irrigation water qualities. Regarding thermotolerant coliform counts, soil irrigated with regular water showed the highest counts. However, *Listeria* spp counts were higher in the soil irrigated with water from the Tajo-Segura water transfer. *Listeria monocytogenes* presumptive colonies were detected in soil irrigated with regular water and wastewater but they were not present in soil irrigated with water from the Tajo-Segura water transfer. When the microbial quality of fruits was evaluated it was observed that all the microbial groups were present below the detection limit (2.5 cfu cm^2 for skin and 5 cfu g^{-1} for pulp samples). The presence or absence of *E. coli* O157:H7 was evaluated by PCR which showed that all the tested samples were negative for this pathogenic microorganisms.

The irrigation water obtained from the wastewater treatment plant showed the highest nitrates content. On the other hand, the different water qualities did not influence the content of nitrates in the soil as the nitrate content of soils irrigated with wastewater and regular water were similar. However, mandarins obtained from trees subjected to the different irrigation water qualities did not show any trace of nitrates.

Conclusions

In general, different water qualities and different irrigation strategies (Fully irrigated and RDI) did not affect the quality parameters such as weight, SSC, pH, TA, firmness. However, irrigation with water from a tertiary wastewater treatment plant influenced the sensory quality of mandarins because reduced the overall visual quality as well as the juiciness and flavour while promote the presence of white membrane. The use of wastewater also reduced the mandarin production, probably due to the high salinity content of this type of water. The different water qualities did not affect the microbial quality and safety of mandarins. The nitrate content of mandarins was very low and independent of the content of fertilizers in the irrigation water.

2.2. Grapefruits

In general, the weight and the size of grapefruit were similar in fully irrigated and RDI fruits except for the case of fruits irrigated with wastewater. Grapefruits obtained from trees fully irrigated with wastewater showed higher size and weight. However, there no differences were observed between the use of regular and water from the Tajo-Segura water transfer. The external colour of the grapefruits was very similar in all the cases with only slight differences between treatments.

The higher weight and size observed in grapefruits irrigated with wastewater could be due to the higher content of organic matter observed in this type of water (54 mg/L COD) when compared to the regular (38 mg/L COD) and water transfer (38 mg/L COD) irrigation water.

The juice production of grapefruit was, in general, a little bit higher in fully irrigated than RDI fruits. This observed difference was more pronounced in fruits irrigated with wastewater than in the rest of the treatments. Fruits fully irrigated with wastewater also showed the highest firmness when compared to RDI. However no difference was observed between fully irrigated and RDI fruits for the rest of the treatments. As observed for mandarins, no differences among irrigation treatments including water quality and deficit irrigation strategies regarding peel thickness and pH. No differences among irrigation treatments including water quality and deficit irrigate. The maturity index is used to evaluate the maturity level of a fruit under specific growing conditions. In this case, we evaluate the maturity index of the grapefruits under different irrigation treatments including water quality and deficit irrigation strategies. However, all the fruits showed a very similar maturity index independently of the irrigation treatment.

The content of vitamin C was evaluated by the independent measured of ascorbic acid and dehydroascorbic acid. As previously found in mandarins, the content of ascorbic acid in the juice was higher than that of dehydroascorbic acid. There was not a clear tendency of irrigation water quality and deficit strategy.

Conclusions

Grapefruits treated with water from a tertiary wastewater treatment plant showed higher weight and size and also higher juice production. This could be probably due to the high content in organic material of this type of water. In general, the irrigation with different water qualities and different irrigation strategies (Fully irrigated and RDI) did not affect the rest of the quality parameters such as maturity index and vitamin C content.

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3. Effects of different regulated deficit irrigation (RDI) during the stage III of fruit growth on quality attributes of peaches

Hélène Gautier, Laurent Gomez, Daniel Plénet, Pierre Rouet, Krystèle Traverse, Hassana Bouhala, Bader Mahaman-Diouala, Gilles Vercambre
INRA, UR1115, Plantes et Systèmes de culture Horticoles, Domaine Saint Paul, Site Agroparc, 84914 Avignon cedex 9, France

Several studies reported the economical interest of using regulated deficit irrigation (RDI) during peach fruit growth to limit water consumption and increase water use efficiency. The present work aimed to determine the impact of applying RDI during fruit stage III on the crop agronomic performances (water use efficiency, commercial crop yield) and the built up of fruit quality.

Two experiments were conducted in 2007 and 2008 at INRA center in southern France (Avignon), on white flesh late-maturing nectarine (*Prunus persica* L. Batsch, cv. Zephir® Monphir). The trees were cultivated in containers equipped with a drip-irrigation system and covered with a polyethylene plastic film, in order to control water supply. They received standard horticultural care except a lack of fungicides which aimed to study irrigation effects on diseases such as brown rot. During fruit developmental stages I and II, all the trees received the same water supply. At the onset of fruit developmental stage III, 4 different irrigation treatments were initiated: control treatment (non limiting water supply), slight RDI (69% of the water supplied to the control in 2007 and 57% in 2008), moderate RDI (46% in 2007 and 39% in 2008) and severe RDI (25% in 2007 and 19% in 2008).

Fruit sampling (2 fruit per tree on 5 trees per treatment) were realised on a fortnight basis and leaf sampling (6 leaves per tree on 5 trees per treatment) were done at 3 dates and kept at -80°C before freeze drying and being ground. Soluble sugars and acids were analysed by HPLC (Gomez et al., 2002), and starch by enzymatic way (Gomez et al., 2007). Fruit sweetness was estimated according to Kulp et al. (1991), considering different sweetness values according to the sugar (glucose: 0.77; fructose: 1.75; sucrose: 1; sorbitol: 0.6). A two-way ANOVA was used to assess the impact of RDI, harvest dates and their interaction (XLStat, Addinsoft, France).

As similar data were obtained in 2007 and 2008, only data from 2008 are presented. During fruit maturation, flesh sugar and acid contents evolved as previously reported (Wu et al., 2002; Génard et al., 2003): total sugar concentration increased while acids content decreased (Fig. 1). Sucrose mostly contributed to the sugar increase, whereas sorbitol showed a characteristic bell-shaped curve with low sorbitol content at the end of the maturation. Most of the acids decreased during this last growth stage, triggering a decreased titratable acidity. The proportion of glucose and fructose increased with water deprivation whereas sucrose contribution decreased. The severe RDI treatment delayed the sorbitol decrease, which might be linked to a delayed ripening (Mahhou et al., 2006). This change in sugar distribution likely increased the flesh osmolarity and offered a best retention of water. The impact of RDI on acid profile was less evident except for the severe RDI treatment which showed a shift in the bell-shaped curve of citric acid which could be due to a delayed ripening.

The most severe water deprivation significantly lowered leaf starch content may be connected to the reduced photosynthesis (-70% compared to the control, data not shown). Under water stress, tree strategy favours fruit growth, limiting the storage of the neo-synthesized carbohydrates. The higher sorbitol content (circulating form of sugar in peach tree) observed under severe water deprivation was in agreement with this change in strategy.

Peach tree agronomic performances were affected by water restriction (Table 1), but only the severe RDI had a dramatic impact on yield and marketable product, despite a beneficial decrease in fruit disease (due to lower brown rot occurrence). In contrast slight to moderate RDI could significantly reduce fruit disease, increase the marketable production and improve the WUE. From an agronomic point of view, a moderate RDI was highly beneficial when no-fungicide spray applications were realised against brown rot diseases. In addition, the flesh composition was not affected by the irrigation level except for the severe RDI treatment (Table 2). The lower sugar/acid ratio observed in the severe RDI treatment was mostly connected to a higher flesh acid content, which could be related to a delayed fruit maturity. Despite changes in sugar distribution, in particular with the RDI 17% treatment, the sweetness was not affected by the water deprivation. As previously reported (Mercier et al., 2009), these minor consequences on fruit quality showed the peach tree capacity to increase its WUE under a moderate RDI.

Conclusions

A moderate RDI treatment during fruit growth stage III seems to be a good mean to improve water saving and agronomic performance without any negative impact on fruit quality. A severe RDI treatment (17 to 25% of ET0) despite an improvement in WUE, strongly reduced yield performance but also the gustative (sugar acid ratio) and nutritional quality (fruit ascorbate content), so it should not be recommended. The present data on fruit quality combined to the findings of work package 2 confirm that management of RDI during peach growth stage III offers an efficient way to control water supply and water loss with limited impact on fruit quality. Moreover, they gave thresholds (water deprivation indicator expressed as %ET0), that should not be exceeded in order to keep optimal fruit yield and quality.

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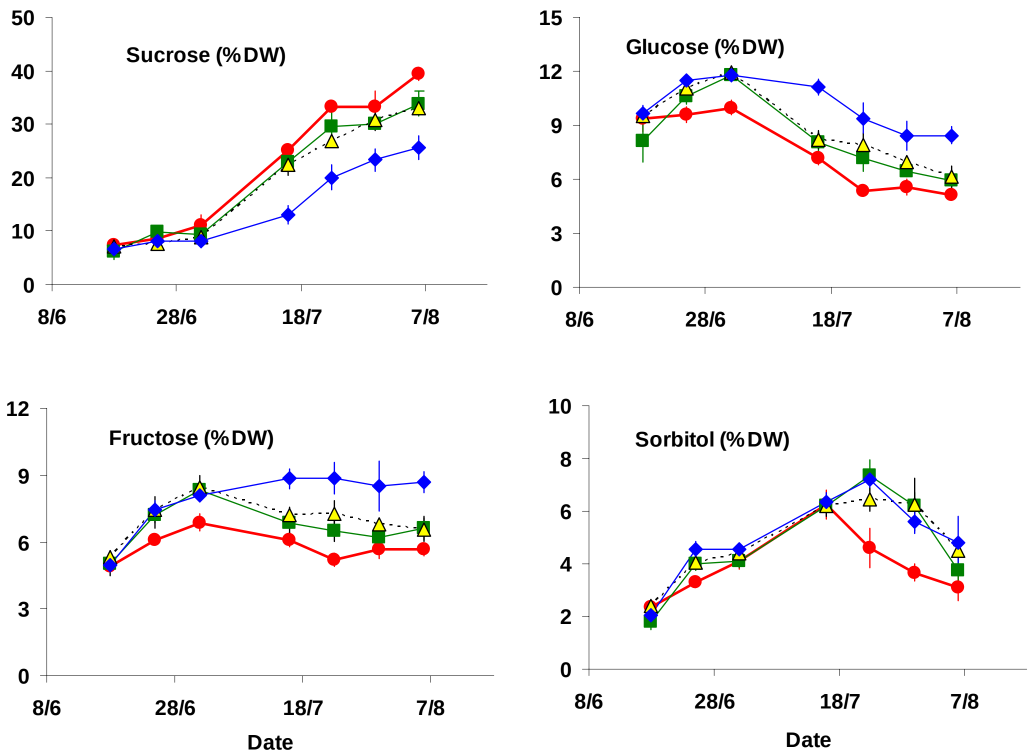

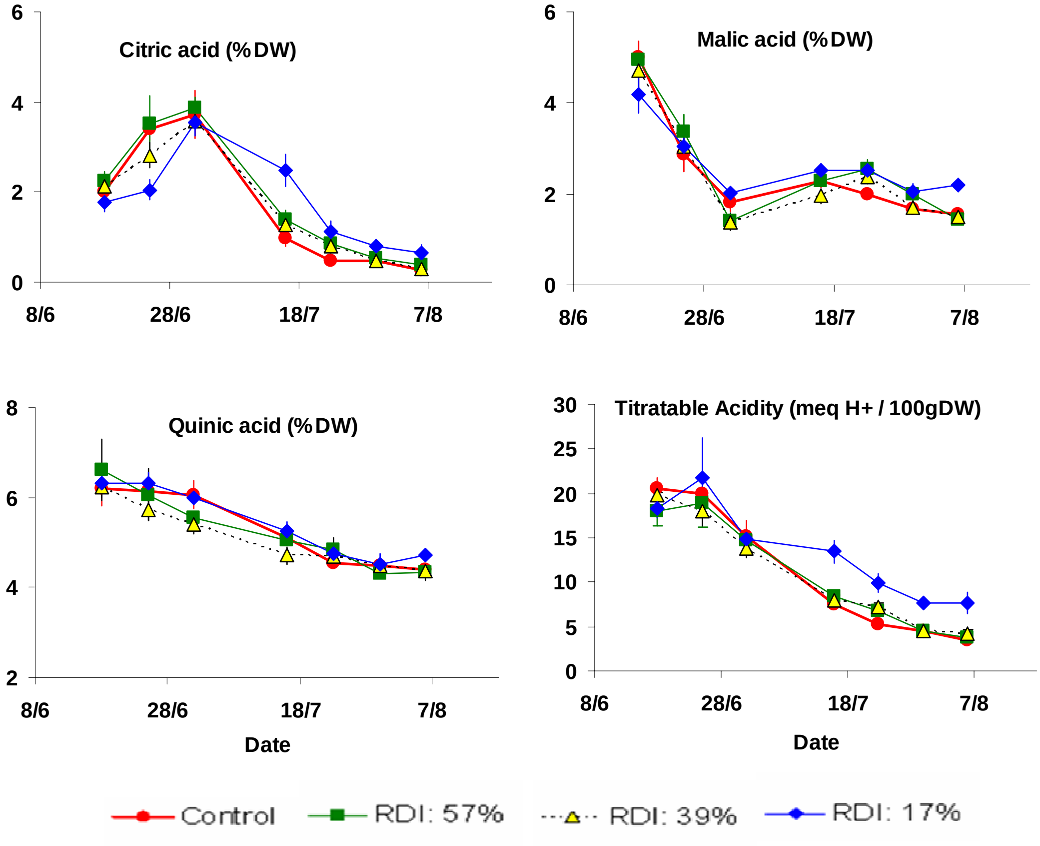

Figure 1: Impact of RDI on flesh sugar and organic acid content in Zephir 2008

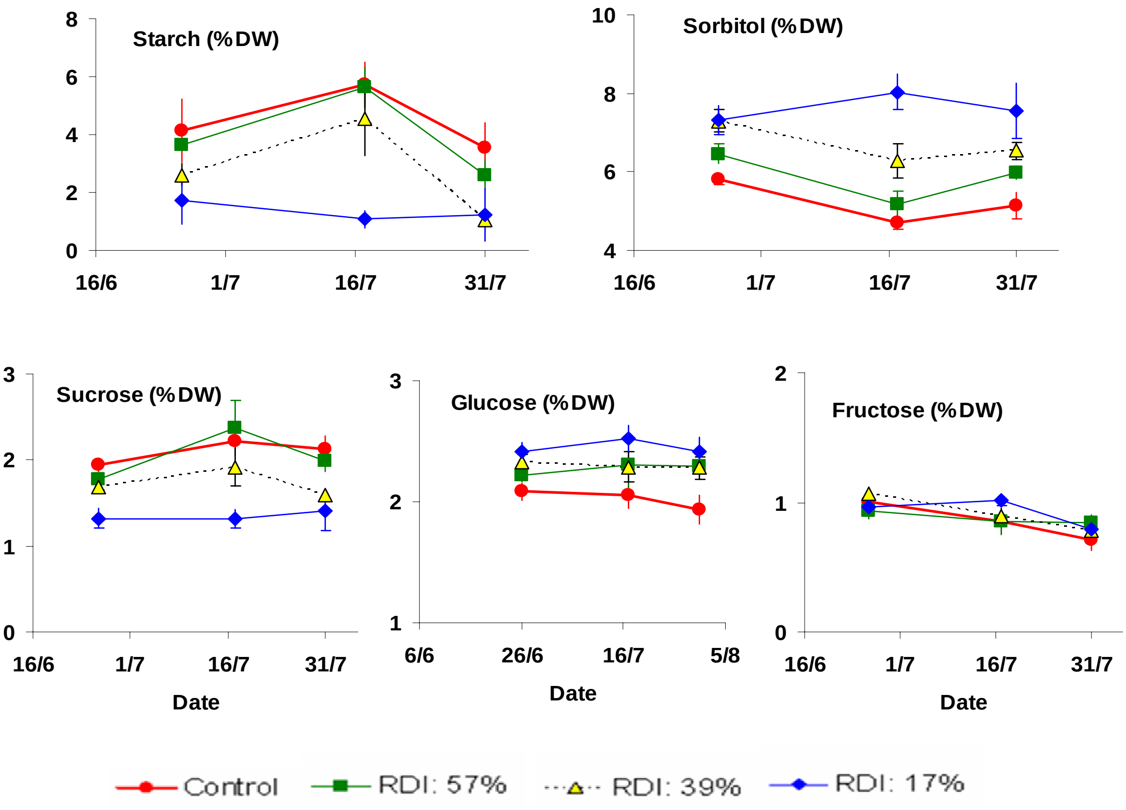

Figure 2: Impact of RDI on leaf sugar content in Zephir 2008.

Table 1: Impact of RDI on agronomic performances

Variables	**Control**	**RDI_57%**	**RDI_39%**	**RDI_17%**		***P***
Gross yield (kg $tree^{-1}$)	33.4 a	27.0 a	25.0 b	18.1 c	↘	<0.001
% fruit disease	35.5 a	13.4 b	16.5 b	6.3 b	↘	<0.001
Marketable product (€ $tree^{-1}$)	12.9 b	16.5 a	13.8 b	7.5 c	↘	<0.001
Water Use Efficiency (kg fruit m^{-3})	9.4 c	18.0 b	23.3 b	42.8 a	↗	<0.001

Table 2: Impact of RDI on flesh quality

Composition (%)	**Variables**	**Control**	**RDI_57%**	**RDI_39%**	**RDI_17%**		***P***
Dry matter	Organic acids	6.3 b	6.2 b	6.2 b	7.6 a	↗	<0.0001
	Sugars	53.3 a	50.2 ab	50.2 ab	47.5 b	↘	0.04
Quality Indexes	Sweetness	95.0	89.1	99.7	100.7		NS
	Sugar/acid ratio	8.53 a	8.08 a	8.11 a	6.29 b	↘	<0.0001

4. Effects of different regulated deficit irrigation (RDI) of fruit growth on quality attributes of peaches growing in Platanoulia and Velestino (Greece)

Eleni D. Pliakoni and Prof. George Nanos, Univ. of Thessaly, Greece

4.1. Peaches in Platanoulia (Tyrnavos)

In Loadel peaches, fruit skin color did not change with storage time in a meaningful manner. As far as the fruit quality is concerned, specific conductivity did not change, total phenol content increased and flesh firmness, soluble solids content, dry matter content and acidity decreased during Loadel peach fruit storage.

In Fortuna peaches, similarly fruit skin color did not change with storage time in a meaningful manner. Also fruit quality was affected similarly to Loadel peaches during storage as specific conductivity and total phenol content increased and flesh firmness, soluble solids content, dry matter content and acidity decreased during Fortuna peach fruit storage.

Conclusions: Clingstone peach cold storage caused partial fruit ripening and partial fruit quality loss except of an increase in nutritional quality based on the total phenol content.

In Loadel peaches, fruit from deficit irrigated trees had similar skin color, higher soluble solids and dry matter content, slightly higher phenol content and slightly lower acidity than fruit from well watered trees without any other significant differences in quality.

In Fortuna peaches, fruit from deficit irrigated trees had more green skin color, higher flesh firmness and acidity and no other significant quality differences compared to fruit from well watered trees.

Conclusions: Loadel peaches from deficit irrigated trees (as leaves experienced stress from the low water availability) seemed to have improved fruit quality compared to fruit from well watered trees. On the other hand, deficit irrigation in Fortuna peaches probably delayed ripening and if left for longer on the tree, they could develop better quality than fruit from well watered trees.

In Loadel peaches (1 year data only), fruit from reflective mulched trees had less green color, lower flesh firmness and acidity and higher specific conductivity, soluble solids and dry matter content and higher total phenol content than fruit from well watered trees.

On the opposite, in Fortuna peaches, fruit from reflective mulched trees had less green color and higher dry matter content and no other quality differences than fruit from well watered trees.

Conclusions: Reflective mulch seemed to improve Loadel peach fruit quality mainly due to earlier ripening. Fortuna peach fruit quality did not clearly benefit from reflective mulch as this cultivar's leaf functioning was found to be negatively affected from the reflective mulch.

4.2. Peaches in Velestino

In Royal Glory peaches with the almost complete red skin color, no clear differences were measured on skin color changes during storage except an initial increase and later on decrease in L* index and an increase in a* with storage time. Peaches showed variations over storage time in some fruit quality parameters. In this respect, specific conductivity increased and later on decreased with storage time, soluble solids content and % flesh dry matter decreased and later on increased with storage time and total phenols decreased and later on increased with storage time. Also, flesh firmness and acidity decreased with storage time.

In Caldesi 2000 nectarines with the partial red coloring of the skin, skin color indexes showed clear changes with storage time. Thus, L* increased and later on decreased, a* increased, b* and hue angle decreased and C* did not change with storage time. Nectarines showed variations over storage time in most fruit quality characteristics similar to peach fruit changes described above.

Conclusions: Skin color can depict changes in skin color (which actually occur) during fruit storage even in deeply red fruit. Various changes occurred in fruit quality characteristics over storage time, with the most clear a decrease in flesh firmness and acidity content and an increase (especially late in storage) in total phenol content.

In Royal Glory peaches, fruit from deficit irrigated trees had different skin color only in 2008 (more clear but less red color) than fruit from well watered trees. Also, fruit from deficit irrigated trees had similar acidity, higher specific conductivity, soluble solids and dry matter content and total phenol content and lower flesh firmness than fruit from well watered trees.

In Caldesi 2000 nectarines, fruit from deficit irrigated trees had similar L* and C*, lower a* and higher b* and hue values than fruit from well watered trees. Also, fruit from deficit irrigated trees had similar specific conductivity, higher soluble solids and dry matter content, flesh firmness, acidity and total phenol content than fruit from well watered trees.

Conclusions: The two cultivars behaved slightly different as far as the fruit quality of deficit or well irrigated trees is concerned. In general, Royal Glory peaches from deficit irrigated trees were riper (and healthier) at harvest and during storage than peaches from well watered trees. Caldesi 2000 nectarines from deficit irrigated trees had better overall quality than nectarines from well watered trees.

In Royal Glory peaches, fruit from reflective mulched trees had darker red skin color than fruit from well watered trees. Also, fruit from reflective mulched trees had similar acidity and specific conductivity, higher soluble solids and dry matter content and total phenol content and lower flesh firmness than fruit from well watered trees.

In Caldesi 2000 nectarines, fruit from reflective mulched trees had similar skin color to fruit from well watered trees. Also, fruit from reflective mulched trees had similar soluble solids and dry matter content and total phenol content to, lower specific conductivity, and higher flesh firmness and acidity than fruit from well watered trees.

Conclusions: The two cultivars behaved slightly different as far as the fruit quality of reflective mulched or well irrigated trees is concerned. In general, Royal Glory peaches from reflective mulched trees were riper (and healthier) at harvest and during storage than peaches from well watered trees. Caldesi 2000 nectarines from reflective mulched trees seemed to be less ripe than nectarines from well watered trees.

In Royal Glory peaches, fruit from the lower shaded part of the tree had less red color, were less ripe and of inferior quality (and nutritional) compared to fruit from the upper part of the tree with ample available light.

In Caldesi 2000 nectarines, fruit from the lower shaded part of the tree had less red color (but without pronounced differences), and were of inferior quality (and nutritional) overall compared to fruit from the upper part of the tree with ample available light.

Conclusions: Fruit from the lower shaded part of the tree had inferior skin color and inferior quality (and nutritional) compared to fruit from the upper part of the tree with ample available light. In both cultivars measured in Velestino, fruit growth was not affected by deficit irrigation or reflective mulch application compared to control (well irrigated, herbicide treated trees).

GENERAL RESULTS:

The reduction of water inputs did not negatively impact fruit safety and quality. The effEct on fruit quality and safety are:

Quality and safety of stone fruits and citrus were not affected when optimum deficit irrigation practices were applied.

Deficit irrigation and water quality of stones fruits and citrus did not play a significant role affecting the content of polyphenols, carotenoids, ascorbates.

Additionally, RDI can also reduce excessive vegetative growth and improve fruit quality

WP 3 and WP 4: EFFECTS OF RDI PRACTICES ON QUALITY AND SAFETY OF ALMONDS AND OLIVES

OBJECTIVES: Study the effects of different RDI strategies and irrigation water quality on the quality and safety of almonds and olives.

CONTRACTORS:

UNIFG, UPTC, UTH, IRNAS-CSIC.

WORK PERFORMED:

Activities were performed on almonds grown in Cartagena (Spain), and on olives grown in Ferrandina (Italy), Volos (Greece) and Sevilla (Spain). Quality determinations were carried out by UNIFG (almonds and olives) in Italy and UTH (olives) in Greece. On almonds kernel and nut the following physical attributes were measured at harvest: thickness, length, width, perimeter of projected area and projected area, roundness, geometric mean diameter, bulk and true density, rupture force, fresh weight, and kernel ratio. The kernels were powdered and the powder was used for the following chemical analyses: water activity, water and ash content. In addition, initially, and after 2, 5, and 9 months of storage at 0 °C and at room temperature, the following attributes were determined on kernel: peel color, rupture force, and oil content. The oil and the defatted powder obtained from the extraction at each evaluation time were separated and stored at –20 °C until the analyses. On the defatted powder, the following analyses were performed: sugar composition, antioxidant activity, extractable phenolic compound. On the oil, the following analyses were performed: oil acidity and peroxide value, tocopherols content. Moreover, initially and at each storage time a discriminative sensorial analysis was performed, using the multiple comparison test. On olives the following physical attributes were measured at harvest: length, width, perimeter of projected area and projected area, roundness, bulk and true density, seed ratio, water and oil content. In addition, initially, and during storage the following attributes were determined: color score (maturity index), firmness, and respiration rate. For oil quality assessing, initially and during storage the following attributes were evaluated: color measurement, free acidity and peroxide value, fatty acid composition, phenols, tocopherols content, total carotenoids and chlorophylls, oxidative stability, and sensory evaluation. Microbial safety of almonds and olives was evaluated by UNIFG (Italy) at harvest and during storage.

RESULTS ACHIEVEMENT:

1.- Effects of different irrigation water reduction strategies on almonds at harvest and during storage

Giancarlo Colelli, Maria Luisa Amodio, Rosaria Cornacchia, Raffaella Rinaldi
Department PrIME, University of Foggia, Via Napoli 25, 71100 Foggia, Italy.

Almond is the most widespread nut crop in the Mediterranean region, where is generally cultivated in arid and semi-arid areas, without any additional water supply except rainfall. Although is well known for being crops resistant to drought, water stress can negatively affect both yield and quality attributes of the fruits. On the other hand irrigation can improve yield and quality although, because of water scarcity for irrigation, and competition for water from other sectors, it is necessary to adopt sustainable water use strategies. Among new irrigation techniques tested on almond, regulated deficit irrigation (RDI) and partial root-zone drying (PRD) were proposed for a more efficient use of water compared to traditional methods (Goldhamer, 1996; Heilmeier et al., 1990). Not many information are found on the effects of water reduction strategies on quality attributes of dried almonds at harvest, and on the impact on almond postharvest quality. The aim of the activities on almonds was to evaluate the effects of different irrigation water reduction strategies on quality of 'Marta' almonds at harvest (2006, 2007, and 2008), and during storage (2007 and 2008) in different conditions.

In 2006, 'Marta' almonds trees from an experimental orchards located in Cartagena (Spain), were submitted to five irrigation treatments: I) Full irrigation at 110% of Etc for all the year, from 1999 (FI); II) Regulated Deficit Irrigation at 100% of ETc for all the year and at 50% of ETc from early June until harvest, from 2003 (RDI 50); III) Partial Rootzone Drying at 70% of ETc for all the year (PRD 70); IV) partial Rootzone Drying at 50% of ETc for all the year (PRD 50); V) Partial Rootzone Drying at 30% of ETc for all the year (PRD 30).

For both 2007 and 2008, 'Marta' almonds were submitted to four irrigation treatments: I) Full irrigation (FI); II) PRD 50 (PRD); III) RDI 50 (RDI); IV) Not irrigated, rain fed from 2006 (NI). In both years, the effect of irrigation treatment, temperature (0 °C and room temperature) and modality of storage (shelled/unshelled) on quality attributes of almond kernels during 9 months of storage was also evaluated.

In 2006, irrigation treatment at higher ETc percentage did not affect almond yield and kernel quality, since no differences were found in physical and chemical attributes compared to fully irrigated almond trees. In relation to water saving, PRD 50 and RDI 50 treatments were the most favourable, while PRD 70 treatments was the least favourable. PRD 30 treatment negatively affected yield and kernel size, although allowed to save the highest amount of water.

When PRD 50 and RDI 50 were applied in 2007 and 2008, results indicated that, despite to lower amount of water applied in PRD and RDI, both these water-deficit treatments did not affect almond yield and kernel quality, since no differences were found in physical and chemical attributes compared to fully irrigated almond trees. PRD strategy seem to be more effective than RDI in maintaining yield; for both studied years in PRD plots similar yield was obtained as in FI plots, while trees with RDI had lower yield than FI trees in the second experimental year. Water use parameters showed that RDI saved a higher amount of water than PRD, but resulted in lower water use efficiency. Almonds growth in non irrigated plot also received the lowest evaluation for general appearance and showed a different peel color at harvest and during storage. Differences in chemical attributes among irrigation regimes observed in 2007 were not confirmed in 2008. Sucrose and α-tocopherol contents, which resulted significantly higher in not irrigated kernels in 2007 compared to all the other kernels, were found not different in 2008. Storing almond with shell resulted in lower color changes in both studied years, while less evident was the effect of storage temperature. The storage temperature had an effect only in 2008, with almonds stored at 0 °C showing lower variation in some color parameters than almonds stored at room temperature. Almonds stored in shell showed a different pattern in sucrose content during storage, and a higher oil content at the end of storage, regardless of the storage temperature. Almonds stored in shell at room temperature had a lower antioxidant activity after 5 months of storage, while tocopherols changes seems to be not dependent on storage conditions, but only on the length of storage.

Conclusions

Results obtained showed that irrigation (fully and deficit) positively affected almond yield and yield components (nut and kernel weight and fruit load) and quality. Both water-saving strategies (RDI and PRD) did not affect almond yield and kernel quality, since no differences were found in physical and chemical attributes compared to fully irrigated almond trees; nevertheless, PRD strategy seems to be more effective than RDI in maintaining yield. Absence of irrigation and PRD treatment at lower ETc value (30%) negatively affected yield and kernel size. RDI and PRD saved a higher amount of water (50% vs. 34-39% of water applied in FI) and improved water use efficiency, with few difference between irrigation treatments. With regard to almond storage, PRD and RDI did not negatively affect almond kernel quality during in-shell storage for up to 9 months, since no differences were found in physical and chemical parameters compared to almonds from fully irrigated trees, while a different behaviour was observed in NI samples, which showed different peel color, more rapid decrease in antioxidant and phenol content during storage, higher total sugars and sucrose content and lower general appearance. Storage modality had an effect on peel color variation, with unshelled almonds showing lower changes compared to shelled ones after 9 months of storage, and also lower decrease in total phenols content. Storage temperature only slightly influenced quality of almonds during 9 months of storage. Results for sensory evaluation did not show a particular effect of irrigation on sensorial attributes.

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2.- Effects of different irrigation water reduction strategies on olives at harvest and during storage

Olives is typical Mediterranean crops, traditionally cultivated in areas with no irrigation. Most of the responses to water stress have a negative effect on growth and production of olive trees and, generally, any additional water supply through irrigation tends to increase olive yield (Patumi et al., 1999). A good water supply is also very important for obtaining satisfactory fruit size of table olives, which is a factor strictly correlated to the commercial value of the product (Proietti and Antognozzi, 1996). Many trials have been carried out on different olive cultivars to determine the effect of auxiliary drip irrigation with low quantities of water (Dettori and Russo, 1993; Solé, 1990), and single-season drought irrigation strategies (Goldhamer et al., 1994). However, there is very little information on the effect of regulated deficit irrigation on oil quality. The aim of this study was to evaluate the effects of irrigation water reduction on quality of the olives at harvest, during storage, and on the oil after processing.

2.1.- Effect of deficit treatment on quality of 'Konservolea' olives at harvest, and on the oil after processing. Years 2006 and 2008.

Giancarlo Colelli[1], Maria Luisa Amodio[1], Raffaella Rinaldi[1], Rosaria Cornacchia[1], George D. Nanos[2]
[1]Department PrIME, University of Foggia, Via Napoli 25, 71100 Foggia, Italy.
[2]Lab. of Pomology, School of Agricultural Sciences, Univ. of Thessaly, Fitoko str, Volos 38446, Greece.

In 2006 and 2008, 'Konservolea' olive trees from an olive orchard located in Anchialos (Greece) were submitted to two different irrigation treatments were applied: I) Control, irrigated from June to August with good quality water (conductivity <700 µS/cm) utilizing 2 sprinkler of 80 L/h per tree; II) Deficit, irrigated as control during the growing season and deficit irrigated only during stone hardening and final flesh swelling when water supplied per day was the 20% of the control.

Irrigation regime only affected oil content, which resulted significantly higher in deficit treated fruits. No differences were found in olives dimensional characteristics and density measurements. Color score evaluation, which was used as maturity index, was not affected by irrigation treatment, indicating that the absence of water did not delay maturity process in olive. Also in 2006 oil content resulted significantly higher in deficit treated fruits and differences in shape and color score were observed between the water regimes; not irrigated olives presented higher value of area, perimeter and length, and lower color score than irrigated fruits. Olives yields obtained were 9.6 ton/ha in 2008 and 16 ton/ha in 2006, without difference between irrigation treatments for both years. While in 2006 irrigation treatment did not affect oil quality, in 2008 irrigation regime significantly affected acidity, with deficit treatment showing a lower value than control No differences in peroxide value and extinction coefficients were detected, while the oil obtained from deficit treated olives showed a higher stability. Deficit irrigation treatment also resulted in higher total polyphenols and chlorophyll content. MUFA/PUFA ratio was significantly higher in oils obtained in deficit irrigation conditions, while the unsaturated/saturated ratio resulted lower for oils from deficit treatment. No difference between treatments were observed for sensorial attributes of oil extracted during storage.

Conclusions

In both years, no differences in fruit yield were observed between irrigated and not irrigated treatments; reduced water supply resulted in an increase in olive oil yield, and lead to some improvement in oil quality, as indicated by a lower acidity and higher stability, polyphenols and chlorophyll contents compared to control. Only in 2006, deficit treated fruits presented higher value of area, perimeter and length, and lower color score than irrigated fruits. For both years no difference between treatments were observed for sensorial attributes of oil extracted.

2.2.- Effect of deficit treatment on quality of 'Maiatica' olives at harvest, during storage and on the oil after processing. Years 2007 and 2008.

Giancarlo Colelli[1], Cristos Xiloyannis[2], Maria Luisa Amodio[1], Raffaella Rinaldi[1], Rosaria Cornacchia[1] Bartolo Di Chio[2]
[1]Department PrIME, University of Foggia, Via Napoli 25, 71100 Foggia, Italy.
[2]Department of Crop Systems, Forestry and Environmental Sciences, University of Basilicata, Via dell'Ateneo Lucano 10, Contrada Macchia Romana, 85100, Potenza, Italy.

For both 2007 and 2008, 'Maiatica' olive trees from an olive orchard located in Ferrandina (Italy) were submitted to two different irrigation treatments: I) Control, irrigated with depurated wastewater utilizing 6 drippers of 8 L/h per tree; II) Deficit, not irrigated with rainfall as the only water supply. For both years, the effect of irrigation strategies on olives and on olive oil after processing was evaluated at harvest and during 20 days of storage at 5 °C. The activities were carried out in cooperation with Prof. Cristos Xiloyannis, University of Basilicata (Italy).

In 2007 differences in shape and firmness were observed between the water regimes; not irrigated olives presented higher value of roundness and firmness than irrigated fruits. In 2008, no differences were found in olives dimensional characteristics and density measurements and irrigation significantly affected oil content and respiration rate; irrigated fruits presented lower oil content and higher respiration rate compared to not irrigated fruits.. Color score evaluation, which was used as maturity index, was not affected by irrigation treatment, indicating that the absence of water did not delay maturity process in olive. Olives yield obtained from irrigated trees was 173 kg/tree, while yield obtained from not irrigated olive was 133 kg/tree, with a difference of 23%. In 2007 olives yield resulted 60 kg/tree and 45 kg/tree for irrigated and not irrigated samples, respectively, with a difference of 25%. In both years, irrigation did not show evident effects on oil color. In 2008, no difference in quality indices of oil extracted from irrigated and not irrigated olives were found; on the contrary, in 2007 peroxide value resulted higher in oils obtained from irrigated olives, and oxidative stability showed significant higher values for oils extracted from fruit submitted to deficit irrigation treatment. Phenolic compounds were negatively affected by irrigation and total polyphenolic content resulted higher than in 2007. Olive oil from deficit irrigated olives presented significant higher value of total tocopherols, while chlorophylls and carotenoids content did not vary with the irrigation regime. Fatty acid profile was influenced by irrigation regime, as well as the balance between monounsaturated and polyunsaturated (MUFA/PUFA) which was higher for oil obtained from irrigated olives than for oil obtained from deficit treated olives.

During storage, irrigation treatment only affected respiration rate of olives, while color and quality indices of olives oil extracted at each storage duration were not influenced by irrigation. Oil quality slightly declined in both irrigation treatments, as indicated by the increase in acidity and the decrease in stability, without any significant differences between irrigation treatments, and extinction coefficients remained within the limit of extra virgin olive oil fixed at 0.22, for both irrigated and not irrigated samples. Polyphenols content was influenced by storage time, with a 4-fold increase in oil from irrigated olives; in oil extracted from deficit irrigated olives polyphenols content remained almost around initial up to 10 day before increasing. Also during storage, oil from deficit irrigated olives presented significant higher tocopherols content than oil from irrigated olives; oil from deficit treated olives showed the lowest carotenoid content, while no effect of irrigation were observed on chlorophyll content. As observed at harvest, fatty acid composition of oil extracted at different time during olive storage at 5 °C was influenced by irrigation treatments. Palmitic, palmitoleic, linoleic and linolenic acids were significantly higher in oil obtained from deficit treated olives than in oil obtained from irrigated olives. Irrigation did not affect the unsaturated/saturated ratio and the balance between monounsaturated and polyunsaturated (MUFA/PUFA) was lower for oil obtained from deficit irrigated olives than for oil obtained from irrigated olives, indicating less changes in fatty acid composition that generally result in a increase of PUFA. Panel test did not show any significant difference in sensorial attributes to be related with irrigation regime at harvest and after storage.

Conclusions

Results showed that deficit irrigation regime negatively influenced olive and olive oil yield, and although it did not negatively affect the quality indices used to classify olive oil by commercial grades, influenced other important parameters such as total polyphenols and tocopherols content at harvest and during storage at 0 °C. Oil from deficit olives showed a higher total polyphenols and α-tocopherol contents and a different fatty acid composition, with a minor oleic acid content, that in a general way did not affect unsaturated/saturated ratio, while a lower MUFA/PUFA ratio was found for this treatment, indicating less undesiderable changes in fatty acid composition during storage. Panel test did not show any significant difference in sensorial attributes to be related with irrigation regime.

2.3.- Effect of different irrigation water reduction strategies on quality of 'Manzanilla' olive oil at harvest. Year 2007.

Giancarlo Colelli[1], Maria Luisa Amodio[1], Raffaella Rinaldi[1], Rosaria Cornacchia[1], George D. Nanos[2]
[1]Department PrIME, University of Foggia, Via Napoli 25, 71100 Foggia, Italy.
[2]Lab. of Pomology, School of Agricultural Sciences, Univ. of Thessaly, Fitoko str, Volos 38446, Greece.

In 2007, 'Manzanilla' olive trees from Seville (Spain) were submitted to four different irrigation treatments: I) Irrigation with enough water to wet the whole rootzone (Pound); II) daily irrigation with a localised irrigation system that supplies 100% of Etc (FAO); III) RDI 50 (RDI); IV) Dry farming with rainfall was the only water supply (DF).

Irrigation regime affected oil color, since differences among treatment were observed for a*, b*, Hue Angle and Chroma values. Pound treatment showed the lowest a* value (0.01) versus value ranging from 1 to about 2 for the other treatment, where positive values indicated more reddish colors and negatives ones greenish colors. Oil from DF treated olives received also the lowest b*, Chroma and an intermediate Hue Angle values. The irrigation regime significantly affected acidity: pound treatment showed the lowest value, while DF showed the highest acidity value. Oil obtained from Pound-treated olives showed also the lowest stability compared to oil obtained from DF and RDI, which showed the highest stability. No differences were observed in peroxide value between irrigation regime. Deficit irrigation treatment and RDI treatment induced a lower tocopherol content compared to FAO and Pound treatments, instead oil from DF treated olives, showed the highest chlorophyll and carotenoid content. With regard to sensory characteristics, olive oil from all the treatments were classified as extra virgin oils. Oils from Pound and RDI regimes were significantly less bitter than oils from FAO and DF regimes. Samples from RDI treatment received a significant higher global evaluation than others treatments. Irrigation treatment strongly affected fatty acid content. Treatments characterized by deficit irrigation (DF and RDI) showed a statistically significant higher content in oleic acid, among the others, whereas irrigated trees (FAO and Pound) had a higher contents in palmitic and linoleic acids. As a consequence, the unsatured /satured and monounsaturated/polyunsaturated fatty acids (MUFA/PUFA) ratios were significant higher in oils obtained in deficit irrigation conditions.

Conclusions

Olive oil beneficiated from a total (DF) or partial deficit treatment (RDI) in terms of stability and fatty acid composition. Oil from stress-treated olives showed the highest unsaturated/saturated ratio, and among unsaturated fatty acids, MUFA/PUFA ratio. In addition, oil from DF and RDI olives, showed the highest chlorophyll and carotenoid contents, the lowest α-tocopherol content and the highest global evaluation value compared to Pound and FAO treatments.

2.4.- Effect of deficit treatment on quality of 'Chondrolia' and 'Konservolea' olives at harvest, and during storage. Year 2008.

George Nanos, Eleni Pliakoni
Lab. of Pomology, School of Agricultural Sciences, Univ. of Thessaly, Fitoko str, Volos 38446, Greece.

In 2008, 'Chondrolia' and 'Konservolea' olive trees from an olive orchard located in Anchialos (Greece) were submitted to two different irrigation treatments were applied: I) Control, irrigated from June to August with good quality water (conductivity <700 μS/cm) utilizing 2 sprinkler of 80 L/h per tree; II) Deficit, irrigated as control during the growing season and deficit irrigated only during stone hardening and final flesh swelling when water supplied per day was the 20% of the control. The effect of irrigation treatment on quality attributes of olives at harvest and during 5 weeks of storage at 5 °C was evaluated by UTH partner; for 'Konservolea' olives the effects of irrigation regime were evaluated also in combination with reflective mulch.

Konservolea olives skin changed significantly during the first week of storage at 5 °C, as observed by a substantial decrease in L*, b*, Chroma and Hue angle and an increase (less negative values) in a* index. Color remained almost unchanged until 5 weeks, when a slight increase in L* and a significant increase in a* and decrease in hue angle were observed. At harvest, olives from control (C) showed the highest L* values, while olives from deficit irrigation treatment (D) showed the lowest b* and Chroma values compared to the other treatments and the difference among the treatments decreased during storage. Deficit treated olives had also higher Hue Angle values than fruit from the other treatments and the difference between D and the other treatments increased with storage time. Besides, reflective mulch did not affect skin color both in control and deficit treated olives. Flesh firmness quickly decreased during the first week of storage, maintaining almost constant until 5 weeks, when it increased probably due to the substantial development of chilling injury. In general, fruit from reflective treatments (R and RD) had lower flesh firmness than fruit from C and D at all storage durations, except after 3 weeks storage when fruit from all treatments had similar flesh firmness. Fruit dry matter content did not change with time of storage for all treatments. Fruit from RD showed the lowest dry matter content at harvest and during storage at 5 °C, while fruit from deficit showed the highest value; evident differences between deficit and control samples were observed when reflective mulch were added. Olives from reflective mulch treatment (R and RD) presented high phenol content compared to the other treatments (D and C); in particular deficit treated olives (D) showed high content compared to control (C) and the differences between the treatments decreased with time. A decrease in total phenol content was observed after 2 weeks of storage for C and D treatments, while for R and RD treatments an increase during the first week, followed by a significant decrease was observed. Finally, chilling injury appeared from the first week of storage and it increased progressively during storage, regardless of treatment. Fruit from the reflective treatments manifested a little higher chilling injury than fruit from C and significantly higher than fruit from D during storage at 5 °C. Only late in storage fruits from D showed significantly lower chilling injury than fruit from C.

Chondrolia olives skin changed significantly during after 1 week of storage at 5 °C, as observed by a substantial decrease in L*, b*, Chroma and Hue angle and an increase (in a* index. Color remained almost unchanged until 5 weeks, although a decrease in hue angle were observed. At harvest, olives from control (C) showed lower L*, b* and Chroma values compared to deficit treated olives (D), but, as observed in Konservolea samples, the differences between the treatments decreased during storage. Flesh firmness increased starting from the third week, to decrease at 5 week of storage, reaching initial value. No differences in flesh firmness and chilling injury were found between the treatments. It is important consider that Chondrolia olives resulted extremely susceptible to chilling injury when stored at low temperatures, so their storage for more than 1-2 weeks was unsuccessful. Fruit dry matter content (%) did not change with time of storage and with treatment except at 3 weeks of storage, when dry matter resulted higher in deficit samples compared to control. Chondrolia olives were characterized by a higher total phenolic content compared to Konservolea olives. In general, a decrease in phenol content was observed after 2 weeks of storage at 5 °C, while deficit treated olives showed higher phenol content compared to control samples during the entire experiment.

Conclusions

In both cultivars, deficit irrigation and mulch did not negatively affect quality of olives at harvest and during storage at 5 °C; in particular no evident differences were found in skin color, flesh firmness and chilling injury (CI) between deficit and irrigated drupes, while dry matter content resulted higher in deficit treated olives. Only in 'Chondrolia' olives deficit treatment resulted in more evident chilling injury symptoms and higher phenol content. In 'Konservolea' olives reflective mulch did not affect skin color but decreased flesh firmness, increased flesh dry matter and CI compared to control fruit.

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3. -Effect of saline water on quality of 'Konservolea' olives at harvest and on the oil after processing. Years 2007 and 2008.

Giancarlo Colelli[1], Maria Luisa Amodio[1], Raffaella Rinaldi[1], Rosaria Cornacchia[1], George D. Nanos[2]
[1]Department PrIME, University of Foggia, Via Napoli 25, 71100 Foggia, Italy.
[2]Lab. of Pomology, School of Agricultural Sciences, Univ. of Thessaly, Fitoko str, Volos 38446, Greece.

Water scarcity in the Mediterranean basin, especially in countries in arid zone with high rates of population growth, urbanization and industrialization, appears as one of the main

factors limiting agricultural development. In order to overcome water shortages and to satisfy the increasing water demand for agricultural development, the use of water of low quality (brackish, reclaimed, drainage) is becoming important in many countries. Recent research developments on salt tolerance of various crops, water, soil and crop management, irrigation and drainage methods will enhance and increase the use of low quality water for irrigation with minimum adverse impacts on yield, soil productivity and environment. The use of saline water is a promising alternative (Chartzoulakis, 2005). Olive is a moderately salt tolerant tree crop (Maas and Hoffman, 1977) that may grow successfully in saline soils where other fruit tree crops cannot be grown. In the last few decades, much research has been devoted to the interaction between salinity and olive cultivation (Marin et al., 1995; Gucci e Tattini, 1997) and to evaluate the effects of long-term irrigation with salinity water on olive trees in order to optimize vegetative growth, productivity and oil quality (Cresti et al., 1994; Klein et al., 1994;Wiesman et al., 2002; 2004).

The aim of this work was to evaluated the effect of saline water on quality of 'Konservolea' olives at harvest and on the oil after processing.

In 2007 and 2008, 'Konservolea' olive trees from an olive orchard located in Anchialos (Greece) were submitted to two different irrigation treatments: I) Control, irrigated from late May to mid September with good quality water (conductivity 717 μS/cm) utilizing 10 drippers of 4 L/h per tree for 24 h every 10 days (with a total water amount of 2800 m^3/ha); II) Salty treatment, irrigated from 21 July until mid September (during pit hardening before oil accumulation) with 2800 m^3/ha of water as for control trees, but with the addition of 0.4 kg NaCl per tree for 7 times, split into smaller quantities per dripper at the beginning of irrigation.

Salt stress treatment significantly affected only water content of olives at harvest, which was significantly lower in salt treated fruits, as expected. No differences were found in olives dimensional characteristics and density measurements, in respiration rate and firmness. Color score evaluation, which was used as maturity index, was not affected by irrigation treatment. Also in 2007 no difference in shape, firmness and respiration rate were observed between the water regimes, while control irrigated olives presented higher value of roundness and color score than salt irrigated fruits. In 2008, olives yield obtained from both control and treated trees was 80 kg/tree, while oil yield resulted 11 and 12 kg/tree for control and salt irrigated trees, respectively. In 2007 olives yield resulted about 30 kg/tree for both treatments, without difference in oil yield.

Salt irrigation did not show evident effects on oil color, as observed in previous year. No differences between treatments were found on olive oil quality indices, except for extinction coefficient at 270, which resulted significant lower in oil extracted from salt treated fruits. Among chemicals parameters, only β-tocopherol content was affected by irrigation regime, resulting lower for oil obtained from control treated olives than for oil extracted from salt treated olives, while in 2007, salt treatment affected negatively hydroxytyrosol and β-tocopherol content and positively carotenoids content. Irrigation treatments did not affect fatty acid profile and sensorial attributes. Total phenol content in the olive oil was not affected by moderate NaCl salinity, while the ratio of unsaturated/saturated fatty acids decreased.

Conclusions

In both years, salt irrigation did not show evident effects on oil color, quality indices, nutritional characteristics, fatty acid composition and sensorial attributes. Salt stress treatment significantly affected only water content of olives at harvest, which was significantly lower in salt treated fruits, while no differences were found in dimensional characteristics and density measurements, in respiration rate, firmness and color score evaluation.

Final considerations

Results obtained during 3 years on almonds and olives lead to the some conclusions:

-moderated deficit conditions did not affect almond yield and quality, while the non irrigated trees showed low yield, size and quality of the nuts;

-irrigation regime did not affect olives dimensional characteristics, density measurements and maturity index, while the effect on yield and oil content varied with location and the severity of water stress;

-a little deficit did not affect yield in olives and gave a quality comparable to that of irrigated olives, and with a higher amount of polyphenols and a better fatty acid composition;

-as for use of salty water no real differences were observed on yield and quality, except for the water content of the fruits;

-for both almond and olives, irrigation treatment with different amount of water did not cause problems from a safety point of view.

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WP 5: SOIL WATER BALANCE MODEL

OBJECTIVES: The main objective of WP5 is the characterization and modeling of the effects of different irrigation strategies on soil moisture dynamics, root architecture growth and plant water uptake. In this framework, two sub-tasks were simultaneously carried out:

1. modeling of the water transfer in the soil and of the water uptake by the distributed plant root system, under various irrigation regimes,

2. modeling of the root system architecture in interaction with the soil water distribution and variability.

Specific experimentations have been carried out enabling measurements (1) of the soil water contents for various irrigation levels, (2) of the water uptake zones, (3) of the root growth and its spatial variation linked with the soil water content distribution and its temporal variation with the whole plant functionning. Objectives were also to get data for the modelling of soil water uptake in case of heterogeneous soil moisture dynamics and root system in connection with different irrigation strategies.

CONTRACTORS: Two main contributors were associated for this work-package : INRA (French National Institute for Agricultural Research) with the EMMAH (Mediterranean Environment and modeling of agri-hydrosystems) and PSH lab (Horticultural Plants and Culture Systems) located in Avignon, South-east of France, and UPCT (Universidad Politécnica de Cartagena) located in the South-east of Spain. Additional work was done by the CEBAS-CSIC (Centro de Edafología y Biología Aplicada del Segura, Consejo Superior de Investigaciones Científicas) and by the Institut Agronomique et Véterinarie Hassan II (IAV) in relation with SAPIAMA (society of farmers located in Moroco).

MATERIAL AND METHODS:

Experimental set up were designed to characterize *in situ* (i) the spatial (3D) distribution and temporal evolution of water content and (ii) the root system architecture or colonization, subjected to different irrigation strategies.

1.1. UPCT

The study was conducted during the growing season 2007 in an almond orchard. Four irrigation treatments were applied to experimental sub-plots, with 12 trees per sub-plot and three sub-plots per treatment: (i) Full Irrigation (FI) treatment, (ii) Regulated Deficit Irrigation (RDI) treatment, irrigated to satisfy the full water requirements except during the IV stage (kernel-filling), where 30% ET_c is supplied, (iii) Partial Rootzone Drying (PRD) treatment, irrigated at 50% ET_c the whole season, and (iv) Non-Irrigated trees

(NI treatment). Trees of FI and RDI were irrigated by means of a single drip line equipped with six compensate pressure drippers (8 L h^{-1} per dripper) per tree. PRD trees were irrigated by two drip lines to allow watering only one side of the root system at the same time. Three drippers per tree side were installed.

In each plot, except in NI, a total number of 25 access tubes were installed, at a spacing of 0.35 m and delimiting a squared area of 1.4 m x 1.4 m (Figure 1). In NI, two access tubes were installed on the tree row at 1 m from the trunk. Soil moisture content was monitored using a FDR humidity sensor (DIVINER 2000® series II). Measurements were made at a weekly interval.

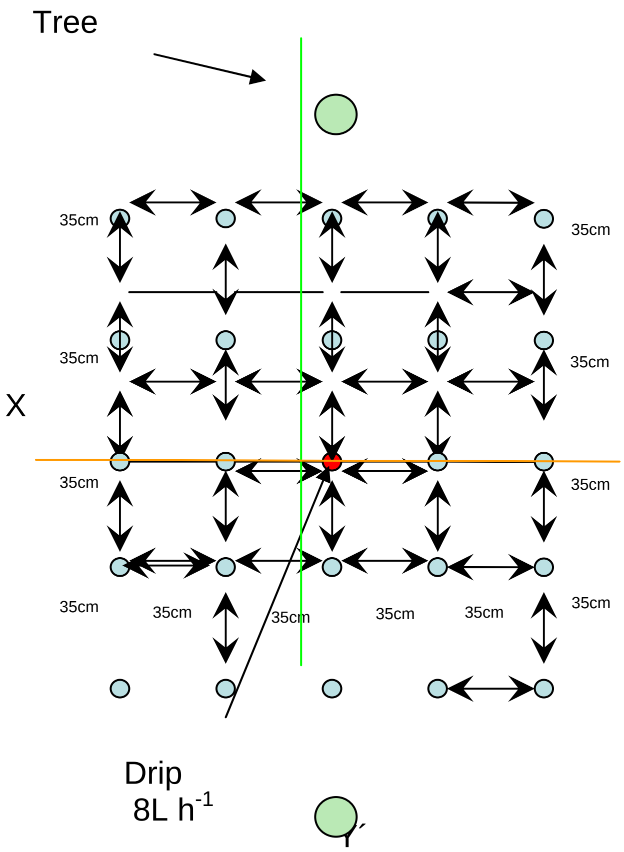


Figure 1: Distribution of the 25 access tubes in the measurement area, for the treatments FI, PRD and RDI. The central tube was 5 cm distant from the dripper (UPCT).

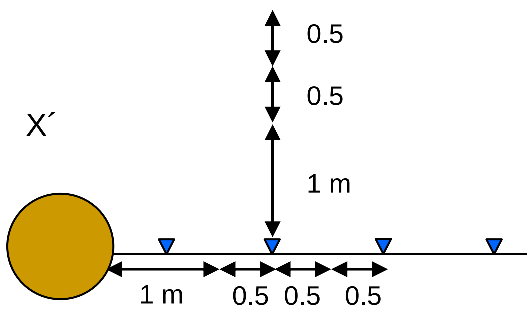


Figure 2 : Schematic layout of the sampling points where soil samples were collected for root system characterization. Blue triangles = emitters; Brown circle = tree trunk.

Root pattern distribution was characterized in all treatments. Soil samples were collected during the winter dormancy of 2007 (November-December) by using a root auger (Eijkelkamp, Agriserch Equipment, The Netherlands) whose cylinder has an operational depth of 15 cm and a volume of 750 cc. Different soil samples were collected from each treatment following the layout presented in Figure 2 and exploring up to 75 cm of the soil profile. For each sample, root density was calculated as the ratio of root dry weight to soil volume.

1.2. INRA experiments

Orchard experiments

In the INRA orchards, the study was conducted during the growing season 2007, 2008 and 2009 in a peach orchard planted in 2005. Three irrigation treatments were established, a full irrigated treatment receiving the full water requirements (100% ET_c) during the whole season (FI), a regulated deficit irrigation treatment (RDI), where only 30% ETc were supplied, and a water deficit irrigation treatment (WDI) based on Maximum Daily Shrinkage of the trunk.

Data on the root system architecture were collected using three complementary methods: (i) minirhizotrons, (ii) monoliths, and (iii) ingrowth cores. In addition to these root observations, repeated samplings of root bark were done monthly to analyze carbohydrate contents in roots. Vegetative shoot and fruit growth were measured throughout the growing season. Root tips were collected from the holes during mesh bag removals. Samples of root barks, composed of the periderm, the cortex and the secondary phloem, were harvested twice a month from February to October. Careful excavation at the root collar allows access to the proximal part of the root system. A piece of root bark (~1 cm² with 2 mm thickness) was collected using a scalpel, from a thick root on 4 trees per modalities. Glucose, fructose, sucrose, sorbitol and starch were extracted and enzymatic analyses using micro-plate reader were carried out following the protocol of Gomez et al. (2007).

The experimental soil design is shown in Figure 3 and aims at getting moisture variations in the zone affected by drip irrigation at different distances from the dripper and in the non-affected zone. The soil depth of the experimental orchard is about 1 to 1.15 m and is limited by a layer of alluvial stones. On two trees of the experimental orchard have both been installed with 6 neutron tubes access. One of the trees is in the fully irrigated zone (irrigation ~PET) and the other is in the water deficit zone (irrigation~PET/3). Electrical Resistivity Tomography (ERT) measurements (ABEM SAS 4000 resistivimeter) were used, enabling the imaging of electrical resistivity of the subsoil. Electrical resistivity is linked to permanent soil characteristics (texture, mineralogy) and to time variable soil characteristics, mainly water content. Thus, time variation of electrical resistivity in space gives indication on water content variation: irrigation effects and distribution of water uptake zones. Two lines of 32 electrodes arrays with 20 cm spacing between electrodes, resulting in a 6.3 m transect were installed on each tree equipped with water content measurements. Apparent resistivities, acquired with the resistivimeter in the field using a Wenner alpha array for electrode measurement protocol, were converted into “true”, space distributed, resistivities with Res2Dinv inversion software (Geotomo software) and imposing the resistivity of the alluvial stone layer (300 ohm.m) at the measured depth of this layer. Measurements of water content and electrical resistivity were done twice a week resulting in 3 to 5 days intervals between measurements.

Pots experiments

Root growth processes have been studied in an additional experiment in pots with rootstock “GF 677”. Soil conditions have been controlled, with different soil densities (1.2 and 1.5 $g.cm^3$) and humidities (0.14, 0.17 and 0.20 $g.g^{-1}$) leading to four distinct soil penetration resistances (2.3, 4.7, 5.2 and 5.9 MPa) since the non compacted pots had the same soil penetration resistance. The root system was observed in term of total growth (fresh and dry mass) and architecture. Global measurements are presented following modalities: compacted-14% (C-14), compacted-17% (C-17), compacted-20% (C-20), non compacted-14% (NC-14), non compacted-17% (NC-17), non compacted-20% (NC-20) whereas data on root architecture were presented following soil penetration resistance. Differences between modalities on leaf area and above-ground and root dry mass were observed.

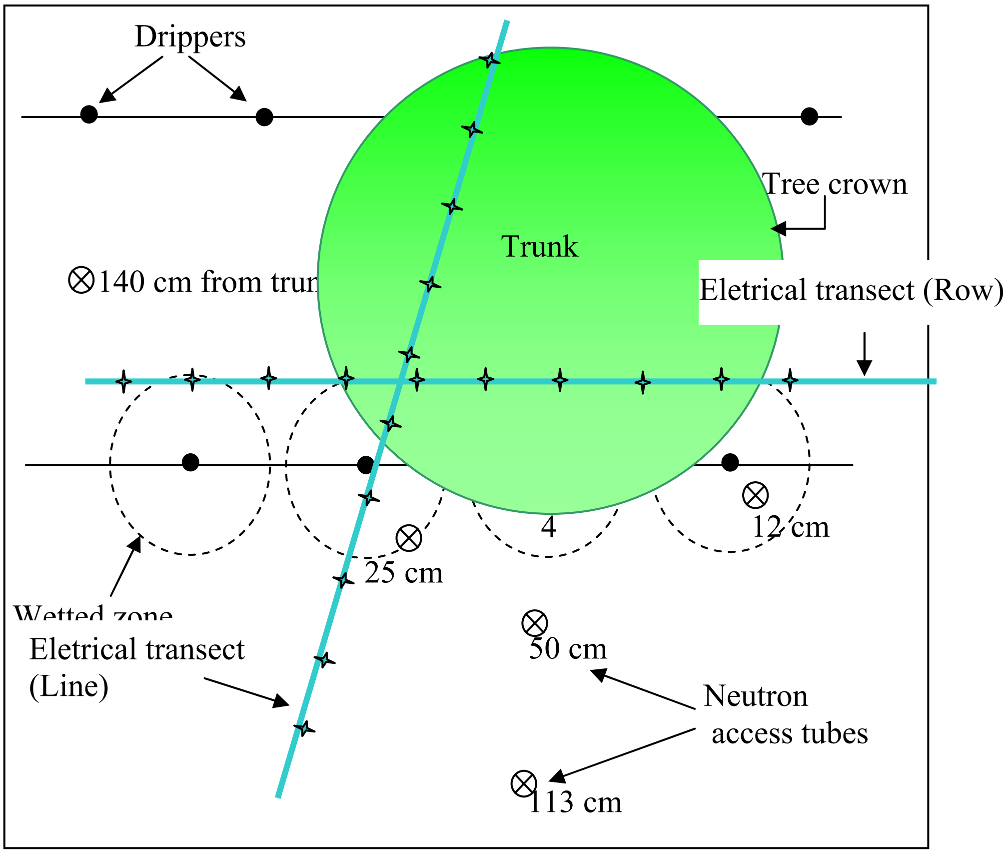


Figure 3 : Scheme of the experimental site for soil moisture variations measurements

RESULTS ACHIEVEMENT:

1.3. Root colonization

The goals were to determine the seasonal fine roots growth in relation with the cultural practice (thinning and irrigation) as well as the effect of the soil properties (soil density, soil water content) on the main root growth processes.

Temporal root growth

The seasonal pattern of root growth has been related to above-ground parts growth (fruits, leaves and new-current year shoots). Growth of organs varies throughout the growing season and periods of intense growth of organs are time specific for each one. Water stress and crop load does not affect the various organs in the same way. The seasonal pattern of relative root growth had two peaks, with variable importance depending on modalities. Indeed, for deficit-irrigated trees, relative root growth was similar whatever the crop load, whereas in well-irrigated trees the crop load affected the relative root growth. In well irrigated condition, the root growth in high crop load trees during the first peak was more than 3-fold higher than in low crop load trees; and the opposite is found during the second root growth flush. Previous studies found a first flush in spring and a second one after fruit harvest but few have been focused on root growth dynamic following both water stress and crop load modalities. Concerning the root observation method, meshes were filled with light substrate of peat and vermiculite, and then the mechanical resistance of the substrate to root growth is small, especially in comparison of the surrounding soil. In addition, the meshes were irrigated regularly throughout the season. Therefore, the root colonization in meshes is promoted by (i) smaller mechanical resistance (well and deficit-irrigated plots) and (ii) larger water availability compared to the surrounding soil (deficit-irrigated plot only). Therefore, our results highlight potential and/or compensational root growth in relation with carbohydrates availability, as water availability was not limited in the mesh.

The maximum shoot leaf area was reached around fruit harvest in all treatments and was the highest for the well-irrigated with low crop load trees. At harvest in trees with low crop load, the shoot leaf area of deficit-irrigated trees was only half of the well-irrigated trees. The shoot elongation was reduced by water stress, which is in agreement with previous findings. From the stage I to the fruit harvest a significant decrease of fruit growth rate with high crop load was observed, whereas the water stress affects the fruit growth only during the final growth stage.

From the onset of the experiment to fruit harvest, pattern of starch contents in root barks and root tip were similar whatever the modality, but the starch content was indeed low in the root tip (Figure 6). Starch was mobilized early in the season and then remained almost null until fruit harvest. After fruit harvest, an important starch accumulation occurred in deficit-irrigated trees. Globally, the trend of seasonal patterns of each soluble carbohydrate was similar; contents were under 15 mg g^{-1} DM until fruit harvest and increased thereafter. However this increase was more or less marked following the crop load and the irrigation treatment. Sorbitol and hexoses contents highly increased in deficit-irrigated trees leading to significant effect of irrigation treatment. The seasonal pattern of hexose content in root tips was rather similar whatever the modality with two distinct peaks. After fruit harvest, hexose contents tended to increase, but this increase was higher and lasted longer in deficit-irrigated trees.

Root bark as well as root tip samplings are an original way to estimate non destructively the seasonal pattern of various carbohydrates in the root system, carbohydrates involved in storage (starch), transport in phloem (sorbitol and sucrose) and growth (glucose and fructose) in the root system at different location (proximal vs distal). Links between these contents and the organs growth (roots, shoots, leaves and fruits) could be seen from the organ level (root tip or fruits) up to the whole tree scale, based on the source-sink relationships. Seasonal patterns of hexose contents in root tips were closed to root growth patterns, with large variation occurring throughout the season and marked by two peaks. Seasonal growth patterns of roots, shoots, leaves and fruits are asynchronous.

Early in the season, the competition for carbohydrates between organs is important and supported by the entire starch mobilization and its low content until harvest. After fruit harvest, the resulting carbohydrate demand of above-ground organs is limited, whereas the carbohydrate assimilation is maximal (leaves completely deployed), allowing the second intense root growth. As the shoot and leaves growth are greatly reduced by water stress, much more than the photosynthesis process, a large accumulation of starch is observed after harvest, especially for water stressed trees. The root growth was observed when the local carbohydrate availability was high, with large carbohydrate contents dealing with sucrose and sorbitol, transported carbohydrates in the plant, or glucose and fructose, used for growth and respiration.

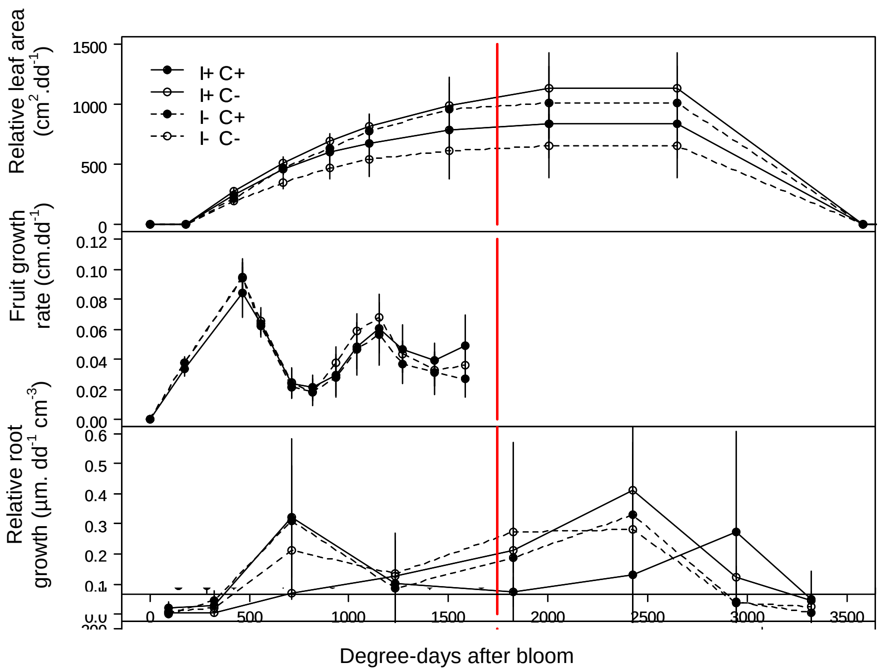


Figure 4 : Mean (± SD) leaf area on a new current year shoot, mean (± SD) fruit growth rate, mean (± SD) relative root growth rate (± SD) in each modality of treatment (I+ C+, I+ C-, I- C+, I- C-) in 2008.

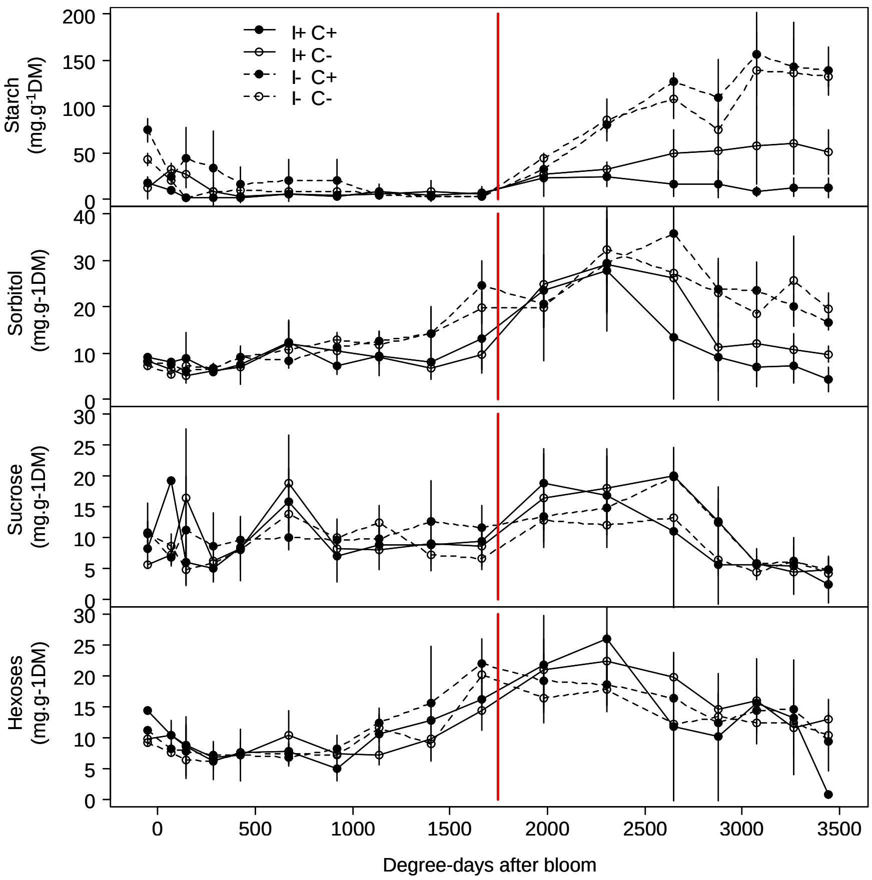


Figure 5 : Mean (± SD) of starch (A), sorbitol (B), sucrose and hexoses contents in root barks, in well-irrigated trees with high crop load trees (I+ C+), well-irrigated trees with low crop load (I+ C-), deficit-irrigated trees with high crop load (I- C+), and deficit-irrigated trees with low crop load (I- C-). Vertical solid line gives the fruit harvest date. Vertical bars indicate ± SD.

Spatial distribution of the root system

The root growth is sensible to several factors in the soil such as soil bulk density, humidity and temperature. The root distribution in the orchard has been studied with trench walls, monoliths and minirhizotrons. Each of these methods allowed to map the number and the location of the roots in soil.

In order to get insight of the root processes affected by the soil properties, an additional experiment in pots were carried out. Large soil compaction and decrease in soil humidity lead to a decrease of the leaf area as well as of the above-ground dry mass. The greatest differences were obtained between C-14 (Compacted soil, 0.14 $g.g^{-1}$) and NC-20 (Non-Compacted soil, 0.2 $g.g^{-1}$), with the leaf area and the above-ground dry mass 2 fold lower.

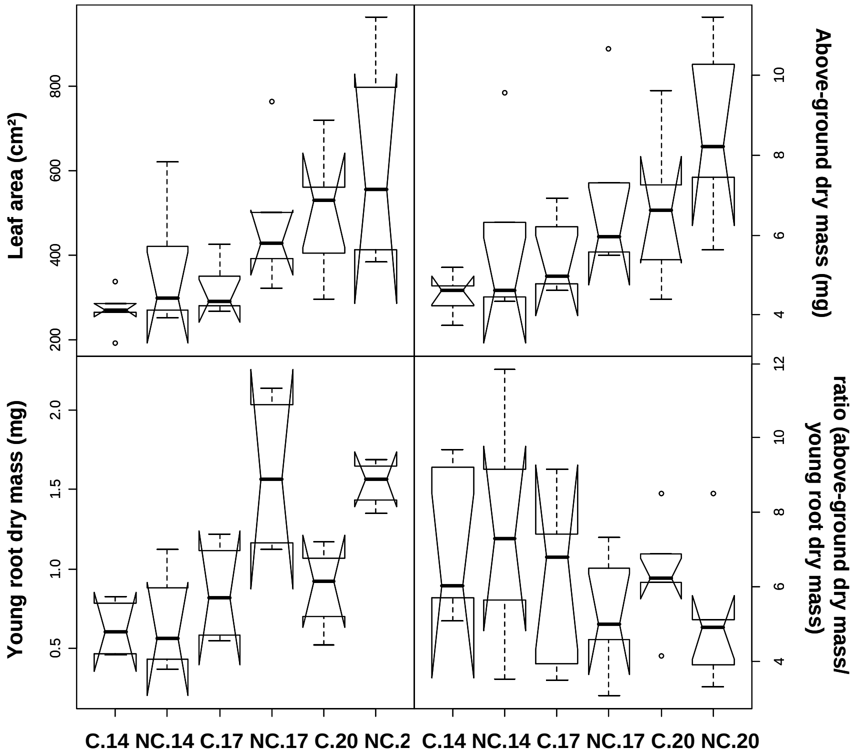


Figure 6 : Boxplots of the leaf area, shoot dry mass, young root dry mass and of the ratio between shoot and root dry mass in function of the bulk soil density and of the soil humidity.

For the total root growth, large differences occur, with an effect of the soil water availability and of the bulk soil density as well. At 0.14 $g.g^{-1}$, the root dry mass did not differ between the two soil compaction, whereas at 0.17 and 0.20 $g.g^{-1}$ the compaction had greatly affected the root dry mass. Regarding the ratio between above-ground and root biomass, this ratio was the lowest in NC-17 and NC-20, where root dry mass was also the most important.

In orchard, whatever the irrigation treatment, the root length density was higher in the row, it means close to drippers. Distribution of roots in water stressed plot appears more homogenous for the upper part of the soil profile (down to 50 cm depth) compared to the well irrigated plot. However, large discrepancies occur deeper, with only marginal root colonization for depth larger than 50cm, and characterized by patches of root, located beneath the dripper zone. Differences in root colonization between irrigation treatments appeared at the layer 40-60 cm where FI have largely higher proportion of occupied square, whatever the distance from the inter-row.

This heterogeneous root colonization of the soil volume was amplified in the UPCT orchard. Root pattern distribution showed a greater root density along the dripper line, the root density being an order of magnitude higher than perpendicular to the drip line (Figure 8), a characteristic of this type of lineally-distributed drip system.

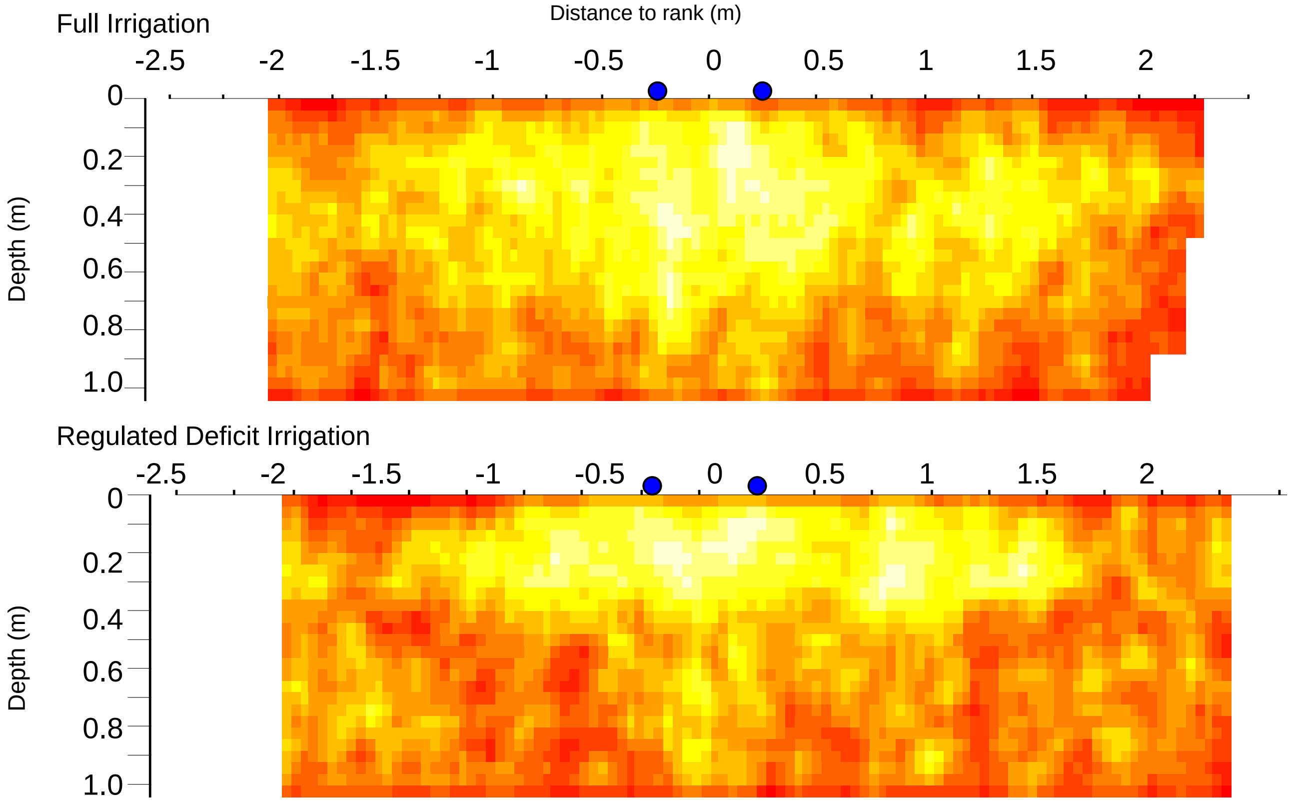


Figure 7 : Map of the root impact on 4 trench wall, for the irrigation control and the regulated deficit treatment. Dipper locations are indicated as the blue circle. White colour indicates the highest root contact number, whereas red indicate no root contact in the square (INRA).

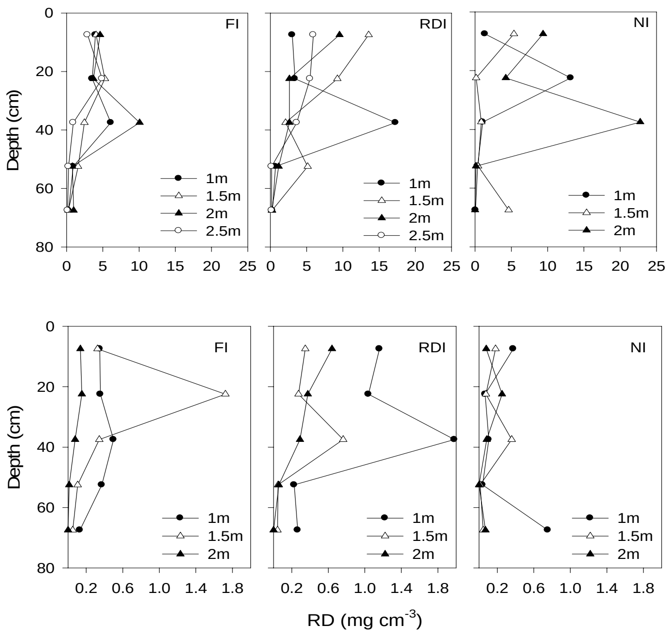


Figure 8 : Root density (RD, mg cm^{-3}) distribution along the drip line (up) and perpendicular to the drip line (down), under different irrigation regimes, at the end of the 2007 growing season (almond orchard, UPCT).

1.4. Soil water content

Temporal and spatial variations

For the INRA orchard, the water balance was calculated with a distributed approach, distinguishing surface of wet, irrigated zone and dry, non-irrigated zone. The observation of soil surface and results of water content give a radius of about 45, 25, 15 cm for the wet bulb around drippers for FI, RDI and WDI zones respectively. Mean water contents of the different irrigation treatments are shown Figure 9. A clear difference is attained between irrigation treatments in both 2007 and 2008 years, with more or less constant water in FI and decrease in RDI, WDI. However, initial water content, before irrigation, was much less in 2008, particularly in the WDI zone. Autumn and winter rainfall 2007/2008 couldn't refill the soil in the most water deficit zones, as well as the spring rainfalls. This lead to different dynamic of water for WDI: a slow, regular decrease in 2007 during ~3 months (ie around mid-September) to reach limiting soil water content, while the same limiting water content is reached in ~1month (ie beginning of July) in 2008.

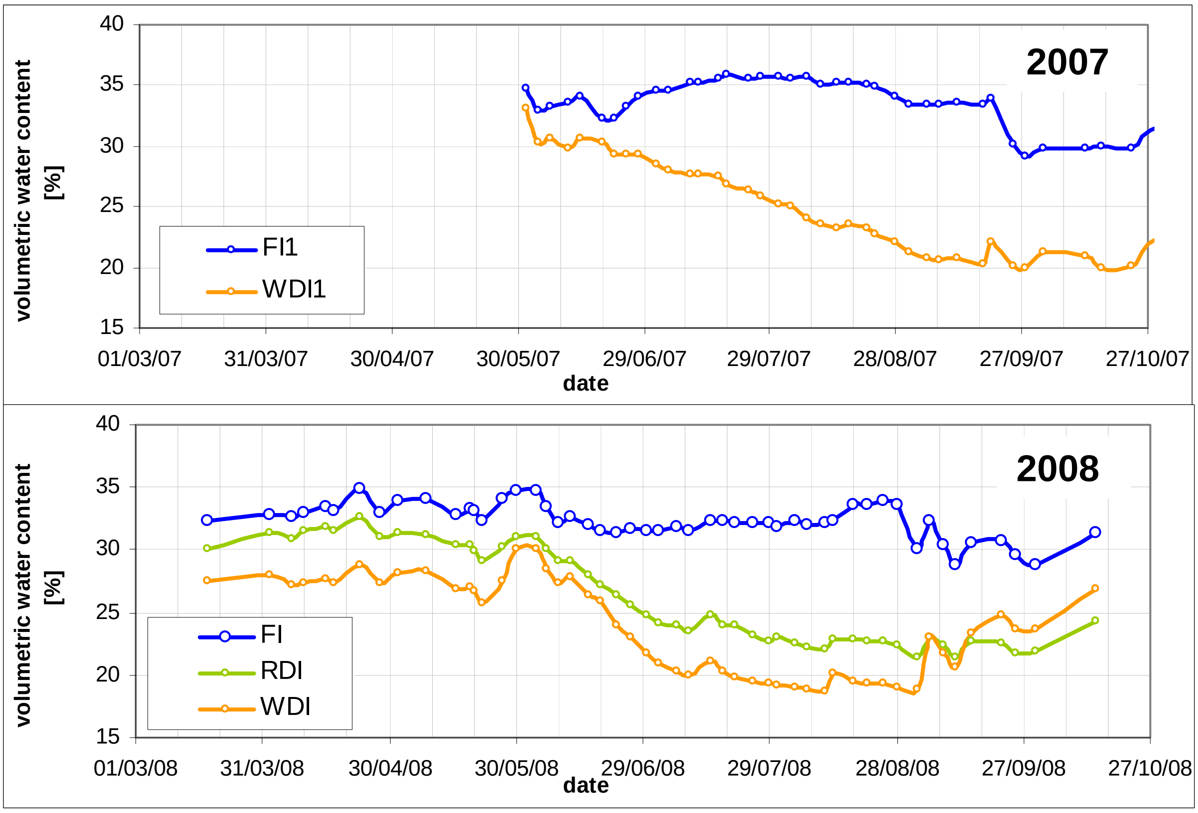


Figure 9 : Mean water content variation, including irrigated and non-irrigated zones, with time for the 2007 and 2008 experimental seasons. Peach tree orchard in Avignon, France. FI : Fully Irrigated treatment, RDI : Regulated Deficit Irrigation, WDI : Water Deficit Irrigation.

In the following, we use a distributed water balance in which an irrigated soil volume around the drippers is distinguished from an unaffected soil volume in order to highlight contribution of the wet, irrigated, bulb and non irrigated soil zone to total evapotranspiration. Indeed, large variation in the soil water content was observed in orchard, depending on the irrigation treatment. Large variations are associated with distance to dripper and to depth (Figure 10).

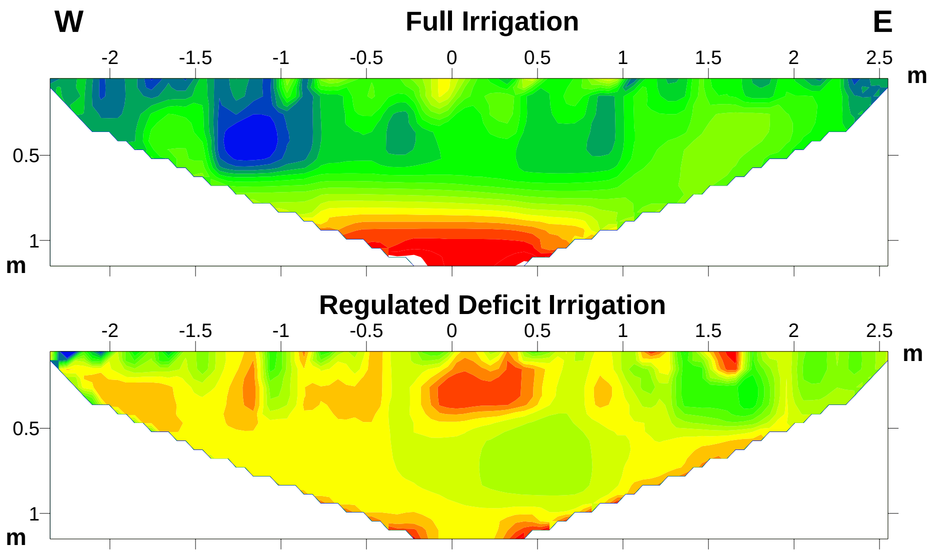


Figure 10 : Soil water content spatial distribution derived form ERT measurements in August 13, 2008. The tree is located at x=0 and drippers are located at x= +/- 0.5, 0.6 m.

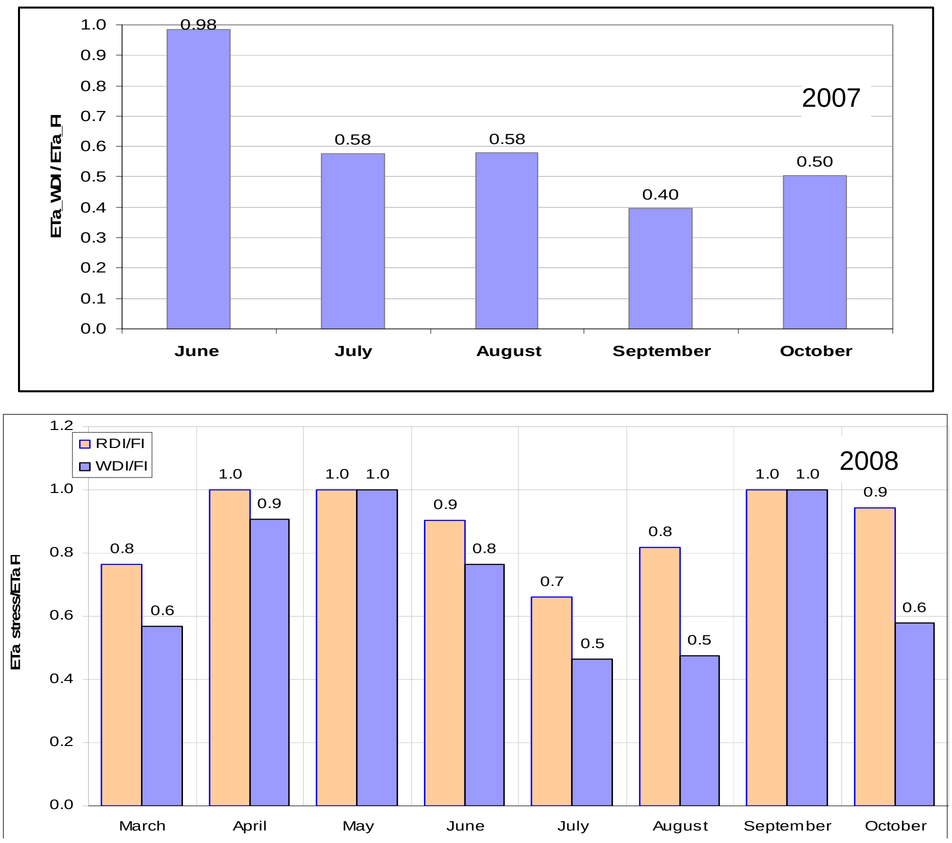


Figure 11 : Relative evapotranspiration (ratio of Eta of stressed zone to ETa of FI zone) as a function of time in 2007 and 2008 experiments. Peach orchard in Avignon, France. FI : Fully Irrigated treatment, RDI : Regulated Deficit Irrigation, WDI : Water Deficit Irrigation

Calculated actual evapotranspiration (ETa) for 2007 and 2008 shows some variations between years, even if irrigation strategies were the same. Decrease of ETa in WDI was already effective in spring 2008 (June) although rainfall were abundant in April and May, while in 2007 ETa of WDI zone was almost equal to that of FI zone. In the summer months, ETa of more stressed zones (WDI) decreased in 2007 and 2008, while RDI treatment could maintain greater ETa. Figure 11 shows the ratio of ETa of stressed zones (RDI and WDI) relative to FI treatment (Relative Evapotranspiration: ETr). In 2008, the efficiency of RDI treatment (for ETr) is clearly visible, compared to WDI. Irrigation water in RDI was about 56% of FI, with an ETr of ~0.8 from June to August. For WDI treatment, irrigation water was about 23% of FI, while ETr reached ~0.6 as a mean from June to August.

From Figure 11, a high reactivity to rain is also noticeable with an increase of ETr in April, May and September 2008 for example, but with rapid decrease thereafter for WDI (June, October 2008), but not for RDI. Finally, a main point to note is that, even in the WDI treatment, ETr hardly fall below 0.5 in 2007 and 2008 while irrigation was about 30-35% of FI zone. This clearly shows that in Avignon's pedo-climatic conditions, transpired water is derived both from stored soil water and irrigation water.

Water uptake by the plant root system

Figure 12 shows the proportion of water originating from the wet, irrigated, bulb and from the dry, non irrigated soil zone to total evapotranspiration estimated from distributed water balance modelling. In 2007, most of the water in FI treatment came from the wetted zone (80-95%), denoting a higher active root density in this zone. In 2008, contribution of wetted zone was more variable (for FI) in relation with rains, except in the summer where it reached 80-90%. In the stressed zones (RDI, WDI), uptake switched in June mainly from stored soil water to wetted soil zone in both 2007 and 2008, but with different temporal patterns. At the end of summer/autumn, the uptake profiles were very different in 2007 and 2008 for all irrigation zones because of the high amount of rain in September 2008. In 2008, the difference between RDI and WDI treatments was that uptake for RDI occurred mainly in the wetted zone and switched earlier and more actively in this zone than for WDI.

Electrical Resistivity Tomography (ERT) was used to map 2D soil water content profiles in 2007 and 2008. Images from ERT showed differences between irrigation treatments, the zones influenced by drippers, apparition of soil cracks (in WDI) and the high heterogeneity of water in soil (particularly in the stressed zones). A calibration of electrical resistivity with measured water content resulted in an estimation of soil water by ERT with an accuracy of ~0.05 cm^3/cm^3. This accuracy was sufficient to estimate water content variation and uptake at a monthly (2007) or seasonal (2008) time scale. Indeed, in 2008, water content was less variable than in 2007, particularly in FI and WDI treatments. In particular WDI zone was much drier than in 2007, as stressed earlier and confirmed by ERT results. Water content and its spatial variations, linked with tree uptake and irrigation, can be exemplified with 2008 data reported (Figure 13). This figure shows the difference in water content between end of June and end of August (i.e. variations during the summer months). This figure shows that variations were greater in the FI zone.

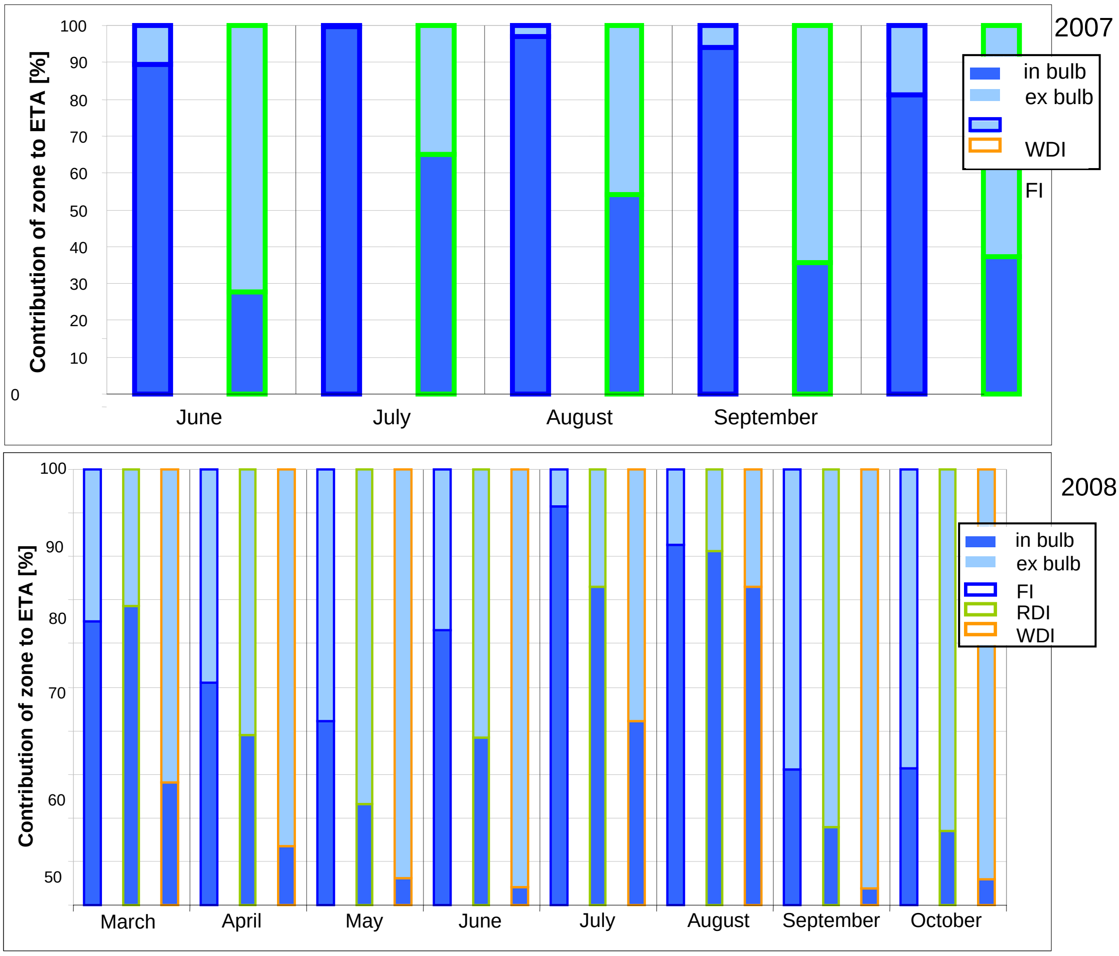


Figure 12 : Estimated proportion of evapo-transpired water coming from the stored soil water in the non irrigated, dry, soil zone or from the wet, drip-irrigated, soil bulb. Peach orchard in Avignon, France. FI : Fully Irrigated treatment, RDI : Regulated Deficit Irrigation, WDI : Water Deficit Irrigation.

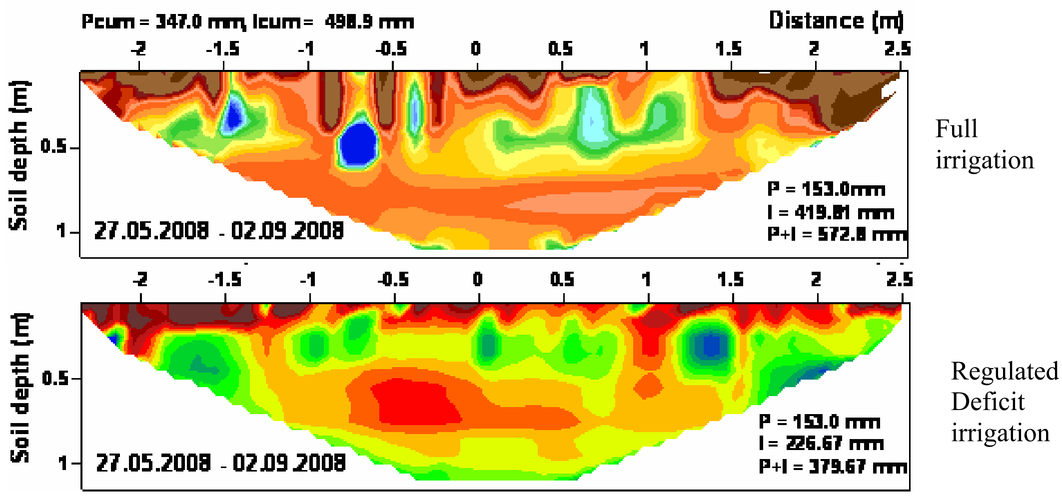


Figure 13 : Vertical maps of differences in soil water content, derived from ERT images, delineating zones of water uptake between end of June and end of August 2008 in FI, RDI, WDI irrigation zones (FI : Fully Irrigated treatment, RDI : Regulated Deficit Irrigation, WDI : Water Deficit Irrigation).

The most important feature is that variations (and so uptake) occur at soil surface (and irrigated zones) but also at depth. The uptake being more and more concentrated below the tree from FI to RDI and WDI, showing the significance of uptake outside the wetted, irrigated soil zones.

1.5. Modelling Soil water transfer and uptake

Soil water models could be extremely valuable in the design of drip irrigation systems (optimal design). These models also represent a fast and inexpensive approach to study and valuate irrigation practices (BIMP), through an analysis of the detailed spatio-temporal distribution of water. Relatively little information is available on the spatial distribution of soil water under drip irrigation, and how it is affected by root distribution, emitter placement and irrigation amounts. A better understanding of the soil water regime in general and specifically the spatial and temporal changes in soil water content as controlled by root water uptake and leaching, will provide alternative means for proper and efficient drip irrigation water management practices.

Two approaches have been conjointly developed by the 2 partners. Firstly, an already available soil water model using analytic resolution of the soil water transfer, solving the Richards' equation over the whole soil volume (HYDRUS 2-D), was used in order to simulate the moisture distribution and its dynamics under drip irrigation (UPCT partner). A specific soil water model was developed (INRA partners) dividing the soil volume in different compartments, with different properties regarding the soil water availability and the root density.

The Hydrus-2D model

HYDRUS-2D is a computer program that simulates two-dimensional soil moisture dynamics (Simunek et al. 1999). The model is based on solving the Richards' equation numerically using finite element scheme. The hydraulic parameters were estimated using van Genuchten (1980) constitutive relationships, based on the soil physical properties. The boundary conditions were specified as a no-flow boundary conditions, i.e. Neumann type boundary conditions, at the left ($r = 0$) and at the right ($r = R$). The lower boundary ($z = Z$) can be defined as Dirichlet type boundary condition. During the irrigation, the upper boundary ($z = 0$) condition changed from prescribed flux to prescribed pressure head type condition. After the irrigation, the upper boundary that involves soil–air interfaces was atmospheric boundary condition. The atmospheric condition was taken into account on an hourly basis. Crop water demand ETc was calculated by multiplying the ETref, the daily reference evapotranspiration calculated with the Pennman-Monteith (Allen et al., 1998), by the coefficient Kc.

The root water uptake is represented using a sink term, $S(h, r, z)$, which represents the volume of water removed per unit time from a unit volume of soil due to plant water uptake. Root water uptake is affected by soil matrix near root system, thus the model of two-dimensional root water uptake could be described as the following equation (Vogel 1987; Simunek et al. 1999) :

$$S(h,r,z) = a(h,r,z)\ S_p(h,r,z)$$

where S_p is the potential water uptake rate, and a(h, r, z) is a water stress response function (Feddes *et a*l. 1978). Various two- and three-dimensional root distribution functions are implemented into HYDRUS (Vrugt et al., 2001). The Root Water Uptake Parameters for the water stress response function suggested by *Feddes et al.* [1978].

From the simulation (Figure 14), it can be seen that:

- the model reproduces correctly the dynamics of changes in soil humidity in the first three layers, as well as the magnitude
- In the deeper layers, the performance of the model is less satisfactory. Causes could be errors in measurements (sensor accuracy is of the order of magnitude of the changes in soil moisture) and/or to changes in soil parameters.

The sensitivity analysis showed that, besides root distribution, the model is especially sensitive to the values of the hydraulic conductivity (soil property) and surface wetted diameter (dripper characteristic). Special care should be taken in choosing realistic values of these two parameters when using Hydrus 2-D for purpose of irrigation design or scheduling.

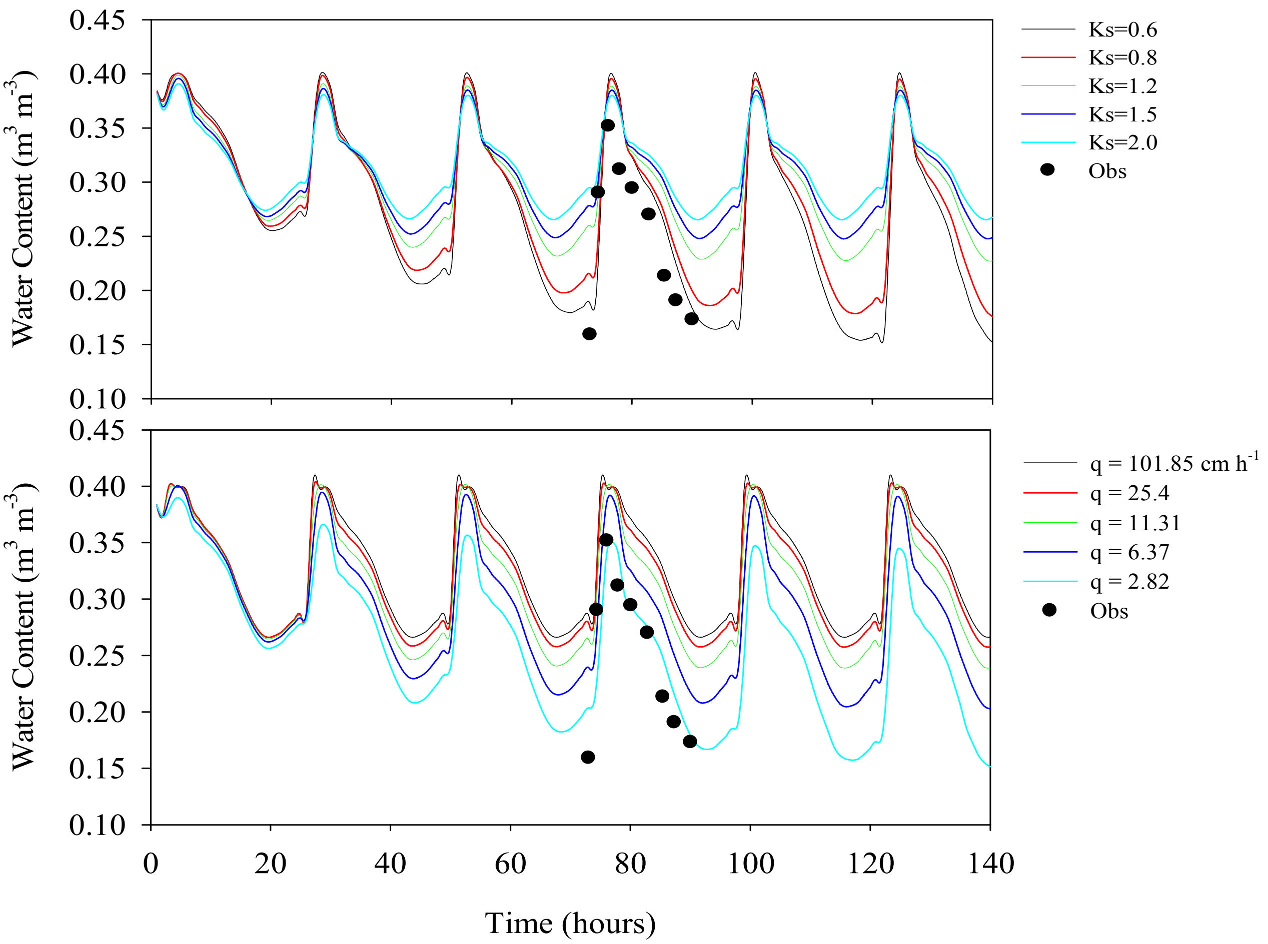


Figure 14 : Sensitivity of the model to K_s (A) and Dw (B) in the 0-10 cm layer.

The INRA-developed model

Based on the experimental evidences, the modelling shall be able to manage coupled uptake of a tree in the wet, irrigated zone, as well as in the dry, non irrigated zone. Figure 15 shows the modelling scheme. Only the main features of the model are briefly recalled here.

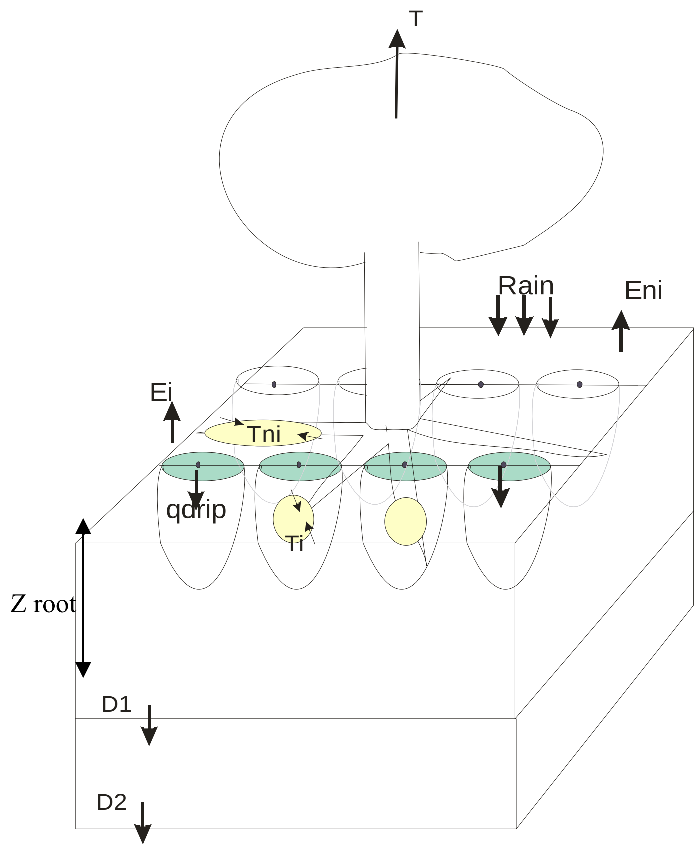


Figure 15 : Conceptual model of irrigated orchard. Soil is divided in 3 zones : wetted zone due to irrigation, rooted irrigated zone (up to Zroot), unrooted non-irrigated zone. Each zone is characterized by a "mean" water content, water potential and root density. Fluxes are (ni= non-irrigated, i=irrigated): Transpiration T, Rain, Evaporation E, Drainage D for each zone.

Root water uptake in the contrasted irrigated/non-irrigated soil zones, with a balancing of the uptake between zones, is determined from water availability in the two soil zones. This is achieved with an estimation of the water potential in the soil and in the plant, which drives the direction and magnitude of water fluxes. Tree root collar water potential is supposed to be known, and is to be coupled with aerial part functioning. The topography is here assumed to be flat with negligible runoff. Calculation of the water balance in the non-irrigated zone relies upon a classical reservoir approach, considering surface or volumetric water fluxes such as rain, evaporation, water uptake, drainage (with the field capacity concept) and a rough water dynamic inside the soil. On contrary, in the irrigated, wetted zone, soil water transfer due to cyclic, time varying irrigation is calculated with an analytical solution of the linearized soil water flow equation.

Evaporation and root uptake fluxes are added to the flow equation via a localised mass-balance approach to get the water balance of the irrigated zone.

The model has been applied to synthetic examples (i.e. Full irrigation or Deficit irrigation, variation in root length density between dry and irrigated zones…) and shows a good qualitative and quantitative behaviour, enabling estimation of the contribution to transpiration of the different soil volume (cf. Figure 16 for example).

For integrating this soil uptake modelling into plant (tree) model, the model has been recoded in Fortran 95. Soil hydrodynamic properties have been made more flexible in order to describe a broader range of soils. To be really effective, the "soil" submodel shall now be included into the tree model (coupling for water and carbon and resulting yield).

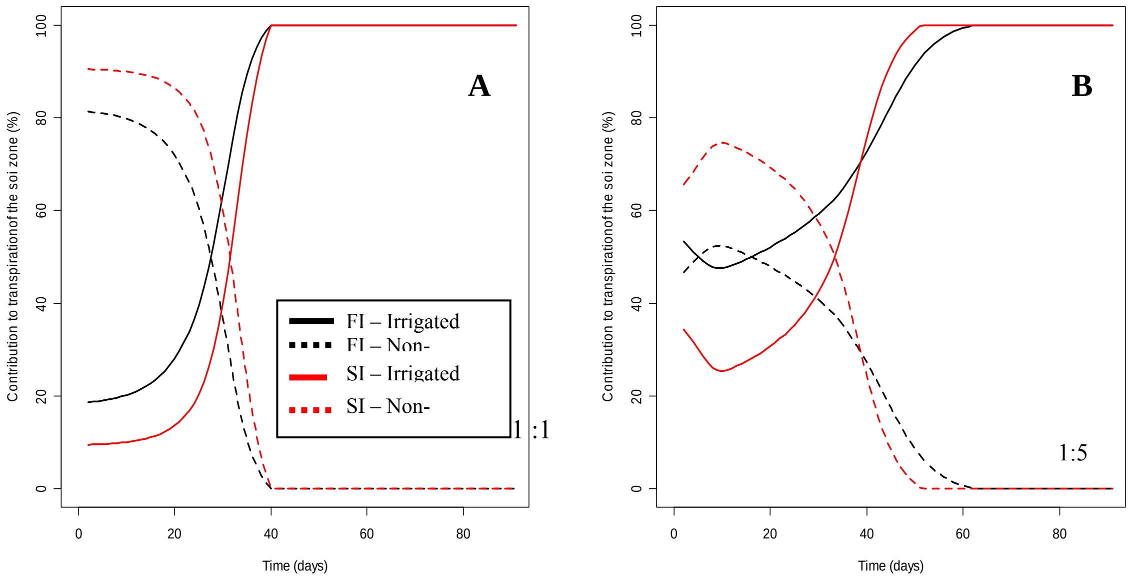


Figure 16 : Example of Soil-Uptake model results: Variation of the contribution to water uptake of the irrigated and non irrigated soil zones with time for: A) a same rooting density in the two soil zones (1:1) and B) a rooting density 5 times greater in the irrigated zone compared to non-irrigated zone.(1:5). Graphs for a Fully Irrigated (FI) and Stress Irrigated (SI) treatments.

1.6. Towards new monitoring of plant parameters

In this topic, we sought for new ways of monitoring plant's parameters linked to water status or uptake that could possibly be used for monitoring / irrigation purposes. The main focus was on the use of electrical resistivity of soil or plant: Stem electrical resistivity for stem water potential determination and the test of an electrical method for estimation of mean root length and absorbing surface area.

Electrical resistivity and plant water potential

In order to get indicator of plant water stress for irrigation monitoring, the potentialities of stem electrical resistivity for estimating plant water potential was investigated. Indeed, time variations of plant water potential (amplitude and rate of decrease/increase) are indicative of the water stress level and of the soil water availability to plants. Measurements of plant water potential are, however, tedious and not easily practicable at the farm level. Measurement of plant stem electrical resistivity is easier can be logged and recorded and numerically processed. As past studies showed some possible relationship between stem resistance and water potential, we tried to look if such relationship exists for in situ measurements and contrasted irrigation conditions. Figure 17 shows some results obtained in 2009 for contrasted irrigation conditions. This figure clearly shows a more or less linear dependence of stem water potential on resistivity. However, 2008 and 2009 results show a strong influence of temperature that needs a detailed correction. Moreover, the relationship seems to vary between days and stems. The variations between days can be corrected by a normalization of the amplitude of variation of resistivity of that day. Nevertheless, a calibration between resistivity and stem water potential is still needed. Such relationship shall be further investigated, as stem water potential is a direct indicator of plant water status.

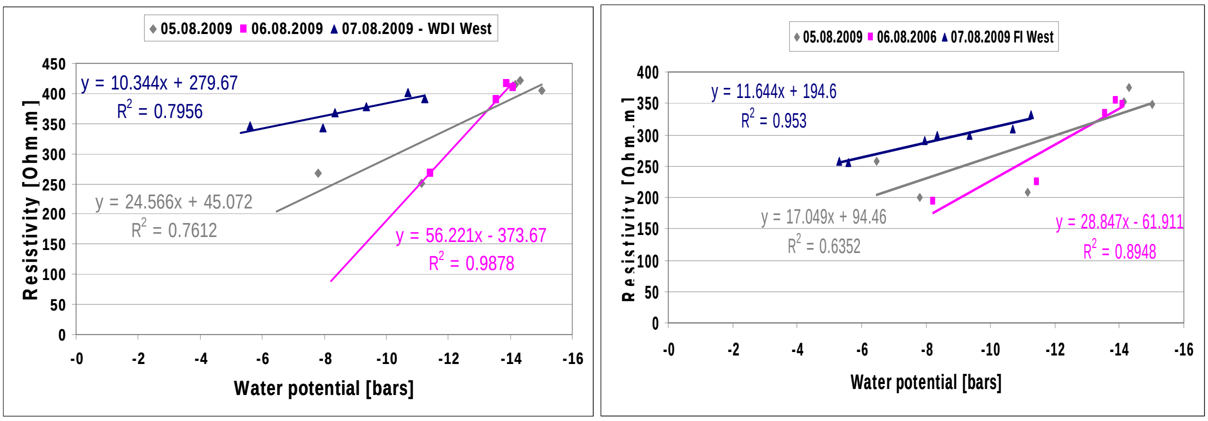


Figure 17 : Relationship between stem electrical resistivity and stem water potential of west oriented stems at different dates of a peach tree located in the Water Deficit and Full Irrigated zone (FI).

Electrical method and root colonization

A method described by Aubrecht et al. (2006) and Cermak et al. (2006), consisting in an injection of electrical current between the tree and the soil with current electrodes placed some distance away from the tree was tested in 2009). The leakage of current from the roots trough soil results in a variation of voltage drop as a function of distance of the tree. Aubrecht et al. (2006) proposed to interpret such variation in terms of "mean" lateral root extension and absorbing surface. However, more or less young, little suberized root surface would be more precise.

Results for trees of the Peach orchard in Avignon are reported in table 1. The absorbing surface area (~0.6 m²/tree) is low, and not significantly different between FI and RDI treatments. These results are consistent with an allometric relationship with trunk diameter derived by Cermak et al. (2006). The estimated mean lateral root extension seems fairly small (~0.6 m) and different from the one derived from water balance estimations (~1.5 m).

Trenches were dug in the field in order to identify deployment of the roots horizontally and vertically. Root impacts on the walls of the trench were recorded to obtain root maps. Results show that about 25% of roots were located at a distance lower than 0.6 m from tree, i.e. far less than a "mean" lateral extension determined by the electrical method. This can be related to the fact that either, in proportion, more young , little suberized, roots are located inside a 0.6 m radius from tree trunk or electrical data are misleading (because of over-estimation of conduction of current in the roots and soil).

Table 1 : Results of electrical measurements for determining mean lateral root extension and absorbing surface area. Results for trees in the Fully Irrgated zone (FI) and in the Regulated Deficit Irrigation zone (RDI).

Zone	*Lroot mean (m)*	*Absorbing surface (m²)*	*Surface from Cermak regression (m²)*
FI	0.58±0.07	0.66	1.02
RDI	0.58±0.07	0.52	0.62

Due to the general poor knowledge of the root system in soil, a more thorough estimation of such a simple method would be worth to carry in different setting with more less soil heterogeneity and root development.

CONCLUSIONS:

The experimental data collected in the 2 sites (UPCT and INRA) are consistent and emphasis the large variation in the soil water content, both during the season and spatially within the soil volume. Large differences aroused especially in the row and between the row with a dry zone and a wet zone associated with the bulb, which is more or less pronounced depending on the irrigation treatments.

Root growth dynamic was highly linked both to above-ground development and soil water content and soil properties. Above and below-ground growth was asynchronous. Carbohydrate supply for roots depended on priorities of allocation within the plants as well as within the root system. Root distribution was higher in wettest soil due to localized irrigation and in lowest soil density. Also the vertical distribution of water soil influenced roots colonization.

The soil water transfer and plant uptake have been modeled using 2 approaches. These modeling frameworks allow a better description of the high spatial and temporal variability of the soil water content, depending on the irrigation strategy. Furthermore, such model allows connecting the root colonization expressed as spatially distributed root density with the soil water content in order to estimate the plant water uptake and get insight of the contribution of the different soil volume (bulb/dry zone …) to the transpiration stream. Further work is still needed to link the soil water model developed to the tree crop model.

WP 6.1: CROP QUALITY MODEL

OBJECTIVES: Orchard management is facing new challenges, instigating new research and fruit production strategies, especially when dealing with durable development and global climate change. An important task is to design a simulation model of the fruit yield and edible quality, under the influence of climate and crop management. Several quality traits are of great importance dealing with a profile of edible quality : dry and fresh fruit mass, concentration of sugars in the flesh, sweetness note… Moreover, the variability of quality criteria is a key issue of fruit crop models, since determining the grower's benefit. It is very high at the tree level for peach. Accordingly, a model at the tree level, emphasizing the within-tree variation and state variables accounting for the effect of technical operations (number of fruits and shoots on the shoots-bearing-fruits, depending on fruit thinning, etc.), has been developed, predicting the main fruit quality and safety. Main objectives were to include the effects of water stress induced by a given irrigation strategy into available crop models. The model requires improvements dealing with (i) photosynthesis and transpiration in link with the plant water status, (ii) radiation interception, (iii) parameters estimation and (iv) disease occurrence, in connexion with irrigation regimes.

CONTRACTORS: Two main contributors were associated for this work-package : INRA (French National Institute for Agricultural Research) with the PSH lab (Horticultural Plants and Culture Systems) located in Avignon, South-east of France, and UPCT (Universidad Politécnica de Cartagena) located in the South-east of Spain.

MATERIALS AND METHODS:

1.1. UPCT experiments

The experiment was carried out on drip irrigated potted-almond trees (cv Marta) (*Prunus* dulcis) placed in a open sky pot orchard. Two irrigation treatments were established: (i) full irrigated treatment (control), watered to satisfy maximum crop water requirements; (ii) deficit irrigated treatment (DI), which received half of the maximum crop water needs. One tree per treatment was placed on an automatic balance (Scaltec Mod. SSH91), which continuously recorded pot weight. Pot soil surface was covered with polyethylene black film to avoid evaporative water losses. Moreover, these two pots on balance were placed into a tank in order to control possible drainage losses. A standard automatic weather station was installed into the pots orchard. A net radiometer was installed above the tree crown to assess the energy balance at the tree scale. Total leaf area of the pots on the balance was measured by defoliating the trees at the end of the experiment. As the trial was carried out during the summer we assumed that vegetative growth process was completed for this date, and considered that the final value was representative of the summer period.

In an almond orchard, the amount of photosynthetic active radiation, PAR, absorbed by a single almond tree was measured at different tree heights during sunny days, at three weeks interval during the growth season, using a ceptometer (linear PAR quantum meter, Delta-T Devices). Leaf area was estimated through the whole season with a plant canopy analyzer (PCA, LAI 2000, Li-Cor®).

1.2. INRA experiments

The data used to estimate the parameters and test the model come from several experiments on vegetative and reproductive growth performed in two locations. These experiments concerned two cultivars of *Prunus persica*, namely, an early-maturing (Alexandra) and a late-maturing cultivar (Suncrest). Routine horticultural care for commercial fruit production was provided, including fertilisation, irrigation, pest control and pruning in the dormant-season and in summer. Diameters, lengths of the axes, insertion and phyllotaxic angles were measured in order to obtain a description of the tree architecture which is a model input. For both cultivars, the diameters of all fruits were measured every 3-5 days. Fruit diameter (mm) was converted to dry mass (g) using allometric relationships for both cultivars (Ben Mimoun et al., 1996). Leafy shoot length (m) was also measured for each FU four times during fruit growth in Alexandra, and once near fruit harvest in Suncrest. Lengths were converted to dry mass (g) following Walcroft et al. (2004).

Furthermore, the model was tested with two Alexandra trees grown in containers. Experiments were performed in 2003 on trees grafted on GF 677 rootstock planted in 1999 and cultivated outdoors in 110 L containers (n = 20). Trees were goblet-trained and received routine horticultural care including winter pruning, daily drip irrigation, and pest control (Gibert et al., 2005). Trees were thinned at 40 fruits per tree. Data on tree architecture and fruit and leafy shoot growth were recorded as previously.

Climatic data sets (global radiation and temperature) collected at INRA weather stations located close to the experimental fields were used as model inputs.

RESULTS ACHIEVEMENT:

1.3. Photosynthesis and transpiration estimation

Photosynthesis : from the leaf to the shoot scale

A method for upscaling photosynthetic capacity from leaf to shoot is presented and validated. The upscaling scheme, based on the concept of a reduction factor, was coupled to the light interception model (cf infra) and used to predict the whole tree photosynthesis model. The description of the water stress effects on C-acquisition, at the fruit-bearing shoot scale, was carried out using the concept of reduction factors. From the maximum leaf photosynthetic capacity of unstressed leaves (at light saturation), two empirical *reduction factors* were derived:

1. one scaling-up from the leaf to the shoot scale in the case of non-limiting water supply (f_{SC}) , accounting for the mutual over-shading of the leaves and their structural and morphologic changes (specific leaf weight, insertion angle, rolling, etc.),

2. one characterizing the effects of water stress at the shoot scale, through a physiologically-based parameter, called 'water stress' factor (f_{WS}).

Therefore the mean leaves photosynthetic capacity is computed as:

$$A_{sm} = f_{sc} \times f_{ws} \times A_{lm} = f_G \times A_{lm,o}$$

In this model, A_{sm} represent the asymptotic values of shoot net photosynthesis at saturating PAR under non-limiting and limiting water supply conditions, respectively. Leaf and shoot net photosynthesis data are available from the WP2 (*Seasonal Characterization of Shoot Gas Exchange of Almond Trees under Deficit Irrigation*). The data were processed in order to derive the values of f_{sc}, f_{ws} and f_G for each measurement date.

The seasonal trend of the scaling factor f_{sc} (Figure 18) was characterized by maximum values at the beginning (f_{sc} = 0.25) and the end (f_{sc} = 0.29) of the growing season, and a relatively constant and low value (f_{sc} = 0.20) during the stage IV (kernel-filling). As above mentioned, the time evolution of f_{sc} throughout the growing season is likely to be ascribed to leaf and shoot structural and morphological changes, linked with the climate as well as with the development (leaf emergence and ageing) and growth of the shoot.

Clearly, the trend of the scaling factor f_{ws} was associated with the stress intensity throughout the season. However, these responses were significantly more damped at the shoot scale than at the leaf scale. This behavior could be ascribed to an acclimation process of almond tree to sustained deficit irrigation, which is directly related to the tree ability to maintain a high photosynthetic capacity under conditions of mild to severe water stress (Fereres *et al.*, 1981; Castel and Fereres, 1982; Torrecillas *et al.*, 1988).

Relationship between f_G and some plant indicators

The analysis of the relationships and correlation level between f_G and some plant stress indicators, such as trunk maximum daily shrinkage (MDS), trunk diameter growth rate (TDG) and midday stem water potential (Ψ_m), indicated a tight correlation between f_G and each of these indicators (Figure 19). The following linear regressions were obtained:

f_G = 0.143 exp(136.87/(MaximumDailyShrinkage[µm] +15.01)) $R^2 = 0.79$, $P < 0.001$

f_G = 0.178 + 0.005 TrunkDiameterGrowth[µm.d^{-1}] $R^2 = 0.65$, $P < 0.001$

f_G = 0.264 + 0.044 Ψ_{stem}[MPa] $R^2 = 0.65$, $P < 0.001$

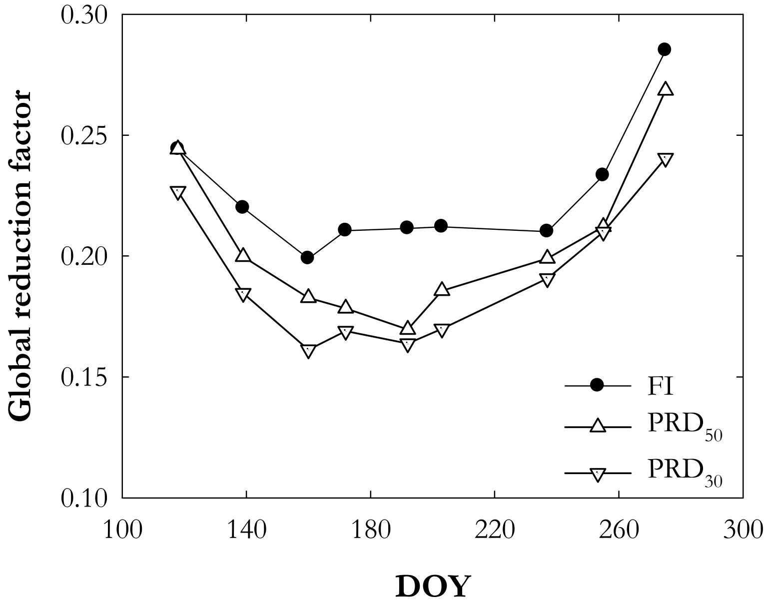


Figure 18 : Seasonal trend of the global reduction factor (f_G) corresponding to the irrigation treatments FI, PRD_{50} and PRD_{30}.

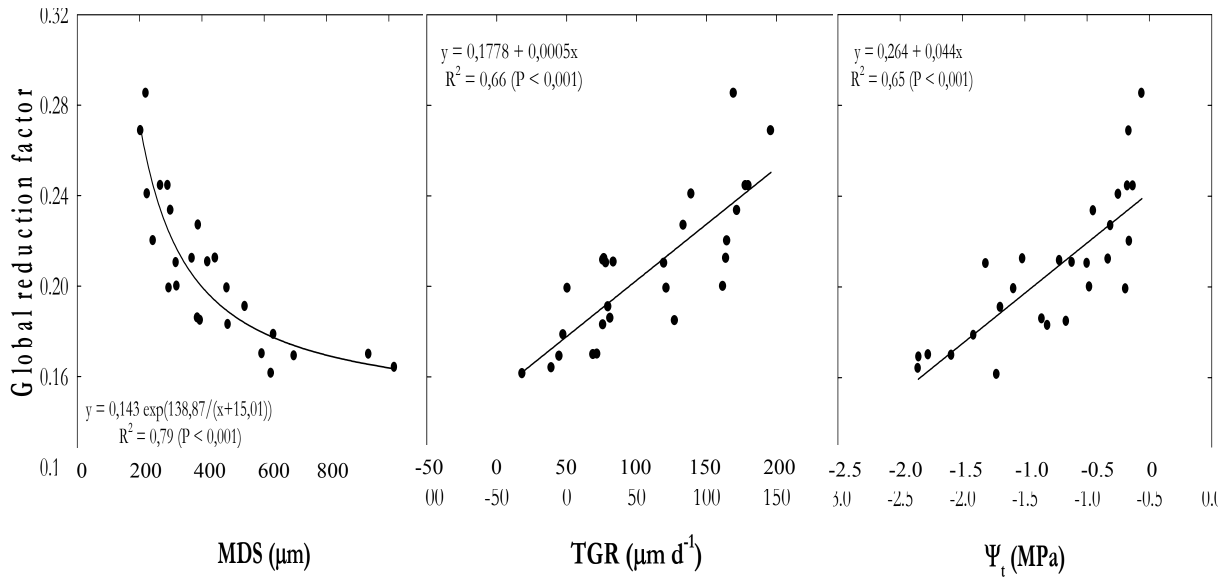


Figure 19 : Relationship between the global reduction factor (f_G) and the maximum daily shrinkage of the trunk (MDS), daily trunk diameter growth rate (TGR), and the midday stem water potential (Ψ_m). Pooled data of the irrigation treatments FI, PRD_{50} and PRD_{30}

Any of the three relationships can be used to estimate f_G at any time in the curse of the season. If the average time trend of $A_{lm,o}$ is available, the maximum shoot net photosynthetic rate can be derived and included in the shoot photosynthesis model. Of the three plant indicators, trunk diameter measurements (MDS and TGR) offer the advantage over stem water potential of providing continuous recordings and easier monitoring. The tight relationship found between f_G and plant water stress indicators such as MDS, TDG and Ψ_m represents a key result in what refers to the assessment and quantification of water stress effects on almond tree photosynthesis. In this aspect, field monitoring of plant water status indicators could therefore provide the required input to a tree model aiming at evaluating the effects of a deficit irrigation strategy on the seasonal pattern of tree photosynthesis. Overall, the results represent an important step towards the elaboration of a management model at the tree scale, including the effects of RDI strategies.

Transpiration and water availability

In order to undertake an integration of the soil water uptake model developed (WP5) with the virtual tree model, and furthermore to take into account the variation of the water availability within the crown, it is necessary to estimate the actual tree transpiration and the stem water potential distribution within the canopy.

An energy balance at the fruit bearing shoot (FBS) level was modelled using the Penman-Monteith equation (see Dauzat et al., 2001) :

$$\lambda E_{n,tree} = \frac{\Delta R_{n,tree} + \rho C_p D / r_b}{\Delta + \gamma(1 + \bar{r}_c / r_b)} \quad \text{(Eqn. 1)}$$

where $E_{n,tree}$ = the tree transpiration rate per unit of leaf area, $\bar{r}_c$ = the equivalent stomatal resistance of the tree canopy (s m^{-1}), $R_{n,tree}$ = the net radiation absorbed by the tree per unit of leaf area, ρ = the air density (kg m^3), C_p = the specific heat capacity (J kg^{-1} K^{-1}) of air at constant pressure, λ = the latent heat of evaporation of water (J g^{-1}), γ = the psychrometric constant (kPa^{-1}), Δ = the slope of the saturation vapour pressure curve at ambient air temperature, D = the saturation vapour pressure deficit of the air (kPa) and r_b= the leaf boundary layer resistance (s m^{-1}).

Leaf boundary resistance was calculated from an empirical equation derived by Landsberg and Powell (1973), which accounts for the mutual sheltering of clustered leaves as:

$$r_b = 58 p^{0.56} (d / u)^{0.5} \quad \text{(Eqn. 2)}$$

where *d* is a characteristic leaf dimension (m), assumed equal to leaf area square root for almond leaves, u is the mean wind speed across the leaf surface, and p is a measure of foliage density to wind given by the ratio of total plant leaf area of the foliage projected onto a vertical plane.

The submodel of light interception already implemented in QualiTree is used to estimate the net radiation absorbed by the FBS. This developed light interception sub-model was initially developed for radiation in the PAR wavelength. It has been extended to take into account long wave radiation. Using specific parameters dealing with transmission and scattering, the thermal infrared radiation is calculated along with the photosynthetically active radiation (PAR) for each FBS.

$E_{n,tree}$ was determined at a hourly basis from weight data given by the balances The equivalent stomatal conductance of the tree (g_c) can therefore be calculated by inverting the P-M equation and rearranging Eqn. 1:

$$g_c = 1 / \left\{ \left[\frac{\Delta}{0.93\gamma} \left(\frac{R_{n,tree}}{\lambda E_{n,tree}} - 1 \right) - 2 \right] r_b + \frac{\rho C_p D}{\lambda E_{n,tree} \gamma} \right\} \qquad \text{(Eqn. 3)}$$

According to Jarvis (1976) and Zhang et al. (1997), stomatal conductance is a function of incident solar radiation (G), vapour pressure deficit (D), air temperature (T), leaf water potential (Ψ_l), soil water content and ambient CO_2 concentration. Jarvis (1976) describes the relationship between g_c and these variables in a phenomenological model, where the maximum stomatal conductance is reduced by stress functions which were all assumed to act independently. Ignoring the effects of leaf water potential, ambient CO_2 concentration and temperature (as they did not improve the model fit for almond trees), the model can be written as:

$$g_{c,J} = g_{c,max} f(G) f(D_s) f(SWP) \qquad \text{(Eqn. 4)}$$

where $g_{c,J}$ is the stomatal conductance to water vapour, $g_{c,max}$ is the maximum stomatal conductance (mm s^{-1}), f(G), f(D_s) and f(SWP) are functions of solar radiation, vapour pressure deficit at the leaf surface and soil water potential, respectively.

This model requires an estimation of leaf temperature to determine D_s. At this aim, the temperature difference between the tree canopy and the atmosphere was estimated under the assumptions of negligible heat storage and soil heat flux (Jones 1992):

$$(T_s - T_r) = \frac{R_n - \lambda E}{\rho_a c_p g_a} \qquad \text{(Eqn. 5)}$$

The f functions used in the model (Eqn. 8) were:

$$f(G) = 1 - \exp\left(\frac{-G}{a} \right); \; f(D_s) = \left(\frac{1 - bD_s}{1 + cD_s} \right); \quad f(SWP) = \left(1 + \left(\frac{SWP}{d} \right)^e \right)^{-1}$$

(Eqns. 6a, b and c, respectively)

Values of $g_{c,max}$ and those of the parameters (a, b, d, d and e) were estimated by non-linear regressions using a statistical package (Statgraphics plus v. 5.1). Data from 15 days were used to parameterize the Jarvis model and 15 different days to validate both canopy conductance and transpiration models.

Table 1 gives the estimated values of the model parameters of the equivalent tree stomatal conductance (Eqn. 4 and Eqns. 6a-c).

Table 1 : Estimated parameters (±ED) in the multiplicative model of the equivalent tree stomatal conductance (Eqn. 4 and Eqns. 6a-c) for potted-almond trees under different irrigation regimes fitted to the selected 15-day data sets. Number of observations = 274. Determination coefficient, R^2= 0.87.

$g_{c,max}$ (mm s^{-1})	7.50±0.22
a (W m^{-2})	220.37±16.35
b	0.177±0.013
c	-0.132±0.024
d (kPa)	27.53±4.45
e	0.88±0.13

The values of g_c derived from the inversion of the Penman-Monteith equation (Eqn. 3) were closely related to those estimated from the multiplicative model of Jarvis (Eqn. 4 and Eqns. 6 a-c) (Figure 21). The comparison was made pooling the data obtained on potted tress subjected to different irrigation strategies (Figure 20). Although there was a relatively high scatter of the data, the slope of the relationship shown was near unity, indicating that the functions proposed in Eqns. 6 a-c are able to mimic the stomatal behaviour of well-irrigated trees and trees under restriction of water supply.

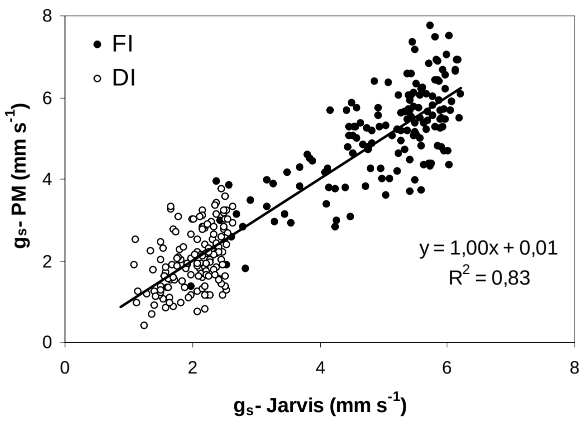


Figure 20 : Comparison between predicted tree canopy stomatal conductance to water vapor, g_s, derived from the Jarvis model, and g_s obtained by inversion of Penman-Monteith equation (from data of measured climate and of tree transpiration rate) under different irrigation regimes. A different data set of 15 days was used to validate the model.

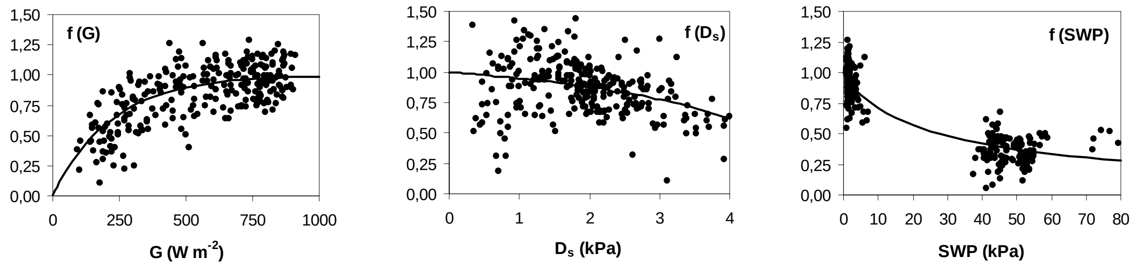


Figure 21 : Functions of the Jarvis multiplicative model for estimating stomatal conductance as dependent of global radiation (G), vapour pressure deficit at the leaf surface (D_s) and soil water potential (SWP).

When tree transpiration rate was estimated from Eqn (1), with the parameters values of g_c given in Table 1, data scatter was much lower (Figure 22) than that observed for g_c (Figure 20). Figure 22 shows that the model performs quite well for estimating tree transpiration rate under contrasting irrigation strategies.

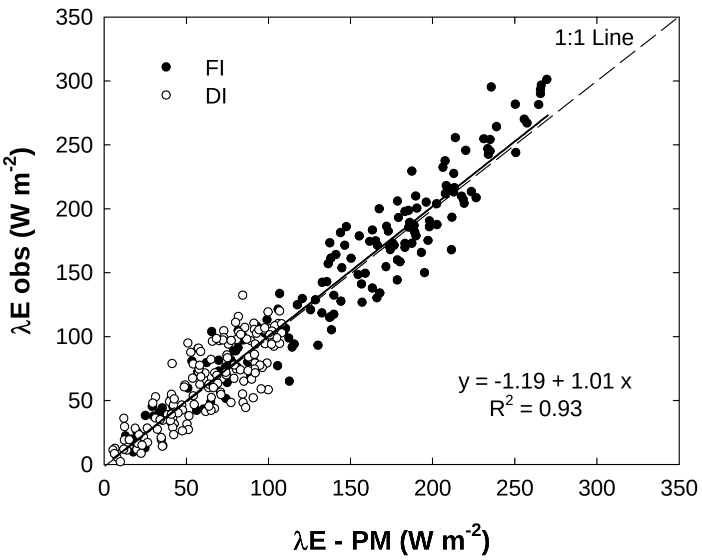


Figure 22 : Comparison between predicted tree transpiration rate, λE, derived from Penman-Monteith equation, PM (Eqn. 4, with the parameters values of gc given in Table 4) and λE measured under different irrigation regimes. A different data set to that used to parameterize the g_s model was used to validate this model at the tree scale.

1.4. QualiTree

This model, which was computerized using object technologies, considers various organs in the tree, with more or less detail according to the model's objectives. Three interconnected sub-models constitute the main frame :

- the carbon sub-model, allowing calculation of the carbohydrate (i) availability (photosynthesis, remobilisation and storage), (ii) demand for the maintenance and growth, (iii) exchange between the various compartments of the tree,

- the fruit water sub-model, derived from the biophysical model of Fishman and Génard (1998) and revised by Lescourret et al. (2001).

- the fruit sugar sub-model simulating the soluble carbohydrate transformation in the fruits (Génard et al., 2003).

According to several inputs (climatic series, initial state of the tree), the model simulates the change of state of the tree from fruit thinning to harvest. Model outputs are kinetics recorded in a database. They include various "intermediate" (*e.g.*, carbon requirements and supply of various organs) and "final" state variables (dry mass of organs, and for fruits, various quality traits: dry and fresh mass, part of dry mass in the flesh, concentration of sugars in the flesh).

Model development

Light interception

A simple model for light interception by an isolated tree was developed (UPCT), adapted from that published by Charles-Edwards and Thornley (1973) and Norman and Welles (1983). The most important assumptions are (i) that the leaves are uniformly distributed within a prescribed volume of space, (ii) that light traversing this volume is attenuated according to Beer's law, and (iii) that scattered light is neglected. The tree crown was initially assumed to occupy a volume that is bounded by the surfaces of a simple ellipsoid. This description has been modified in order to allow representation of more complex form. In peach orchard, the tree is often goblet-trained, ie the shoots growing in the centre of the crown are pruned in order to allow light penetration deeper in the vegetation. A second ellipsoid was therefore included, this ellipsoid being without leaves. Additional plan were also added, allowing cutting the vegetation at the bottom and top of the tree (Figure 23). Moreover, the tree is located in an orchard, and neighboring tree could impact the incident radiation (shade), following the orchard density. The orchard was characterized by specifying the row and in-between row spacing, as well as the row orientation relative to the north location.

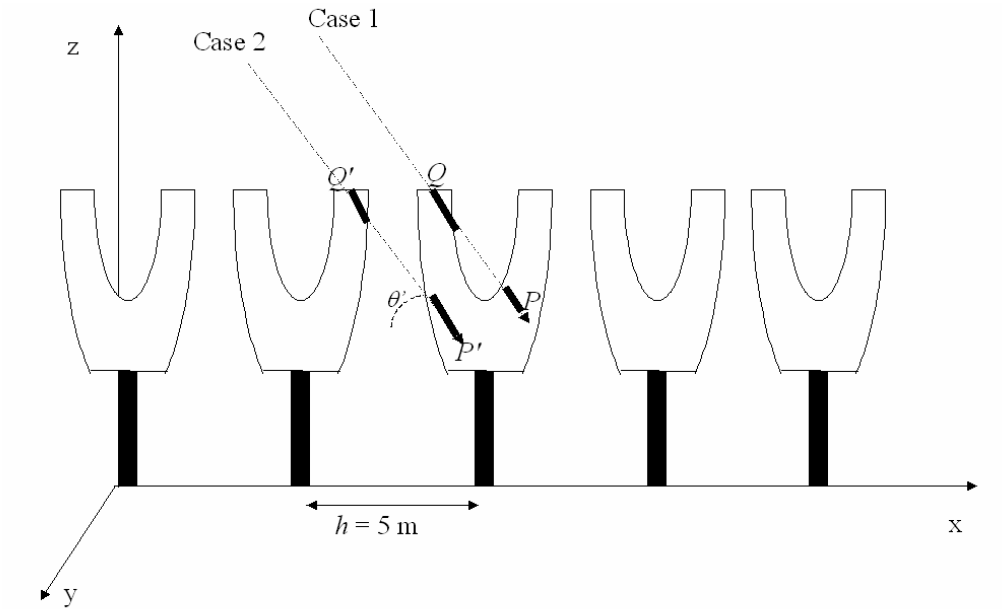


Figure 23 : Schematic diagram of the tree within the orchard and calculation of the path length through the vegetation. *h* is the row spacing, *x*, *y* and *z* the Cartesian axes. *θ* is the elevation angle, *Q* or *Q'* the position where the ray enters the canopy and *P* or *P'* the position of the FU. Two cases are represented: (1) the path goes through the area with no vegetation, so two path lengths are calculated within the same canopy; (2) the path goes through the vegetation area from a neighbouring tree.

Due to the fact that field-almond trees were planted in Southern Spain at a relatively high spacing (6m x 7m, this study), the assumption that trees are not affected by the surrounding trees appears to be valid. A good agreement between observed and estimated values of transmitted PAR by the tree canopy, indicates that the model performs satisfactorily. A unique relationship was found between observed and measured values of absorbed PAR determined at different tree heights. The slope of this relationship is 11% lower than the ideal value of 1 and the intercept is relatively low. An example of the spatial distribution of the transmitted PAR by the tree canopy at the soil surface derived from the model is presented in Figure 22.

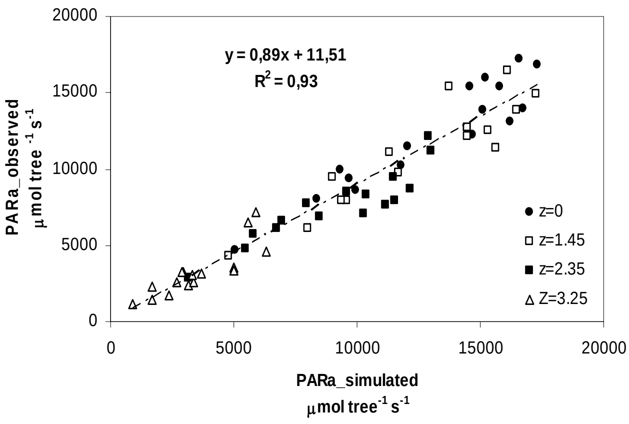


Figure 9. Relationship between the observed and estimated PAR_a (absorbed photosynthetic active radiation) by a whole tree at four different heights (0 m, 1.45 m, 2.35 m and 3.25 m).

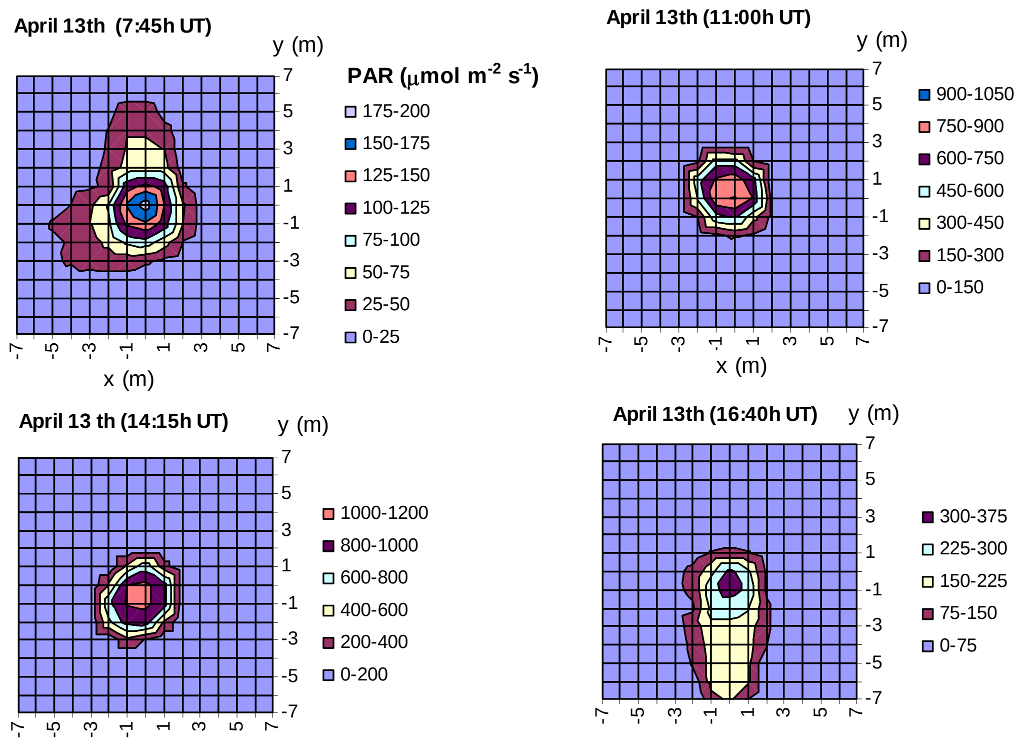


Figure 10. Simulated values of the special distribution of transmitted photosynthetic active radiation, PAR, at the soil surface in spring at different hours of day. The axis x= 0 m and y = 0 m correspond to the position of the tree trunk.

Carbon exchange

Apart the light interception improvement, one of the most important adaptations undertaken in the model was the new way of calculating the carbon transfers. In the previous version, distances between trunk and water sprouts and other organs were 1, whereas distances between two different stems and between a stem and the root system depended on the number of nodes between them. This approach proved to be rather unrealistic. Thus, a new assessment of distances among plant organs has been developed. The new version accounts for the relative positions of the main organs, namely old wood (considered to be located at the barycentre of the stems), root system (barycentre of the stems/shoot:root ratio at equilibrium), and water sprouts (barycentre of the stems except the trunk). Using these relative positions, the model calculates the metric distances between the different organs, namely, the distance to be covered by a carbon flux from a source to a sink organ, which is a more realistic approach. Furthermore, there are two equations describing the capacity of carbon transfer, a general one for the whole tree with only one parameter (Kex) and another one with two parameters (Kex and Ka) for the FBS that relates the assimilate transfer ability to the number of leafy shoots.

Parameters estimation

Several parameters were estimated based on literature data. According to several authors (Miller and Walsh, 1988; Grossman and DeJong, 1994a, b; Rufat and DeJong, 2001), peach root system mass varies from 27 to 38% of the old wood (trunk and branches) compartment mass, approximately. Thus, a percentage of 30% was initially considered for calculating initial mass of roots. However, QualiTree needs the values of coarse and fine root masses separately. Fine root mass in the peach-tree root-system is highly variable, from 13% to 62%, depending mainly on the age of the tree (Rieger and Duemmel, 1992; Rieger and Marra, 1994; Hipps et al., 1995). The initial values for fine root dry mass were assumed to be proportional to the current-year aboveground parts of the tree (Kozlowski et al., 1991). The proportionality coefficient was referred as a shoot:root ratio at equilibrium (*SReq*, see section 2.5).

Moreover, QualiTree needs carbon reserve values for the different compartments as initial inputs. The values for old wood (8%) and coarse roots (8%) were obtained from the works of Jordan and Habib (1996) and Mediene et al. (2002). Reserve values for stems (5.5%) and leafy shoots (16%) at initial stage of fruit development were obtained from Lescourret and Génard (2005).

The parameters corresponding to fruit quality traits can be found in Fishman and Génard (1998), Génard et al. (2003), and Lescourret and Génard (2005). A summary of the parameters concerning the C exchanges within the plant, used in this study for running the model, is presented in Table 2, including their source. Values for most of these parameters were taken from Grossman and DeJong (1994a,b), Ben Mimoun (1997), Lescourret et al. (1998), and Lescourret and Génard (2005), with the following exceptions.

Potential leafy shoot growth parameters, namely, initial relative growth rate (RGR_{ls}^{ini}) and maximal dry mass (DM_{ls}^{max}), necessary in the logistic equation combined with a temporal component for calculating leafy shoot growth were estimated from data collected on unpruned and defruited stems in Alexandra (Bussi et al., 2005).

Carbohydrate remobilization figures are very similar in different plants such as peach, pistachio and dogwood; between 0.01 and 0.02 d^{-1} in all cases (Moing and Gaudillère, 1992; Ashworth et al., 1993; Spann et al., 2008). Therefore, for trunk, coarse roots and stem wood compartments, 0.02 d^{-1} was the reserve mobilization value considered in the simulations. For leafy shoots and fine roots, the value obtained by Lescourret and Génard (2005) for young tissues was used.

Shoot-root ratio at equilibrium (*SReq*), defined as the ratio between current-year aboveground and belowground parts of the tree at the end of the reproductive period, was estimated from works published by authors who studied peach trees varying in age and growing conditions (Grossman and DeJong, 1994a; Rieger and Marra, 1994; Hipps et al., 1995; Tworkoski and Scorza, 2001; Mediene et al., 2002). For unpruned and unthinned peach-trees under no water stress, and different ages ranging from 1 to 7 years, they observed shoot:root ratios varying from 3.5 to 6.3, depending on the tree age, with an average of 4.6, which was taken as a parameter value.

Four parameters were estimated for all trees: the parameter expressing the capacity to export assimilates for organs other than FU (k); the parameter expressing the capacity of FU to export assimilates per leafy shoots (k_{FU}); the initial relative growth rate of fine roots (RGR_{fr}^{ini}) and that of old wood (RGR_{ow}^{ini}). The value of initial relative growth rate of coarse roots (RGR_{cr}^{ini}) was considered to be equal to that of the old wood. Moreover, the initial relative growth rate of leafy shoots (RGR_{ls}^{ini}) was estimated for trees grown in containers. A sensitivity analysis was undertaken in order to observe the influence of several parameters (concerning carbon transfers in the tree and the initial relative growth rates of different organs) on the model outputs. It was carried out by varying ±20% the value of each parameter. The model was considered sensitive to a parameter for a given output when a 20% change in this parameter led to a change in the output of more than 25%.

Simulation

In order to observe the behaviour of the model, simulations and analyses were carried out on two different peach tree varieties already implemented in the model: an early-maturing cultivar (Alexandra) and a late-maturing cultivar (Suncrest). Description of these trees can be found in Nicolás et al. (2006).

Simulations describing several agrotechnical scenarios dealing with irrigation, thinning practices and aphid attacks were performed in order to evaluate the ability of the model as a tool for management purposes. The virtual scenarios have been conceived from field observations (Grechi et al., 2008). In summary, three different thinning and three patterns of attack with all the possible combinations between them were simulated.

The variables considered in this analysis were the total yield of the tree, the fruit average dry mass, the leafy shoot total dry mass and the leafy shoot average dry mass. Moreover, several quality traits were taken into account: flesh dry mass, sweetness index, flesh ratio and the fruit average fresh mass.

Results from the simulations

Simulation outputs showed a good agreement with the observed data concerning fruit and vegetative growth. The variability over time of fruit growth was well predicted (Figure 24).

The sensitivity analysis showed that parameters related to the initial relative growth rates of tree organs had a significant influence on the model outputs. The two cultivars behaved differently; the late-maturing cultivar studied was more sensitive than the early-maturing cultivar, namely, the variation of the same parameter in both trees influenced more outputs in the late-maturing cultivar than in the early-maturing one.

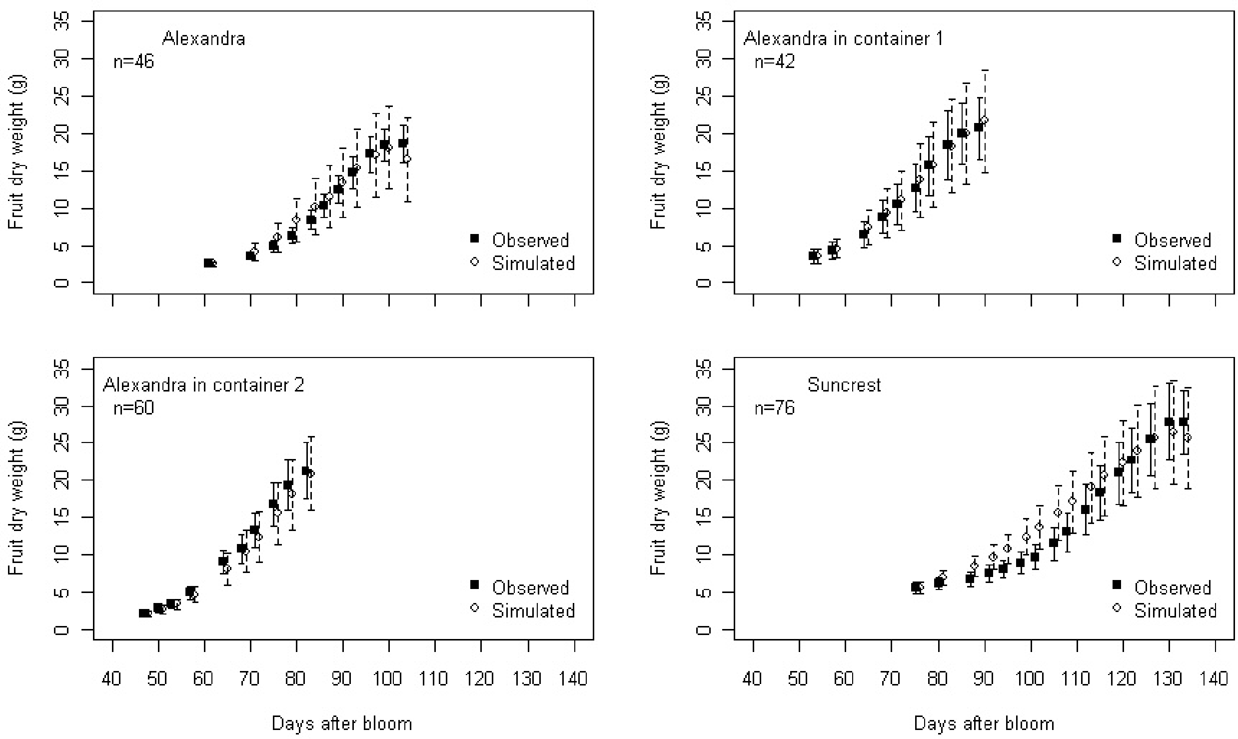


Figure 24 : Test of the model against experimental data for the Alexandra and Suncrest trees and two Alexandra trees grown in containers. Variation of fruit growth among monitored shoots (mean ± SD) according to DAFB, either observed (black squares and black lines) or simulated (white circles and dotted lines). The total number of measurements (n) is indicated on each plot.

Dissemination of results

A paper describing the main features and equations of this virtual tree model and another paper showing different aspects of the use of this model are prepared to be submitted to a scientific journal. The second paper will include the results from the parametrization and calibration of the model for peach trees as well as a sensitivity analysis and the results from its application for simulating diverse agrotechnical scenarios dealing with thinning practices and pest attacks. After the publication of these two papers, a third one dealing with the internal functioning of the model is planned to be written.

Currently, the virtual tree model (ALEXIS) is fully operational and can be accessed via internet (https://w3.avignon.inra.fr/alexis/, access restricted by password) thus facilitating its use by the different partners working on the IRRIQUAL project.

1.5. Epidemiology and irrigation strategies

Brown rot, one of the main polycyclic diseases in stone fruit, can cause as much as 30 to 40% of peach crop losses (Lichou et al., 2002). This disease occurs both in the orchard and after harvest. Cuticular cracks are likely to play a major role for fungal infection (Fourie and Holz, 2003a; Nguyen-The, 1991). The cuticular crack density was shown to mainly vary with the intensity of the fruit growth itself varying with the fruit crop load and irrigation regimes (Knoche and Peschel, 2006; Knoche et al., 2004; Milad and Shakel, 1992; Opara and Tadesse, 2000; Peet and Willits, 1995; Peschel and Knoche, 2005). The occurrence of *M. laxa* on nectarine fruits having various growth patterns associated with different fruit crop loads or irrigations regimes, has been observed (INRA) in relation with the cuticular crack surface area over the fruit, and the conidial density on the fruit.

Crack observation

A method for quantifying the cuticular crack surface area on a whole fruit basis was proposed. By using a stratified sampling design, the spatial distribution of the cuticular cracks over three regions (stylar end, peduncle, and cheek), their morphology, and the estimation of the total proportion of cuticular cracks on the fruit were studied. These features were examined during fruit development and in response to several fruit growing conditions corresponding to various crop loads and irrigation regimes. Cuticular cracks on nectarine fruit occurred during the final rapid fruit growth stage. Larger fruit presented higher cuticular crack densities in the apical regions than in the cheek regions. Thin and larger cuticular cracks occurred continuously during fruit development. Cuticular cracks represented 10% to 12.5% of the fruit surface area for well irrigated or low crop load trees, whereas they covered less than 4.5% for the heavy crop load and water deficit treatments. Cheek regions largely contributed to the total cuticular crack surface area (>60%), regardless of the fruit growing conditions. After irrigation was restricted, cuticular crack development was limited. A positive relationship was established between the cuticular crack surface area per fruit surface area and the fruit fresh weight.

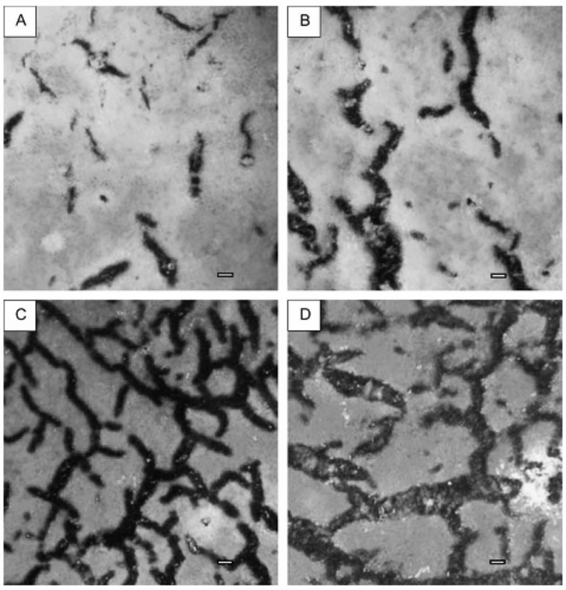


Figure 25 : (A) Thin cuticular cracks on cheek at 100 d after full bloom(DAFB); (B) thin and large cuticular cracks on cheek at 125 DAFB; (C, D) mixed thin and large cuticular cracks merged together on the stylar end at 125 DAFB. Bar scales, 0.1mm. The pictures were taken on ‘Zephir’ nectarine fruit from the well irrigated treatment.

Model development

A model of fruit surface conductance to water vapour diffusion driven by fruit growth was proposed. It computes the total fruit conductance by integrating each of its components: stomata, cuticle and cracks. The stomatal conductance is computed from the stomatal density per fruit and the specific stomatal conductance. The cuticular component is equal to the proportion of cuticle per fruit multiplied by its specific conductance. Cracks are assumed to be generated when pulp expansion rate exceeds cuticle expansion rate. A constant percentage of cracks is assumed to heal each day. The proportion of cracks to total fruit surface area multiplied by the specific crack conductance accounts for the crack component. The model was applied to peach fruit (Prunus persica) and its parameters were estimated from field experiments with various crop load and irrigation regimes.

The predictions were in good agreement with the experimental measurements and for the different conditions (irrigation and crop load). Total fruit surface conductance decreased during early growth as stomatal density, and hence the contribution of the stomatal conductance, decreased from 80 to 20 % with fruit expansion. Cracks were generated for fruits exhibiting high growth rates during late growth and the crack component could account for up to 60 % of the total conductance during the rapid fruit growth. The cuticular contribution was slightly variable (around 20 %). Sensitivity analysis revealed that simulated conductance was highly affected by stomatal parameters during the early period of growth and by both crack and stomatal parameters during the late period. Large fruit growth rate leads to earlier and greater increase of conductance due to higher crack occurrence. Conversely, low fruit growth rate accounts for a delayed and lower increase of conductance. By predicting crack occurrence during fruit growth, this model could be helpful in managing cropping practices for integrated plant protection.

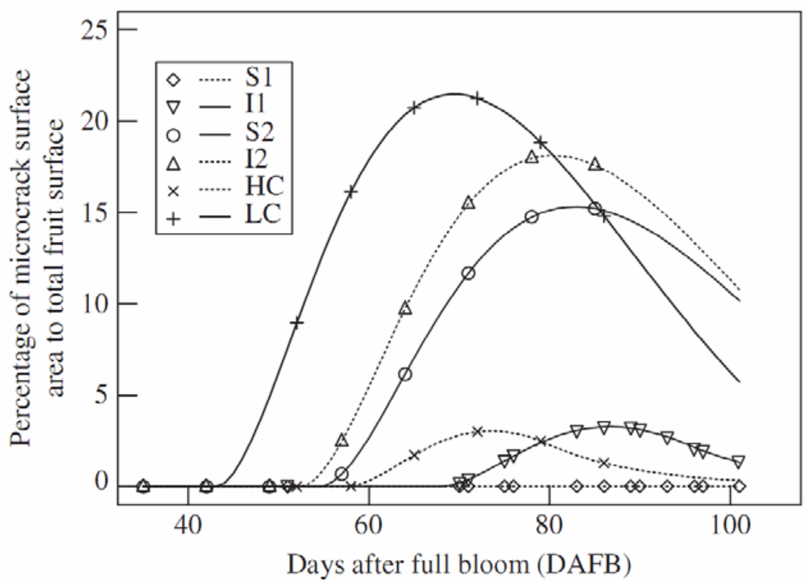


Figure 26 : Time-course of the percentage of crack surface area relative to total fruit surface area for stressed (S1) and irrigated (I1) treatments, and stressed (S2), irrigated (I2), high crop (HC) and low crop (LC) treatments.

Disease occurrence

The effects of cuticular crack surface area and inoculum density on the infection of nectarine fruits by conidia of Monilinia laxa were studied using artificial inoculations with conidial suspensions and dry airborne conidia. Additionally, the effect of ambient humidity on fruit infection was evaluated. An exploratory analysis indicated that (i) ambient humidity did not significantly explain the observed variability of data, but that (ii) the incidence of fruit infection increased both with increasing inoculum density and increasing surface area of cuticular cracks. The product of these two variables represented the inoculum dose in the cracks, and was used as a predictor of fruit infection in the model. Natural infection in the orchard was observed to increase throughout the season. The relationship between the probability of fruit infection by M. laxa and the artificially inoculated dose in the cuticular cracks was well described by a logistic regression model once natural inoculum density was taken into account (pseudo R2= 65%). This function could be helpful for estimating the risk of fruit infection at harvest based on fruit size and natural inoculum density.

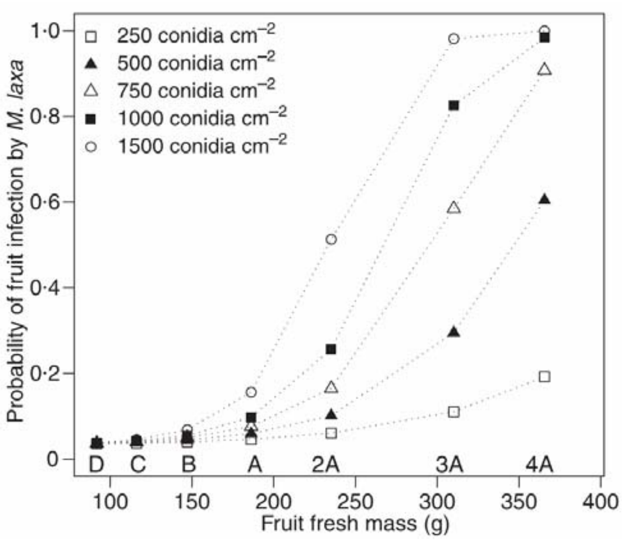


Figure 27 : Sensitivity analysis of the model of nectarine fruit infection by Monilinia laxa to the input variables inoculum density and mean fruit fresh mass. The latter variable corresponds to mean commercial grades (indicated by letters D, C, B, A, 2A, 3A and 4A) inducing variable fruit and cuticular crack surface areas. The cuticular crack density is deduced from the fruit fresh mass.

Integrating the model of fruit surface conductance to water vapour diffusion into the quality model components of QualiTree will improve their predictive abilities and their sensitivity to growing conditions –especially irrigation strategies. As a main point of this conductance model is the prediction of cuticular crack occurrence, a link can be easily established with the model described above that predicts the probability of fruit infection, using crack area as main input. On the whole, a fruit simulation framework tool is available, able to react to irrigation strategies, which takes into account a wide quality profile including not only size and edible quality but also the fruit storage potential (as described by the probability of disease occurrence).

CONCLUSIONS:

Substantial progress in the description and formulation of tree processes driving photosynthesis, C-balance and fruit quality attributes, linking plant development and fruit growth with the plant water status, have been achieved through the IRRIQUAL framework.

An original way was developed to up-scale the photosynthesis from the leaf scale basis to the photosynthesis at the Fruit Bearing Shoot scale, and to integrate the effect of Regulated Deficit Irrigation strategy on the gas exchange. A first scaling factor is accounting for the mutual over-shading of the leaves and their structural and morphologic changes (specific leaf weight, insertion angle, rolling, etc.), in the case of non-limiting water supply. A second scaling factor is associated to the water stress and its effect on the photosynthesis at the shoot scale.

Furthermore, the transpiration was satisfactory estimated using the Penman-Montheith equation, based on a radiative balance model. The stomatic conductance was ascribed using a multiplicative reduction model allowing to take into account the main factor affecting the photosynthesis, ie PAR, VPD and water potential.

The virtual tree model QualiTree has been greatly improved. Firstly, a radiation interception model have been developed allowing the estimation of the radiation and its variation within the crown, accordingly to the Fruit Bearing Shoot position. The developed model has been proved to accurately simulate the radiation interception. Secondly, a new way of calculating the carbon transfers have been developed. The new version accounts for the relative positions of the main organs, the model calculates the metric distances between the different organs, namely, the distance to be covered by a carbon flux from a source to a sink organ, which is a more realistic approach. Finally, parameters estimation was made based on literature data and on direct estimation through vegetative and reproductive growth. The resulting improved crop tree model QualiTree was used to perform various agrotechnical scenarios dealing with irrigation, thinning practices and aphid attacks. Simulation outputs showed a good agreement with the observed data concerning fruit and vegetative growth. The variability over time of fruit growth was well predicted. QualiTree model offered satisfactory results in describing fruit and leaf growth within peach trees. It also proved to be a useful tool for simulating the effect of diverse agrotechnical scenarios on fruit size and quality.

Furthermore, the cuticular cracks have been shown to play a major role for monilia infection, and cuticular crack density was shown to vary with the intensity of fruit growth, itself varying with irrigation regimes. The relationship between the probability of fruit infection by M. laxa and the artificially inoculated dose in the cuticular cracks was well described by a logistic regression model once natural inoculum density was taken into account. A model has been developed, quantifying fruit surface conductance to water vapour diffusion driven by fruit growth. It computes the total fruit conductance by integrating each of its components: stomata, cuticle and cracks. This sub-model could be helpful for estimating the risk of fruit infection at harvest based on fruit size and natural inoculum density.

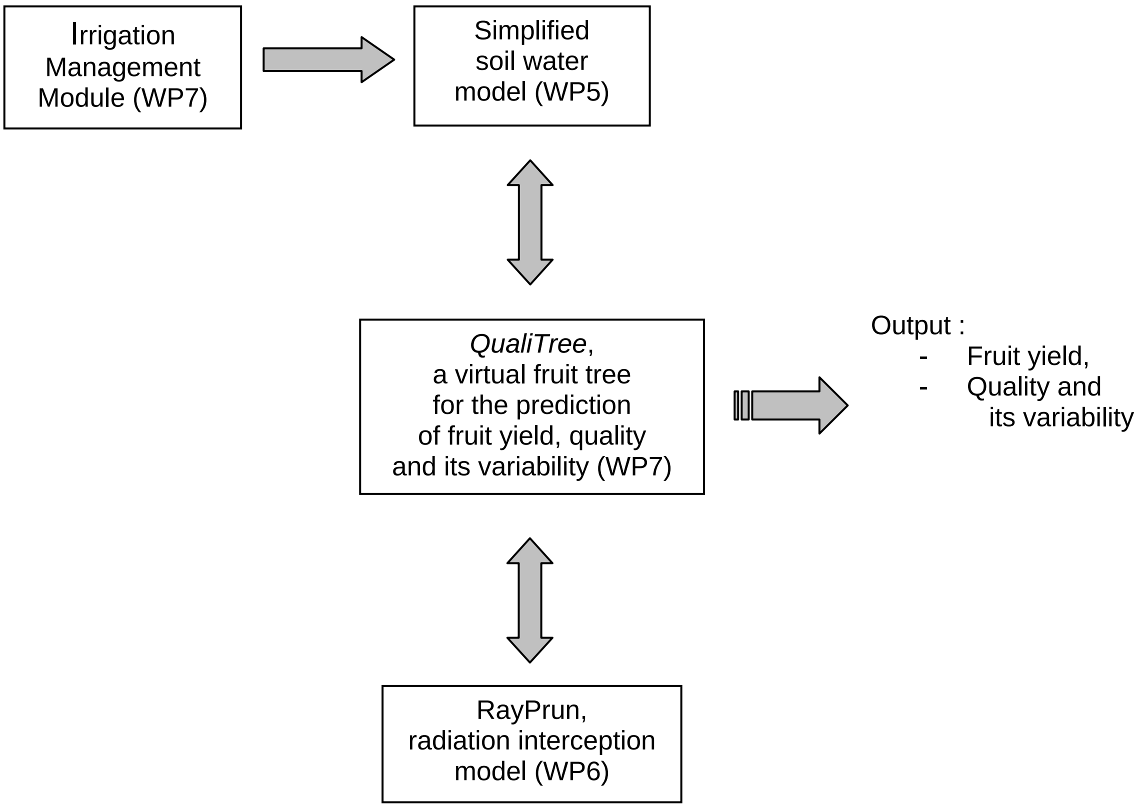


Figure 28 : Schematic diagram of the integration of the different submodels in the QualiTree Fruit model during the IRRIQUAL project.

Actually, complementary models have been developed in the frame of the IRRIQUAL project (Figure 28): (i) a soil balance model including a spatialized root water uptake, a root growth model in relation with the soil properties and the endogenous carbohydrate availability, and (ii) QualiTree, a virtual tree model. The parameters have been estimated for various dataset (location and/or variety). Furthermore the link between these models should be done, and integration of the soil balance model in QualiTree should be achieved. Objectives is to give irrigation scenario (calendar and quantity in relation with climate), and allows an estimation of the soil water flow, root colonization, plant water uptake, and therefore plant and fruit functioning. The output should deal with the yield and edible fruit quality.

WP 6.2: FRUIT QUALITY MODEL

OBJECTIVES: Orchard management is facing new challenges, instigating new research and fruit production strategies, especially when dealing with durable development and global climate change. An important task in this development is not only to focus on yield and safety issues, but also to address the fruit quality as influenced by different RDI strategies and use of water from different origins, varying from purified to waste water. As stated in the Framework Program, this work-package (WP6.2) deals with the development of quality models for fruits of several Mediterranean fruit trees species (peach, olive, almond, citrus). This final report should be regarded as a summary of work reported on in earlier, yearly, WP6.2 reports of the Irriqual project.

CONTRACTORS: HPC, Wageningen University (Netherlands)

RESULTS ACHIEVEMENT:

Analysing quality attributes using quality models

The overall effect of irrigation treatment like RDI (Regulated Deficient Irrigation), PRD (partial root drying) compared to control in combination with the effect of water quality (regular water, water transfer and treated waste water indicated as tertiary water) has been examined with regards to quality attributes of fruits of the four different tree species. External quality attributes have been examined such as size, skin colour, firmness and rupture force, external chilling injury, water loss but also internal quality attributes such as pH/TA, sugar-acids, phenol content, flesh colour, procyanidins, carentoids and gallic acid. In all cases differences between irrigation and water quality treatments on quality attributes manifested not so much by different start or end levels, different reaction rate constants but by changes in maturity with regard to a certain quality attribute. An indication for maturity for each fruit is a typical model parameter of relatively new type of state of the art quality models with a number of examples published in Postharvest Biology Technology. This type of quality model is oriented towards the underlying (simultaneously occurring) processes that cause the observed phenomena, rather than the phenomena themselves. This means that for each phenomenon, or in this case quality attribute, a quality model needs to be build. These models incorporate a parameter that indicates the time needed for a fruit to reach a reference maturity, the biological age. Statistical analysis is then carried not on the measurements themselves but, provided all other model parameters are constant, on the biological age per fruit per irrigation treatment or water quality treatment.

Grapefruit

For the 2007 grapefruit dataset water loss, colour and firmness models were developed and calibrated for grapefruits stored at 5 °C. The 2008 grapefruit was extended by a mild RDI treatment next to the water quality treatments, but no storage was applied. Water loss of the 2007 grapefruits was unaffected by water quality, but other quality attributes were affected in terms of maturity. Maturity was affected by water quality or RDI as shown in Fig. 1. Small maturity effects, applying non-linear regression mixed effects, are indicated by ‘riper’ or ‘unriper’. Bigger, statistically significant (on the 5% level) differences between treatments are also indicated when present.

For both grapefruits datasets more mature fruits, with regard to skin colour, are harvested when full irrigation (like in 2007) is applied. However, when RDI is applied the trend seems to reverse, less mature fruit in terms of skin colour for the tertiary treatment. Hypothesis is that skin colour maturity depends on the availability of water with a low EC (water transfer) when RDI is used and vice versa. So, when tertiary water, having a relatively high EC, is used in a non-RDI irrigated orchard riper fruits are encountered. The weight effect for the tertiary water/control grapefruits is not well understood. The tertiary water treatment contains a higher EC that would normally limit cell elongation during phase I and II but might enhance the number of cells. Elongation might be optimal in case of full irrigation in comparison to the RDI treatment, resulting in large fruit. It is unclear why the RDI fruit of the water transfer are bigger than those of the control. Perhaps the RDI treatment might influence the bio-allocation due to less shoot growth during phase I and II towards the fruits.

Tertiary (waste) water and water transfer water will, in general, produce riper fruit (colour, firmness, taste, pH). The combination of tertiary water with full irrigation will not only produce fruits with a higher weight but also with a better taste (sugar/acid ratio). On the other hand, water transfer in combination with no RDI treatment will produce less mature fruits.

Oranges

For a 2007 orange dataset three RDI treatments (+control) were used, in increasing intensity. The most restrictive treatment influenced the fruit diameter (smaller), while the fruit diameter of the other treatments was not significantly different from the control treatment. Weight loss over time, primarily caused by water loss was described based on a new type of water loss model. The fraction not available for evaporation was highest for the most restrictive RDI treatments. This indicates that less water is available for evaporation the RDI treatments (probably linked with the lower fruit diameter), perhaps due a higher permeability of the skin. In other words, a severe RDI treatment will affect size (smaller) and water loss (lower).

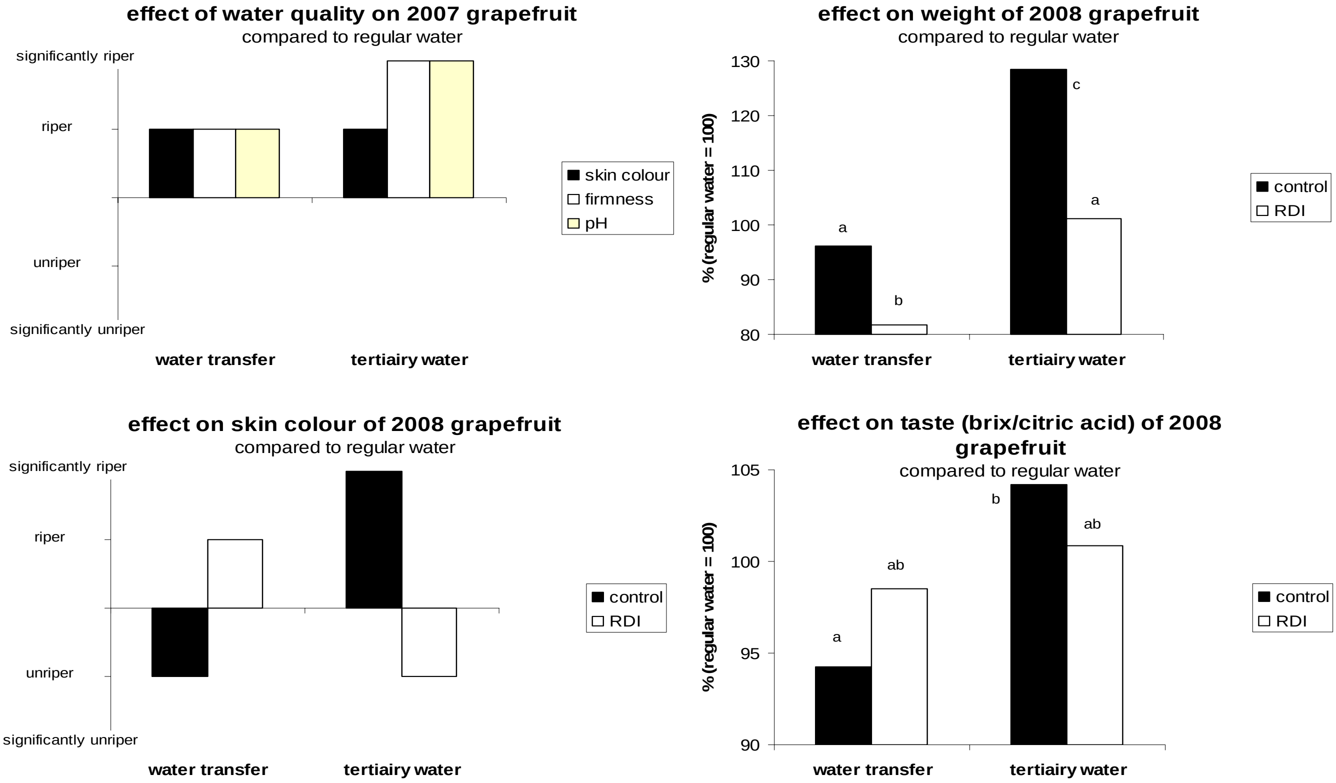
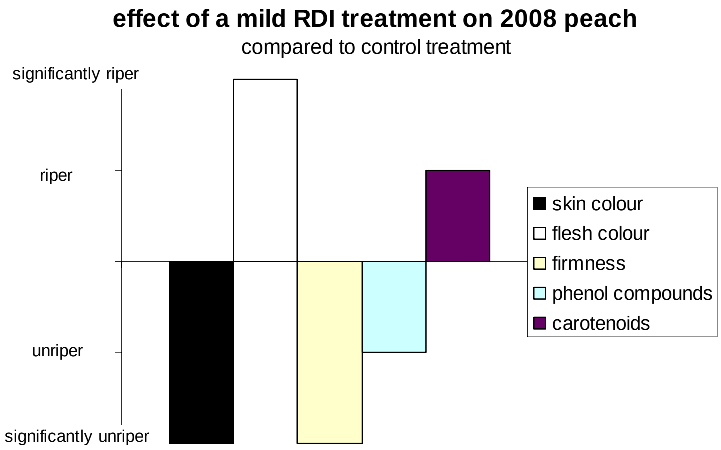


Fig. 1 Overview of maturity, weight and taste effects of water quality and RDI treatments.

Peach

Modelling efforts of 2006 and 2007 have been aimed to predict the firmness behaviour (closest attribute to eating quality) of nectarines and peaches by measuring the chlorophyll content on the flesh in previous years. A model, linking firmness and colour behaviour of these stone fruit, has been published. In the 2008 peach dataset it was investigated whether irrigation treatment affect the flesh colour (both red and green) development, next to a number of external quality attributes such as size, water loss, skin colour, firmness and internal quality attributes such as carentoids and phenols. External quality attributes were measured repeatedly every few days. Samples were removed every few days for destructive evaluation. Peaches were stored at three temperatures (12, 20, 25 °C). These temperatures are not the commercially recommended ones for long storage, but that was not the aim here. Aim was to elucidate and quantify quality processes that may (or may not) be affected by a mild RDI irrigation treatment. Due to the storage at different temperatures it was possible to improve several quality models, e.g. the water loss model, firmness and colour models.



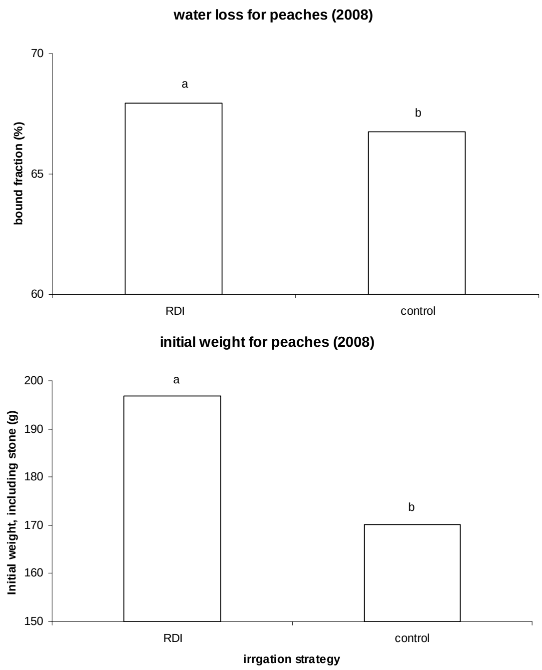


Fig. 2 Overview of maturity and weight effects of a mild RDI treatment for peach.

Control fruit are more mature in terms of skin colour and firmness, but less mature in terms of flesh colour (Fig. 2). Less mature should here be described as the chlorophyll decay process being less advanced. Apparently, the irrigation treatment affects ripeness on different levels. Perhaps the skin colour is affected by the thickness of the canopy (skin colour) while the flesh colour is water availability. The other important quality attribute, firmness, indicates riper fruit for the control fruit, and the health promoting compounds (phenols and carentoids) show mixed results. RDI peaches have about a 15% higher weight than those of the control fruit while water loss is lower, and RDI fruit resist water loss better. RDI peaches showed significantly more rot during storage.

Almonds

Four irrigation treatment were applied to almond orchards in 2007, varying from NI (no irrigation), RDI, PRD (partial root drying), and FI (full irrigation). Quality attributes like skin colour, rupture force (firmness), sugars, phenols, tocopherols and oil content were measured at harvest, after 2, 5 and 9 months for three replicates as function of time, storage temperature and modality (shelled or unshelled). Most quality attributes did not show differences with regard to the irrigation treatments (Fig. 3), only slightly riper (more brittle) almonds were found with regard to firmness for NI and RDI. It is temping to try to connect weight loss with firmness as water loss over time will likely increase the brittleness of the almonds. However, it might be more complicated as for the RDI almonds showed often weight increase and weight loss for NI almonds, while for both more mature almonds were found.

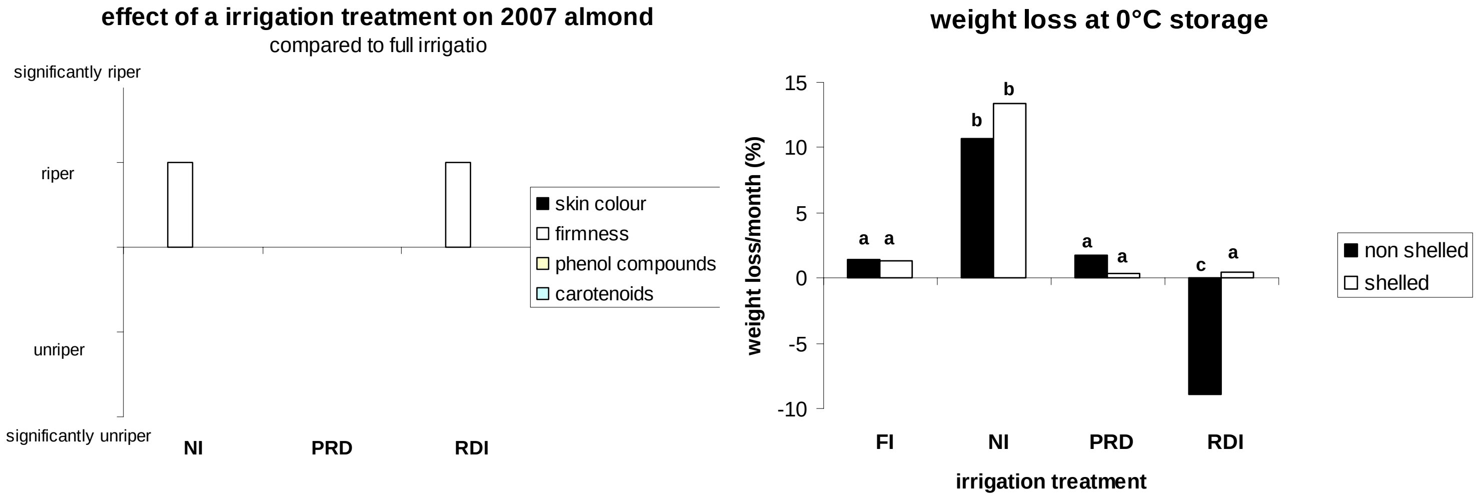


Fig. 3 Overview of maturity and weight loss effects of several irrigation treatments for almond.

Olives

A RDI treatment (+control), an under the tree canopy reflective mulch treatment and a combination of the two were applied during several seasons to olive trees of two cultivars. The olives are used for table olives and depending on the fresh fruit market demand and fruit size also for olive oil extraction. Per treatment 500 olives were examined for quality attributes such as skin colour, flesh firmness, % flesh dry weight and total phenol content during storage at 5°C up to 5 weeks.

Control treatment produces riper fruit (with regard to skin colour and firmness) while the reflective treatment produced the more immature fruit, although these results are non-significant (Fig. 4). The finding that control irrigation produces riper fruit with regard to skin colour has also been found for grapefruit and peach. Low temperature storage will typically induce chilling injury in olives. Logistic modelling of chilling injury incidence resulted in the initial chilling injury incidence that showed that RDI olives are a bit more susceptible for developing CI in cold storage for one cultivar, although this effect is not significant.

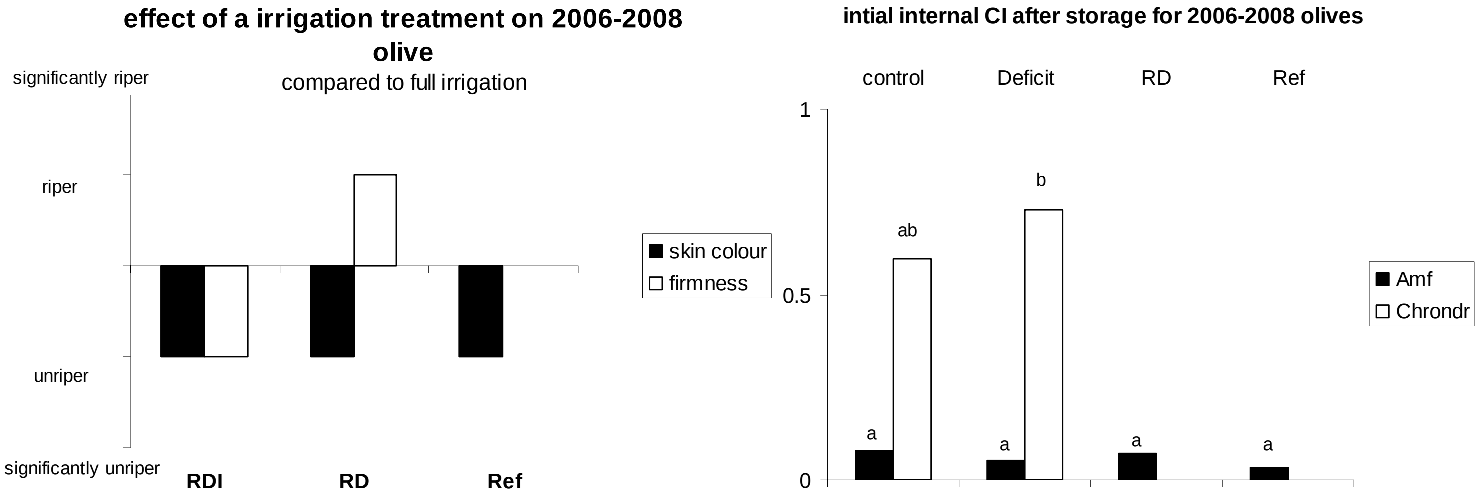


Fig. 4 Overview of maturity and chilling injury incidence of several irrigation treatments for olive. On the right hand side the two cultivars (Amf and Chondr) are compared.

CONCLUSIONS:

Mild RDI treatments appear to have the effect to produce bigger, riper and more tasteful fruits (Grapefruit, Peach) while strong RDI treatments produce smaller fruit that withstand water loss better (Orange). For almonds, no strong effects of RDI and PRD are found on quality attributes, and for olives only mild positive effects on maturity are found. This seems to point to a full recommendation to apply a mild RDI treatment with regard to quality attributes. However it has to be taken into account that also more rot (peach) and chilling injury (olives) has been found for RDI treatments. In principle these are not quality attributes, but logistical issues that might be solved choosing different cultivars (olive).

WP 7: DECISION RULES FOR IRRIGATION SCHEDULING. INTEGRATION INTO A FARM MANAGEMENT MODEL

OBJECTIVES:

WP7.1 -In-situ valuation of decision rules for RDI scheduling with respect to water use efficiency, fruit quality and safety (WP7.1). The main tasks were the elaboration and field valuation of appropriate management and decision rules for deficit irrigation strategies.

WP/.2 Elaboration and test of an orchard management model (WP7.2), which included the following tasks (i) development of a orchard simulator including irrigation strategy and practices (ii) integration of the decision rules and crop models into the simulator and (iii) analysis and evaluation of the simulation outputs.

1. SYNTHESIS OF WP7.1 (In-situ valuation of decision rules for RDI scheduling with respect to water use efficiency, fruit quality and safety)

1.1. Context of the study

Measurements of trunk diameter fluctuations (TDF), which permit continuous and automated registers of the changes in tree water status, have demonstrated their sensitiveness to changes in tree water supply in a number of fruit tree species. Among TDF-derived indices, maximum daily trunk shrinkage (MDS) is considered to be the most reliable and consistent for mature fruit trees. Stem potential (Ψ_s) is other potential indicator for scheduling fruit-trees irrigation, but requires more labour, and specific equipment and skills.

Since plant water status indicators integrate both the soil water available to plants and the evaporative demand of the atmosphere, reference (or threshold) values are required for plant-based irrigation scheduling. These reference values can be obtained by relating the actual values of a certain plant indicator (e.g., MDS) in non-limiting soil water conditions with meteorological variables. Thus, the MDS signal (actual MDS/reference MDS) should primarily reflect soil water availability, values higher than 1 indicating plant water stress.

In WP7.1, field experiments were carried out throughout several growing cycles by INRA (on peach trees) and UPCT (on almond trees). They were specifically designed to evaluate the pertinence and practical feasibility of scheduling decision rules based on baselines and threshold values, and evaluating their performance with respect to yield and quality of the fruits. To this aim, reference baselines and threshold values were determined and tested for two plant-based indicators, namely (i) MDS, and (ii) stem potential (Ψ_s). Once validated, the baselines and threshold can be used for managing irrigation in commercial orchards (see WP7.2, on-farm management model).

1.2. Reference baselines, threshold values and decision rules for deficit irrigation management in almond orchards (UPCT)

The aim of the study was to evaluate the usefulness and functionality of maximum daily shrinkage (MDS) and stem potential (Ψ_s) for scheduling regulated deficit irrigation (RDI) in commercial orchards. Plant water relations as well as agronomical response of almond trees under different irrigation control strategies were characterized throughout of the period 2006-2008 and used to evaluate the strategies. The specific objectives of the field study treatments were:

- Validating baselines using MDS
- Comparing different methods of irrigation scheduling, based on (i) climate variables and (ii) plant water indicators (MDS and Ψ_s).
- Testing signal threshold values in plant indicators-based measurements for irrigation management.
- Comparing the agronomical response of almond trees to different RDI strategies using MDS and ψ_s as plant water indicators.

1.2.1 Materials and Methods

The experiments were implemented on mature almond trees (*Prunus dulcis* (Mill). D.A. Webb cv Marta), self-compatible, of late flowering and early harvest, and presenting high kernel's quality. The trees are spaced 7 x 6 m and the drip irrigation system has only one lateral per tree line, with 6 drippers of 8 L h^{-1} per tree. In all plots except the control ones (CTL), irrigation scheduling treatments were applied according to threshold values of MDS or ψ_s signal intensity (SI), the latter is defined as the ratio $MDS_{treatmentl}/MDS_{CTL}$ or $\psi_{s,treatment}/\ \psi_{s\ CTL}$ (deficit treatment/control treatment). All irrigation treatments were designed according to a randomised block statistical design with three replicates of 12 trees per treatment.The control treatment was scheduled following the standard climatic method (100% standard crop evapotranspiration). The deficit irrigation treatments were scheduled by restricting water supply during stage IV (kernel-filling), considered as the less critical period for almond trees subjected to RDI strategies. The characteristics of the irrigation treatments were the following:

1 - CTL. Control, irrigated at 100% ETc (crop evapotranspiration). ETc was determined from the reference crop evapotranspiration, ETo and use of crop coefficients (FAO 56-Penman-Monteith method).

2 - FI_1, irrigated to maintain the MDS signal intensity (SI_{MDS}) around 1during the whole irrigation season.

3 - RDI, irrigated to maintain SI_{MDS} around 1 - 1.1, except during Phase IV or kernel filling period (≈June – mid August) in which SI_{MDS} was maintained around 1.5.

4. SWP. Irrigated to maintain the ψ_s signal intensity (SI_ψ) around 1 during the irrigation season, except during stage IV in which SI_ψ was maintained around 2.3 (2^{nd} year) and 2.5 (3^{rd} year).

Trunk micromorphometric fluctuations were continuously recorded with a set of linear transducers LVDT (Linear Variable Differential Transducer) placed on six trees of each experimental treatment. Midday stem water potential (ψ_s) was monitored every week with a pressure chamber using the technique of bagged leaves. Maximum stomatal conductance (g_{sm}) was measured every week with a portable gas exchange system (CIRAS II) at photosynthetic photon flux of ≈ 1400 μmol m^{-2} s^{-1}. At harvest, weight of the in-shell nuts, kernel per hectare and kernel fraction and weight were determined. Besides, the fruit defaults were counted and expressed as percentage hull-tight, empty and double. In order to study the tree's physiological and agronomical response to the irrigation treatments, the variables showed in Table 1 were monitored.

1.2.2 Main Results

Validating baselines for MDS-based scheduling

The suitability of trunk diameter reference baselines for irrigation scheduling of mature drip-irrigated almond trees was assessed from data of the control (well-watered trees) treatments. Day-to-day variations in MDS were related with meteorological variables, MDS showing significant relationships with most of them. The mean air vapour pressure deficit during the period 10.00 h – 15.00 h solar time (VPD_{mx}) was the environmental parameter that best correlated with MDS. The relationships obtained were similar for all the phenological phases, except postharvest, when MDS showed a tendency towards lower values for a given atmospheric evaporative demand. The increase in trunk diameter over the three years also appeared to affect the relationships to some extent. As a practical procedure, it is proposed determining the baseline periodically (every one or two years) during the early stages (II-III) of the almond phenological cycle, for use as reference MDS for the subsequent growth stages, because over longer periods several factors affecting the stability of the baseline, in particular trunk diameter growth, might introduce changes in the baseline.

Variable/parameter	Equipment	Frequency
Water relations		
Stem water potential value at midday (covered leaf)	Scholander pressure chamber	Every weeks
Photosynthesis rate, transpiration and stomatal transpiration, at leaf level	CIRAS-2 (PP System).	Weekly
Leaf Temperature	Thermoradiometers	Continuous (CR1000)
Vegetative growth of fruit		
Trunk Dynamics	Calliper	Each phenological period
Biomass eliminated by pruning	-	Annual
Tree Dimension Characterisation	Photographs	Annual

Table 1. Monitored plant parameters

Irrigation scheduling based on MDS signal intensity

Figure 1A-F present the evolution of the MDS signal intensity (SI_{MDS}) and cumulated applied water in the FI, RDI and CTL treatments during the three years of study. Irrigation scheduling using as criteria a threshold value of SI_{MDS} was somewhat delicate to apply, due to the time-lag response and sensitivity of the MDS signal to the reduction of water application in the deficit irrigation treatments. In the treatment RDI (SI_{MDS} threshold = 1.5 during Stage IV and 1 -1.1 afterwards) in the 1st and 3rd year, it was not possible to reach the value of 1.5 during the second half of stage IV. The period indicated as NI in figures 1C and 1F corresponds to a non-irrigation period at the end of stage IV during which the trees of the control treatment were deprived of water to the aim of obtaining an early harvest. This explained why SI was about 0.5 during this period.

Irrigation scheduling based on stem water potential

Overall, the values of ψ_s were coherent with the intensity of soil water deficit over the three years in the different treatments (Figure 2). The relevant result is that maintaining throughout the deficit irrigation period (i.e. Stage IV) a desired threshold value for ψ_s signal intensity (of about 2.5) appears to be more easily achievable and tractable than maintaining a desired MDS-signal threshold (of about 1.5) for MDS. Furthermore, ψ_s is relatively more sensitive to changes in soil humidity during the periods of high climatic demand (Figure 2) than MDS.

Gas exchange

Gas exchange data (leaf transpiration) and derived photosynthetic attributes (leaf maximum stomatal conductance, g_{sm}) are in agreement with the observed reduction in water consumption. RDI treatments showed lower g_{sm} values than the control during stage IV reaching 45% and 20% of reduction in 2006 and 2007, respectively, to be compared with, water savings of 54% and 32% respectively. During the severe stress period of 2007 (Fig.2), the reduction of g_{sm} in the RDI treatment was 49% with respect to the control, leading to a reduction of 39% in water consumption.

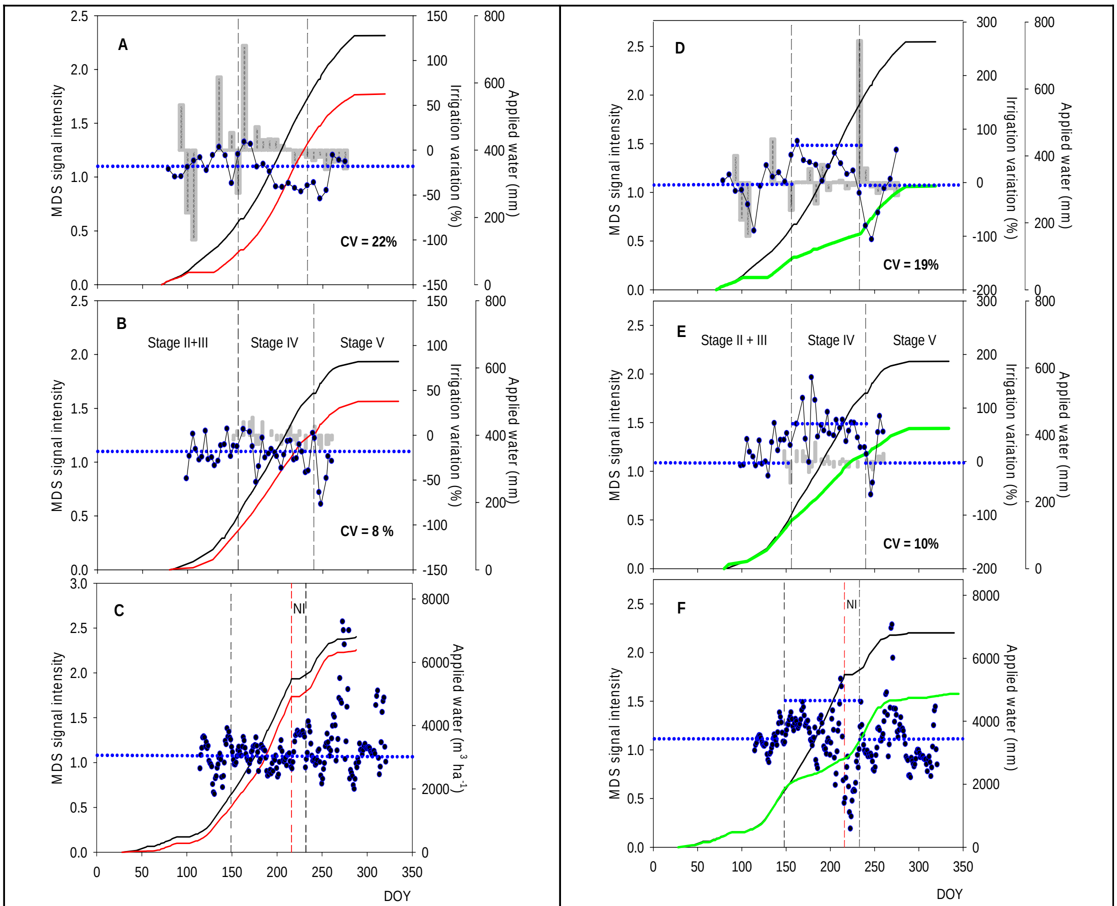


Figure 1. Seasonal patterns of signal intensity values in 2006 (A and D), 2007 (B and E) and 2008 (C and F) of the FI (left) and RDI (right) treatments, cumulative water applied for CTL (black line), FI_1 (red line) and RDI (green line) and water applied variation (grey bars, %) in FI_1 and RDI during 2006 and 2007. Intensity signal values corresponding to five measurements during 2006 and 2007.

Agronomical response of almond trees to deficit irrigation strategies

The average annual yield kernel was 2073 kg ha^{-1} for the control treatment during the experimental period. In the first year, kernel yield was similar in the three irrigation treatments, in spite of the lower kernel weight showed in RDI, maybe due to the higher water stress reached in this treatment just before harvest ($\psi_s \approx$ -2.4 MPa) as well as the higher number of harvested fruits. In the second year FI_1 and RDI presented a significant yield reduction (≈ 30% reduction). Only SWP treatment showed yield values similar to the control. Kernel weight presented statistically similar values between treatments, ranging between 1.26 g kernel^{-1} for RDI and 1.31 g kernel^{-1} for CTL and SWP (Table 2).

In the last year of study, the control treatment presented the highest kernel yield, but the values reached in the SWP treatment were close to those the control. These results showed that in trees submitted to a severe water stress ($\psi_s \leq$ -2.2 MPa) in stage IV, the accumulation of photo-assimilates in kernel was not affected. FI_1 and RDI presented again lower values in yield components.

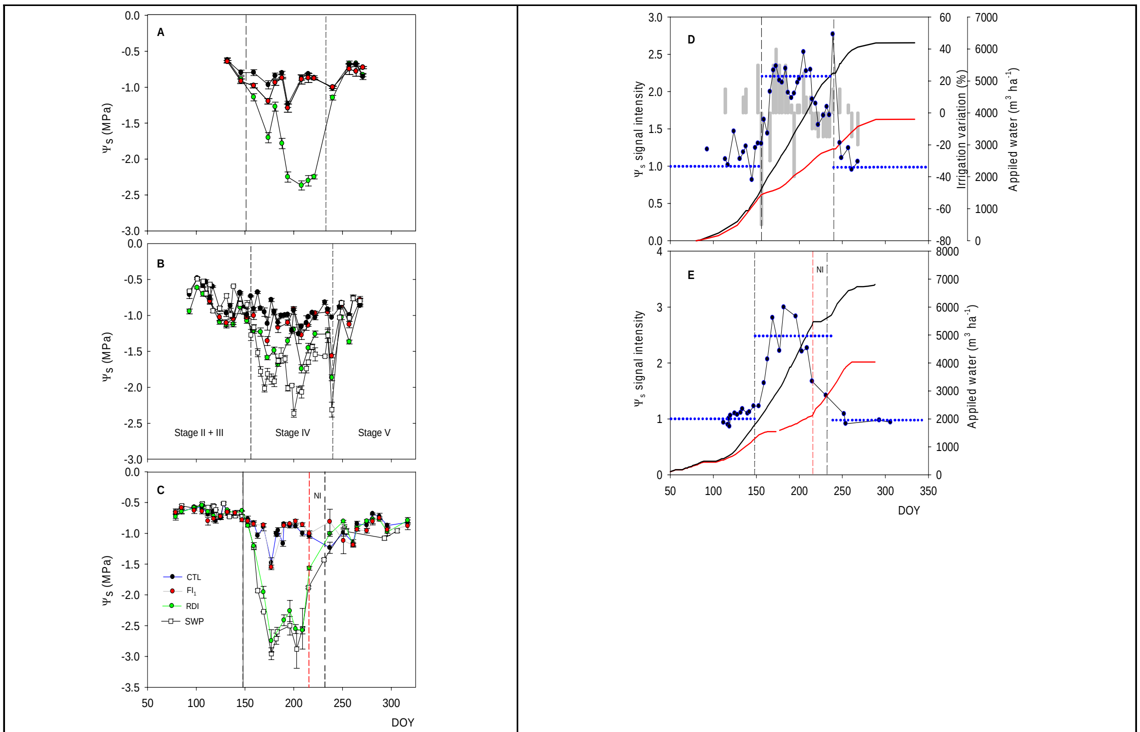


Figure 2. Seasonal patterns of midday stem water potential (Ψ_s) during 2006 (A), 2007 (B) and 2008 (C) for all the irrigation treatments (left), signal intensity values in 2007 (D) and 2008 (E), cumulative water applied (D and E) for CTL (black line) and SWP treatment (red line) and water applied variation (D, grey bars). Each symbol indicates the average of five measurements. Each bar represents the standard error of the mean value.

Tabla 2. Mean yield components and water use efficiency

	Yield (in-shell nuts) kg ha^{-1}	Yield (kernel) kg ha^{-1}	Kernel fraction (%)	Kernel weight g kernel^{-1}	WP$^{(1)}$ Kg m^{-3}
2006					
CTL	5763a	1712a	29.68a	1.49a	0.23 b
FI_1	5172a	1569a	30.26a	1.51a	0.28 b
RDI	5190a	1590a	30.58a	1.29b	0.51 a
2007					
CTL	6753a	1994a	29.52a	1.31a	0.32b
FI_1	5702b	1596b	27.99a	1.21a	0.32b
RDI	4747c	1388b	29.23a	1.26a	0.33b
SWP	5273b	1617ab	30.66a	1.31a	0.42a
2008					
CTL	7934a	2512a	31.6a	1.35b	0.36b
FI_1	6173b	1797b	28.9b	1.58a	0.28c
RDI	5010c	1493c	29.8b	1.18b	0.31c
SWP	6365b	2022b	31.6a	1.17b	0.47a

(1) WP was calculated by the ratio kernel yield to irrigation water applied (WA)
(2) Mean values followed by different letters within the same column and year indicate significant differences according to Duncan multiple range test ($p<0.05$)

Water use efficiency was significantly improved under the SWP treatment, whereas the MDS-based treatment (RDI) presented a high inter-annual variability (from o.31 to 0.51 Kg m^{-3}), reflecting the problems in maintaining the MDS-threshold.

During the 1st and 2nd years, there were no significant effects of the irrigation treatments on fruit defaults. However in the 3rd year, the fraction of hull- tight fruits was the highest in the control treatment, due to irrigation water withholding (during 16 days) at the end of stage IV. This suggests that withholding irrigation before harvest is not beneficial to fruit quality.

1.2.3 Conclusions

The main conclusions from the UPCT study are the following:

(i) MDS as well as stem water potential (ψ_s) are suitable indicators of plant water stress.

(ii) MDS can be used to establish reference baselines for scheduling irrigation in almond trees, due to its linear response to evaporative demand. Among climate variables, VPD_{mx} was the best predictor of MDS in the case of almond trees. As a practical procedure, it is proposed determining the baseline periodically (every one or two years) during the early stages (II-III) of the almond phenological cycle, for use as reference MDS for the subsequent growth stages. Over longer periods several factors affecting the stability of the baseline, in particular trunk diameter growth, might introduce changes in the baseline. Our results also suggest that crop load could affect the slope of the baselines in Stages IV and V.

(iii) It appears possible to schedule deficit irrigation using MDS-baselines and signal intensity threshold. However, suitable management with MDS is not straightforward and requires (i) careful check of the functioning of the LVDT sensors and (ii) skills in analysing and interpreting the MDS signal intensity. It would be advisable to develop an algorithm or a decision support system (e.g. expert-system) which could help the grower or the technician to maintain the desired MDS threshold.

(iv) ψ_s appears most robust and accurate to discriminate differences in plant water status. Overall, scheduling deficit irrigation with ψ_s appears more reliable than scheduling with MDS.

(v) Withholding irrigation before harvest is not beneficial to fruit quality.

1.3. Plant threshold values and decision rules for deficit irrigation management in peach orchards (INRA)

The objective of the RDI is to control reproductive and vegetative growth while improving water use efficiency without affecting overall crop production and quality One of the bottlenecks of RDI application is that the practice requires that tree water status be continuously monitored by means of suitable plant-based indicators. As far as peach tree is concerned, there is neither agreement on the most suitable indicator, nor on established and validated thresholds or baselines. INRA contribution to WP 7.1 was to carry out investigations aiming to test threshold values of plant-based indicators during stage III of peach fruit development. The main goals were (i) to establish links between midday stem water potential (Ψ_s)and trunk micrometric fluctuations, namely the maximum daily shrinkage (MDS) and (ii) to propose practical decision rules for irrigation scheduling based on plant indicators thresholds.

1.3.1. Materials and Methods

The experiments were conducted in 2007 and 2008 in the INRA centre located at Avignon in southern France (43°91'N, 4°85'E). One cultivar of *Prunus persica* (L.) Batsch was used (cv. Zephir® Monphir, white flesh late-maturing nectarine). The trees were cultivated in container equipped with a drip-irrigation system, in order to control water supply. They received standard horticultural care (pruning, fertilization, thinning), but no fungicide application was made in order to study the effects of deficit irrigation on diseases such as brown rot (*monilinia laxa*).

Irrigation treatments

At stages I and II of fruit development, all trees received the same amount of water. At the onset of the stage III, different irrigation treatments were applied, Water supply was calculated so as to maintain stable stem water potentials during the whole course of the study period. In 2007, four treatments were carried out from 26 June (Start of Stage III) to 9 August (harvest) with 5 replications:

- **Control** (CTL), with well-watered plants (1660 L $tree^{-1}$ during stage III).

- **RDI-69** treatment, receiving 69% of the water supplied to CTL (1139 L tree^{-1}).

- **RDI-46** treatment, receiving 46% of CTL (768 L tree^{-1}).

- **RDI-25** treatment receiving 25% of CTL (410 L tree^{-1}).

In 2008, four treatments were applied from 17 June (Start of Stage III) to 7 August (harvest);

- **Control** (CTL) with well-watered plants (2296 L tree^{-1} during stage III).

- **RDI-57** treatment receiving 57% of the water supplied to CTL (1301 L tree^{-1}).

- **RDI-39** treatment receiving 39% of CTL (894 L tree^{-1}).

- **RDI-17** treatment receiving 17% of CTL (393 L tree^{-1}).

Measurements

Midday stem water potential (ψ_s) was measured twice a week by means of a Scholander-type pressure bomb using the technique of bagged leaves. Predawn water potential was measured once a week. Trunk micrometric fluctuations were continuously recorded with a set of linear transducers LVDT (Linear Variable Differential Transducer) placed on four trees of each experimental treatment. The daily diameter trunk fluctuations were used to calculate the maximum daily shrinkage (MDS). In parallel variables relative to growth were measured once a week (80 fruit diameters per treatment and 20 shoots per treatment in 2007; 40 fruit diameters per treatment in 2008). Fallen fruits before harvest were counted. At harvest, number and weight of the fruits per tree were determined. Fruits were sorted out and weighted according to their grade. Fruits with brown rot were counted. The total soluble solids content was measured on 6 fruits per grade on each tree. Water use efficiency (WUE, kg fruit m^{-3}) was calculated for each irrigation treatment as the mean of 5 replications.

1.3.2. Main results

Relationship between midday stem water potential and maximum daily shrinkage

Pooling all treatments, it was found a close linear relationship between ψ_s and MDS for the two years (Figure 3) with high R^2 values (R^2 = 0.85 in 2007, R^2 = 0.74 in 2008, excluding RDI-17). Ψ_s values of -1.0 MPa, -1.5 MPa and -2.0 MPa corresponded to MDS values of approximately 40 µm, 90 µm or 130 µm in 2007, while they corresponded to MDS values of 90 µm, 210 µm or 330 µm in 2008. The slope and offset of the relationship Ψ_s and MDS being different among years, it was not possible to propose a unique relationship linking the two indicators.

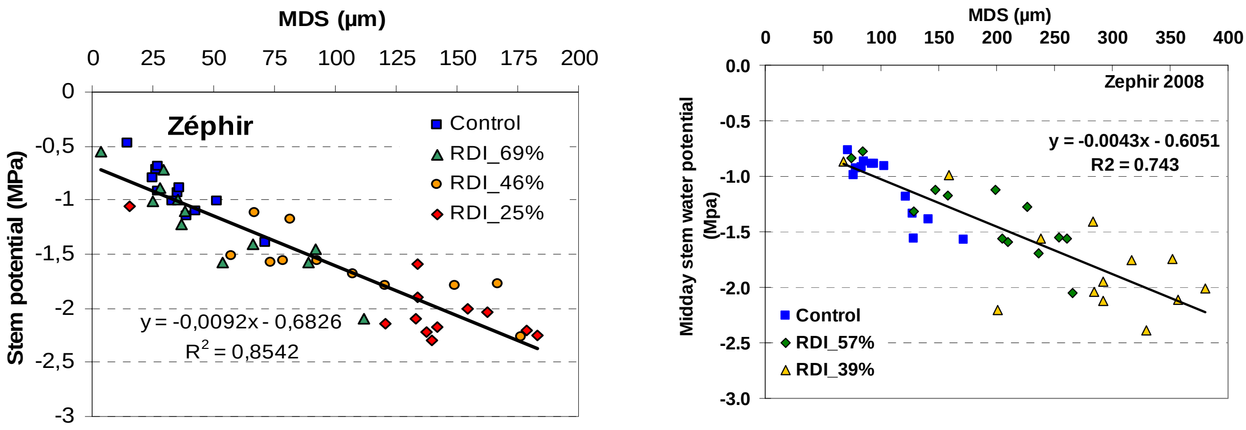


Figure 3: Relationship between maximum daily shrinkage (MDS in µm) and midday stem water potential (in MPa) for Zephir in 2007 and 2008 according to water treatments.

Agronomic and economic performances

Water supply restriction led to an immediate decrease of fruit growth rate in Zephir (Fig. 4). In 2007, the fruit growth decrease (with respect to CTL treatment) was significant in the treatments RDI-46 and RDI-26 but not in RDI-69%. Treatments RDI-46 and RDI-69% did not lead to a significant modification of agronomic performances compared to CTL (Table 3). In 2008, RDI-57and RDI-39 led to a significant decrease of yield and fruit weight (Table 4).

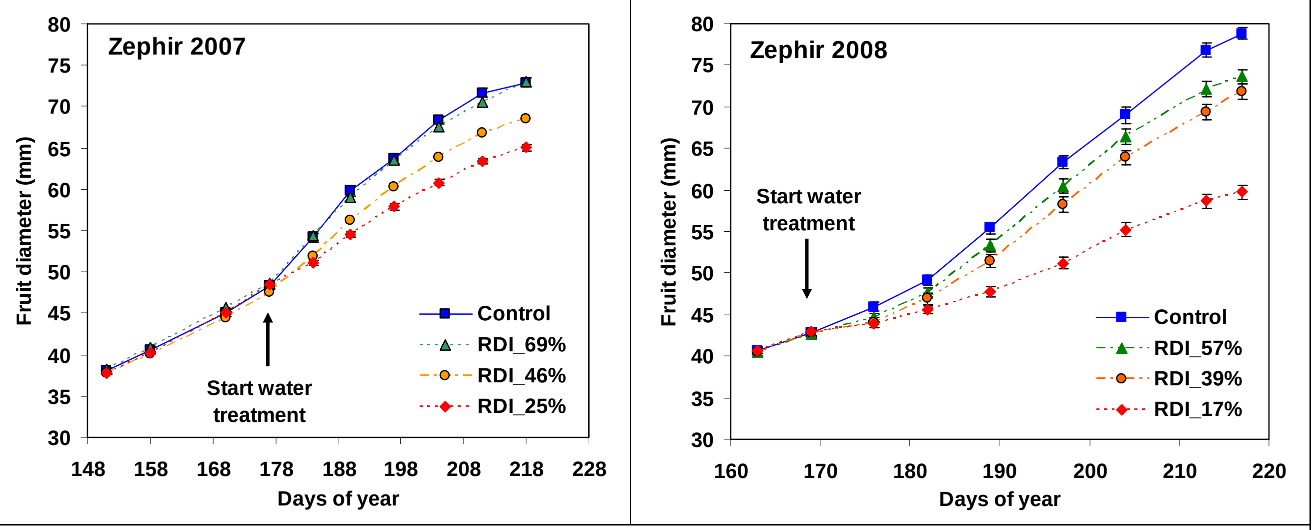


Figure 4: Evolution of fruit diameters (mean ± standard error of mean, in mm) for Zephir in 2007 and 2008 according to water treatments during stage III of fruit growth.

TSS content was significantly increased in RDI-46 and RDI-25 (2007) and in RDI-17 (2008). RDI treatments highly improved water use efficiency in the two years. The reduction of water supply induced a significant decrease of fallen fruits and fruit brown rot incidences compared to CTL. Without fungicide application, the treatments RDI-46 and RDI-69 (Year 2007) presented economic performances identical to CTL with a net improvement of fruit quality and water use efficiency. In 2008, the best economic performance was obtained in RDI-57. When accounting for the cost of an effective fungicide protection which would have allowed controlling brown rot, the treatments RDI-69 in 2007 and RDI-57 in 2008 appear to be the best compromise. Applying more severe water deficit would reduce fruit size and therefore economic profitability.

Table 3: Agronomic and economic performances for Zephir in 2007 according to water treatments (*P*, Probability of ANOVA test; values on the same line followed by different letters are significantly different at P< 0.05, Tukey test)

Variables	**Control**	**RDI-69**	**RDI-46**	**RDI-25**	***P***
Gross yield (kg tree^{-1})	19.2 a	18.6 a	17.0 a	14.6 b	<0.001
% fruit disease	23.7 a	18.3 a	11.0 b	6.3 b	<0.001
Mean fruit weight (g)	202.9 a	201.8 a	186.7 a	161.4 b	<0.001
% fruit size≥67mm	96.7 a	94.3 a	89.2 a	69.1 b	<0.001
Marketable fruit yield (kg tree^{-1})	14.6 ab	15.2 a	15.1 a	12.7 b	0.027
Marketable product (€ tree^{-1})	12.3 a	12.5 a	12.0 a	9.2 b	0.003
TSS content (% Brix)	16.8 c	17.2 bc	18.0 ab	18.2 a	0.003
WUE (kg fruit m^{-3})	11.5 d	16.3 c	22.1 b	35.6 a	<0.001

Table 4: Agronomic and economic performances for Zephir in 2008 according to water treatments (*P*, Probability of ANOVA test; values on the same line followed by different letters are significantly different at P< 0.05, Tukey test)

Variables	**Control**	**RDI-57**	**RDI-39**	**RDI-17**	***P***
Gross yield (kg tree^{-1})	33.4 a	27.0 b	25.0 b	18.1 c	<0.001
% fruit disease	35.5 a	13.4 b	16.5 b	6.3 b	<0.001
Mean fruit weight (g)	222.6 a	182.0 b	178.8 b	131.7 c	<0.001
% fruit size≥67mm	97.1 a	88.0 a	81.4 a	31.7 b	0.001
Marketable fruit yield (kg tree^{-1})	21.5 ab	23.4 a	20.8 ab	16.8 b	0.026
Marketable product (€ tree^{-1})	18.3 a	18.3 a	15.9 a	8.1 b	0.001
TSS content (% Brix)	14.7 b	15.1 b	14.9 b	17.1 a	<0.001
WUE (kg fruit m^{-3})	14.6 c	20.8 bc	28.0 b	46.1 a	<0.001

Agronomic and economic performances

Midday stem water potential and maximum daily shrinkage used as indicator of the water status of the trees are strongly correlated. When the water stress increases, ψ_s decreases and trunk shrinkages increase more and more strongly. These results confirm those observed for peach (Goldhamer et al., 1999; Marsal et al., 2002) or on plum tree (Intrigliolo *et al.*, 2004). Our results allow quantifying the correspondences between MDS and ψ_s for the phase III of fruit growth of peach. However, the relationships are very different according to year.

To use these tree water status indicators as a tool to manage irrigation scheduling, it is necessary to determine thresholds values below (for Ψ_s) or above (for MDS) which the gross yield is affected. Figure 5 represents the agronomic and economic performances expressed as a fraction (yield index) of the CTL yield with respect to the mean value of ψ_s over stage III when there was no fungicide application against brown rot diseases. If we consider that a decrease of gross yield becomes significantly important below a yield index of 0.9, Ψ_s threshold was close to -1.6 MPa in 2007 and -1.4 MPa in 2008. On the other hand, the optimal level for the marketable products (marketable yield × fruit price) was found to be approximately -1.5 MPa in 2007 and -1.6 MPa in 2008. The ψ_s threshold values were rather consistent among years, an encouraging result in what refers to the use of Ψ_s threshold in optimizing deficit irrigation scheduling.

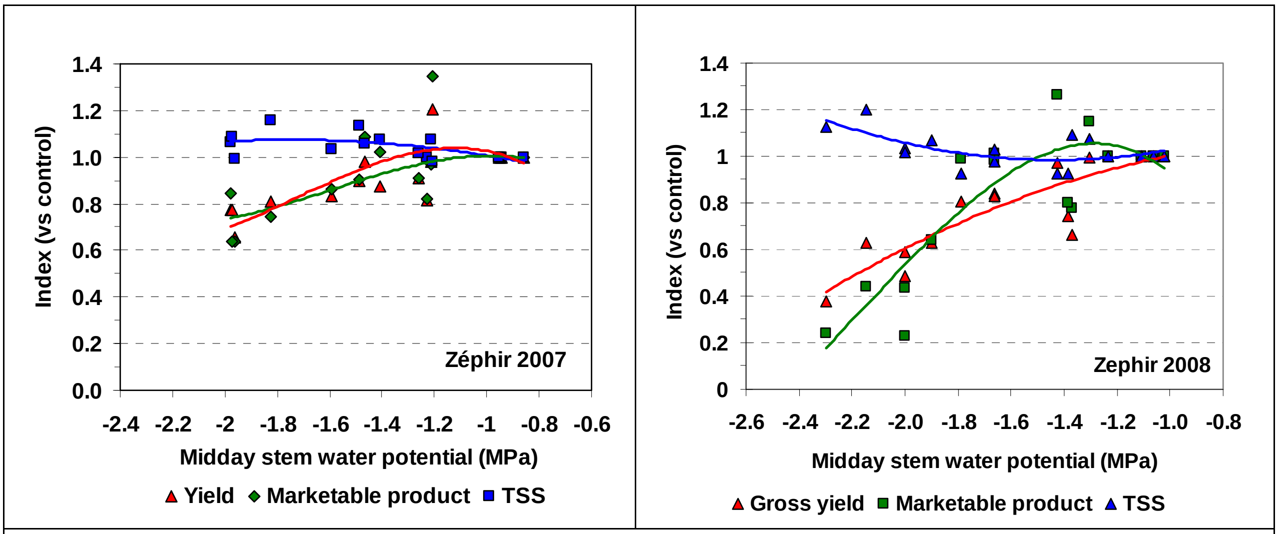


Figure 5: Relationship between midday stem water potential and performance indicators (gross yield, total soluble solids content, marketable product (marketable yield * fruit price) expressed as an index of the Control) for Zephir in 2007 and 2008.

A similar analysis was conducted for MDS, but results were less conclusive. The MDS threshold corresponding to a yield index of 0.9 ranged from 80 to 100 µm (year 2007) and from 140 to 210 µm (year 2008). It seems therefore that the MDS threshold was year-dependent, varying within a wider range than did Ψ_s.

1.3.3. Conclusion

Concerning the agronomic and economic effects of RDI strategy, the main conclusions from the INRA study are the following:

(i) Gross yield was not significantly affected by moderate water deficit (RDI-69 in 2007) applied during the phase III of fruit growth, in agreement with results of previous studies. With increasing water restriction, gross yield appears to decrease proportionally to the decrease in mean fruit weight. This led to an important reduction of the percentage of fruit size greater or equal to 67 mm, the fruit size presenting the highest market value.

(ii) Without use of fungicides, the RDI treatments reduced the percentage of fruits with brown rot disease. Therefore, the marketable yield was less affected and decreased much less faster than gross yield.

(iii) RDI increased sugar content (up to 1.2% Brix) improving the gustative fruit quality.

(iv) RDI improved water use efficiency.

Concerning the suitability of the studied plant indicators for RDI scheduling:

(v) The ψ_s threshold values based on yield performance index were rather consistent among years, an encouraging result in what refers to the use of ψ_s threshold in optimizing deficit irrigation scheduling with respect to agronomic or economic criteria. The main disadvantage of ψ_s is the difficulty in acquiring data (manual measurement, important fluctuations related to the conditions of measurement) for its routine application in commercial orchards.

(vi) The main advantages of MDS are its capacity to detect very quickly the onset of water stress, its automation and the relative facility to implement sensors and obtain continuous information. However, under severe water stress, MDS is not a reliable indicator because the absence of reconstitution of the water storage during the night tends to reduce the amplitude of contraction. Moreover, the study seems to indicate that MDS threshold based on yield performance index is year-dependent, a behaviour that might hinder the use of MDS threshold to optimise RDI scheduling with respect to agronomic criteria. Further research will be necessary to disentangle the factors explaining the variability of MDS thresholds and to propose reliable decision rule based on MDS threshold.

2. SYNTHESIS OF WP7.2 (Orchard Management Model)

2.1. Context of the study

In the case of fruit trees, modelling approaches combining advantages from crop and ecophysiological models may provide useful tools for understanding and managing fruit quality. In WP7.2, a virtual tree model (QualiTree) describing C transfer within the plant between fruiting units, an "old wood" compartment gathering the trunk and branches, and roots, reproductive and vegetative growth and the development of fruit quality was developed by the INRA team and evaluated. It only concerns growth of the parts of adult trees during the growing season after bloom and not plant development from the seed stage, since it focuses on fruit quality and not on tree development. The model is able to describe the variability of fruit and leafy-shoot growth within the tree since it accounts for the effect of tree architecture on carbon allocation and considers each fruiting unit (FU) as a subunit. Moreover, it permits including management practices, such as summer and winter pruning, fruit thinning and irrigation scheduling. Such practices influence light interception by the canopy, a key factor governing photosynthesis that explains part of the within-tree variability of fruit growth. Light distribution is highly variable within the tree, both spatially (higher shoots receive more irradiation) and temporarily (due to changes in solar position). It differs between cultivars and constitutes a source of heterogeneity in fruit production.

In this sense, an interesting feature of QualiTree is that a submodel for calculating the amount and distribution of daily light in the canopy (RayPrun, developed by the UPCT team, see Irriqual WP6 Final Report) was coupled to QualiTree.Accordingly, the RayPrun light interception model was incorporated into QualiTree. Rayprun embodies the advantages of simple models while considering temporal changes in leaf density within the canopy and features of orchards such as special canopy shapes caused by tree training and possible between-tree competition for light according to planting distances.

QualiTree was parameterized for two different peach-tree cultivars. Afterwards, the model was tested by comparing model predictions with experimental data from situations (cultivar, growing conditions) either used for parameterization or not. The variables considered were the fruit and leafy shoot dry masses. Finally, the behaviour of QualiTree was studied under three aspects: (1) Is the model capable of reproducing different tree behaviours concerning carbon exchanges? (2) Is it sensitive to parameters involved in the representation of C demand and exchange? (3) Is it able to react to diverse agronomical scenarios?

The first question allows to assess the ability of the model to describe carbon exchanges within the tree in different cultivars as they were suggested to occur in nature by experimental results, whereas the second one permits to think about potential genotypic effects, which are increasingly being taken into account by ecophysiological models. The third question deals with the capacity of the model to be used in the future for management purposes. In order to answer this question, simulation experiments were performed. Field observations involving fruit thinning practices were taken as a basis for designing these theoretical experiments. Fruit thinning was chosen because it is one of the major practices affecting fruit size and quality (Berman and DeJong, 1996).

2.2. Model components

2.2.1. The light interception module

Rayprun is a relatively simple model predicting radiation interception by a tree within an orchard, based on the analytical model proposed by Charles-Edwards and Thornley (1973) Rayprun calculates the light-flux density incident on a horizontal surface at various positions lying inside or outside a single plant canopy. Basic assumptions are: (i) The beam travelling through the canopy is attenuated according to Beer's law,(ii) the foliage is uniformly distributed in the space volume occupied by the canopy, (iii) the relative frequency of leaf angle is the same as for surface elements of a sphere, known as spherical distribution of leaf angle in which all orientations are equally represented. In QualiTree, the photosynthesis is calculated at the scale of each FU.

2.2. QualiTree model

QualiTree (Génard et al., 2008) differently to other fruit tree models accounts for the variability of C allocation within the tree and, simultaneously, accounts for the influence of the agronomical practices in the ecophysiology of the plant (Figure 8). The within-tree variability comes from different sources and it has been suggested to be very important (Gary et al., 1998) and worthy simulating (Génard et al., 2008). Previous works (Nicolás et al., 2006, Génard et al., 2008) showed that QualiTree reproduced fruit and leafy shoot dry masses and then within tree variability in a satisfactory way showing that our approach may be adequate for agronomical purposes. It was also capable of reproducing the differences in autonomy to carbon transfers in both varieties as suggested by experiments in orchard conditions. Therefore, it is capable of simulating autonomy (as in cv, Suncrest) and a non-autonomous behaviour (as in cv. Alexandra) at the same time. This differentiation between cultivars is modelled using different parameters between cultivars. The differences in these parameters allow accounting for differences in C transfer between cultivars as observed in field experiments (Nicolás et al., 2006).

2.3. Experimental data used for calibration and test of the model

The data used to calibrate and test the model come from several experiments on vegetative and reproductive growth performed in two locations. These experiments concerned two cultivars of *Prunus persica*, namely, an early-maturing (Alexandra) and a late-maturing cultivar (Suncrest).

Furthermore, the model was tested with two Alexandra trees grown in containers. Experiments were performed on trees grafted on GF 677 rootstock planted in 1999 and cultivated outdoors in 110 L containers (n = 20). Trees were goblet-trained and received routine horticultural care including winter pruning, weekly drip irrigation, and pest control. Trees were thinned at 40 fruits per tree and measures taken from 35 to 85 DAFB (full bloom on 24 March). Data on tree architecture and fruit and leafy shoot growth were recorded as previously.

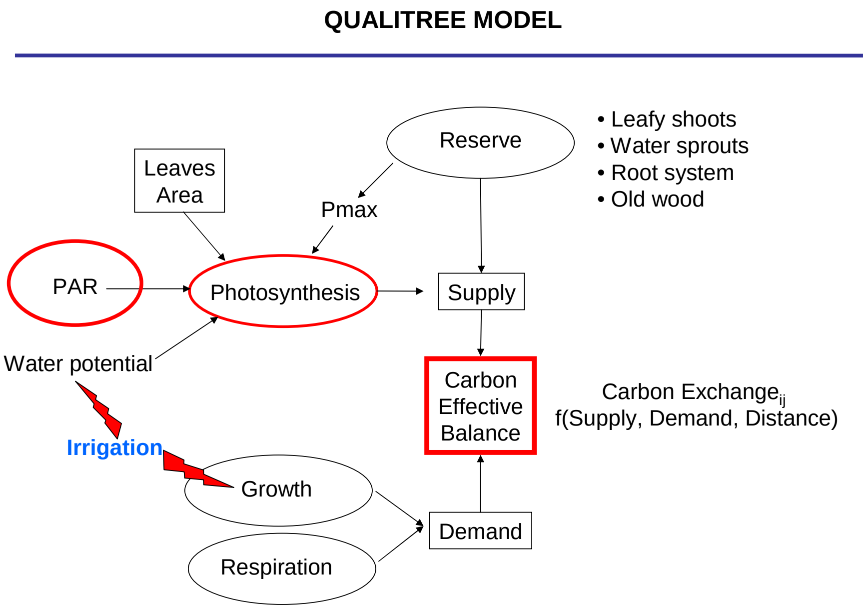


Figure 8. Conceptual scheme of QualiTree

2.3. Input data

Climatic data sets (global radiation and temperature) collected at INRA weather stations located close to the experimental fields were used as model inputs.

Data on diameter and length of the different tree parts (i.e. trunk, scaffolds, branches and FU) were used for describing the initial state of the virtual trees. Specifically, these data were used for building a distance structure among the different tree compartments and, in addition, to define the dry biomass of each tree part. For this purpose, the trunk, branches and FU were considered as conic-section structures and their volume (*V*) calculated. The obtained volumes were transformed into biomass using a wood-density value of 0.77 g cm^{-3} (dry mass:fresh volume) (unpublished experiments). According to several authors, peach root system mass varies from 27 to 38% of the old wood (trunk and branches) compartment mass, approximately. Thus, a percentage of 30% was initially considered for calculating initial mass of roots. However, QualiTree needs the values of coarse and fine root masses separately. Fine root mass in the peach-tree root-system is highly variable, from 13% to 62%, depending mainly on the age of the tree. The initial values for fine root dry mass were assumed to be proportional to the current-year aboveground parts of the tree. The proportionality coefficient was referred as a shoot:root ratio at equilibrium.

QualiTree also needs carbon reserve values for the different compartments as initial inputs. The values for old wood (8%) and coarse roots (8%) were obtained from previous works. Reserve values for stems (5.5%) and leafy shoots (16%) at initial stage of fruit development were obtained from Lescourret and Génard (2005).

2.4. Parameters estimated from experiments and literature

The parameters corresponding to fruit quality traits can be found in Génard et al. (2003), and Lescourret and Génard (2005). Parameters concerning the C exchanges within the plant were taken from Grossman and DeJong (1994a,b), Ben Mimoun (1997), Lescourret et al. (1998), and Lescourret and Génard (2005).

2.5. Agronomical scenarios

In order to observe how thinning intensity affects peach fruit size, a simulation experiment was designed. Using both cultivars separately, thinning was performed at the stage II of fruit growth (61 and 75 DAFB in Alexandra and Suncrest, respectively). Three scenarios were simulated for each variety: no thinning, intermediate thinning (15 cm between fruits) and commercial thinning (25 cm). Three different factors were considered for the analysis of outputs: Cultivar (Alexandra or Suncrest), thinning intensity (no thinning, 15 cm and 25 cm between fruits) and pest attack (yes-no). Further analysis of the pest attack data considered two factors: the pattern of attack ("pattern") and the percentage of vegetative dry mass lost per day ("percentage": 2% or 5% per day). The modalities of pattern were regrowth, no regrowth and attack later in the season. An evaluation of the effect of each factor and of their combination on four output variables (fruit yield, fruit average dry mass, total dry mass of leafy shoot and average dry mass of leafy shoot) was performed by variance analysis using complete models.

Moreover, four fruit quality traits (average fruit fresh mass, dry matter content of the flesh, proportion of total mass consisting of fruit flesh and sweetness index calculated according to Génard and Souty, 1996) were analysed for the Suncrest cultivar only since no parameters of the fruit quality processing have yet been estimated for Alexandra. All data analyses and graphs were carried out with R software version 2.7.1 (R Development Core Team, 2008).

2.3. Some simulation results

Agronomical scenarios

Thinning affected fruit yield in both cultivars. Yields of the 15 cm and the 25 cm thinning treatments were 68% and 38.5% that of the unthinned treatment, respectively in the case of Alexandra. For Suncrest, they were 68% and 43.9%. For the global analysis involving the main effect of the three factors, the cultivar and the pest attack exerted a significant influence on the four variables considered. Thinning only influenced fruit yield and fruit average dry mass. Alexandra fruits were 4.6% (15 cm) and 7.2% (25 cm) bigger than those of the unthinned treatment, whereas Suncrest fruits were 19.8% (15 cm) and 30% (25 cm) bigger than those of the unthined treatment. Simulated pest attacks affected more to the fruits of the late-maturing than to those of the early-maturing cultivar. Fruit yield decreased up to 38% in some cases. In general, interactions were not significant except that between cultivar and attack for fruit yield and fruit average dry mass, and that between cultivar and thinning for the average fruit dry mass. The quality traits were significantly influenced by thinning and attack but not by their combined effect.

2.3. Conclusion and perspective

The management model developed in Irriqual was capable of reproducing the effects of cultural practices such as thinning. It was shown that the average seasonal relative growth rates of the different organs were sensitive to the changes in the values of their respective initial relative growth rates for both cultivars. However, parameters referring to C transfer within the plant did not have great influence on the results.

The results from the agronomical scenarios indicate that, as reported in field conditions by many authors, fruit load exerted a strong influence on the final fruit average dry mass simulated by our model. Simulation results indicated a greater effect of thinning on fruit size for the late-maturing than for the early-maturing cultivar, because the period of fruit growth is much longer. The cultivar and the intensity of thinning exerted a greater influence on fruit size and quality than the pest attacks.

In conclusion, QualiTree offered satisfactory results in describing fruit and leaf mass variability within peach trees. The simulation of fruit quality traits will be tested in the future. QualiTree proved to be a useful tool for simulating the effect of diverse agronomical scenarios on fruit size and quality. Currently, practices such as thinning and pruning can be simulated. Further developments are planned for improving the model, such as the linkage of a water uptake model which would permit to simulate irrigation practices, widening the predictive capacity of the model. This task will be pursued by the INRA and UPCT teams in the years to come.

WP 8: DEVELOPMENT OF A PROTOTYPE GENERATOR FOR IRRIGATION WATER DISINFECTION

OBJECTIVES: CONTARIEGO has focused on the development of water disinfection processes, developing an alternative technology based on the application of ultrasounds to decrease the level of algae and bacteria in irrigation reservoirs. The process is effective and ecologically friendly; the grower saves time and money and fewer polluting chemical products are needed. Filtering processes are improved and the harvest quality increases.

CONTRACTORS: CONTARIEGO.

RESULTS ACHIEVEMENT:

1.1. PHASE 1. Technological development:

(*Task 8.1 according to ANNEX I:) "Development of a prototype of ultrasound generator for irrigation water disinfection. (months: 1-14). Firstly, a laboratory scale prototype will be developed, which will allow different ultrasonic frequency and power ranges to be tried, as needed for the experimental design."*

Deliverable 13*: Development of the ultrasound prototype (month 12*).

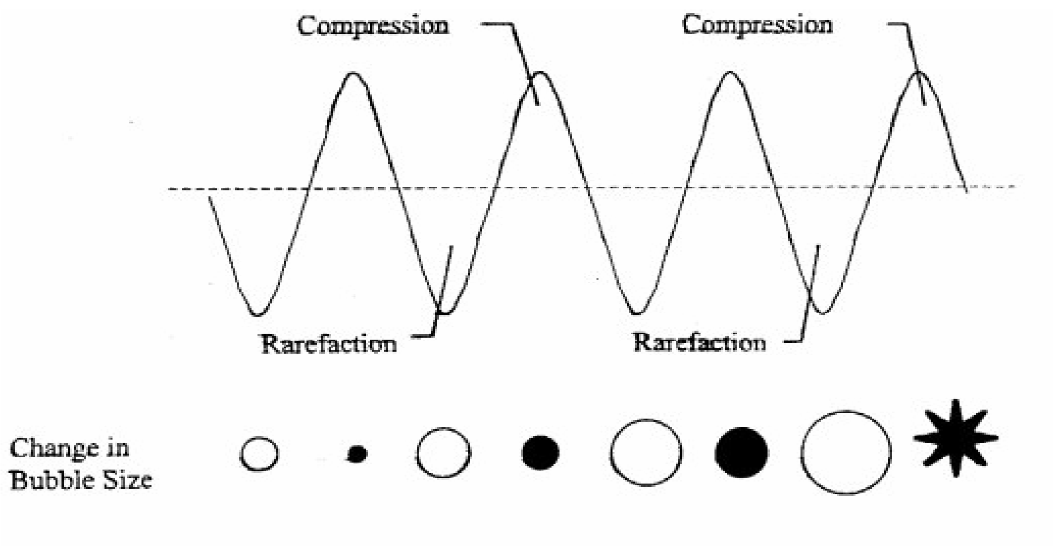
It is necessary to improve the water of reservoirs if irrigation is to be successful. The problems at the present time are the following:

- Irrigation water quality must be improved because of the direct consequences for human health.

- The scarcity of water means that methods should be developed to optimise its use.

- The accumulation of algae harms apparatus, blocks filters and pumps and slows down the irrigation process, sometimes at key moments of production (see RDI, strategies of deficit irrigation).

During this phase, a prototype of ultrasounds apparatus was developed and perfected. The system, which improves irrigation water quality, is based on a physical phenomenon that a liquid medium undergoes when exposed to ultrasounds – a process known as acoustic cavitation. Such cavitation affects algae and bacteria, disturbing their cell structure and damaging their viability. Their quantity in reservoirs is diminished and the water quality is improved.



Sound Motion Related to Bubble Growth and Implosion (IES, 1998)

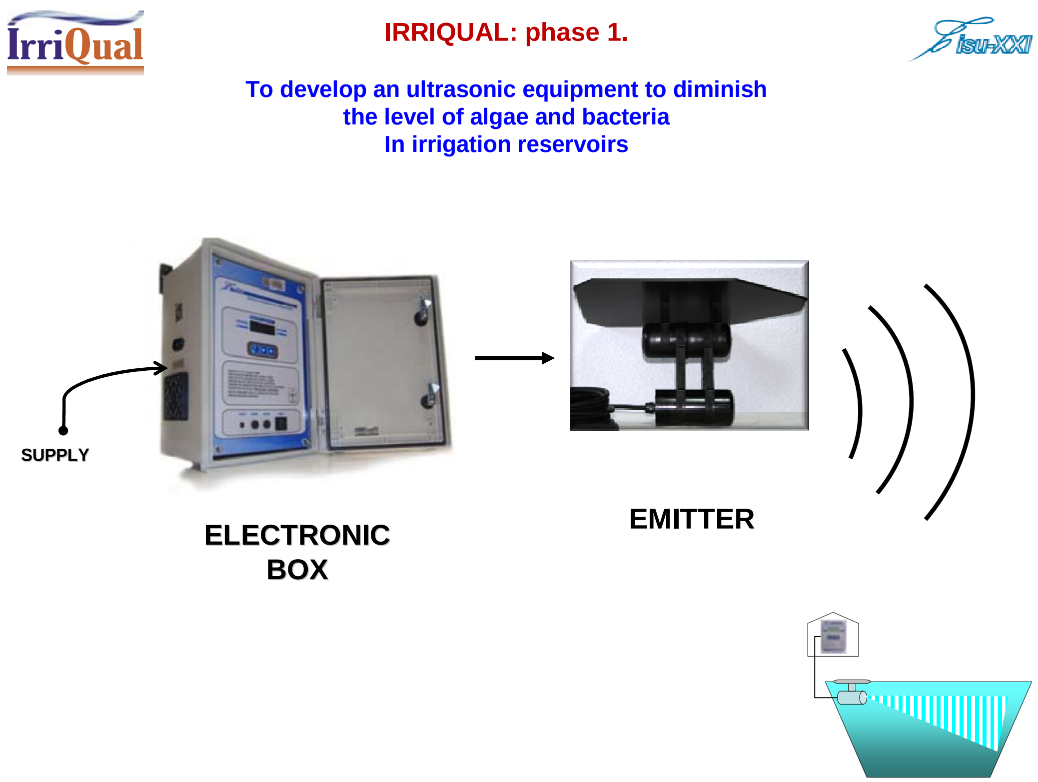
This disinfection system was developed in accordance with a series of premises, which have been incorporated into the equipment during its development and which can now be said to conform its characteristics:

- The ultrasounds emitter must be submergible.
- The treatment is aimed at agricultural reservoirs, which should be borne in mind when considering the costs of production.
- The system must be able to focus treatment on problematic organisms (algae and bacteria) without interfering with other, inoffensive organisms – for example, fish.
- The treatment must be effective as regards the resulting water quality. It is not sufficient for the system to work as a preventative treatment in good quality waters, and it should prove its suitability for all types of water, especially recycled waste waters – the reality frequently faced by growers.
- The equipment must be manageable and permit installation of as many machines as is necessary to treat reservoirs of any dimension.
- The system must be environmentally friendly – non-contaminating and energy efficient.

All these details form part of the TISU equipment, although we have gone one further and made it possible to adapt the treatment to each kind of alga, since each type is affected differently by the frequency of ultrasounds treatment. For this reason, the TISU apparatus has the following characteristics:

- The ultrasounds emitter can vibrate at a wide range of frequencies.
- The microprocessor permits the operator to choose the frequency desired.

- We have developed specific programs for the most common kind of algae.



1.2. PHASE 2. Study at laboratory scale:

(Task 8.2. according to ANNEX I) "Evaluation at laboratory scale of different ultrasound treatments on macro-algae and micro-organisms (months: 11-25). The next step was the selection of most effective ultrasound treatments to eliminate the main algae and micro-organisms present in different water sources. The selection of the treatments will be carried out at laboratory scale by using contaminated water with different algae, as well as water inoculated with different pathogenic and spoilage micro-organisms. The synergic effect of different disinfection treatments combining ultrasound techniques with heat and ozone treatments will be also undertaken at laboratory scale."

Deliverable 42*: "Effects of the ultrasound treatments on the predominant groups of macro-algae and microorganisms present in different water sources"*

This paper examined the effects of ultrasound treatments on the predominant groups of algae and micro-organisms present in different water sources. An evaluation at laboratory scale of different ultrasound treatments and some physical factors that influence on the efficacy of the treatments were also studied.

The study of the effects was carried out at laboratory scale by using contaminated water with different algae c from real reservoirs. The trial was set up using square polypropylene tanks, measuring 2m x 2m x 0.5m. One tank was exposed to ultrasonic waves and another tank was the control tank, (inoculated, but without ultrasonic treatment). The ultrasonic equipment had a power of 150 W and the standard frequencies program of TISU® was used.

The predominant groups of aquatic organisms were studied according to the following classification:

- Filamentous algae
- Unicellular algae: Cyanobacteria and Green Algae.
- Macro-algae.
- Zooplankton
- Bacteria

The results indicated that ultrasound treatment was an effective technique to control the presence of algae in water. The ultrasonic waves provoked irreversible structural damage to the cells, because they altered the membrane integrity and damaged the photosynthetic system. Furthermore, the acoustic cavitation provoked by ultrasonic waves altered the gas vacuole, and even provoked involution of the cell content; therefore the algae suffered a loss of viability. The evolution in algal and bacterial levels indicated decreases in all cases, while, in the control tank, the level of microorganisms increased exponentially. The studies of zooplankton were not so determinant and in this case, the general decrease was a consequence of the parallel decrease in algae.

EFFECTS: on filamentous algae

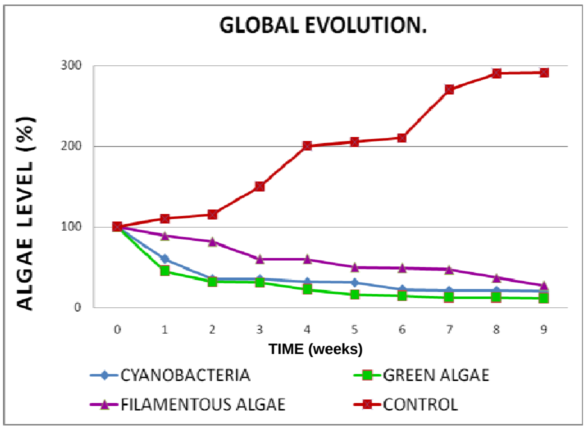
Day 0 Day 5 Day 10 Day 20

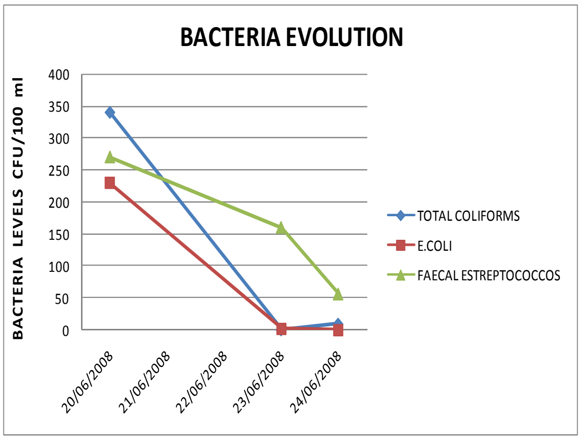
The results showed that:

During the first stages, the level of algae decreased more intensely that in the following phases. Low levels were maintained until the end. Those results indicated that the ultrasonic treatment could act both as a curative method and as preventive method.

Finally the removal rate varied at around 4% in the treated tank, while the final level in the tank without treatment oscillated around 300% of the initial level. This means that the 96% of the algae were removed in the treated tank, meaning that irrigation-related problems would also decrease around this percentage.

The results also indicated that there are some important physical factors that influence the effectiveness of the treatments such as time of irradiation, frequency and power.





1.3. PHASE 3. Studies in real reservoirs.

(Task 8.3. according to ANNEX I): In-situ evaluation of the effectiveness of the disinfection process in real conditions (i.e. irrigation ponds) (months: 22-36). In the last development stage, the suitability of the selected treatments will be validated in real conditions. Therefore, the effectiveness of the treatments will be evaluated, based on the microbial quality of the irrigation water and the reduction of visible algae present in irrigation ponds.

Deliverable 65*:"Efficiency of the ultrasound treatment to different water quality at laboratory scale and in real conditions" (month 36).*

In the third phase of the effectiveness of the disinfection process was studied, using ultrasounds to decrease the levels of algae and bacteria in real irrigation reservoirs. For this, four different types of reservoir were considered, depending on their localization, dimensions, origin of the water they contained and number of machines installed.

RESERVOIR	TYPE 1	TYPE 2	TYPE 3	TYPE 4
LOCALISATION	Siscar, Murcia. Spain.	Tomelloso, Ciudad Real. Spain.	Sapiama, Agadir. Morocco.	Miraflores-Jumilla, Murcia. Spain.
DIMENSIONS	60 x 30x 5 m.	400 x 300 x 10 m.	90 x 45 x 5 m.	300 x 150 x 15 m.
WATER ORIGIN	Untrated Agricultural Waste Water	Water Depuration Station	Undeground Storages and Canals.	Undeground Storages and Canals.
QUALITY OF WATER RECEIVED (1 -10)	2	3	6	9
MACHINES INSTALLED	2 TISU®	10 TISU®	1 TISU®	2 TISU®
OVERALL REDUCTION	80%	70%	80%	95%
OWNER'S EVALUATION	very positive	positive	positive	very positive

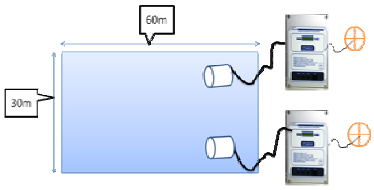
The results showed that the ultrasounds equipment reduced the level of alga and bacteria by around 80% and can therefore be considered suitable for improving the quality of the water intended for irrigation; the process also improved the functioning of the filtering equipment.

Type 1: Small reservoir with very low quality water.

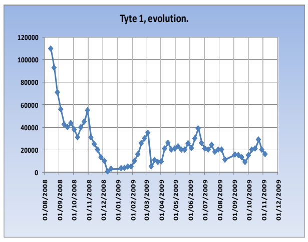
RESERVOIR	TYPE 1
LOCALISATION	Siscar, Murcia. Spain.
DIMENSIONS	60 x 30x 5 m.
WATER ORIGIN	Untrated Agricultural Waste Water
QUALITY OF WATER RECEIVED (1-10)	2
MACHINES INSTALLED	2 TISU®
OVERALL REDUCTION	80%
OWNER'S EVALUATION	very positive

Type 1: Siscar, Murcia. Spain. Before and after the treatment.

Detail of turbidity.



Type 1:small reservoir. untreated agricultural waste water

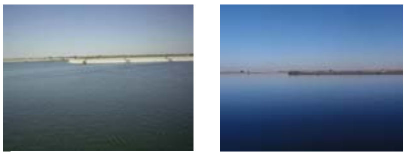


Type 1. Ultrasonic treatment.

Evolution level of algae vs time.

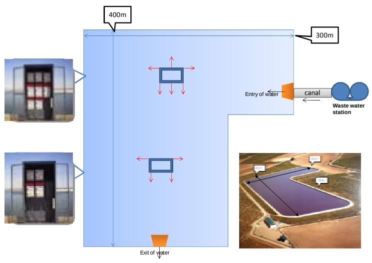
Type 2: Very large reservoir with low water quality.

RESERVOIR	TYPE 2
LOCALISATION	Tomelloso, Ciudad Real. Spain.
DIMENSIONS	400 x 300 x 10 m.
WATER ORIGIN	Water Depuration Station
QUALITY OF WATER RECEIVED (1-10)	3
MACHINES INSTALLED	10 TISU®
OVERALL REDUCTION	70%
OWNER'S EVALUATION	positive

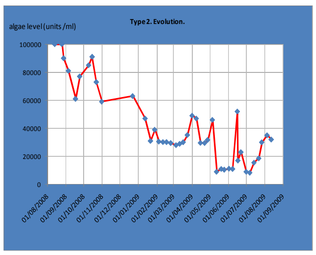


Type 2. 13-08-2008 **Type 2. 13-03-2009**

Type 2. 13-08-2008 **Type 2. 13-03-2009**



Type 2: very large reservoir. Treatment waste water.



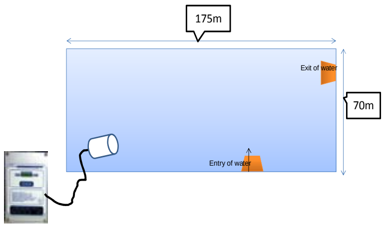
Type 2. Ultrasonic treatment.

Evolution level of algae vs time.

Type 3: Medium sized reservoir with medium water quality.

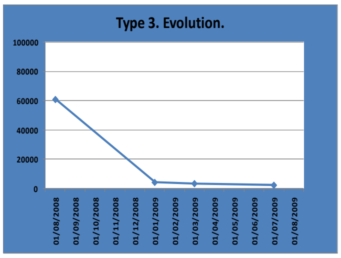
RESERVOIR	TYPE 3
LOCALISATION	Sapiama, Agadir. Morocco.
DIMENSIONS	90 x 45 x 5 m.
WATER ORIGIN	Undeground Storages and Canals.
QUALITY OF WATER RECEIVED (1-10)	6
MACHINES INSTALLED	1 TISU®
OVERALL REDUCTION	80%
OWNER'S EVALUATION	positive


Type 3. Sapiama, Taroudant. Before.



Type 3: Medium sized reservoirs with water of medium quality.

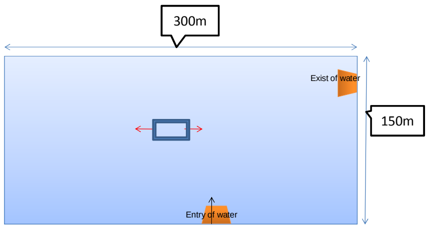

Ultrasounds emitter with float.
Type 3. Sapiama, Taroudant. After.



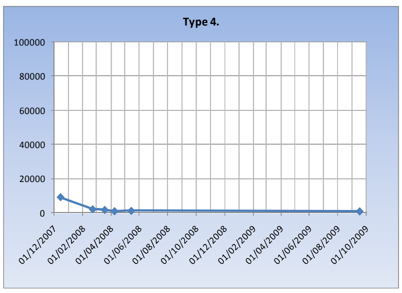
Type 4: Very large reservoir with high water quality.

RESERVOIR	TYPE 4
LOCALISATION	Miraflores-Jumilla, Murcia. Spain.
DIMENSIONS	300 x 150 x 15 m.
WATER ORIGIN	Undeground Storages and Canals.
QUALITY OF WATER RECEIVED (1-10)	9
MACHINES INSTALLED	2 TISU®
OVERALL REDUCTION	95%
OWNER'S EVALUATION	very positive


Type 4. Miraflores. Murcia.
Detail of turbidity.



Type 4: Very large reservoirs with good quality water.



The findings also pointed to the substantial influence that the quality of the water that the reservoirs receive has on the results. The dimensions, to, have an influence in this respect. However, in both cases such an influence can be easily offset by increasing the number of machines installed in a proportion that approximates one machine per 100 m^2

CONCLUSIONS:

The main conclusion is the standardization of the treatment, meaning that the treatment is effective, regardless of the type and size of the reservoir, the type of water and the characteristics of the filtration systems. With the correct number of machine installed (one per 100 m^2) the problem of algae and bacteria can be reduced around of 80%. At real level this means:

- the filtration systems work better;
- fewer chemical products have to be used;
- water quality is improved;
- bad odours and noise are reduced;
- post harvest infections are avoided.

WP 9: WATER IRRIGATION AUTOMATISMS

OBJECTIVES: Development of a prototype real-time, interactive sensor arrangement for measuring soil moisture and trunk diameter fluctuation was assembled and tested for precisely and automatically scheduling irrigation in fruit trees.

Hardware

The sensor arrangement is depicted on "Photo 1" and consists of a centrally located receiver connected to a computer and communicates, through Radio Frequency Identification RFID, with multiple sensor nodes installed in the field. Each sensor node consists of a multisensor capacitance probe (up to six capacitance sensors), an LVDT sensor, a specially designed circuit board, and a radio transmission unit, powered by a solar panel, which continuously collect and transmit data to the central receiver.

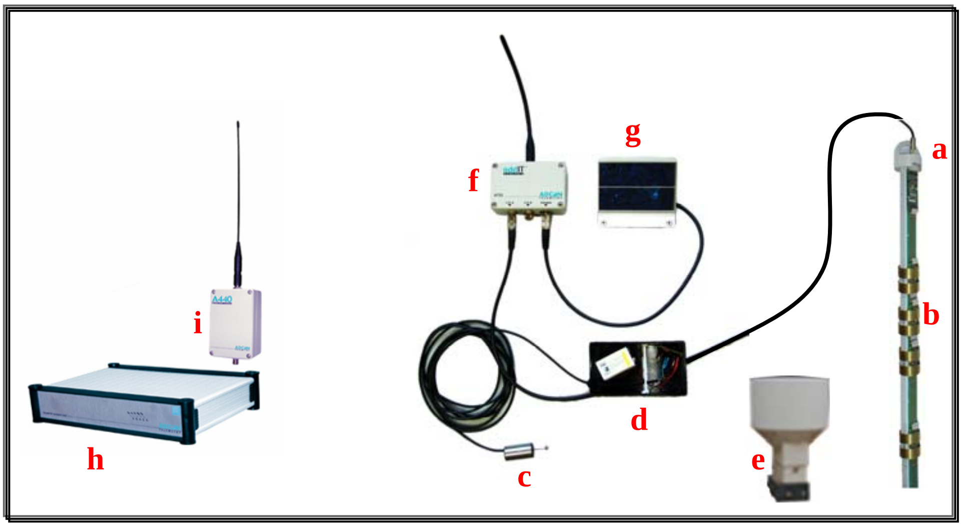


Photo 1: Components of the automatic Irrigation scheduling prototype. a) multisensor capacitance probe, b) capacitance sensor, c) LVDT sensor, d) special circuit, e) rain gauge, f) radio transmission unit RTU, g) solar panel, h) telemetry gateway, i) radio modem.

This arrangement offers, on one hand, a real time monitor of the micro-morphometric variations of the trunk diameter and on the other hand, it monitors the relative soil water content and the vertical advance of the wetting front during irrigation. A PC-algorithm was developed to assess the soil-plant water status and consequently to take the corresponding decision on "When?" and "How much water to apply?"

A total of at least 6 nodes of sensors are required to get a reliable automatic irrigation system. The first set of 3 nodes is installed on healthy trees maintained at optimum soil water conditions by applying daily irrigation equivalent to 1.1 ETc. These are the control trees. The next set of 3 nodes is installed on three trees selected randomly from within the rest of the orchard. These are the observed trees.

Software

The PC-algorithm uses a series of input variables and thresholds values to run properly and prevent undesired field troubles. The input variables are described as follow:

12- "Start_time": it is the daily time at which the PC-algorithm is executed. It is recommended to be executed daily after sunset.
13- L_MxTD and U_MxTD values: These are the lower and upper limits of the time interval through which the maximum trunk diameter or "MxTD" is reached. The MxTD occurs normally in the period between dawn and 3 hours after sun rise.
14- L_MnTD and U_MnTD values: These are the lower and upper limits of the time interval through which the minimum trunk diameter or "MnTD" is reached. The MnTD occurs normally in the period which extends from 1 hour before noontime till sunset time.
15- $MDS_{i\text{-}obs}$: It is the maximum daily shrinkage of the observed trees. It is calculated as the difference between MxTD and MnTD.
16- $MDS_{i\text{-}ctr}$: It is the maximum daily shrinkage of the control trees. It is calculated as the difference between MxTD and MnTD
17- SI_i: The signal intensity is computed as the ratio of the $MDS_{i\text{-}obs}$ value of the observation tree to the $MDS_{i\text{-}ctr}$ value of the control tree.
18- SI_threshold: It is the value of the signal intensity above which the plant is considered under water-stress conditions and irrigation should be triggered ON.
19- MAD value. It is the management allowable soil-water depletion above which any decision on additional water application driven by the plant water status should be carefully supervised.
20- Min_IrrigTime value. It is the minimum time of irrigation required for the wetting front to move through a wet soil from the surface down to the limit of the plant root zone.
21- Max_IrrigTime value. It is the maximum time of irrigation required for the wetting front to move through a dry soil from the surface down to the limit of the plant root zone.
22- Δ_SWC_{max} value: It is the percentage of increment in the soil water content at the lower limit of the plant root zone and upon which the decision on irrigation cease is taken.

The developed main algorithm consists of 2 complementary sub-algorithms called "A" and "B". On daily basis, the sub-algorithm "A" reads the values of the trunk diameter recorded during the previous 24 hours, filters them and computes the corresponding signal intensity "SI". Consecutively, the sub-algorithm "B" reads the SI values and decides whether to irrigate or not. In the affirmative case, it computes every 15 min the increments in the soil water content or "$\Delta\theta_i$" at different depths and estimates the advance in depth of the wetting front below the emitter. When an increment of 20% in $\Delta\theta$ is detected at the deepest sensor installed at the lower limit of the plant root zone, the irrigation system is turned OFF. A detailed diagram of both sub-algorithms A and B is shown on figures 1 and 2.

Description of the first sub-algorithm "A"

Every day at a predetermined time schedule (e.g. 08:00 PM), the algorithm runs over the values of the trunk diameter recorded during the previous 24 hours and execute the following procedures:

1- The recorded values are reproduced using a single exponential smoothing equation with minimum RMSE. This procedure aims to eliminate any abrupt value due to electronic troubleshoots and to verify that the evaluated curve follows a standard circadian pattern.
2- The daily maximum and minimum values of the trunk diameters ($MxTD_i$ and $MnTD_i$ respectively) are identified and memorized together with their time of occurrence. The time of occurrence is used in the background to check if the analyzed curve follows the expected pattern or not.
3- The daily difference between the $MxTD_i$ and the $MnTD_i$ is computed and registered in the memory as the maximum daily shrinkage or MDS_i.
4- The signal intensity index or SI is computed as the ratio of the $MDS_{i\text{-}obs}$ value of the observation tree to the $MDS_{i\text{-}ctr}$ value of the control tree.

Description of the second sub-algorithm "B"

This procedure is triggered in continuous to the first one and follows the following steps:

The default state of the irrigation system is OFF.

1- If the average SI value is less than the SI_threshold value then the irrigation system remains OFF.
2- If the average SI value is higher than the SI_threshold value and the soil water store "SWS" is lower than the MAD value then:
    i. The irrigation system is triggered ON.
    ii. The initial time "t_0"is recorded
    iii. The initial value of the soil sensor at the lower limit of the plant root zone is recorded "θ_0".
    iv. Every 15 min:
        1. The elapsed time "$\Delta t = t\text{-}t_0$" of irrigation is compared to Max_IrrigTime and Min_IrrigTime:

   a. If Δt is larger than Max_IrrigTime then the irrigation system is triggered OFF and an ALARM message is issued.
   b. If Δt is shorter than Min_IrrigTime then an ALARM message is issued.
2. The increment in the soil water content "Δ_SWC = $\theta - \theta_0$", at the lower limit of the plant root one is compared to Δ_SWC_{max} value:
   a. While Δ_SWC is less than Δ_SWC_{max} value then the irrigation system is maintained ON.
   b. If Δ_SWC is greater than Δ_SWC_{max} then the irrigation system is turned OFF.

3- If the average SI value is higher than the SI_threshold value and SWS is higher than the MAD value then:
   i. The irrigation system is triggered ON.
   ii. The initial time is recorded
   iii. The initial value of the soil sensor at the lower limit of the plant root zone is recorded
   iv. An alarm message is issued warning about abnormal conditions in the system/field.
   v. A counter is initialized to count the number if irrigation events during which the previous conditions are fulfilled.

A graphical user interface "GUI" is under development. It includes data entry about the soil, the plant and the atmosphere. Soil characteristics are used to recommend the appropriate position and depth at which the soil sensors should be installed. The plant phenological stages are included to be considered when regulated deficit irrigation strategies are implemented. Climatic data are added to compare the amount of irrigation water with the actual climatic demand.

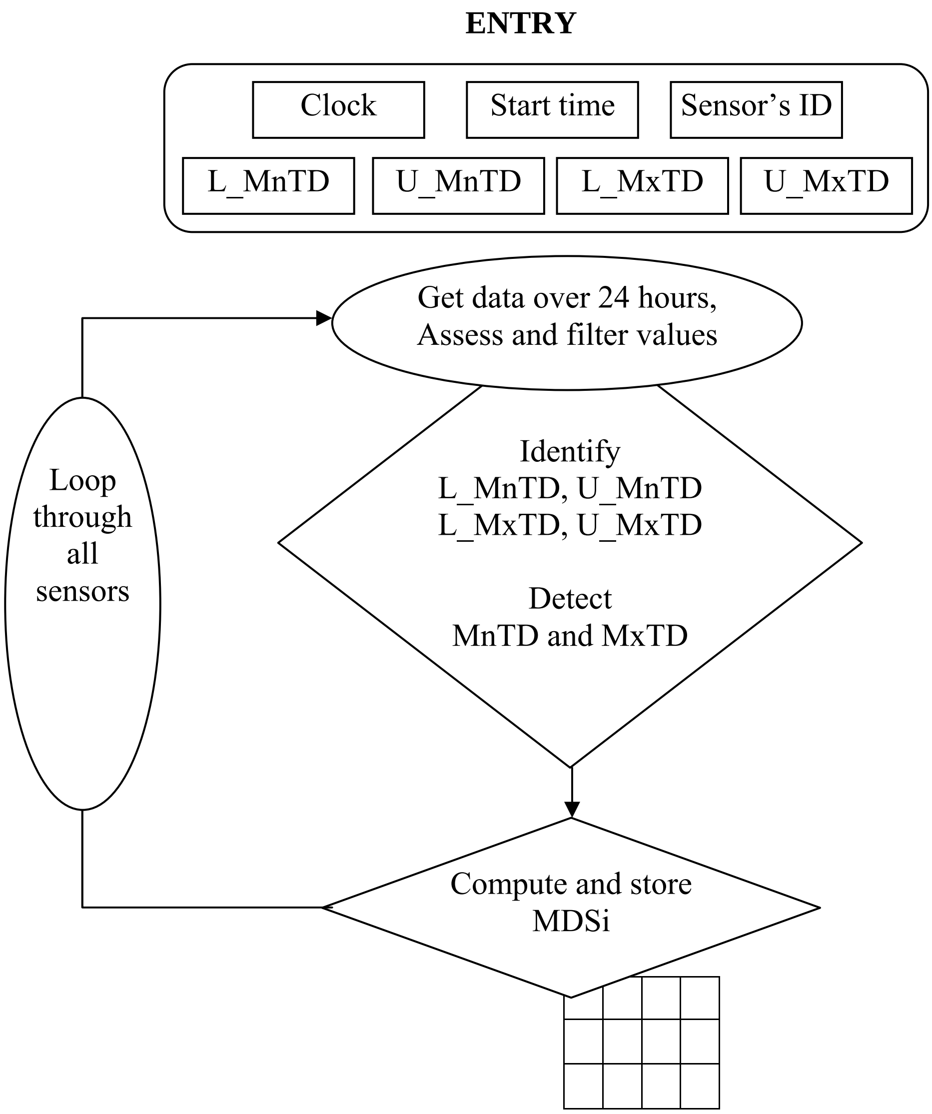


Figure 1: Structure of the sub-algorithm "A" which computes the signal intensity derived from the trunk diameter variations..

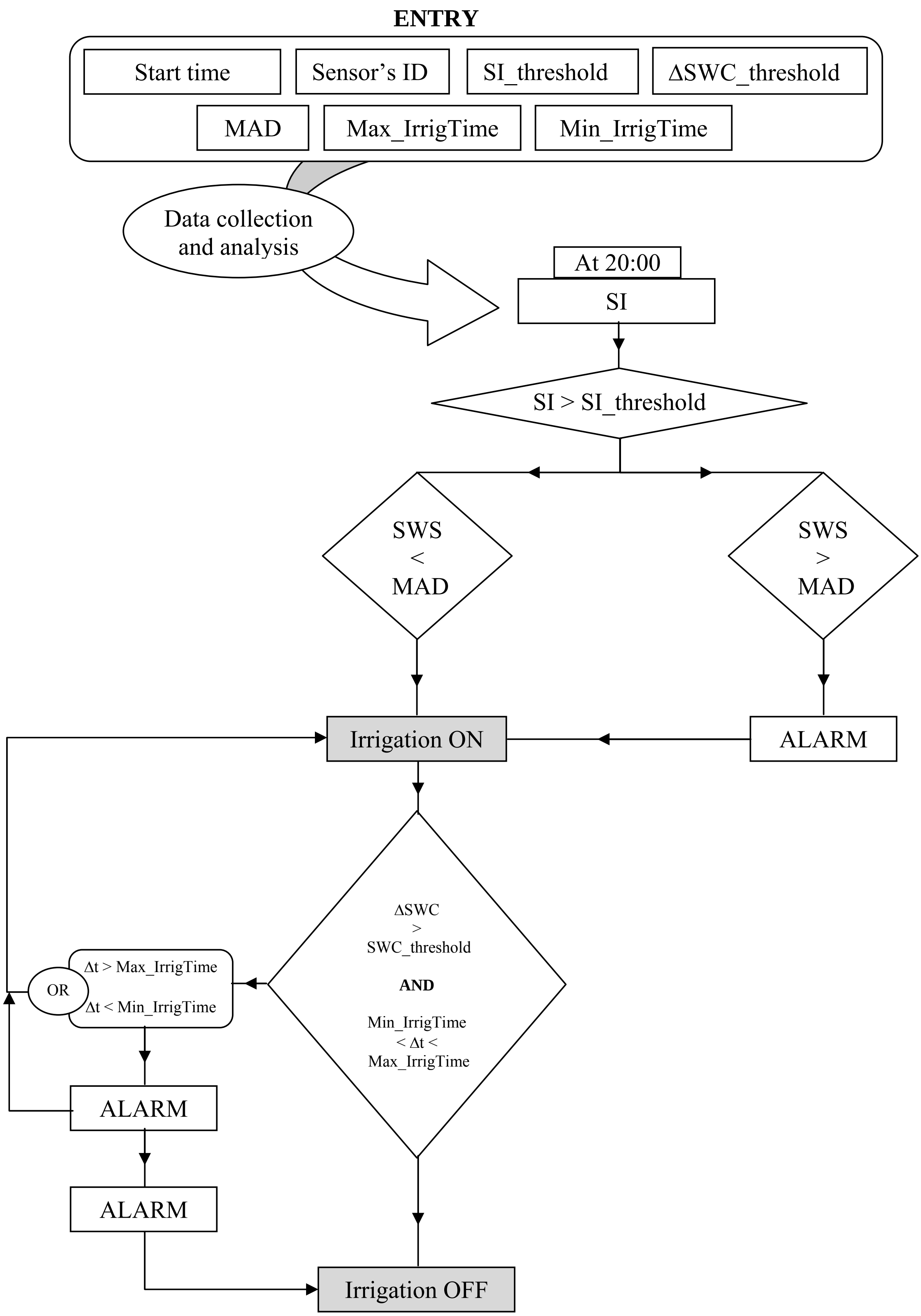


Figure 2: Structure of the sub-algorithm "B" which controls the irrigation electro-valves.

WP 10: FOOD RISK ASSESMENT

CONTRACTOR: CSIC

MAIN FOOD RISK ASSESMENT CONSIDERATIONS:

Consumption of fresh fruits and vegetables continues to increase in many countries owing to consumer preferences for fresher, more nutritious foods that also happen to meet the needs of busier lifestyles. Nevertheless, Globalization of the food supply introduces hazards from these regions into other areas and disseminates pathogens over wide geographical areas. In addition to their increasing popularity in consumption patterns, fresh fruits and vegetables have also become increasingly important vehicles in foodborne disease statistics. Consequently, consumption of fruit and vegetable products is commonly viewed as a potential risk factor for infection with enteropathogens such as Salmonella and Escherichia coli O157, with recent outbreaks linked to lettuce, spinach and tomatoes. Routes of contamination are varied and include application of organic wastes to agricultural land as fertilizer, contamination of waters used for irrigation with faecal material, direct contamination by livestock, wild animals and birds and postharvest issues such as worker hygiene. The ability of pathogens to survive in the field environment has been well studied, leading to the implementation of guidelines such as the Safe Sludge Matrix, which aim to limit the likelihood of viable pathogens remaining at point-of-sale. The behaviour of enteropathogens in the phyllosphere is a growing field of research, and it is suggested that inclusion in phyllosphere biofilms or internalization within the plant augments the survival. Improved knowledge of plant–microbe interactions and the interaction between epiphytic and immigrant micro-organisms on the leaf surface will lead to novel methods to limit enteropathogen survival in the phyllosphere.

This is the general situation, but in the framework of the IRRIQUAL project after making and exhaustive bibliographical revision and monitoring the microbiological data obtained in the project, we could conclude that variation in the safety status of considered products as consequence of changes in irrigation procedures and quality of water is almost neglectable. Probably the lack of important variation on contaminating microorganisms is mainly due to the nature of the vegetables considered in the project, large trees that produce fruits at a relatively high distance from the soil.

The main conclusion regarding the safety of the considered fruits is that the contamination could be a risk after product is harvested and in this case washing to a recommended protocol is an appropriate risk management action for the vast majority of consumption events, particularly when good agricultural and hygienic practices are followed and with the addition of refrigerated storage for low acid fruit. Additional safeguards are recommended for aggregate fruits with respect to the risk from protozoa.

To carry out a Risk Assessment could be of interest if the scope of the assessment is limited to pathogenic micro-organisms in fresh fruit. ‘Fresh fruit’ is defined as ‘perishable fruit that has not been frozen or manufactured into articles of food of a different kind or character'. Elements of a USDA definition in the regulations (7 CFR Part 46; United States Department of Agriculture) of the Perishable Agricultural Commodities Act has been used in this definition. In this case, the output of the risk assessment could be a list of organisms that constitute a significant risk (considering both likelihood and consequence) in the consumption of fresh fruits allowing a selection of appropriate risk management measures. The Codex elements of risk assessment (hazard identification, hazard characterization, exposure assessment and risk characterization) could be applied qualitatively to identify and assess each potential hazard in turn (Codex Alimentarius Committee 1999). With this approach in mind any data (or the lack thereof) can be weighed subjectively in the estimation of risk from each hazard.

WP 11: COLLECTION OF KNOWLEDGE ON PRESENT SITUATION FOR IRRIGATION AND FERTILIZATION AND DEVELOPMENT OF Irrigation Best Management Practices

OBJECTIVES:

A. Acquire knowledge on the present situation for irrigation and fertilization practices for the major tree crops in Lebanon (peach, citrus), Greece (peach, olive) and Morocco (citrus)

B. Conclude on specific drawbacks and strong points for each area and crop and ways to help adoption of best management practices (BMPs) to improve irrigation and fertilization efficiencies

C. Based on the above conclusions targeted irrigation BMPs for various uses and crops were developed.

CONTRACTORS: UTH, IAV, LARI

A. Present situation for irrigation and fertilization practices for the major tree crops of each participating country

There were three partners involved. The **IAV Morocco** contractor completed survey work on citrus as the most important tree crop in Morocco and of major export potential. The **LARI Lebanon** contractor collected information on peach and citrus in two areas of the country. The **UTH Greece** contractor collected information for olive in one region and peach in two regions of Greece.

The information gathered included practical information including the irrigation practices used, infrastructure available, monitoring tools used or available, fertilization practices and the willingness to change present practices to more efficient irrigation and fertilization methods and practices.

In short, irrigation and fertilization practices could be seriously improved; monitoring tools were or were not available but often improperly used; the willingness to change depended on the water scarcity in the area and to a lesser extend on water cost; guidelines for irrigation and fertilization BMPs would be the basic tool, if properly used from the involved stakeholders, to improve current practices.

B. Conclusions on specific drawbacks and strong points for each area and crop and ways to help adoption of irrigation and fertilization BMPs

1. LARI, LEBANON

The diagnosis of Stone fruit trees and citrus trees irrigation and fertilization practices in Lebanon was conducted following a survey of a large sample of 260 farms in the main producing zone of citrus (Coastal South) and of Stone fruits (Bekaa Valley).

The results obtained from the survey led to the conclusions:

The management of irrigation and/or fertigation is done in an empirical manner. The farmers are not adequately educated and there are not effective extension services for farmers.

In one area of 4000 ha, water from the Litani river dam is used in a pressurised network to irrigate all farms connected. Here management of water use is easy as the water volume used can be easily followed and improved. In other areas water from the Litani river network is supplied in reservoirs and water can (and is, in a large percentage) be applied by pressurized drip and microsprinkler systems. Finally, in many areas, the water is pumped from many source points from a large number of wells of interconnected underground aquifers above their capacity to refill, thus reducing groundwater availability which will lead to further water shortage.

Although several farms still practice flood or basin irrigation, drip and micro spray systems are widely used. The citrus production is decreasing due to old cultivars, better revenue from bananas in the same region and the large size of trees. Basin or microsprinkler irrigation are practiced mainly on this crop, thus its abandonment will result in reduced water consumption for citrus, but larger use of water for banana plantation irrigation.

The adopted programs of fertilization are not scientifically based. The total application of major elements N, P, K in 2006 was much higher and almost double of the regional recommendations. During 2007, due to high fertilizer prices, most farms were underfertilized. The changes in fertilization practices over 1-2 years may affect fruit production but will not affect soil fertility. On the opposite, low income from the farms may result in long term underfertilization, which will result in decreased soil fertility.

Monitoring irrigation is not yet well understood in many orchards. It depends more often on empirical estimation by the farmer and thus the amount applied depends on duration of irrigation. Such approach led to extreme variations in terms of quantities supplied per tree. There is no used equipment in the farms to evaluate soil water content or plant water needs. This is mainly due to lack of training of the growers and advisors, the low concentration and dependence of small farms on large cooperatives or exporting firms, which could force them to adopt improvements in any aspect of production practices including the high cost irrigation and fertilization.

We also noticed positive attitude and acceptance from farmers to switch to pressurized irrigation or any method, such as RDI, which would reduce water use and thus irrigation cost. But the farmers' motive was mostly that reducing water use would reduce their energy input (pumping costs) and not saving water.

It is clear that water scarcity is an important issue in Lebanon. Any possible improvements and innovations in the irrigation management, as the ones proposed from the IRRIQUAL project, would have little influence to Lebanese citrus and stone fruit growers if they are not forced by central authorities or if proper training is not made available.

As far as the adoption of Irrigation Best Management Practices is concerned the following are necessary for the Lebanese citrus and stone fruit growing areas:

Cooperatives or central authorities, like the Litani River authority, should develop a monitoring system for water quantities available, used and required, and water quality over each region as this will be necessary for all other management activities. The infrastructure is present in some areas and the knowledge has improved due also to the involvement of Litani River authority and LARI research institute to the IRRIQUAL project.

Properly equipped meteorological stations could supply information on timely water needs of trees for irrigation. A good framework of meteorological stations exists in Lebanon and data central acquisition could actually improve the knowledge of water requirements by each crop in each area.

Training could encourage growers to adopt simple or low cost techniques such as tensiometers or Techmark capacity probes to evaluate irrigation needs, leaf nutrient analysis for fertilization, water quality measurements, etc. The presence of specialised personnel, its further training in best management practices and technological innovations available would make them able to become leaders and guides for training farmers and practitioners to better management of irrigation and fertilization. This was to a large degree achieved by the IRRIQUAL project.

Central regional or governmental reinforcements could force growers to restrict water use by installing water volume meters in each well together with logging information on crops and area irrigated per user. This would make water use monitoring possible for authorities but the farmer as well, as measuring the water volume applied in an irrigation event is not always easily measured as, an example, in flood irrigated farms.

Central governmental support could also be given on subsidizing the installation of pressurised drip irrigation systems to conserve water together with proper guidance on water use, and the leaf, soil and water analysis laboratories and costs. This would be major support to improve productivity of the farm and of the water used and, in most cases, to improve fruit quality. This, in turn, would support better farm use, increased farm income and rural population well-being.

Universities and LARI should further support education of agriculturists on irrigation and fertilization BMPs and innovations.

2. UTH, GREECE

Questionnaires were collected from three tree growing areas in central and northern Greece: Anchialos, with intensively cultivated and heavily irrigated olive farms in central Greece; Tyrnavos, a peach and pear producing area in central Greece with somewhat scarce water resources; and Veria, a peach producing area with ample water resources at the moment.

Olive production area in Anchialos, central Greece

The olive farms in Anchialos region are intensively cultivated mainly for table olives with many improvements compared to traditional olive production areas. There is no systematic guidance by experts on most of farm management practices besides plant protection, thus many mistakes were found in the way olive cultivation is done in the area. These mistakes are mainly overfertilization and overirrigation. It is characteristic that almost nobody takes into consideration the farm soil characteristics, leaf analysis, expected fruit production and tree vegetation growth to decide when and how much fertilizer and water to apply. The data collected from the questionnaires and the experimental farm used in the area have shown us that the outcomes of the IRRIQUAL project would easily improve the current practices to reduce water use, improve fertilizer efficiency and, most probably, improve final product quality, which today is good as far as fruit size is concerned but low as taste and storage ability of table olives and very low for oil content. At this moment water scarcity is not a problem farmers are faced with and this results in their unwillingness to change any of the practices they apply today. Only proper training and reasoning, using the outcomes from the IRRIQUAL project as well, would help in understanding the importance of better irrigation and fertilization management.

At this moment, private collectively owned deep wells supply ample water by using electricity for pumping, so conserving water will not be easily adopted. Of course, possible future reduction in water quality and quantity would result in easier adoption of innovations by the local farmers. The one of the problems in implementing efficient irrigation water management in the area is the presence and use of collective water wells, which makes irrigation scheduling more difficult to implement. With proper technical guidance and training, collective water wells could very efficiently be used after the decision of a periodic irrigation schedule between the farmers in each well and the installation of identification card readers in each well. In this way, each grower would have his (her) own ID card and would be charged the water quantities used per farm he (she) cultivates. Regional mapping of farms has been completed and electricity is used for all wells, thus making the above water use management system easily applicable.

Soil water monitoring is also difficult to implement as most soils are heavy but also stony, making capacity probe installation difficult and readings without any secure outcome. The large size olive trees with the trunk having various abnormalities (outgrowths) are also bad candidates for using sap flow meters or trunk size changing equipment. Thus, we could at least manage to develop an ETc calculation and dissemination system to convey information of 100% ETc to the growers and advisors of the area. With the proper training on the irrigation management, a good use of this information would be expected and a much better efficiency of water use of the local water resources will be achieved.

As far as fertilization is concerned, there were no leaf analyses of olive farms to guide us on their needs. Scarce knowledge of the soils of the area we collected concluded that the soils contain ample silt and lower clay, ample potassium and magnesium and low (1-2%) organic matter (due to continuous soil cultivation over the last 4 decades). More efficient fertilization can be applied only with proper training and wider use of the low cost leaf nutrient analysis in public and private facilities present in the area. As a number of table olive farmers are already certified under integrated production protocols, they have already adopted fertilization based on leaf and soil analysis.

Peach production area in Tyrnavos, central Greece

The peach farms in Tyrnavos region (Central Greece) produce fruit for canning and fresh market on mainly very good quality soils (mainly sand and much less clay) for tree cultivation. Water level in the underground aquifers was a few meters below the surface due to the neighboring Pinios river, but is rapidly decreasing due to overuse of water capacity of the aquifers for vast areas of cotton and corn production. Thus, water scarcity is of concern in the area.

In only one part of the region centrally managed water distribution systems exist with public wells and pressurized distribution systems. In that part of the area, water use management may be easier as the crops and the area irrigated is easily logged. In the rest of the region, most wells are private and many are collectively used from a number of farmers having small parcels of land around the well. Thus, their use is completely independent and almost unable to be controlled because it is not obligatory for the farmers to report what crops they cultivate and to what extend (as corn, cotton, vegetables and tree crops are cultivated with any rotation the farmer decides based on expected prices) and there is no central cooperative or authority collecting this type of data.

Due to Integrated Production protocols used in the area many improvements were done on cultivation techniques including plant protection, pruning and weed management. On the other hand, monitoring of plant nutrition and water needs and quality is not performed at all or regularly, thus these practices are basically done without any guidance. Water quality data we collected showed a significant contamination of the aquifer from nitrates as most wells contained around 50 ppm nitrates. This should be taken into consideration for fertilizing the low nitrogen requiring tree crops like apricots and pears cultivated extensively in the area and to a lesser extend the rest of the tree crops. Water use efficiency is good due to widely used drip irrigation with in-line pressure compensated drippers (very few farms are irrigated with microsprinklers), but many improvements could be proposed for irrigation volume and scheduling. This, of course, would require the setup and management of properly equipped meteorological stations to calculate and disseminate water use requirements per crop over the irrigation period. The proper training of advisors and farmers could help in the adoption of better irrigation practices and improved water use efficiency in the area. The best management practices guidelines would also help adoption of better techniques and understanding of irrigation management.

The fertilization of peach farms is characterized of luxurious use of all elements through soil applications and fertigation. Due to Integrated Production certification requirements many farmers have completed soil and (fewer farmers regularly) leaf analyses. This makes more difficult to decide how much and what to be used every year at each farm depending on the soil, crop vegetation strength and expected crop. Proper training and better enforcement of the requirements for leaf and soil analyses would improve fertilization efficiency and tree health and productivity.

In general, the unwillingness of farmers to adopt innovations to irrigation management could be overcome by forcing them through local authorities or by training them on the outcomes from the IRRIQUAL project. Thus, training on the importance of water saving on fruit quality and environmental protection, on the proper use of irrigation water to conserve it, on the methods to evaluate water needs and the integrated approach on irrigation and fertilization is probably the most important way to achieve some improvements in water use in the area.

Peach production area in Veria, northern Greece

The peach farms in Veria region (Northern Greece), the major peach producing region in Greece, are focused on canning peach production and are certified under Integrated Production protocols. This certification has introduced many improvements on peach cultivation techniques including fruit harvest time and quality, weed and prunings management and plant protection, many improvements on fertilization although variable, but only a few things on proper irrigation management. Throughout the region there is ample infrastructure to collect river water and distribute it mainly by open canals to all farms in each district. The farmers usually pay a low fee (around 60 euros per ha) and they can use as much water as they wish. The low cost freely available irrigation water in ample quantities makes reducing water use by more efficient irrigation techniques or the use of appropriate instrumentation and methodology not easily adoptable. Thus many farmers still flood irrigate their peach farms with detrimental effects on fruit quality but with low cost. As the water is available through a network of open canals, pressurized systems for drip or sprinkler irrigation are costly, but, through the cooperatives and due to Integrated Production certification needs, many farmers progressively adopt these costly systems for more efficient irrigation and better fruit quality. The strong farmer unions and the adequate number of farm advisors for integrated production (in parallel with the regular guidance meetings with the farmers) could be useful in introducing irrigation innovations through proper best management practices. Unfortunately, the low prices for peaches this last two periods made transformations slow down and all involved decision makers to be focused on rescuing the production system to sustain the economic viability of the region as peaches were and are the major crop produced and any other fruit species can be extensively cultivated and there is not enough market for any fruit crop.

Thus, there are many possibilities for the introduction of innovations to irrigation management in the three studied areas in Greece based on the work completed by the IRRIQUAL project, but require different strategies for each area.

3. IAV, MOROCCO

The diagnosis of citrus irrigation and fertigation in Souss valley area was conducted following a survey of good size sample of 33 farms in the main producing zone of citrus (Taroudant and Ouled Teima). Sampling is based on very scientific criteria that include size of the orchard and GAP certified or non-certified. Other parameters include location near to main roads and the relationship with GPA (Groupe des Productions Agricoles).

The results obtained from the survey led to the conclusions:

- The majority of interviewed farmers have low training level in term of school education. Therefore, the management of irrigation and/or fertigation is done in an empirical manner. These persons require training but will adopt innovations in a slower manner except if these improvements in water management proposed through IRRIQUAL or other related projects could be enforced from higher level stakeholders (exporters, local authorities, technical advisors is charge).

- The main variety is Clementine traditionally well known and appreciated followed by another late Clementine cultivar named 'Nour'. The two varieties aim to prolong the harvesting season of Clementine. Economical considerations justify the choice of the two important varieties. Moreover, the farmers have expressed their satisfaction with the two varieties' profitability during the last years.

- The application of quality standards and traceability required by GAP certification standards has contributed to the improvement of production practices. Technical advisors following regular visits to farms and proceedings to mineral analyses are a good illustration. These technical advisors could be the target training group for innovations and better irrigation water and fertilization management of citrus orchards.

- The scarce water resources in the region were translated by a real running towards mobilization of water at orchard level. The presence of an important number of water resource points, the abandonment of many wells and tubewells, successive deepening of wells and tubewells, systematic installation of basins for the storage of water are aspects which are going to considerably weigh down the cost of pumping and thus to push the farmer to reduce water wastage.

- Although several farms still practice the gravity irrigation, drip and micro spray systems are widely used. They were installed by professional specialists. Due to low water quality, the heads of filtration stations are either equipped suitably by filters for filtration of pumped water or no. Maintenance of filters is systematic, daily in the majority of farms, but can go up to two or three times a week in others.

- Connecting farms to electricity network facilitated the use of immersed pumps assuring that water is pumped from deep wells. At the same time, the installation of electric-powered motor pumps at the level of basins helped minimize load loss and gaining pressure for orchard irrigation with drips or micro-sprinklers.

- The adopted programs of fertilization are not rationalized according to the varieties of citrus, types of soil, exported elements by fruit and pruned plant materials. The programs of fertilization were standardized for all the varieties and for all the situations. Total application of major elements N, P, K is very high and almost double of the regional recommendations. In collaboration with the Good Agricultural Practices application managers, this matter could seriously be improved as overfertilization straightforward negatively affects fruit quality, the environment and increases the production costs. The Fertilization Best Management practices developed through IRRIQUAL are constructed towards efficient fertilization and nutrition of citrus trees and their adoption could help towards cost reduction and fruit quality improvement.

- Monitoring irrigation is not yet well understood in many orchards. It depends more often on proper estimation of the farmer and thus the amount needed depends on time of irrigation. Such approach led to extreme variations in terms of quantities supplied per tree. Indeed, the hourly supply varies considerably, not only from farm to another but sometimes even within the same orchard depending on adopted densities, flow rates of drippers and the number of drippers per tree. Proper choice of drip lines pressure-adjusted and proper irrigation layout design in the orchards could reduce this lack of irrigation uniformity.

At the present time, water scarcity is a major concern for citrus producers in the main production zone in Morocco. The use of many deep wells to withdraw underground water makes future questionable. On the other hand, the citrus producers have big farms, they are working collectively with Citrus Producing and Exporting Groups and many are certified in the Good Agricultural Practices protocols. Thus, cooperation and training are easy to implement. So we believe that the irrigation best management practices can easily be adopted in many farms in the area. We also believe that innovations in irrigation management for conserving water could easily be adopted as long as water resources are scarce and citrus prices are good.

The use of modern equipment for monitoring plant water requirements and for supplying water to the plants as needed has been in the rise during the last 5 years; these instruments include compact weather stations, capacitive probes, dendrometers (LVDT sensors), tensiometers, and data collected using remote control. The soil humidity readings using the capacitive probe can be influenced by several factors such as salinity, temperature, clay content, and organic matter content. Our studies have demonstrated that the technique of capacitive probes is not fully perfected. The difficulties appear already at the time of installation of the probes and persist at the interpretation of the curves of variation produced by water movement in the soil.

Furthermore, construction of rainwater collecting points such as ponds should be the governmental intervention in the area for more sustainable management of water resources.

Through the IRRIQUAL project innovations on irrigation management were developed, knowledge was accumulated, best management practices were assembled and some training was realised. Thus, our effort would be to continue this training, to further publicise the IRRIQUAL results in an easily understandable manner by the stakeholders and, furthermore, to develop together with authorities and cooperatives guidelines to be adopted or forced to be applied by the water users. These have to be coupled with the effects of proper irrigation and fertilization on fruit quality, which is of the highest importance with citrus destined for export markets.

Available data indicate that water requirements for a citrus grove under drip irrigation are in the vicinity of 800 to 900 mm/year in the citrus growing area of Morocco. The 800 mm/year is the threshold limit that seems to have consensus among practitioners and gives an optimum yield (total production, fruit size and quality). In addition, the scientific research accomplished in the IRRIQUAL project showed that a young 'Nules' Clementine grafted on *Citrus macrophylla*, and planted at 1666 trees/ha, produces, at its second year after planting, 45 tons of fruit per ha, for a water height of less than 400 mm. At a regional scale, a rigorous follow up using capacitive probes and dendrometers led to production of approximately 40 tons/ha for a 6-year old orchard of early Clementine for a water quantity of 550 to 600 mm.

C. Development of irrigation (and fertilization) best management practices

The scope of this work was the development of irrigation and fertilization BMPs with the incorporation of the collected knowledge on present situation for irrigation and fertilization for each crop, the conclusions from the above of major points related to the development and adoption of the BMPs and the innovations and knowledge developed on irrigation through the IRRIQUAL project.

The following were developed

A. The detailed irrigation BMPs which are meant to be used by persons involved in irrigation management with a certain knowledge background to be qualified for irrigation management (certain farmers, governmental and private stakeholders related to irrigation). They cover in 56 pages in detail the following:

Summary

Introduction

Basic Principles of Irrigation

Planning New Irrigation Systems

Pre-Season Checks

Planning the Season's Irrigation

Operating the Irrigation System

Reviewing the Seasons' Irrigation

Tables with various useful data and information sheets

B. General irrigation BMPs were developed for public dissemination with the purpose of pointing out the importance of proper management of irrigation as a cultural practice to properly use irrigation water and distribution systems (see below in detail). They contain in 5 pages with short paragraphs the following:

Rate irrigation highly within the management system

Get to know the soils on the property

Design, construct and maintain irrigation systems correctly

Monitor all aspects of each irrigation event

Use objective monitoring tools to schedule irrigation

Use more than one tool for scheduling irrigation

Retain control of irrigation scheduling

Remain open to new information

C. Specific irrigation BMPs were developed for use by all involved stakeholders (farmers, monitoring personnel-scientists, local authorities, etc). These specific BMPs were developed for olive, peach and citrus. The BMPs for the first two crops were written in English and Greek and for the third crop in English and French. The specific irrigation BMPs contain (as an example in olive):

Important points from the physiology of olive tree

The soil of the olive orchard

Water application method

Quantity of irrigation water

Irrigation with high conductivity (saline) water

Irrigation and olive tree nutrition

Irrigation and soil - weed management

Irrigation and pests and diseases

Conclusions

D. Specific fertilization BMPs were also developed for olive, peach and citrus to be used from all interested stakeholders. The fertilization BMPs contain (as an example in olive):

Introduction

Planning of fertilization management before planting the olive orchard

Planning of fertilization management during the olive orchard life span

Fertilizing during the first years of the olive orchard

Fertilizing mature olive orchards including:

- Quantity and fertilizer materials to be used
- Time and method to apply the fertilizing materials
- Evaluation of fertilization efficiency

All the above BMPs will be published in the internet for the maximum dissemination possible. Below, for convenience and sparing of space, only the short general irrigation BMPs are presented:

Irrigation Best Management Practices for Tree Crops in the Mediterranean region (short version)

Through IRRIQUAL project, a multinational EU-supported project for irrigation of trees and quality and safety of fruit in the Mediterranean region, general or specific to major tree crops detailed BMPs for irrigation were developed and are available in the project's website. These short guidelines herein were developed to attract the interest of involved stakeholders and pinpoint the important steps in the best management of irrigation practices in an area of the world with, in most cases, limited and continuously decreasing water resources.

Rate irrigation highly within the management system

Irrigation in most of the Mediterranean regions producing agricultural products is either one of the most important factors in the production system or the single most important factor affecting possibilities for production, farm productivity and fruit quality. Over the next years, all of us involved in agricultural production in the Mediterranean region must accept that irrigation will be the number one factor limiting and affecting agricultural output (product and economics) no matter how low is the cost of water today. Thus, we have to get prepared for the worst in the years to come. Of course this needs to translate into action in order to have any impact on management input and production output. Our first priority from today (if not too late anymore) must be as stated: 'It is worth the money we put into it, it is worth the effort we put into it every day'.

When irrigation is seen as a low priority, it is no wonder if management input is minor, and if irrigation performance is poor. This is common in various Mediterranean countries where plant protection rates higher than anything else and other practices that increase the production costs or affect the environment and product quality are of low priority. Likewise, it is not surprising that all of the best irrigators place irrigation as a high priority in their growing system, and that their management input into irrigation is of a high level. It is also worth mentioning that most of the 'good' growers exhibit a high level of management input across the whole enterprise. It is not a case of concentrating on irrigation alone. Successful fruit growers tend to practice intensive management in all areas of the total growing system.

Get to know the soils on the property

Efficient irrigation is very difficult without good information about the capacity of the soil being irrigated to retain water and make it available to the roots of the crop, and in what layers of the soil profile the roots of the crop are growing. Soil analysis before planting is mandatory in integrated production protocols for crop and farm certification and is extremely useful for appropriate crop selection, irrigation system layout, and irrigation management once the crop is planted. Survey for soil types present in a farm or region can also be broadly useful for irrigation management.

Even on existing orchards, irrigation management can be greatly improved by an understanding of the soils. Soil sampling for analysis should be done properly by the farmer or a professional, as soil analysis can provide valuable information beyond soil texture on all nutrients and factors like pH and organic matter content.

Design, construct and maintain irrigation systems correctly

Irrigation system design should be performed by a licensed professional who must also supervise the construction and set up. Poor irrigation system set up and operation can make good irrigation management almost impossible. Very often irrigation system setup, age and maintenance are the limiting factors in the farmers' ability to manage irrigation as well as they would like.

Farmers and consultants should manage irrigation according to a set of standards for irrigation system design and operation, as follows for drippers and sprinklers (micro or overhead):

- variation in emitter discharge rate between any two emitters within a valve unit should not exceed 5%.
- for non-pressure compensating emitters, this can be approximated by restricting the variation in emitter pressure between any two emitters within a valve unit within ±10%. Try to install high quality tested pressure compensating emitters as they have lower variability in the farm.
- emitter pressure at all emitters should lie within the range of pressures recommended by the manufacturer.
- distribution uniformity for a full cover irrigation system should aim to exceed 75%, while less than 67% is unacceptable.

All of these standard practices should be strictly adhered to in the design stage. All irrigation system designs should take into account any available soil surveys. Data should be found on the quality tests performed on irrigation equipment by authorized laboratories.

As irrigation systems age, overall pressure decreases and flow rate increases as nozzles wear, and variation in both increases. Pressure and flow rate decreases can also appear with time due to lower water level in wells or surface water bodies even in the same year. This can and should be monitored by water volume meters. Distribution uniformity usually decreases over the years. Existing irrigation systems should undergo a general check annually, preferably during the non-irrigation season to allow major faults to be remedied. Drip and undertree microsprinkler systems require regular flushing, at least annually, and possibly chemical treatment, especially drip/micro irrigation systems and especially more often if salts are present in the irrigation water.

Drip and undertree microsprinkler systems should undergo a more thorough test every 2 to 4 years, while overhead sprinkler systems require a detailed test every 5 to 10 years. Replacement or overhaul of components should be conducted as required to return the system operation to the standard practices outlined above.

The selection and maintenance of the pumping plant for an irrigation enterprise can have a dramatic impact on the financial efficiency of the enterprise. Selection should not be based entirely on capital cost, as running costs are a very significant component of the total cost of pumping. Consultants can conduct pump performance tests, but regular overhauling (every 3 to 5 years) is the best means of maintaining the performance of an irrigation pumping plant.

Monitor all aspects of each irrigation event

First of all, a good planning of irrigation early in the season is necessary. This will be based on the capacity of the irrigation system: which tree crop needs more water certain periods and which less water. Monitoring is vital to efficient irrigation management, but monitoring is not confined simply to the decision of when to irrigate. All aspects of the irrigation event should be monitored such as the irrigation volume per event and soil holding capacity with plant root depth, to allow adjustments to be made to refine irrigation management.

Knowing the soil water capacity and monitoring soil moisture before irrigation is important in scheduling the timing of irrigations, so as to avoid prolonged periods of stress due to inadequate soil moisture, without applying unnecessary irrigations or water quantities, which lead to excessive drainage, and possibly to waterlogging.

Monitoring of system performance and uniformity of application during the irrigation allows adjustments to the system configuration as required, in order to apply the water more evenly over the area being irrigated. This is not necessary at every irrigation event, but is an aspect of system maintenance as discussed above.

Monitoring of soil moisture after an irrigation event can provide valuable information about the fate of the water applied, especially if information is available at a number of depths within the soil profile. Inadequate depth of irrigation can lead to salinity problems within the root zone, whilst over-irrigation leads to excessive drainage and loss of water. Monitoring can identify problems with the depth of irrigation applied, and allows irrigation depth to be adjusted in the future. An auger and some digging are only needed to actually collect this information. Other instrumentation properly installed and maintained, like capacitance profile probes, can collect and transfer automatically information regarding soil water content.

Use objective monitoring tools to schedule irrigation

Monitoring for irrigation scheduling can take many forms, and there is a vast array of tools available. Whilst there is no one "correct" tool or approach, it is vitally important that scheduling is based on quantitative measurements.

If subjective or qualitative methods of scheduling are used, it is very difficult to be consistent from one irrigation event to another. Good quantitative information provides consistency and confidence in management decisions. Cheap reliable approaches are available for soil water monitoring (like conductivity meters) although many sophisticated equipment (like capacitance probes or lysimeters) are available for farmer and institutional use to monitor soil water or plant reaction to water availability (stem water potential, daily trunk shrinkage) and climatic conditions (calculation of crop evapotranspiration). The IRRIQUAL project developed a lot of knowledge on the best use and efficacy of soil and plant monitoring equipment for the Mediterranean tree crops and soils. Stem water potential is generally accepted as the best plant monitor for water stress but at the moment, there are no automatic methods for its estimation. Maximum daily trunk shrinkage was used as the best automated method to monitor plant stress and evaluate irrigation efficiency. Capacitance probes are also accepted as good automated method to convey information on soil water content and irrigation efficiency. These last parameters were used in the IRRIQUAL project to closely monitor irrigation requirements in trees. Other models on soil, plant and fruit quality are also being developed in an attempt to precisely and automatically find the water needs and the reaction of the trees to irrigation.

Use more than one tool for scheduling irrigation

Whilst it is important to use an objective monitoring tool to schedule irrigations, it is dangerous to rely exclusively on a single information source, and to ignore other evidence which may suggest that there are problems with the irrigation regime. There are many ways to assess the water status of the crop and the soil water content, some rather less precise but no less useful as indicators of irrigation success. Ease of automation is also a matter of concern.

Usually, much of the decision to irrigate must rely on a particular quantitative tool or two, one for tree response and one for soil water content. But other factors must also be taken into account like climatic conditions, weed and tree status, fruit production and time of ripening, and, of course, species and cultivar particular needs. As an example peach tree irrigation volume can be manipulated depending on the period of the fruit pit hardening and harvest time. Combinations of monitoring methods were described above.

The use of additional sources of information improves the quality and reliability of the information on which management decisions are based, and thus ultimately improves the quality of the decisions themselves and the result, i.e. efficiency of water use (kg of produce per m^3 of water used).

Some of the alternative sources of information for the farmer him(her)self that can be used are:

- Regularly walking through the orchard, monitoring the appearance of the trees/vines and weeds for evidence of stress.
- Periodically digging holes to check soil moisture visually or by feel.
- Checking drains and testwells after each irrigation to assess the level of drainage produced by the irrigation.
- Monitoring weather patterns and the weather forecast, to aid in predicting irrigations.
- Knowledge of the crop cycle, and especially of the critical periods during which stress should be avoided or could be applied without significant crop losses.

Retain control of irrigation scheduling

With modern technology, it is possible to set up irrigation systems to operate entirely automatically, based on the readings from a probe or a set of probes. This is tempting, as it leaves one less thing for the irrigator to worry about.

Similarly, it is easy to allow a consultant to dictate the irrigation schedule, based on his or her measurements, or to blindly irrigate because the scheduling tool being used indicates that it is time to.

The correct irrigation management dictates that the irrigator should take into account the data from the scheduling tool(s) or the recommendation of the consultant, but retain the power to vary the schedule using his/her own judgement, and other tools.

Ultimately, it is the management skills, and the proper training together with proper available guidelines, of the individual irrigator which determine how well the site performs, and good irrigators back their own judgement, based on their knowledge of their property, rather than blindly following the advice of a machine or an outsider.

Remain open to new information

Openness to new ideas and actively seeking out information are important attributes in successful farmers of any crop. Top managers have extensive personal networks, which they actively maintain and nurture. These networks provide timely information on a multitude of subjects and issues.

The development of and access to information about irrigation for the array of crops cultivated in a region by an independent stakeholder should be priority in all irrigated agricultural areas in the Mediterranean region.

In the case of larger, corporate operations, employee and member relevant education is as important as is encouraging the employees to make a meaningful contribution toward management decisions.

Long time stakeholders involved in fruit production will not accept changes as easily as newcomers, who are usually more willing to seek information and try innovative methods, technology and ideas. The necessity, like high production costs with low value produce and water scarcity, could be the strongest driving forces for seeking and using new information and tools for sustainable use of water in the Mediterranean region. But there is no reason to reach this low point to become active.

All knowledge should be available to all stakeholders and should be used as effectively as possible today and not tomorrow, because tomorrow things will be worse.

WP 12: EVALUATION OF SUSTAINABILITY

CONTRACTORS: UPCT, CSIC,

MAIN RESULTS ACHIEVED:

The results of the research carried out in different Regions point at the technical and economic superiority of regulated deficit irrigation strategies.

The **analysis of basic Technical-Economic indicators** for the peach and citrus farms surveyed show a greater profitability of RDI strategies with respect to conventional strategies. In all cases, RDI strategies increase the productivity of water and, in some cases also the productivity of other farm inputs such as labour and fertilizers. Moreover, RDI strategies increase Total Factor Productivity.

The **Static analysis of irrigation strategies and water productivity** has been focused on the magnitude “water application”. Several indicators have been calculated to compare the strategies RDI/Control and RDI/Commercial farms, for both crops and for the different water qualities. First, the Marginal Rates of Return show a significant economic potential for the substitution of conventional irrigation strategies for other more sophisticated ones (CDI), being such potential greater the better water quality is. Second, the Specific Rate of Surplus shows in all cases the potential superiority for assuring their reproduction of the RDI strategies against the “Control” and “Commercial farms” irrigation strategies. Again, results are better for higher water quality. Last, the comparative analysis of water productivity ratios show that water productivity is greater for RDI strategies with respect to the Control strategies and those in the commercial farms. Water productivity increases with water quality, both for RDI and control strategies.

For the **dynamic analysis of the productive cycles**, several coefficients and ratios that describe and evaluate the logic and internal dynamics of irrigation strategies have been calculated. The results show the large differences existing between the logic and dynamic of the RDI strategies and the Control irrigation strategy and, especially with the strategies applied in the commercial farms. RDI strategies present a large level of irregularity in water application, especially for citrus and higher quality irrigation water. On the contrary, there exists a high level of regularity and homogeneity in the water application in commercial farms, especially for mandarin, what indicates the existence of conventional irrigation strategies. The inner coherence of the process dynamics of RDI strategies and of the relations with their corresponding Control strategies is very high, what results from the differential water applications carried out in the corresponding intervals of the productive cycle. The results show a greater efficiency of RDI strategies in all cases, a result that is related with the coherence of the irrigation schedule.The proposed methodologies are appropriate for the comparative analysis of irrigation strategies and the assessment of their sustainability. However, there are some limitations mostly related with data availability that should be taken into account. First, more and more varied observations from experimental plots/farms and for more years (consecutive productive cycles) are necessary to provide for a more consistent analysis. Second, for a better dynamic analysis, data should be available taking as reference the phenological phases of the crop.

WP 13: DISSEMINATION OF KNOWLEDGE

	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	WP9	WP10	WP11	WP12	Total
Peer Review Papers	0	10	5	4	0	5	7	0	6	0	0	0	37
Conference (Oral) and Procedings	0	11	6	4	3	6	6	0	7	1	3	2	49
Ph.D. Thesis	0	2	1	0	0	1	1	0	1	0	0	0	6
Disemination courses	0	3	3	0	0	0	0	0	2	0	2	0	10
Product Presentation (Catalogues)	0	0	0	0	0	0	0	3	0	0	5	0	8
Others	Web Page (2), Project Leaflet, Final Conference Difussion												4
TOTAL DISEMINATION ACTIVITIES													**114**
Web Pages searched in Google (looking for IRRIQUAL)													**2130**

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Ph.D. Thesis

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6. R. Alcobendas (CEBAS-CSIC). Mejora de la productividad del agua en melocotonero mediante el desarrollo y validación de modelos de producción agraria. 2010.

Dissemination courses

1. Organization of a course for stakeholders and SME: "Jornada sobre nuevas tecnologías para la programación del riego en cultivos leñosos" (Meeting day on new technologies for irrigation scheduling in fruit trees). Organisation: A. Pérez Pastor (UPCT), R. Domingo Miguel (UPCT) with the support of Foundation Séneca (Murcia Regional Government). Spain, April 2007.

2. Organization of a course for stakeholders and SME: " Aguas residuales depuradas. Proyecto Integral de Reutilización". Centro Integrado de Formación y Experiencias Agrarias (CIFEA, Torre Pacheco, Murcia).Spain, March 2008.

3. Conference "Innovaciones en la aplicación del agua de riego" in the Master "Gestión Integrada del Agua", for technical personal of Spanish Water Authorities and Water Base Confederations. Organiced by Universidad de Zaragoza and Ministerio de Medio Ambiente. Cartagena (Murcia). December 2007.

4. In Greece, the results have been communicated regularly to informal meetings with possible end users or third parties interested in the use of irrigation water. This last year at least two formal presentations of results have been communicated in the main areas of olive and peach cultivation of central Greece or/and northern Greece.

5. In November, CEBAS-CSIC organi$zed "Jornadas de Riego Deficitario Controlado en Frutales". Fuentelibrilla (Murcia).

6. In December 2008, CEBAS-CSIC organizad "Jornadas de Riego Deficitario Controlado en Cítricos. Aplicaciones y Beneficios". Molina del Segura (Murcia).

7. Organization of a course for satkeholders and SME: "Especiallización en Depuración y Reutilización de aguas residuales". Centro Integrado de Formación y Experiencias Agrarias (CIFEA). Molina del Segura (Murcia). November-December 2009.