IX INTERNATIONAL SYMPOSIUM
ON IRRIGATION
OF HORTICULTURAL CROPS

BOOK OF ABSTRACTS

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Welcome to the Symposium

Dear participant,

The International Society for Horticultural Science (ISHS), the Working Group Irrigation and Water relations, and the University of Basilicata are pleased to welcome you in Matera to attend the IX International Symposium On Irrigation Of Horticultural Crops.

We are proud of the rich and varied scientific and cultural programme offered in the hope that it will meet your expectations in terms of novelties and innovations.

More than 190 contributions (67 oral and 130 poster presentations) will be presented during this meeting divided into eight sessions.

Competition for scarce water resources in many places at global level is very strong today. Available water resources are constantly diminishing at increasing rates. Adaptation of agriculture to varying conditions induced by climate change is necessary because some changes in climate can no longer be prevented.

The current focus of our International Society for Horticultural Science addresses drought issues, especially in countries most affected by water scarcity, and is encouraging its member scientists to find solutions to combat and mitigate the adverse effects of drought. Along this line, a new session has been dedicated to "Climate and water resource prospects: social and economic aspects", including keynote speakers from several international institutions involved in water management and supply (FAO, ICID, UNCCD, CIHEAM IAM, IWMI). The debate of this first session will help better define the new research challenges.

One of the important challenges for scientists is to increase and facilitate the transfer of innovations and technologies to the end-users. Encouraging scientists, technicians and farmers to work together is thus a necessity. Along this line, the Symposium includes also a "Festival of Innovation on Water and Irrigation" to involve farmers associations and networks at national and international level, and key actors of the latest technologies and innovations. This Festival is addressed both to local technicians and to researchers from all over the world and it aims to bring the scientific world of research closer to the world of work by addressing the technical aspects through thematic workshops, training and networking activities.

Matera is a UNESCO World Heritage site and the 2019 European Capital of Culture. It is the first inhabited zone dating from the Paleolithic period, while later settlements bear witness of a number of significant stages in human history, perfectly adapted to its terrain and ecosystem. Basilicata and neighbouring regions of Southern Italy boast many other beautiful and interesting sites for a relaxing time and cultural tourism.

We wish you a pleasant stay!

Cristos Xiloyannis & Bartolomeo Dichio

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Session 1 – Climate and water resource perspectives: social and economic aspects

Water resources: challenges of the water-energy-food nexus

Felix Reinders

President: International Commission on Irrigation and Drainage

Water gives life and is crucial to development all over the world. It waters the fields; nurtures the crops and stock; provides recreation; it support mines, industry; electricity generation and it provide life for plants and animals that make up ecosystems. The agricultural sector is by far the biggest user of water in the world accounted for 70% of the world's total water withdrawal. In Africa and Asia it is 85-90% of all the freshwater used is for agriculture. To satisfy global demand for food, by 2025, agriculture is expected to increase water requirements by 1.2 times. Irrigated agriculture plays a major role in the livelihoods of nations all over the world and although irrigation is one of the oldest known agricultural techniques, improvements are still being made in irrigation methods and practices. During the last four decades, irrigation systems in the world made mayor advances in technology development and the uptake of irrigation increased by 81 percent from about 153 Mha in 1966 to more than 300 Mha in 2019. The expansion of irrigation in the next 40 years might however not be that extensive due to pressure on water resources as well as the impact of climate change.The 300 million hectares of irrigation which is about 19% of the world's cultivated lands accounts for almost half of the value of global crop production. The International Commission on Irrigation and Drainage, has released its roadmap to ICID Vision 2030 with the main drive "A water secure world free of poverty and hunger" and in summary it states as follows: "Water, as the main input for food production, has played the most significant role in population growth and societal evolution over much of the recorded human history. Numerous civilizations flourished and then also became extinct because of the way they managed their agricultural water. By being a direct or indirect part of 7 out of 17 Sustainable Development Goals, water assumes inclusive dimension both as a natural resource for rural development and an essential input commodity for industrial and human life-style consumption." Under the limiting natural resources, climate change and rising conflicts, the task of ICID network has become even more critical and daunting. The newly emerging and competing demands for water, coupled with the uncertainty of impact of climate change on food productivity, have challenged the ICID stakeholders and partners to redouble their efforts. ICID Vision 2030 for a water secure world free of poverty and hunger through sustainable rural development through its mission to facilitate prudent agricultural water management by encouraging interdisciplinary approaches to irrigation and drainage management is an expression of intent of the network to help various stakeholders in moving towards a 'World we Want'.

Invited lecture

Climate futures: using scenarios to support practical land and water resilience-building measures for adapting to climate shifts and extreme

Rachael Mc Donnell

Principal Researcher at International Water Management Institute

Farmers and horticulturalists in many parts of the world will relate how they are experiencing today the impacts of a drier, hotter and more extreme climate. Many water and farming systems have been identified as being at risk to drought and floods as recent events in various parts of the world have highlighted this all too painfully. This presentation will present the results from various ongoing climate change studies and use these as the starting point for discussions on the possibilities and challenges of implementing practical measures for climate change adaptation to manage water and food security under climate shifts and extremes.

Invited lecture

Solutions to adapt to climate change: governance and strategies for water resource management and infrastructures

Fathi Lebdi (FAO)

Agricultural Water for Africa Coordinator chez United Nations FAO

FAO agricultural water management continues to be developed with the water Governance pillars, for Irrigation infrastructures and water resources management and operation, I a water scarcity and CC context. Impacts of Climate change (in particular drought) are taken in consideration to mitigate, to adapt and to contextualize solutions by developing technical approaches and capacities and facilitating the adoption of the proposed solutions.
The technical solutions are focusing on large, medium and small scale water systems with strategic objectives of food security and nutrition, ending hunger is some areas in particular in Sub Saharan and improving the resilience to drought.
Proactive approaches are developed in terms of concepts and in the field, with the participation of the stakeholders.
We will present here some examples on small-scale water resources management and infrastructures nexus energy, in remote areas and with community involvement including the governance and management part, in Mediterranean region, Africa Sub-Saharan and NENA region.

Invited lecture

Constrains for an effective innovation transfer of water management and technologies in the Mediterranean region

Nicola Lamaddalena

Head of the Land and Water Dept – CIHEAM Bari Institute

The Mediterranean basin is a complex system of environmental, economic and socio-cultural diversities. In the Region, water is one of the most important issues and lies at the forefront of discussions on global sustainability and food security.
Irrigation, in most of the Mediterranean regions, often absorbs around 80% of the total available water resource, therefore, improving Water Use Efficiency at each step of the chain, from the reservoir to the root zone, and enhance water saving management techniques in agriculture are priority issues. Three main water saving domains should be addressed: i) increase water use efficiency and water productivity, ii) improve irrigation system performance (hydrology and hydraulic related measure of water saving), iii) use of recycled non conventional waters. Technological as well as sustainability goals have to be identified accounting for an equal balance of social, economic, environmental and institutional dimensions. Also climate change impacts should be taken into account. In addition, successful water saving must be sustained by improved transferable methodologies of participation and Stakeholders involvement. From the technological point of view, importance has been given to innovative means for irrigation system modernisation, decision support systems, innovative devices for monitoring, control and quantification of saved water volumes, and improved models that allow unravelling of negative and positive impacts of water saving at the different scales.
Several constraints to the adoption of technologies and innovations by farmers can be identified as: the extent to which the farmer finds the new technology complex and difficult to comprehend; how readily observable the outcomes of an adoption are; its financial cost; the farmer's beliefs and opinions towards the technology; the farmer's level of motivation; the farmer's perception of the relevance of the new technology; the farmer's attitudes towards risk and change; the correctness of options adopted in the design of modern irrigation systems.
The adoption of innovations in natural resource management is also related to the relevant role of the extension service and research.

Invited lecture

Drought Preparedness at the UNCCD

Daniel Tsegai (UNCCD)

Programme Officer at United Nations Convention to combat Desertification

Drought affects all parts of our society, from food production to public health, and there is a growing need to help Parties, communities, agriculture, businesses, and individuals threatened by drought to plan accordingly. Through the new Strategic Framework (2018-2030), the UNCCD is increasing its attention to drought. One out of the five strategic objectives of the Framework is focusing on drought with the aim to "mitigate, adapt to, and manage the effects of drought in order to enhance resilience of vulnerable populations and ecosystems". The focus is on proactive drought risk management, particularly on 'prevention' and 'preparedness' rather than 'recovery' measures. The COP guided, for example, the process of developing national drought plans and drought preparedness systems, promoted the use of the UNCCD drought resilience, adaptation and management policy (DRAMP) framework that aims to reduce drought risk and increase resilience, and most importantly the COP requested the secretariat and the GM to implement a drought initiative(Decision 29/COP.13). Against this backdrop, the need for establishing drought preparedness systems that includes monitoring and early warning systems, assessing vulnerability and drought risk mitigation measures for timely drought action is increasing becoming vital to tackle drought before it occurs. The presentation will highlight the UNCCD's Drought Initiative.

Invited lecture

Water footprinting: assessments, impacts and economic perspectives

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Farmers in the United Arab Emirates use groundwater for irrigation. Sustainable water requirements are uncertain in this hyper-arid region, where groundwater resources are under pressure. Yet, excess irrigation is required to avoid salt accumulation. Over-watering of the crops threatens the quantity and quality of groundwater. The Government of Abu Dhabi has passed Law 5 to restrict groundwater use. Farmers must improve their practices to match irrigation with water demand.
Brackish groundwater irrigates food crops including dates, which are salt tolerant, and vegetables which are sensitive. This is important for food security.
Here we quantify the water footprints of WFgreen, WFblue and WFgrey, in L kg-1 to assess the impacts of food production on the quantity and quality of groundwater. Sap flow sensors measured the water use, ETc (m3 y-1) of three date varieties irrigated with salinities of electrical conductivities (EC) of 5 and 15 dS m-1. Lysimeters were used to measure the water use of a range of field-grown vegetables irrigated with 'sweeter' water having an EC of < 1.0 dS m-1.
Our recommendation has been for irrigation to be at 1.5 ETc to provide a 25% leaching fraction, with an additional 25% factor-of-safety. The WFgreen is zero because of the low rainfall. The WFblue equals ETc / Y, where Y is the crop yield (kg). For dates, we found WFblue = 646 L kg-1 while for vegetable crops the value of WFblue ranged between 42 (tomato) to 312 (capsicum) L kg-1. The grey-water footprint, WFgrey, is expected to make a significant contribution to the total water footprint. We quantify this for nitrogen and salt. Salt is the most important.
The benefit-cost ratio (BC) of the prior dilution of the brackish groundwater with desalinated water for irrigation is assessed for dates. A decision support tool for irrigation allocation has been developed to help manage the groundwater usage.

Keywords: date palm, vegetable production, water footprint, nitrogen footprint, salt footprint, desalinated irrigation

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Invited lecture

(ROSA Ref. n.199)

Session 2 – Non conventional water use: saline and urban wastewater

Long-term irrigation olive orchard with reclaimed wastewater

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Utilization of reclaimed wastewater (RWW) presents an alternative to irrigation of agricultural crops with fresh water (Fr), especially in dry areas characterized by water scarcity. While RWW often contains considerable amounts of valuable plant nutrients, it is also typically characterized by high salt content, which can impair agricultural yields and have environmental repercussions. The objective of this study was to determine the effect of long-term utilization of RWW and fertilization practice on soil properties and trees performance. We evaluated irrigation and nutrient management of olives with RWW versus Fr in a long-term field experiment. Two olive cultivars (Barnea and Leccino) were subjected to irrigation with RWW, either with standard or reduced fertilization, and irrigation with Fr with standard fertilization. During the eight years of the experiment, considerable amounts of N, P and K were delivered with the RWW. Trees irrigated with RWW receiving no additional fertilization were not negatively impacted, indicating sufficient nutrient allocation by the RWW. Fruit yield was higher in RWW treatments compared to the Fr, probably due to the presence of P. In the autumn of each year, soil salinity was higher in the reclaimed wastewater compared to the fresh water treatment, but this did not lead to increased leaf Na or Cl concentrations or to reduced tree productivity. From an agronomic point of view, the lack of response to salinity implies that irrigation of olive with reclaimed wastewater is sustainable as long as precipitation ensures sufficient seasonal leaching of salts. However, sodium absorption ratio of the soil solution slowly and steadily increased in the reclaimed wastewater treatments resulting in a high exchangeable sodium percentage (14%) reaching nearly double that of the fresh water treatment. The latter observations highlight the likelihood for adverse effects of long-term irrigation with reclaimed wastewater on the deterioration of soil physical and chemical properties.

Keywords: reclaimed wastewater, olive, irrigation, fertilization, soil salinity, soil sodicity

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Invited lecture

(ROSA Ref. n.34)

Treating water for reuse: testing an adoption decision-making model with nursery and greenhouse growers

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Nursery and greenhouse growers make up the agricultural sector that uses the most water worldwide. Technologies are emerging across the globe designed to treat water so that is can be reused. However, many growers are not adopting new treatment technologies despite the projected lack of water in the future and obvious need to implement solutions so water can be reused. While research effort has been devoted to the development of water treatment techniques, there is a deficiency of research on how growers make decisions regarding adoption of the new techniques offered. The decision-making process is complex. In general, people make decisions individually (which is influenced by personal cognitive factors) and collectively (because of peer pressure and societal norms). Perceptions of an innovation influence both the individual and collective decision-making process. This research used an online survey to test a decision-making model that takes into account individual and collective influences on decision-making. The 191 growers surveyed in the United States identified two individual cognitive factors (critical thinking style and problem-solving style) and their perceptions regarding adoption characteristics of water treatment technologies. Problem-solving style predicted perceptions of the relative advantage and compatibility of treatment technologies while critical thinking style predicted compatibility, trialability and implementation of water treatment technologies. All five perceived adoption characteristics of water treatment technologies played a role in the nursery and greenhouse growers' adoption. When developing new water treatment technologies scientists need to keep existing systems in mind; the more compatible they are, the more likely a grower is to adopt. In addition, when educating about new water treatment technologies, scientists needs to consider emphasizing the advantage of the new technology over what is already being used and provide opportunities for growers to try the new technology before committing to complete adoption.

Keywords: water treatment, technology adoption, nursery grower, greenhouse grower, water reuse

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(ROSA Ref. n.1)

U.S. consumer perceptions of water sources and uses regarding production and enjoyment of ornamental plants

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Competition for potable water resources will likely increase, creating potential issues for sales of ornamental plants. Research has shown that many consumers favor products produced or manufactured in an environmentally-sustainable manner. Our goal was to understand how water source (e.g. fresh water, recycled, water, or a blend of both) would influence consumer perceptions of purchasing ornamental plants. An online survey of 1543 respondents assessed U.S. consumers' perceptions of water source and water demands during the first year of establishment in the landscape. A partial factorial conjoint design using 3 (plant genus) x 3 (price) x 3 (water source) x 2 (water need [irrigation required during the first or most seasons] was employed. Findings for herbaceous perennials and small trees were similar. Consumers placed the greatest relative importance on plant genus, followed by production water source. Relative importance of water use in the landscape and price were similar and lower than the other two attributes. Fresh water use in production was preferred over recycled water and least preferred was a blend of fresh and recycled water. Requiring irrigation water only during the first season of establishment was preferred over irrigation required during most seasons of production. More education is needed to help perennial plant purchasers understand the benefits of using recycled irrigation water during plant production.

Keywords: marketing, survey

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(ROSA Ref. n.100)

Saline reclaimed water and deficit irrigation strategy affected eco-physiological traits in almond trees under Mediterranean conditions

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The evaluation of non-conventional water resources such as reclaimed water and water saving techniques has gained importance during the last decades in arid and semiarid areas. This study assessed effects of two irrigation water sources, desalinated DESERT water (DW) (tertiary wastewater obtained from secondary wastewater treated using an innovative system powered by solar energy, till reaching ECwof 1 dS m-1) and RW (secondary treated wastewater with ECw1.2 dS m-1mixed with the brine produced on the DESERT prototype till reaching an ECw of 3 dS m-1) with two irrigation strategies: control full irrigation (FI, 100% of ETc) and regulated deficit irrigation (RDI, at 80% of ETc during the kernel-filling period) in almond crop (Amygdalus communis L. cv. Tuono grafted onto Rootpak 20â). Trees were planted on 100 L pots with representative loam soil of the area (Apulia Region, Southern Italy). Our results showed that saline RW caused significantly lower leaf total chlorophyll content in all the phenological phases due to the high concentration of leaf phytotoxic elements (Na and Cl). Nevertheless, RW increased leaf dry mass area since there was a higher solutes concentration. RDI strategy decreased leaf gas exchange and stem water potential (SWP), regardless of the water source, at the end of RDI period. Concretely, net assimilation rate and Fv'/Fm' relationship were significantly reduced in TW-RDI and RW-RDI, affecting PSII photochemical efficiency. Water use efficiency increased in all stressed treatments, mainly in RDI treatments, due to a partial stomata closure in order to avoid vascular damage by vessel cavitation. Saline stress induced by RW did not reduce the SWP and leaf gas exchanges parameters. These results highlight that, under Mediterranean conditions, RW and RDI strategies can be a reliable practice for almond irrigation, even if long-term studies to establish more suitable management practices mainly under salinity conditions must be developed.

Keywords: chlorophyll, leaf gas exchanges, treated waste water, water potential, water stress, water use efficiency

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(ROSA Ref. n.160)

Human faecal bacteria endophytic load and heavy metal concentration in apple and nectarine tree irrigated with secondary treated wastewater

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Secondary treated wastewater (STW) could represent an opportunity to mitigate irrigation water shortage in summer periods. Unfortunately the utilization of STW in agriculture could be associated with environmental and health risks, given its potential source of chemicals (e.g. heavy metals) and human pathogens (e.g. *Salmonella spp.* and *E. coli*). This work investigates how the irrigation with STW, on apple and nectarine tree, could affect pollutants accumulation in vegetative (i.e. shoot) and reproductive (i.e. fruit) tissues related to the different physiological traits (e.g. apple fruit xylem dysfunctionality) of the two species. Three years old trees were grown in pots and drip irrigated separately, for a continuous season, with Tap water (TW) and Secondary treated wastewater (STW) respectively. Furthermore a laboratory trial was carried out on 3-month old GF 677 micropropagated plants to better asses the internalization and translocation of two different *E.coli* strains: *E. coli* DH5α and *E. coli 1576*, the first a disarmed strain and the latter a potential surrogate organism of *E. coli O157:H7*. The continuous irrigation with STW did not affect heavy metal concentration in both leaves and fruits with concentrations in fruit tissues within international limits imposed for human consumption in both species. Most of the differences on the heavy metal concentration were related to a genotype effect. The absence of *E. coli* and the stable load of total coliforms (TC) into the STW-irrigated soil were observed. An overall higher load of total bacterial count (TBC) was detected in nectarine compared to apple trees. Independently from the species the TBC in STW-irrigated shoot was almost doubled than in TW-irrigated shoot. A higher load of TBC was observed in shoot rather than fruits. No *E.coli* and few TC were detected in the vegetative and reproductive tissue (only for nectarine) of both species, completely respecting the microbiological European regulation for foodstuffs. In the GF 677 plants, both the *E.coli* strains had a root epiphytic and endophytic behaviour, more enhanced in *E. coli 1576*. Any *E. coli* was able to translocate in the areal part of the plant (i.e. above the inoculation point). These results are encouraging a widespread use of STW as a safe water source especially when utilizing drip irrigation systems for irrigating fruit tree crops. Further studies are foreseen to deeply investigate how STW may influence these parameters in open field conditions and for a prolonged time.

Keywords: water reuse, drip irrigation, fruit tree crop, pollutants, human bacteria pathogens plant uptake, *E. coli*, food safety

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(ROSA Ref. n.207)

Session 3 - Evapotranspiration, irrigation requirement and modeling

ET of applied water and the cup+ model

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In 2011, a user-friendly Excel application program (CUP) was developed to improve the computation of ET, dissemination of crop coefficient (Kc) data, and crop evapotranspiration (ETc) information for use in California. CUP computes reference evapotranspiration (ETo) from either monthly mean or daily values of solar radiation, maximum and minimum temperature, dew point temperature, and wind speed using the standardized reference ET equation. The program uses a cubic spline curve fitting technique to derive one year of daily weather and ETo data from the monthly data. The daily ETo and rainfall data are used to estimate a crop coefficient (Ke) for bare soil evaporation (E) as a function of mean of ETo and rainfall wetting frequency for the entire year. The daily bare soil Ke values are employed as a baseline for in- and off-season soil evaporation estimates. For orchard and vine crops, CUP accounts for canopy size and cover crop contributions to ETc. Crop and soil information are input and used to determine seasonal Kc curves and to characterize soil water characteristics within the rooting zone. In 2014, the application name was changed to CUP+, and the ability to adjust ETo for climate change and to estimate ET of applied water (ETaw) were added to the model when using input daily climate data. The program generates several useful tables and charts including crop water requirements by month, by season, and by year and seasonal ETaw. This paper presents the information on CUP+ and how ETaw is used for water resources planning.

Keywords: water resources, evapotranspiration, crop water requirements, modeling, resource planning

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Invited lecture

(ROSA Ref. n.137)

Towards modelling the impact of climate change on irrigation demand

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Agricultural water demand for irrigation is closely aligned with local climate and water resources. Already today, water availability for irrigation is limited in areas with negative climate water balance (CWB). General climate change scenarios predict more negative CWB due to reallocation of precipitation in cultivation-free periods. The synthesis of local studies demonstrates region specific climate change effects. To ease decision making for future irrigation infrastructure, projections of region and crop specific irrigation demand are required. In this context, the range of potential scenarios - based on simulation framework- has to be revealed, too.

This study aims at identifying the impact of climate models and emission scenarios on the simulation of irrigation demand of a model crop. With onion, the climate change impact was simulated for i. precipitation-free periods, ii. crop specific CWB, considering soil characteristics and temperature-driven plant growth and iii. irrigation demand based on FAO56 for two different growing regions in Germany. The model framework consisted of two regional models, COSMO-CLM (a dynamic) and WETTREG2013 (an empirical-statistical) model for downscaling. Both were driven with the earth system model MPI-ESM-LR. Two emissions scenarios (Representative Concentration Pathways = RCP), RCP2.6 as optimistic, and RCP8.5 as pessimistic projection, were applied. Simulations cover averaged 30-year time intervals of three periods: 1971 - 2000 (the reference period), 2031 - 2060 and 2071 - 2100.

Simulated future irrigation demand, using RCP2.6, maintained at the status quo. A detectable climate change impact occurred with RCP8.5: Duration of precipitation-free periods, relevant for irrigation, increased. Crop specific CWB became more negative and irrigation demand increased. However, these results and corresponding ranges differed between the climate models. Thus, the simulation framework has a strong impact on simulation results, irrespective of the climate trend. Model ensembles are required to reduce uncertainties in revealing the impact of climate change on irrigation.

Keywords: emission scenarios, climate models, climate water balance, onion, simulation

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(ROSA Ref. n.6)

An update on the theory and application of surface renewal for estimating ET

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For well-watered crops and landscapes, energy-limited crop or landscape evapotranspiration (ETc) is often estimated using crop coefficient (Kc=ETc/ETo) factors, where ETo is the standardized reference evapotranspiration (ET). Surface renewal (SR) is a method based on high-frequency temperature data to measure sensible heat flux density (H) that is used in conjuction with other energy flux data to estimate latent heat flux (LE) and then ETc. In recent years, the surface renewal (SR) method has been widely used to measure crop ET to develop and improve Kc values. For deficit irrigated crops, there is no easy way to accurately estimate the impact of water stress on canopy growth or transpiration, so an in situ measurement is necessary to accurately determine the actual ET (ETa) for ETa£ETc. However, relatively low-cost SR H estimates are now used for direct measurement of ETa for deficit irrigated vegetation. In most SR research, uncalibrated SR estimates of sensible heat flux (H') are calibrated against sonic anemometer H, and the calibration factor is then used with SR H' data to estimate H when the measurements are collected at the same height above a similar crop. More recently, two distinct methods to estimate SR H without the need for calibration against sonic anemometer H data were developed. In this paper, we will provide an update on recent theroretical and application advances in the use of SR methods for determining ET.

Keywords: evapotranspiration, irrigation, energy balance

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(ROSA Ref. n.83)

Determining orchard specific crop coefficients for improved irrigation management in citrus

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Crop coefficients are widely used for both irrigation planning and scheduling, largely due to the simplicity and accuracy of the approach. However, for tree crops these crop coefficients are highly orchard dependent and there is therefore a need to derive orchard specific crop coefficients. The challenge is therefore to adjust crop coefficients for specific orchard and this often starts by partitioning evapotranspiration into transpiration (T) and evaporation and using a dual crop coefficient approach. Measurements of citrus transpiration conducted across multiple seasons, growing regions, tree size and species revealed that canopy size was a major determinant of transpiration, on both a daily and seasonal basis. A number of descriptors of canopy size (volume, leaf area index (LAI) and fractional interception of photosynthetically active radiation intercepted by the canopy (fIPAR)) were regressed against Kt values in order to find the best parameter for adjusting Kt values for specific orchards. Simulated daily and average monthly fIPAR showed a strong positive correlation with Kt, with a satisfactory R2 of > 0.7. However, both LAI and canopy volume resulted in rather poor relationships with Kt values. These results demonstrate that the amount of light intercepted by a citrus canopy is important in determining T under non-water limiting condition. The strong correlation between fIPAR and Kt suggests that Kt could be predicted from measured fIPAR for different orchards in which T measurements are not available and of particular importance is the consistency of the relationship for all the orchards in which measurements were made. This latter aspect was particularly important as it means that perhaps one relationship exists for citrus. Therefore, T coefficients of citrus can be estimated from the fraction of intercepted radiation of the canopy. The one factor limiting the widespread use of this approach would be accurate estimates of fIPAR.

Keywords: Radiation interception, transpiration crop coefficients, evapotranspiration partitioning, canopy volume, leaf area index

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(ROSA Ref. n 41)

Using HYDRUS-1D for estimating evapotranspiration and soil water content of irrigated winter wheat under different water managements in semi-arid region of Morocco

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The objective of this study is to evaluate the potential of the HYDRUS-1D model for estimating actual crop evapotranspiration (AET) and soil moisture (Θ) at different depths (5, 10, 20, 30 and 50 cm) over an irrigated winter wheat under different water managements in the semi-arid region of Tensift-basin (central of Morocco). The study fields which were equipped by meteorological stations, soil moisture sensors and eddy covariance systems, were irrigated by drip and flood irrigation. The simulation was performed at a daily time step during two growing seasons: 2002/2003 and 2015/2016. Firstly, HYDRUS-1D has been calibrated on one wheat field during 2002/2003 cropping season by using the Levenberg-Marquardt method for optimizing various parameters of Van Genuchten equation (Θ s, a, n and Ks, L). The calibration was based on the combination of those parameters that provide the best efficiency between measured and simulated soil moisture at different depths. Afterward, the validation was done on other fields of conducted during 2002/2003 and 2015/2016 wheat seasons based on the comparison between observed and simulated values of f Θ and AET.
The obtained results showed that the HYDRUS-1D model simulates reasonably well AET and Θ The average values of the Root Mean Square Error (RMSE) between observed and measured AET and Θ were 0.48mm/day and 0.04 cm3/cm3, respectively.

Keywords: HYDRUS-1D, evapotranspiration, eddy covariance, irrigated winter wheat

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(ROSA Ref. n 58)

Water requirements and crop coefficient for low-chill peach trees in subtropical climates

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Determination of plant water requirements is key to increase water conservation and maintain nutrients in the root zone. The objective of this study was to determine the water requirement, crop coefficient (Kc) and soil water depletion coefficient (Ks) of young and adult peach trees. The low-chill peach cv.'TropicBeauty' grafted on 'Flordaguard' rootstock was used. The first study determined the daily actual evapotranspiration (ETA) of young peach trees for 31 months using three weighing lysimeters to measure water losses every 30 min. Kcwas determined dividing ETAby Penman-Monteith reference evapotranspiration (ETo) estimated at the site. Kcwas plotted against day of the year (DOY) and a tree-segment linear and quadratic equations were fitted to the data. Kc values for young trees (<3 yr old) ranged from 0.20 to 0.63 depending of the phenological stage. There was a significant linear correlation between projected canopy area and trunk cross sectional area with measured ETA. The second study was conducted for 24 months with mature peach trees (>3 yr-old) cultivated similarly to a commercial setting in a sandy soil. Soil water balance was determined by measuring soil volumetric water content with capacitance soil moisture sensor in the 0-90 cm soil depth layer every 10 min. Crop evapotranspiration (ETc) and available soil water depletion was estimated daily. Average daily Kcwas calculated by the ratio of ETcto ETo. Kcwas plotted against DOY and a tree-segment linear and a quadratic functions were fitted to the data. Kcranged from 0.30 to 0.69 depending of the phenological stage. There was a significant linear relationship between soil water depletion coefficient (Ks) and available soil water depletion for peach trees. The maximum allowed available soil water depletion before trees undergo water stress was estimated in 25.8% of the soil field capacity for a sandy soil.

Keywords: crop evapotranspiration; Florida; subtropical; weighing lysimeters

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(ROSA Ref. n.16)

Session 4 - Water relations, soil and plant water stress assessment

Assessing soil and plant water status for irrigation management

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The study of the water relations of the soil-plant-atmosphere system (SPAC) is essential for the management and conservation of water in agriculture. A solid understanding of crop water relations was established many decades ago due to the fascination that so many scientists had with this subject matter. What has advanced more recently is the engineering and the technology that enable us to overcome the main limitations that existed in the quantification of water status within a dynamic SPAC. Spatial variability of soil-water properties is the main challenge for soil water assessment. The highly dynamic nature of plant water status and its variability within a field, and even within the plant, represent the main limitations for the assessment of plant water status. The need for the precise assessment of soil and/or plant water status is evident in two situations that are becoming more common. On the one hand, irrigation water scarcity leads to the adoption of deficit irrigation, a situation where crop water status monitoring is almost mandatory to avoid harmful water deficits. On the other hand, irrigation automation is being experimented under high-value crops in areas where water is expensive, as a mean of conserving water and reducing costs beyond what can be achieved using conventional irrigation scheduling methods. The advantages and pitfalls of the many new methods proposed for such applications, relative to the established methods used in irrigation management, will be presented.

Keywords: soil, plants, water, irrigation management

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Invited lecture

(ROSA Ref. n.196)

Physiological responses of radish (*Raphanus sativus* L.) to controlled water limitations - Potential effects on tuber quality and shelf life

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Radish (Raphanus sativus L.) is very sensitive to inadequate water supply. Controlled mild water deficits during growth are assumed to induce various acclimation processes in plants. This in turn may positively affect overall performance of produce and potentially improve their shelf life. The effects of various soil water conditions were evaluated in relation to plant physiological activity (photosynthesis and gas exchange), tuber yield, and plant water relations (incl. transpiration) during growth and postharvest. Experiments were performed on potted climate chamber-grown radish plants. While controls were continuously watered (15-17 ml per plant), deficit irrigation was simulated by gradually reduced watering to 6 ml per plant during a 12 d growth period. Reducing soil water content by 20 % and 50% only insignificantly affected photosynthesis by limiting stomatal conductance. Thus plant development and tuber growth were not affected. Limited water availability only slightly reduced tuber water contents and water and osmotic potential, but not pressure potential. It eventually increased the sugar contents and proline concentrations indicative of some osmotic acclimation, which is also manifested by as lowered osmotic potential at the turgor loss point. In addition, overall tuber conductance to water vapour diffusion significantly declined in deficit-irrigated plants. This may reflect improved postharvest quality and prolonged shelf life of radish tubers due to lower water losses during sales. Comprehensively evaluating the effects of preharvest conditions on postharvest behaviour potentially provides solutions to improve overall postharvest quality of perishable vegetables such as radish.

Keywords: deficit irrigation, osmotic acclimation, photosynthesis, postharvest quality, transpiration, water relations, yield

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(ROSA Ref. n.121)

Effects of two covering nets on water use efficiency and productionin California nectarine cultivar

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Mediterranean Basin is characterized by high evapotraspirative demand of the orchards. In semi-arid conditions, where water availability is limiting, the efficient water management is an issue. This purpose can be reached reducing water supply and water consumption, thus increasing water use efficiency. The use of hail nets is a common practice for high revenue orchards. Covering materials could be multipurpose if they were used to modify the orchard microclimate according to the plant needs. The aim of this study was to investigate the effect of light intensity modulation on microclimate, plant functionality, productivity and water use on a late ripening nectarine (cv. California). Two different shading hail-nets with neutral transmissivity, high diffusivity and a shading capacity of 10 (H) and 30% (S) were evaluated. In 2017 and 2018, leaf net photosynthesis (Pn), stomatal conductance (gs), transpiration (Tr), stem water potential (Ψs), fruit growth, shoot length, productivity and fruit quality were measured. The moderate reduction of solar radiation decreased temperature and VPD increasing Ψs and Pn. Fruit growth was strictly dependent by skin transpiration and photo-assimilates downloaded in the fruit. During fruit cell expansion, fruit Absolute Growth Rate (AGR) increased with VPD till its maximum. The excessive VPD reduced AGR because of the high water imbalance in the fruit (water-in vs. water transpired) and the reduced photo-assimilation. The moderate light reduction decreased temperature and VPD within an optimum range for plant functioning and fruit growth. Productivity was 20% higher in S than in H and the opposite was observed for water consumption. Fruit size was higher in S than in H, however sugar content and the over-color were slightly affected. The use of covering nets seems to be promising. Further research should be performed to better define the degree of light reduction as well as the quality of light.

Keywords: Prunus persica, leaf gas exchanges, WUE, fruit quality, productivity

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(ROSA Ref. n.116)

Tolerance of different olive cultivars to salt stress

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Water depletion due to by high levels of soil salinity causes a strong stress in plants, which may lead to metabolic imbalances including the production of reactive oxygen species (ROS). Plants can develop tolerance against ROS through the production of antioxidant enzymes and arrangement of the concentration of osmolytes, such as proline, inside cells. Olive is considered as a moderately salt tolerant species, however level of tolerance to salt appears to be cultivar-dependent. In this work the biochemical and physiological impact of salt stress, induced by 100 and 200 mM NaCl on pot-grown plants of the olive cultivars Fadak86, Royal de Cazorla, Koroneiki, and Arbequina were assessed. The levels of gas exchange, chlorophyll content, vegetative growth, and the expression of glutathione reductase (GSH), catalase (CAT) and proline concentration, have been measured. In severe and prolonged salt stress, all studied cultivars showed a decrease of Net Photosynthesis, chlorophyll content and proline concentration and an increase in the expression of GSH and CAT. The increase of CAT and GSH in salt stress, induced by high levels of NaCl on the cultivars examined, indicates the presence of a high oxidative stress in progress. 'Arbequina' and 'Fadak86' showed a low tolerance to salt stress and died after 220 days of treatment while 'Koroneiki' and 'Royal' showed a greater resistance, probably due to a higher expression of CAT and GSH in control coditions. It will be interesting to investigate whether the higher expression of CAT and GSH, in basal conditions, may represent a possible prognostic marker of olive trees in the salt stress response.

Keywords: salt stress, Olea europaea, photosynthesis, proline, antioxidant enzyme

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(ROSA Ref. n.183)

Sap flow and diameter variation in apple tree with different water supplyin pre- and post-harvest

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In order to control tree water status, beside measurements of environmental variables and soil moisture variations, leaf water potential and midday stem water potential can provide useful information regarding plant water relations. Sap flow and stem diameter contraction measurements can be used to study water relations and water consumption. Maximum daily shrinkage (MDS) can be a sensitive indicator of plant water use and water deficits being highly correlated to leaf water potential.

Sap flow (SF) and MDS in one branch of six apple trees were determined using the Compensation Heat Pulse method (CHPM) and by micrometric branch diameter fluctuation measurements during the summer of 2014 in an apple orchard located near Havelock North, New Zealand. One branch per tree west oriented, was equipped with sap flow and diameter variation sensors placed close to each other at branches with approximately same diameter. Midday stem (ψs) and leaf (ψl) water potentials were measured in leaves of each branch. Midday leaf gas exchanges were also monitored at the same days. In addition, leaf area index (LAI) of the vines and per branch and fruit dry matter per branch have been measured in the end of the growing season. Irrigation was turned off to half of the trees (T0) after DOY 31. Midday stem water potential decreased during the non-irrigation period. The SF and MDS values were very tightly correlated pre-harvest (r^2=0.69), whereas this correlation decreased substantially post-harvest (r^2=0.16) as both SF and branch variations (BV) had smaller fluctuations during the day.

Results showed that MDS was a better indicator of mild water deficit than sap flow while, both sensors responded well to VPD_m and ETo values. The effect of fruit on SF rates and branch shrinkage (BS) was examined during pre and post-harvest period. The SF decreased approximately 60% after fruit harvest. BS values had smaller variations during post-harvest being decreased values about 44%. These results highlighted the effect of the fruit on the leaf transpiration.

The integration of measurements of both MDS and SF are promising methodology to monitor the water status and water consumption, improving water use efficiency and irrigation management.

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(ROSA Ref. n 192)

Learning from the past to improve the future: tree-ring as a retrospective tool to investigate orchard irrigation management

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In this study, tree-ring annual growth was used for the retrospective analysis of the impact on the orchard of irrigation management. Ring-width data were collected in two of the oldest, still in full-production, apple "Cripps Pink", grafted on M9 and two of the nectarine "Big Top", grafted on GF677, orchards of the Emilia-Romagna region. In the selected orchards (four for each species), irrigation was performed differently over the years, according to extensionists' suggestions and grower experience. These species were chosen for their different physiological behaviour in response to soil water availability which is anisohydric and isohydric, for apple and nectarine, respectively. Ten wood core samples in each orchard were randomly collected above the grafting point, using a wood corer. Each core was then prepared and polished using a microtome, and all ring widths were measured using a binocular microscope coupled to a measuring table and to a time series analysis software. Finally, single-tree ring-width chronologies were cross-dated to assign each individual tree-ring to its exact year of formation. For each orchard, monthly precipitation and air temperature were collected from the closest weather stations. For each year, over a period of 17 years (2000-2016), tree growth data (assessed using ring-width as a proxy) at each orchard were compared to local climate records of precipitation and temperature, using correlation analyses. For some orchards, ring-width was positively related to precipitations and negatively to temperatures, indicating the occurrence of water shortages during the summer. This effect was slightly more pronounced for nectarine than for apple, probably due to its isohydric behaviour. These data indicate that irrigation was not properly managed in some orchards, suggesting the need to adopt precise irrigation strategies for future efficient water supplies.

Keywords: growth-rings, apple, nectarine, orchard water management

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(ROSA Ref. n.35)

Development of baseline data for using mid-day stem water potential for olive

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The use of mid-day stem water potential (SWP) for determination of tree water status has become more routine in deciduous tree crops such as almond, walnut, and prune. This information can be used to diagnose the water status of the tree and decide if the tree is being properly irrigated and prevent under or over irrigation. To assist with interpreting SWP measurements in canning olive, a baseline was developed on 'Manzanillo' trees in five commercial low volume irrigated olive orchards in the northern Sacramento Valley of California. The baseline is designed to predict what the expected SWP reading would be when soil moisture is not limiting and contributing to tree stress. Baseline SWP varies by plant species and is influenced by changing climatic conditions. In order to do this, SWP, climatic, and irrigation data was collected over a range of weather conditions. These data were then correlated with vapor pressure deficit (VPD) to develop a baseline model and table that predict SWP in olive trees. The "best fit" linear regression model for predicting baseline SWP levels in table olives where soil moisture is not limiting was achieved by measuring VPD in olive orchards as opposed to using VPD measured at the nearest CIMIS short grass reference weather station. Even when soil moisture is not limiting, baseline SWP levels are expected to range from about -1.1 to -1.8 MPa tension in canning olive when temperature ranges from 30 to 40 ° C and 25 to 65 percent relative humidity. This new predictive model shows the capacity to distinguish instances when an orchard is fully irrigated and higher (more negative) SWP levels reflect hot, windy weather conditions, from times when SWP indicates significant tree water stress and irrigation is appropriate. Research has shown that the baseline for trees can be quite different for different species. This work that we have done with olive indicates that baseline SWP readings for olive will be significantly more negative than almond, walnut or prune.

Keywords: Olive, SWP, pressure chamber, water stress

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Session 5 - Sensing technologies relevant to the precision irrigation

Plant-based sensing for irrigation management in the field

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Optimizing irrigation is a challenge for sustainable agriculture. The water status of most annual crops is strongly related to soil water status due to shallow, dense root systems and low hydraulic resistance (Rplant). Such crops can be managed with soil moisture measurements and models of ET. However, trees and vines have characteristics that complicate meteorological and soil-based methods: tall, discontinuous rough canopies and deep, low density and erratic root systems with relatively high hydraulic resistance. The high Rplant leads to a greater dependence of water potential on evaporative demand, and dynamic daily water potentials. Sap flux gauges and meteorological modeling can be used to estimate crop water use though discontinuous canopies and crop level effects on stomatal conductance complicate such models. With uncertainty of root distributions and strong weather response, direct measurement of plant water status is desirable in woody crops like winegrapes that require regulated stress for best fruit quality. Methods have been developed to estimate or measure plant stress though few are well-suited to commercial use. Remote sensing of spectral characteristics may relate to water status, but is indirect and has many interferences. Some measure a tissue response to water potential variations, such as visual symptoms of stress or dendrometers (shrink/swell sensors) and turgor gauges on trunk, leaf or fruit. These also are indirect and correlations to tissue properties often change. Other methods measure plant water potential directly: the pressure chamber, stem psychrometer or embedded microtensiometer or microosmometer. The much higher temporal resolution with continuous monitoring of stem potential will raise questions about diurnal patterns of plant growth and function, and if irrigation management at much shorter intervals will be valuable. No single measure or model will provide optimal irrigation management, and the need to integrate direct and remote sensing with modeling will be discussed.

Keywords:water potential, sensors, fruit crops, nut crops, irrigation, drought stress, water use model, sap flow, root distribution, hydraulic resistance, remote sensing

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Invited lecture

(ROSA Ref. n.188)

Assessment of canopy transpiration from temperature: applications for almond orchards

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Almond growing is increasing throughout the Mediterranean area, and especially in Spain, because of the high prices fetched by this commodity in recent years. This has led to the establishment of new, intensive almond orchards in many Spanish irrigation schemes, even though traditionally, almonds have been grown in Spain in marginal soils under low-input conditions. The expansion of irrigated almonds has increased irrigation demand, which for Western Andalusia has been quantified in recent research as high as 7,000 m3/ha. Considering the societal requirements to decrease the share of fresh water diverted in agriculture, it remains essential to optimize almond water productivity in irrigated schemes which may be achieved through precision irrigation. To do so, we need an accurate estimation of the spatial distribution of water requirements within irrigated orchards. This work proposes a methodology to map water use by almond trees based on their canopy temperature and its relationship with crop transpiration. For this purpose, we have developed the Non-water Stress Baseline for the crop and implemented a methodology to obtain the Crop Water Stress Index using information acquired with infrared thermometers installed over selected trees. After that, this information was combined with high-resolution airborne thermal imagery acquired over the whole experimental area to derive a transpiration map. This new approach enables the segmentation of the area according to their needs, providing relevant information for precision irrigation management and system re-engineering.

Keywords: transpiration, water stress, irrigation management, orchard trees, CWSI, canopy temperature, airborne thermal imagery

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(ROSA Ref. n.42)

Precision drip irrigation for horticulture: methods for managing spatial variability from vineyard and orchard trials in Israel

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Horticultural cropping systems including fruit tree orchards are commonly faced with non-uniformity causing water-induced spatial variability in growth, yields and product quality that should/would justify variable rate irrigation (VRI). These crops are typically drip irrigated, making them unique compared to crops irrigated via center pivot sprinklers for which precision water management is more established.Decision making for VRI orchards for the most part is similar to that for field crops under center pivots: data (soil maps, sensors for plant water status, etc.) provide spatial information regarding conditions affecting yields and algorithms are built to guide irrigation regimes. The difference arises in statistical handling of the data. Trees in orchards are independent points and treatment of tree based data is not the same as the continual data in field crops. While the statistics for field crops can assume continuity between measured points, this is not the case for an orchard where trees do not fill the entire space. The presentation will bring examples from current research projects and developments. The topics covered will include: Potential for spatial VRI management in lowering vineyard/orchard variability, saving water and increasing profits. Multivariable spatial consideration in determining management zones for irrigation and for determining optimum number and placement of sensors or sampling sites to represent zones. Remote plant and crop stress indices as proxies for stem water potential modeled irrigation scheduling.

Keywords: variable rate, drip irrigation, wine grapes, peaches, crop water stress index, remote sensing, stem water potential

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(ROSA Ref. n.36)

Using a decision support system (Vintel) to determine the relationship between soil water content and whole-grapevine transpiration

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'Vintel' is a decision support system that provides irrigation recommendations in grapevine to maintain a desired predawn leaf water potential (Ψpd). Ψpd is calculated from the fraction of transpirable soil water (FTSW). FTSW is computed daily using a soil-plant-atmosphere continuum model using sub-models for vine growth, light interception, transpiration, soil evaporation, water run-off and cover crop evapotranspiration. This work focuses on vine transpiration, that is calculated from light interception and then modulated to account for the stomatal response to water deficit using a bilinear function response to FTSW reported in the literature. If FTSW is higher than 0.4 no reduction in transpiration is considered. Below this threshold, relative transpiration is reduced linearly with FTSW from 100% to zero. This approach produced satisfactory results with Vintel users that irrigate frequently but FTSW and Ψpd values decreased too rapidly when vines were subjected to long periods of water deprivation (a common practice in wine regions). To understand this issue, Ψpd, early-morning, mid-morning and midday leaf conductance (gs) were measured during 2017 and 2018 in four vineyards in the South-East of France. The vineyards included Grenache, Cinsault and Syrah grafted onto SO4 and Syrah grafted onto 140 Ruggeri. Each vineyard was grown under irrigated and non-irrigated conditions and eight days of measurements were performed between budbreak and harvest for each plot, year and irrigation treatment. Independently of the hour of measurement, relative gs was lower than that expected using the bilinear function. For this reason, for the plots included in this study, 'Vintel' predictions of Ψpd were improved using a sigmoid relationship that starts decreasing vine transpiration around FTSW values of 0.6 and accelerates as FTSW values get close to zero. This research opens an interesting discussion about the existence or not of a unique response of vine transpiration to water stress.

Keywords: crop modelling, irrigation scheduling, plant physiology, precision agriculture, Vitis vinifera, water stress

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(ROSA Ref. n.4)

Water stress mapping using low-cost thermal sensors mounted on an All-Terrain Vehicle (ATV)

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Under the current drought conditions, the availability of water for irrigation is the key factor for the long-term sustainability of vineyards growing in arid and semi-arid areas. Irrigation scheduling is complex and often involves several approaches and different plant water status indicators. In this sense, pressure chambers have been widely employed to measure stem water potential (SWP) which is considered as one of the most reliable indicators of water status in vineyards. However, this method is highly time-consuming and labour intensive, which results in an inadequate sampling method considering the intra-block spatial variability. It is well known that evaporative cooling of leaf as a result of transpiration can be a useful indicator of water stress. In this regard, measurement of canopy temperature (Tc) has been proposed as an alternative method of determining vineyard water status. The application of Tc as a water stress indicator has been widely documented in grapevines using different techniques and platforms, however, the use of thermal sensors mounted on an all-terrain vehicle (ATV) is an innovative, fast and reliable option for studying spatial variability of water status. The goal of this study was to evaluate an automatic water stress mapping approach under natural spatial variability conditions, using low-cost thermal sensors. Field experiments were conducted in commercial vineyards in Chile and Spain. Thermal measurements were acquired around solar noon, using an arrangement of four low-cost thermal sensors mounted on ATV. Thermal measurements were geo-located and performed contactless on both sides of the canopy at different heights. The Crop Water Stress Index (CWSI) was calculated using canopy temperature and natural references. SWP was measured in selected vines using a standard protocol, the SWP values were used as a reference method to analyse the suitability of the thermal approach. The selected vines were geo-located using a DGPS equipment to compare with the thermal information extracted in the same positions. A customized R script was developed to implement all calculations an automatic mapping from the data collected by the thermal system. CWSI values obtained from low-cost thermal sensors at 4 different heights were compared to SWP values measured at sampling points across the vineyards. In most of the cases, CWSI values showed a significant correlation with SWP, when clear different water stress conditions were expressed in the analysed vineyard blocks (determination coefficients - r2, over 0.6). This approach gives to the winegrowers an opportunity to determine water status within-field variability, which has a relevant effect in the existing variability in yield, grape composition and, therefore, in potential wine quality.

Keywords: water stress, crop water stress index (CWSI), intra-block spatial variability, stem water potential.

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(ROSA Ref. n.65)

Estimation of the spatial and temporal variability of evapotranspiration components in a vineyard with the two source energy balance model (TSEB) using both thermal airborne and the fusion of Sentinel 2 and 3 imagery

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Accurate estimates of crop water status in heterogeneous crops by means of remote sensing thermal imagery has been mostly achieved through airborne imagery, but not so much with satellites. The lack of spatial resolution in the thermal infrared bands in most of the currently available satellites is, among others, one of the reasons that limits its practical implementation for irrigation purposes. One of the commonly used spatial methods to estimate crop water status is the so called crop water stress index (CWSI), which can be either empirically or theoretically estimated using thermal imagery, and has been successfully regressed with the stem water potential (Ystem). This study aims to compare two methodologies to calculate the spatial and temporal variability of CWSI in a vineyard using images from both airborne and satellite platforms, as well as to evaluate its feasibility to estimate Ystem. To achieve it, three flights were conducted throughout the growing season of 2018 with an aircraft equipped with a multispectral and thermal camera. Concomitant with image acquisition, Ystem was measured in fourty vines homogeneously distributed in the vineyard. In the same days, a data mining sharpening method was used to fuse images from Sentinel 2 and 3 in order to increase the spatial resolution of temperature observations derived from Sentinel 3. The empirically based CWSI was obtained using the algorithms developed in previous studies with the same variety. On the other hand, the theoretically based CWSI was calculated through the Two-Source Energy Balance (TSEB) evapotranspiration model, which estimates separately the soil evaporation, the actual (Ta) and potential (Tp) vine transpiration. Besides this, this study also evaluated novel approaches to estimate the biophysical parameters of the vegetation, which are needed to run the TSEB model.

Keywords: evapotranspiration, remote sensing, TSEB, vineyard

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(ROSA Ref. n.27)

Scheduling regulated deficit irrigation in olive using leaf turgor measurements: another twist for the method

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The Global Agenda of the United Nations targets Sustainable Development in 2030. In case of agriculture, sustainable intensification must be carried out under a holistic approach, which integrates precision irrigation, digital farming and new crop tendencies. However, the implementation of precision irrigation is technically demanding and expensive, which curtails its acceptance by the farmers. Nonetheless, the leaf turgor pressure sensors (ZIM probes; commercially known as Yara-water sensors) are one of the promising tools for monitoring plant water status and for irrigation scheduling. In fact, they have been shown useful to schedule a regulated deficit irrigation strategy in a commercial super-high-density (1667 trees ha-1) olive orchard. Notwithstanding, this irrigation approach presents limitations beyond certain level of drought stress (Ψstem < -1.7 MPa), when the readings of the sensor are unexplained and no longer related to turgor. This limitation makes the sensor useless for irrigation scheduling in certain periods of the olive growing cycle. Here we present the results of an experiment with two-year-old potted olive (Olea europaea cv. Arbequina) trees in which irrigation was withheld to achieve values of stem water potential (Ψstem) below -1.7 MPa. The trees were monitored continuously with ZIM probes and leaf thickness sensors. The aim of this work was to assess the significance of the ZIM probe records in order to establish new indicators for irrigation scheduling in periods of severe drought stress. Our main result showed that diel dynamics of ZIM probe records agree with those of leaf thickness sensors, suggesting that ZIM probes could be useful for irrigation scheduling of trees under severe stress.

Keywords: automatic irrigation scheduling, ZIM probes, stem water potential, Olea europaea, super-high-density olive orchard, drought stress

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(ROSA Ref. n.57)

Recent developments of the DIDAS program

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The DIDAS program assists in drip-irrigation system design and irrigation scheduling. It is based on analytical solutions of the linearized water flow equation. The problem of water flow and uptake is described by superposing solutions for positive sources (on-surface or subsurface emitters) and negative sinks (root systems). The design tool, based on the relative water-uptake rate (RWUR) criterion, assesses the effects on water-use efficiency of geometrical attributes: distances between emitters along drip lines, separation between drip lines, depth of subsurface emitters, and size and depth of root systems. The optimizing tool for irrigation scheduling is based on a relative water-uptake volume (RWUV) criterion. DIDAS was programmed in Delphi, runs on a PC under the Windows operating system, and requires no further software. The drip-irrigation scenario is constructed via a few GUI windows, which also contain a library of the required soil input parameters, and a best-fitting procedure to determine them. DIDAS can be downloaded freely from https://app.agri.gov.il/didas/. About 1400 people from 110 countries downloaded the first or second DIDAS versions (1.0.1 and 1.1.1, respectively). In the lecture we briefly introduce recent developments of the DIDAS program: 1. New layouts of drip irrigation systems, for example, a ring shape dripline; 2. A module for the design of supplementary drip irrigation over shallow groundwater accounting for water uptake from both groundwater and irrigation; 3. A module for soil salinity management, based on solutions for steady water flow and uptake for the various drip irrigation scenarios, and on differentiating the applied water to evaporation from the soil surface, uptake by the plant roots, deep percolation through the root zone and deep percolation outside of the root zone; 4. Modules for sprinkler irrigation assuming spatially homogeneous water application at the soil surface and water uptake by arrays of plant root systems.

Keywords: Drip irrigation DSS

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(ROSA Ref. n.40)

Mapping Evapotranspiration by combining Optical/Microwave remote sensing data (multi-resolution) and surface-atmosphere exchange modeling

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A precise estimate of evapotranspiration is fundamental for determining the crop water needs and subsequently for optimizing water management practices and irrigation regimes. Soil moisture and land surface temperature are the essential components of the hydrological cycle, especially, for controlling soil evaporation and plant transpiration. For that purpose, the microwave-derived near-surface soil moisture and thermal-derived land surface temperature are integrated simultaneously within a energy balance model. A two-source energy balance model named TSEB-SM is first derived from the TSEB formalism by explicitly representing soil evaporation using the empirical parameters (,) of the relationship between and soil surface moisture. For the fraction cover fc£0.5, the model calibration consists of inverting at Terra and Aqua overpass times. When fc>0.5, the calibration consists in estimating the Priestly Taylor coefficient (aPT)at the daily scale. The procedure is applied over a rainfed wheat field in the Tensift basin, central Morocco. The mean retrieved values of soil resistance calculated for the entire study period using satellite data are (7.32, 4.58). The calibrated daily aPT for S1 and S2 ranges between 0 and 1.38, and is mainly dependent on the rainfall distribution along the agricultural season. For all four seasons, TSEB tends to significantly overestimate latent heat fluxes. When using satellite data, the overall mean bias values are 119, 181, 94 and 128 W/m2 for S1, B1, S2 and S3, respectively. The errors are much reduced when using TSEB-SM with a mean bias of 39, 62, 4 and 7 W/m2 for S1, B1, S2 and S3, respectively. The analysis of the retrieved (arss, brss) and aPT variabilities using satellite data indicate the robustness of the approach to retrieve a water stress indicator at the daily time scale.

Keywords: TSEB, remote sensing, soil moisture, soil resistance

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(ROSA Ref. n.61)

Session 6 I – Tree crop irrigation management (drought and fruit quality)

Tree water use and irrigation management for salinity and drought

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Understanding the vadose-zone dynamics of root-water uptake functioning and tree water-use (TWU) is critical for establishing water requirements for irrigation. In this talk we present data from a number of field experimental that address different aspects of irrigation management of tree crops. The first study is on avocados in the Highlands of Kenya where fruit quality and yields are often low because the trees have been poorly managed and without irrigation. Government-supported irrigation schemes are slowly coming to the Highlands and the farmers will then need to know when and how much water is needed to irrigate their trees. Sap flow data are presented to show how tree water responds to the local microclimate and soil water availability. We are also using laboratory data on fruit dry matter content to develop a simple decision support tool that calculates the Time-to-Harvest for both fresh fruit and those that are processed for oil.
The second study on tree crops (date palms and forestry) comes from the United Arab Emirates where irrigation is essential due to very low rainfall (< 100 mm/y) and high rates of potential evapotranspiration (> 2400 mm/y). Sap flow data are used to determine irrigation allocation for a range of trees species based on simple estimates of the tree's leaf canopy dimensions, combined with the salinity of the irrigation water and the local microclimate.
The third study is from kiwifruit in New Zealand, that grow in a moist maritime climate that has plenty of annual rainfall, but often experiences long dry-spells during summer. We show how the water balance of kiwifruit is being measured using a combination of time-domain reflectometry (TDR), drainage flux meters (DFMs) and run-off plots. Good data from detailed field experiments is essential for developing appropriate irrigation schedules that match irrigation supply with plant water demands.

Key words: sap flow, soil moisture, irrigation scheduling, water stress, modelling

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Invited lecture
(ROSA Ref. n.201)

Assessing crop water productivity and water saving in an orchard under precise irrigation: risks from ambiguous terminology andsimplified concepts

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Water use in agriculture is an issue of interest not only for agriculturalists, but also for hydrologists, environmentalists, policy makers and a variety of professionals working on the use of water resources. This is behind the lack of agreement often seen in the literature, on the use of terms and concepts as common as water use efficiency or crop water productivity. Water lost by drainage, for instance, can be seen as a loss by a farmer but not necessarily by an hydrologist working at the basin level. There is, in fact, a lack of consensus in the literature on aspects related to the assessment of to what extent a certain irrigation approach leads to an improved crop water productivity or increasing water savings. In this work we revisit widely used concepts and terms used to evaluate water use efficiency in precise irrigation. This comprehensive irrigation approach involves the use of localized irrigation, deficit irrigation, sensors and data transmission systems, and digitalization, resulting in complex systems requiring substantial investments. The correct assessment of the agronomical and environmental use of water achieved with precise irrigation is, therefore, crucial to decide on the benefits of adopting the related technology. In this work we have used data from a long-term experiment in a hedgerow olive orchard with 1667 trees ha-1 to illustrate the need for both precise terminology and rigor on the use of concepts and variables related to the assessment of irrigation approaches, and to outline that care must be taken when interpreting data published in numerous papers in which neither of those two requirements were achieved.

Keywords: water use efficiency, olive, super high density orchard

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(ROSA Ref. n.44)

Establishing the appropriate drip irrigation agronomic design for optimizing crop performance and water use efficiency in woody perennial crops

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Drip irrigation is nowadays widely recognized as the most efficient irrigation system. However, there are still uncertainties on the more appropriate agronomic design to employ (i.e. the number of emitters and pipe lines). In the present work, we summarized the research carried out during the last 4 years in several woody perennial crops (almond, persimmon, lemon and clementine trees) in southeastern Spain (Murcia, Valencia and Albacete regions). Several irrigation agronomic designs were compared maintaining a similar amount of water application but varying the number of emitters and pipe lines installed in the orchards. The results showed that, in mature clementine and under sub-surface drip irrigation, increasing the number of emitters slightly improved crop performance and increased water use efficiency. In young persimmon trees, no clear advantages were found when a double drip irrigation lines was compared to a single pipe line per tree row. Despite soil evaporation was not experimentally determined, it seems that this component played an important role in the orchard water use efficiency and water balance. Increasing the number of emitters per tree may improve crop performance only when soil evaporation is minimized either by employing subsurface drip or by shading the wetted areas by tree canopies. Further research is undergoing to continue with the field trails in the young orchards to better quantify the mid-term effects of the irrigation system designs under testing.

Keywords: almond, citrus, drip lines, persimmon, emitters, water status

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(ROSA Ref. n.106)

Improving the management of localized irrigation method to increase its efficiency in a Mediterranean kiwifruit orchard

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Kiwifruit is a high demanding water crop species reaching up to 10-12,000 m^3 ha^{-1} seasonal irrigation water under Mediterranean climate (dry and warm summer). Under these conditions localized (drip) irrigation method is mandatory to pursue as high as possible water use efficiency (e.g., yield per unit of irrigation water supplied) in orchards. However, kiwifruit is often irrigated using methods wetting the whole soil surface (e.g., microjet) to match the high water requirement and sometimes the need for thermoregulation.

This 2-year study compared various irrigation methods on yield and water footprint (consumption method) of a Mediterranean kiwifruit orchard trained to pergola. (cv Hayward, 625 p ha^{-1}). The following methods were compared: drip (2 drippers per plant, 10 L h^{-1} discharge rate each), one drip pipeline per row (1_{DP}, with a 2.5 L h^{-1} dripper every 0.6 m), two drip pipelines per row (2_{DP}, one pipeline per side installed at approx. 0.5 m from row) with a 2.5 L h^{-1} dripper every 0.6 m) and microjet (MJ, 1 dripper a plant, 40 L h^{-1}). That various methods were managed according to standard (empirical) criteria adopted in the area (Drip, MJ) or based on the daily soil water balance (1_{DP}, 2_{DP}) calculated through evapotranspiration and soil moisture data (down to 0.9 m) and to soil water holding capacity.

The 2-year mean seasonal irrigation volume reached approx. 9,300 (Drip), 8,250 (MJ), 7,250 (2_{DP}) and 6,350 (1_{DP}) m^3 ha^{-1}. Yield was similar among treatments reaching a mean value equal to 42.5 (Drip), 45 (MJ), 45 (2_{DP}) and 43 (1_{DP}) t ha^{-1}. Mean fruit dry matter concentration and °Brix were not influenced by the irrigation method. Hence, an overall improvement of the irrigation water efficiency might be envisaged for those treatments (1_{DP}, 2_{DP}) whose irrigation management was based on soil water balance.

It might be concluded that appropriate irrigation management (i.e., 2_{DP} and 1_{DP}) reduced irrigation volume compared to standard irrigation management with no impact on yield and some fruit quality traits. Results on classical components of water footprint (consumption method) green, blue, grey are also discussed.

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(ROSA Ref. n.191)

Effects of climatic variables on water use efficiency of an apple orchard

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Against the background of the climatic change, we assessed from 2013 to 2017 the impact of meteorological variables on water use efficiency (WUE) in an irrigated apple orchard, as the ratio between gross primary production (GPP) and evapotranspiration (ET) measured by eddy covariance. The orchard was located in South Tyrol (northern Italy) with trees of the cv. Fuji/M9. Irrigation was carried out alternating drip and overhead sprinkler systems. 2014 and 2016 were characterized by relatively cool summers (on average 20.3 and 21.3 oC, respectively), average vapor pressure deficit (VPD) of 8.2 and 8.8 hPa, respectively, and average irradiance of 1834 and 1979 MJ m-2, respectively. 2013, 2015 and 2017 were, on the contrary, warmer (average T = 22.0-23.1 oC), with higher irradiance (2048-2137 MJ m-2) and VPD between 11.2 and 11.9 hPa. Averaged across the summer, WUE ranged from 2.8 to 4.3 g C/kg H2O, with lowest values recorded in the warmer years and the highest in the wetter and cooler ones. In all years, GPP increased at increasing ET values, but when ET values were above 4 mm day-1, GPP either leveled off or even decreased at increasing ET. Regardless of the year, daily WUE decreased with a log trend at increasing values of both air T (R2=0.35), irradiance (R2=0.52) and VPD (R2=0.60). Such behavior is the result of the fact that ET always increased at increasing values of air T, radiation and VPD, while GPP either was irresponsive (to air T and VPD) or increased only slightly (to increasing radiation). Under the experimental conditions, reducing temperature and the evaporative demand increased the WUE, while such an effect was not observed reducing water availability. The consequences of these results are relevant in the frame of the likely scenario caused by climate change.

Keywords: evapotranspiration, gross primary production, irrigation, climate change, horticultural crop

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(ROSA Ref. n.89)

Evaluation of water footprint for table olive groves of *Olea europaea* L. – cv. Conservolea

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As agriculture appears to be globally the greatest water user and water scarcity, due to fresh water shortages or deterioration of fresh water quality, is listed as one of the largest global risks, efficient use of water resources is closely linked to sustainable agricultural practices. Water Footprint (WF) has been largely employed during the last decade as a useful tool for planning efficient water management strategies at global, national, regional or even water basin level. WF is an indicator that is based on calculation methods and tools regarding the amount of water used along the full supply chain of a product. 'Conservolea' is a local table olive cultivar assigned as a Protected Geographical Indication (PGI) product of Arta, Greece. It is the main table olive cultivar in the area, it has a significant impact on local economy and it exhibits favorable economic and market prospects. In this study the WF of cv. Conservolea was calculated based on actual data from four olive groves and the results are presented and discussed. All four groves were conventionally cultivated according to the local practices regarding pruning, fertilization, plant protection, etc. Three of the olive groves were irrigated, while the fourth was rainfed. The WF of the four olive groves ranged from 326 to 981 m3 Mg-1 of olive fruit. The results provide a first yet solid assessment of the WF of table olive crop in the area and underline the effect of different agronomic practices on WF. Practical difficulties regarding the calculation of WF that need to be further investigated and resolved are pointed out.

Keywords: table olive yield, water requirements, efficient irrigation management, micro-sprinkler, Blue Water

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(ROSA Ref. n.55)

Improving water use efficiency in irrigated orchards - The LIFE + AGROCLIMAWATER case study

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The objective of this work was to improve the water efficiency of tree crops and save water, using as case study nine (9) irrigated orchards in Crete – Greece (7 in western Crete with high annual precipitation and 2 in eastern Crete with very low annual precipitation), under proper agricultural interventions. The study is a part of LIFE + AGROCLIMAWATER project, which aims to develop a climate change adaptation strategy for agriculture and prepare the agricultural sector for adapting to climate change. The selected pilot farms represent the most typical crops in Crete (olive and citrus trees), as well as the typical soil, landscape and agricultural practices differentiation for each crop (field slope, water availability, soil type, management regime). Each of the nine pilot farms has been divided in two parts, the first one is used as a control part, while the other one as the demonstration part where the interventions were applied. The interventions applied in order to improve water efficiency were: a) practices for the reduction of water evaporation losses from soil surface (soil mulching, cover crops, etc.), b) modified pruning for reduction of transpiration water losses , c) x practice for reduction of deep percolation water and nutrient losses, d) application of organic matter by composted olive mill byproducts and olive tree pruning residue, and e) application of irrigation according to the crop water needs. In order to evaluate the results after the 2nd year of implementation of the suggested agricultural practices for saving water, the following performance indicators were estimated: the water use efficiency (WUE) and the economic water productivity (EWP). In most of the fields, the results indicate that water saving and crop yield can be significantly improved based on the above interventions.

Keywords: water efficiency; tree crops; proper agricultural interventions; economic water productivity

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(ROSA Ref. n.144)

Effects of different irrigation regimes on vegetative growth, yield and fruit quality of young pomegranate (*Punica granatum* L.) trees cv. `Wonderful´

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In this study, a field experiments were carried out during two successive seasons (2017 and 2018) and corresponded to the first two years of cv. 'Wonderful' pomegranate plant growth, when water irrigation management is a critical aspect for the successful cultivation for commercial production. In semiarid regions of Italy, water is a scarce resource and its efficient use has to be prioritize. The trials were designed with the objective to search for an optimum irrigation scheduling by analyzing the effects of four different irrigation regimes (100%, 75%, 50%, and 25% of crop evapotranspiration - ETc) on young trees to reach optimal vegetative growth, yield and fruit quality. The pomegranate commercial orchard (5.5 x 3 m apart), drip irrigated, was located in the countryside of Foggia (Apulia region, Southern Italy). Weekly values of ETo and Kc, estimated by climatological and shaded area approaches (Allen et al., 1998; Xiloyannis et al., 2004) were used. Results showed that after two consecutive seasons the largest increase in the trunk girth (73.8 mm) was obtained in the 100% ETc, which value was significantly superior to those of 75%, 50% and 25% ETc irrigation treatments (62.6, 60.5 and 57.7 mm, respectively). Annual shoot growth, total yield per tree, number of fruits per tree and size of fruits, recorded on the second season, decreased significantly with the restriction of Etc water volumes applied to the crop. While, total polyphenols and antioxidant activity in pomegranate juices were higher in the water deficit treatments (average 4359 mg GAE L-1 and 37.99 mol TE L-1, respectively) than the full irrigated one (3466 mg GAE L-1 and 29.39 mol TE L-1, respectively). Finally, minor differences among irrigation treatments in the color of fruit skins, arils and juices and in the soluble solid, pH and titratable acidity of juices were observed.

Keywords: Annual shoots growth, trunk girth, skin color, arils color, juice color, total phenols, antioxidant activity.

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(ROSA Ref. n.3)

Session 6 II - Tree crop irrigation management (drought and fruit quality)

The effects of water deficits on fruit cracking and sunburn damage in Cripps Pink apple

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Apple growers in Australia are faced with extremely variable climates that can severely impact on fruit quality. Rainfall is arguably the most variable, causing a reduction in regional water resources for irrigation at one extreme and intense localised rainfall events at the other. Many apple orchards have adopted deficit irrigation strategies to cope with reduced irrigation allocation. Previous studies on the impact of deficit irrigation on apple fruit quality have mainly focussed on soluble solids, colour and fruit size with few studies on physical defects. The objective of this study was to investigate the effects of water deficits on sunburn damage and fruit cracking after intense summer rainfall events. Irrigation treatments were imposed over a 3-year period in a commercial 'Cripps Pink' apple (Malus domestica) orchard in the Goulburn Valley Region of Victoria, Australia. Treatments were 38, 50, 74, 100 and 162 % of grower irrigation practice. Regular measurements of stem water potential showed that deficit irrigated trees were consistently water stressed in years 1 and 3. There were few differences in stem water potential between treatments in year 2 due to regular rainfall events. Sunburn necrosis tended to increase as stem water potential decreased but this only occurred in year 3 with approximately 4 % of the harvested fruit in the 38 % treatment showing sunburn necrosis. The effects of water deficits on fruit cracking were much more pronounced. Approximately two-thirds of the harvested fruit in the 38 % treatment in years 1 and 3 were cracked. Water stress appeared to increase the susceptibility of fruit to cracking. Fruit cracking was partly attributed to a greater concentration of soluble solids that most likely increased turgor pressure following heavy rainfall leading to cracking of the skin at the calyx end.

Keywords: Malus domestica, stem water potential, rain, yield, soluble solids concentration

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(ROSA Ref. n.204)

Analysis of deficit irrigation strategies for almonds

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Although almond tree is a water deficit tolerant crop, and it is able to produce (low yields) in heavily water scarce conditions, the best yield results are presented when the crop is managed under irrigation conditions, or expressed more accurately, when most of its water requirements are satisfied. Since irrigation water amounts to fully satisfy almond water demands are usually very high, different irrigation strategies have been reported in technical and scientific papers, during the last 3 decades, to define when and how to apply reduced amounts of irrigation water (much less than full water requirements) to get the maximum possible yield. However, the presented results seems to have a high degree of discordance, mainly because de lack of precise irrigation strategy definition. Most of these technical and scientific reports express the irrigation strategies based as a percentage of the complete irrigation water requirements, applied in each of the sensitive phenological stages of the almond tree, without taking, in many cases, no additional consideration to the environmental (soil, weather) and orchard management (canopy volume, pruning, irrigation system) conditions. Many of these conditions are essential to evaluate the effect of the different irrigation strategies. The present work analyzes the critical issues to define a deficit irrigation strategy, being the most relevant ones: Canopy Volume (which is essential to determine full water requirements), Plant Water Status Thresholds (based on almond tree sensitivity in each one of the phenological stages, and seasonal VPD), and Weather Forecasting (to estimate whole season water requirements). Based on these elements, a methodological approach is proposed to define and to schedule deficit irrigation strategies for almond trees.

Keywords: water stress, growth, yields, almond, physiological indicators of water stress

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(ROSA Ref. n.76)

Sustainable strategy of irrigation in fruit orchards: environmental impact at sub-basin level

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Climate change is gradually affecting regional and global food production. Warming temperatures and a greater incidence and intensity of extreme weather events may lead to significant reductions in crop yields. The LIFE AgroClimaWater project provides adaptation strategies to increase water productivity in fruit orchards, reducing pollution and resource use, by monitoring the soil profile in order to optimize irrigation volumes and avoiding percolation in the deep layers and nutrient loss.
The experimental sites of fruit orchards have been divided into two plots: one managed with sustainable practices (no-tillage, compost addition, mulching of pruning residues, cover crops and guided irrigation through optimized water balance, reduced K_c and monitoring of soil moisture) and another one conventionally managed (weeding, empirical addition of mineral fertilizers and empirical irrigation). Effectiveness of cultivation practices applied in sustainable plots was assessed by monitoring the soil moisture (from 0 to 90 cm depth), Water Use Efficiency (WUE), Water Footprint (WF), Nutrient Use Efficiency (NUE); these parameters and indicators were compared to conventionally managed plots.
The results revealed that the sustainable management orchard leads to a 33.60% decrease in the WF, a 21.28% increase in the WUE and a nitrogen use efficiency (NUEN) greater than 1.5 times in the sustainable orchard compared to that conventional orchard.
Results at farm scale have been projected at sub-basin scale. The adoption of optimized irrigation management on sub-basin scale could reduce the environmental impact at territorial level, increasing fruit quality and water productivity, with beneficial effect on natural resources (soil and water) conservation and restoration.

Keywords: soil moisture monitoring, water use efficiency, optimized water balance, nutrient loss, nitrate leaching

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(ROSA Ref. n.193)

Timely water deficit in 'honeycrisp' apple reduces bitter pit incidence with little impact on fruit quality

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'Honeycrisp' is among the top produced apple cultivars in Washington State. The environment in Washington State leave this cultivar predisposed to producing large fruit that are susceptible to bitter pit. Plant water status, fruit size, and bitter pit incidence were found to be significantly correlated. Currently, there is little knowledge as to how 'Honeycrisp' responds to water limited conditions at different developmental stages. Beginning in 2017, three- year old 'Honeycrisp' were subject to four irrigation regimes for two years to compare fruit size, quality, bitter pit incidence, and return bloom. Treatments included a well-watered control maintained at 80-90% of soil field capacity along with deficits of early season 15-45 days after full bloom (DAFB), mid-season 45-75 DAFB, or late season water limitation 75-105 DAFB. During deficit periods, soil moisture was reduced to approximately 30-40% of field capacity. In 2017, fruit firmness and soluble solids content were greater from trees treated with late season water deficits compared to the well-watered control. Bitter pit incidence decreased by 15% for the mid- season and late season treatments and increased by 20% for the early season treatment compared to the well-watered control. Due to the bienniality of Honeycrisp, return bloom was significantly decreased in the second year but there was no difference among treatments. With low return bloom, a decrease in crop load contributed to an increase in fruit size in 2018. However, there was still nearly a 10% decrease in bitter pit from the early and late season water limitations and more than 20% decrease from the mid-season treatments both compared to the well-watered control. Early season temperatures appeared to affect bitter pit incidence for early season water deficits. These finding indicate that middle and late season periodic deficits can be used to reduce bitter pit incidence in Honeycrisp apple.

Keywords: water deficit, honeycrisp, Malus domestica, fruit quality, bitter pit

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(ROSA Ref. n.93)

Optimization of the irrigation schedule in field-grown strawberry results in higher water use efficiency and improved taste quality

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Open field strawberry in Belgium is always drip irrigated. Most field-grown June bearing variety is Elsanta. Irrigation is a necessity to achieve a consistent production. Often field-grown strawberry is cultivated under plastic rain cover to protect the strawberry fruits from rain impact. Also temperature is higher under the rain cover which speeds up the growing cycle, and results in an early strawberry yield, in the beginning of May. Common practice among strawberry growers is to maintain the root zone humid, with soil matrix potential (Ψsoil) close to -10 kPa. Since this Ψsoil approximates field capacity, there is a high risk of water and nutrient leakage out of the root zone. A dryer irrigation schedule would reduce this risk, and possibly improve water use efficiency. Secondly the tempered water uptake could result in a higher concentration of sugars and improved taste quality. To test this hypothesis an experiment was set up in 2017 where a conventional irrigation regime, where 65 mm irrigation was applied, was compared with a deficit irrigation (DI) regime irrigated with only 21 mm. Marketable yield in both treatments was equal, although ?soil decreased to -70 kPa in the DI treatment. Predawn plant water potential Ψ plant was lower the DI treatment, which indicated moderate water stress. This was reflected in taste quality parameters. Fruits in the DI treatment had a higher concentration of total soluble solids and a higher concentration of sugars, and acids, Also fruit aroma was significant affected by irrigation. Although overall variability in fruit quality over the experiment was high, this is an additional motivation for strawberry growers to cultivate June bearing field-grown strawberry under plastic rain cover at a dryer irrigation regime.

Keywords: Plant Water Potential, Watermark Sensor, Total Soluble Solids, Fruit Aroma

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(ROSA Ref. n.15)

Irrigation levels and proline application effects on morphological characteristics of strawberry

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In the Mediterranean region of Turkey, strawberry production is a substantial part of the agricultural sector, offers high rates of employment and farm income. Optimizing water application and effective cultivation practices are of considerable importance in improving strawberry yield. In this study the response of strawberry cultivar (Fragaria ananassa Duch. cv. Fortuna) to four irrigation regimes (IR125, IR100, IR75 and IR50) and proline use were investigated, by evaluating the morphological parameters (Leaf araea, Plant dry matter, Crown number) under high tunnel conditions in the Mediterranean environment. Proline, was applied five times starting from December to May via foliar application, as 20 mM. From the initiation of the treatment to the end of the trial, a total of 552, 447, 342 and 237 mm of water were applied to treatments IR125, IR100, IR75 and IR50 respectively. The IR50 treatment caused a significant decline in morphological parameters, indicating that the irrigation amount did not meet the plant water requirement. Rised irrigation water incresed Leaf area, Dry matter and Crown number significantly. Furthermore, the proline application increased the 24% of leaf area, 25% of plant dry matter and crown number. Under water stress conditions (IR50), proline applications considerably aided the reduced growth rate via increasing Leaf area, Plant dry matter and Crown number by 20%, 58% and 26% respectively, when compared to control. Consequently, in the protected cultivation, the IR125 irrigation level and the proline application favored the vegetative growth as well as by total marketable fruit yield and its components.

Keywords: Plant grown regulator, stress, subtainable agriculture

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(ROSA Ref. n.104)

Nitrogen (N) application needs to meet irrigation demands or it will compromise almond vitality and productivity

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Mineral N application by irrigation (fertigation) could optimize N supply to trees and minimize costs or environmental concerns. Yet, with no research to support it, farmers merely follow past recommendations of granulated N application and reach even lower N efficiency (~55% instead of 70%). We hypothesized that fertigation actually enables excessive N uptake by trees, compromising their physiological performances, and reducing their productivity. Hence we constructed a large scale lysimeter experiment of almond trees fertigated by 0 to 200 ppm N and measured their water and mineral (N, P, and K) uptake, physiological performances, and productivity. We learned that N uptake is limited, nearly constant throughout the growing season, mainly factored by N concentration (in irrigation) and transpiration, and could be satisfied by low concentrations in irrigation (30 ppm). We also reasoned that lower N levels would be ultimately used, but detain growth and render all additional resources in the field wasteful. Yet most importantly, we realized that excessive N promotes shoot over root growth, essentially limiting transpiration, and drawing trees to pseudo-drought stress (hydrated trees irrigated with 150 ppm N transpired 50% than trees irrigated by 60 ppm N). Such trees also lower photosynthesis, shift their carbohydrate to amino acid assimilation, accumulate starch in roots instead of developing them, and basically suffer from (an additional) metabolic stress. We embedded these findings into a mass-balance model, which incorporates environmental conditions and tree physiology, to determine proportional N fertigation. We concluded that N uptake could reach 80% efficiency by fertigation while benefiting both farmers and the environment.

Keywords: irrigation, fertilization, nitrogen, physiology, almond

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(ROSA Ref. n.91)

Session 7 - Vineyard irrigation: grape and wine quality

Vineyard irrigation: grape and wine quality

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Water availability is arguably one of the major factors limiting canopy growth and grape production in vineyards. Climate change is forecasted to make precipitations more erratic and increase temperatures in many wine regions, making drought events more frequent in vineyards. Many wine grape growers are already used to cope with drought and water deficit, as many premium wine regions are characterized by warm and dry summers. In these regions, growers often apply sub-optimal irrigation levels, known as deficit irrigation strategies. This is because moderate to severe water deficits can improve grape and wine quality, despite limiting canopy growth and vine yield. Deficit irrigation affects fruit composition, improving the biosynthesis of several secondary metabolites that determine grape and wine quality, such as flavonoids (e.g., anthocyanins) and volatile organic compounds. Moreover, deficit irrigation reduces berry size and the canopy growth, favoring the concentration of the secondary metabolites synthesized in the berry skin and a cluster microclimate optimal for the synthesis of several of these metabolites, respectively. An increased concentration of secondary metabolites in grapes normally results in wines with better sensory features; particularly for red wines, whose quality is strongly affected by the concentration of anthocyanin and tannins. However, recent studies have indicated that deficit irrigation strategies could also affect the quality of white wines. Indeed, water deficit induces the biosynthesis of grape terpenes. These compounds characterize the aroma of several white grapes and wines such as Viognier, Riesling, Gewürztraminer, and Muscats. The development and assessment of deficit irrigation strategies for white grape varieties deserve further consideration in future years; particularly in light of climate change, that will result in seasonal drought events also in wine regions that historically produce mostly white grapes.

Keywords: anthocyanins, aroma, deficit irrigation, flavonids, terpenes, water deficit

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Invited lecture

(ROSA Ref. n.195)

Partial root drying and other strategies for reducing irrigation water consumption in Chilean vineyards without affecting water status, yield and wine quality

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Chilean wine is well known in the World, and wine grape (Vitis vinifera) cultivation have a high economic importance in Chile. The central region of Chile has an optimal climate for producing high-quality wines, however climate change and drought has threatened water security making difficult to establish new vineyard and affecting vine vigor, yield and wine quality. In this work we present the results of three seasons of evaluations to determine the effects of irrigation water savings combined with different strategies for reducing water stress in 'Syrah', 'Carménère' and 'Merlot' vines. In 'Syrah', vines were subjected to the following treatments: T0) Control, with conventional irrigation regimes used by local growers; T1) Water shortage equivalent to 50% plus mulching; T2) Water shortage equivalent to 50% plus netting and T3) Water shortage equivalent to 50% applied as Partial Root Drying management (PRD). In 'Carménère', plants were subjected to: T0) Control, with conventional irrigation regimes used by local growers; T1) Water shortage equivalent to 50% of T0; T2) PRD irrigation resulting in a 50% reduction in irrigation volume compared to the control. In 'Merlot', plants were subjected to: T0) Control, with conventional irrigation regimes used by local growers; T1) Water shortage equivalent to 50% of T0; T2) PRD irrigation resulting in a 50% reduction in irrigation volume compared to the control; T3) Water shortage equivalent to 50% of T0 applied with subsurface drip irrigation. Among the measured parameters, we evaluated plants water status variables (stomatal conductance, stem water potential, relative water content), yield, and wine quality (pH, acidity, alcohol content, polyphenols content, color). As results, water shortage without a mitigation strategy affected water status variables as well as yield. In contrast, strategies such us PRD, mulching and netting did not negatively affect water status, yield and/or wine quality but permitted to save significant amount of water during the season.

Keywords: water stress mitigation strategies; plant water status

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(ROSA Ref. n.170)

Sustainable irrigation strategy on organic Red Globe table grapein Apulia region

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Table grape vines (Vitis vinifera L.) are generally grown under irrigation in arid climate regions, characterized by low rainfall and high environmental evaporative demand, such as Southern Italy. However, in recent years the need to reduce water consumption in irrigated vineyards has risen considerably because of increased water costs and restrictions on allocated amounts of irrigation water. Research was carried out during the 2015-‘16 seasons in an experimental vineyard located in Apulia region, where the climate is sub-arid Mediterranean. Red Globe vines grafted onto 140 Ruggeri rootstock were trained to “tendone overhead trellis” and covered with plastic film. Two watering regimes, corresponding respectively to 100% (V1) and 80% (V2) of daily crop evapotranspiration were compared. In order to quantify vine water status, midday stem water potentials were measured from berry set to harvest. Moreover, parameters of physiological leaf functioning were measured on a typical summer day on well-exposed main leaves. At harvest, bunch and berry weight, berries per cluster and berry diameters. were assessed. On aliquots of berry juice, total soluble solids, pH and titratable acidity, were determined. During berry growth midday stem water potential values were statistically different and the lowest vine water stress was shown by V1 treatment. Leaf gas exchange differed significantly only for leaf transpiration and no difference was noted for water use efficiency. Water availability significantly affected berry growth, inducing the lowest berry weight in mild water stressed vines (V2 treatment). As a consequence of the mild water stress applied, fruit yield was not significantly affected by the different water regimes. Finally, results in this trial show that a mild water stress affect cluster and berry weight, increase total soluble solid concentration, skin berry color and polyphenols content of organic Red Globe vines, with a positive reduction of irrigation cost.

Keywords: deficit irrigation, stem water potential, berry weight, skin colour, polyphenols.

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(ROSA Ref. n.52)

Effects of different deficit irrigation strategies on yield components and must quality of cv. Touriga Franca (Vitis vinifera L.) under Mediterranean climate conditions in Douro Region

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Located in the northeast of Portugal, Douro Region is characterized by high temperatures and low rainfall during growing season of vines, which may jeopardize yield and must quality. In 2018, a deficit irrigation trial was conducted with field-grown Touriga Franca in this Region. Four irrigation regimes were applied in three replicated blocks in order to reduce the impact of crop evapotranspiration (ETc): R0 (no irrigation, Control), R25 (25% of ETc), R50 (50% of ETc) and R75 (75% of ETc). Water was applied weekly (I8) or bi-weekly (I15) from veraison until 15 days prior to harvest. Leaf water status, canopy growth, microclimate conditions, yield and quality of musts were evaluated. This year was characterized by higher precipitation and lower temperatures than the average, both at veraison and at the beginning of maturation, and hot and very dry conditions in the final period of maturation. In this essay, no significant differences were found in canopy density neither in total leaf area. The level of water deficit, assessed through the predawn water leaf potential (Ψ0), was higher in I15 than I8 being the lower values obtained in R0 and R25. At harvest, the majority of the I8 modalities had higher values of probable alcohol (%), pH and total acidity with statistically significant differences between Control and R75. Anthocyanins were also higher in I8 trial, but there were significant differences in I15 between R0 or R25 (171,17 and 183,33 mg/L, respectively) and R75 (215,67 mg/L). Yield was affected by the frequency of irrigation, with higher values in I15 than I8. Regarding the average weight per bunches on I15, R50 (218,1 g) was statistically higher than R25 (185,9 g) and R0 (175,0 g). The yield per vine was higher in R50 (2,41 kg) and in R75 (2,36 kg) when relating to the Control (1,82 kg).

Keywords: Canopy growth, deficit irrigation, evapotranspiration, leaf water status, microclimate

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(ROSA Ref. n.30)

Increasing yield and water use efficiency in wine grape vineyards with variable rate drip irrigation

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Wine grape vineyards are traditionally developed and managed uniformly, using identical scion/rootstock combinations and applying equal inputs to each vine throughout a block. However, variability in terrain and in soil properties, especially water holding capacity, causes considerable and undesirable variation in fruit yield and quality. With the premise that irrigation is the cultural management tool with the largest effect on vine performance, a variable rate drip irrigation (VRDI) system was implemented in early 2013 in a drip-irrigated Cabernet Sauvignon vineyard located in the Lodi region of California. The VRDI system occupied a 4.05-ha area inside a block measuring 12.5 total ha and was split into 140 15x15-meter irrigation zones. Each zone was watered independently during three seasons with weekly schedules based on crop evapotranspiration (ETc) estimates using data from Landsat and a nearby weather station. Irrigation was scheduled with the objective of decreasing spatial variability while maintaining high yields. Yield was mapped the year prior to commencing the study and each year thereafter using mechanical harvesters fitted with yield monitors. Results were compared to an adjacent, conventionally drip irrigated (CDI) section of the vineyard, also measuring 4.05-ha. VRDI increased yield and water use efficiency in all three years and decreased vineyard variability. This proof of concept prototype is now the template for the ongoing development of a simple and affordable commercial system.

Keywords: variable rate drip irrigation, wine grapes, Vitis vinifera L., yield map

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(ROSA Ref. n.25)

Combined effects of rootstock and irrigation on gas exchange, fruit quality and yield in `Merlot´ and `Sangiovese´ grapevines

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The rootstock/scion combination plays an important role on grapevine tolerance to water stress. An experiment was carried out on 5-year-old potted grapevines (Vitis vinifera L. cvs. Merlot and Sangiovese) plants to evaluate the combined effect of two rootstocks (SO4 and 1103 Paulsen) and three irrigation regimes (Full Irrigation, FI; Regulated Deficit Irrigation 1, RDI 1; Regulated Deficit Irrigation 2, RDI 2) on leaf gas exchange, fruit quality and yield. Twelve combinations of variety-rootstock-irrigation regimes were evaluated in this experiment. Control grapevines (FI) were fully-irrigated from budburst through harvest, whereas RDI 1 and RDI 2 vines were subjected to water deficit from fruit set through veraison and from veraison through harvest, respectively, and fully irrigated for the rest of the irrigation period. Plant water status was monitored by measuring the stem water potential, which reached minimum values of -0.8, -1.7, -2.1 MPa, in FI, RDI 1 and RDI 2, respectively. Significant differences in stomatal conductance (gs) and net photosynthetic rate (Pn) between RDI 1 and the other two irrigation treatments were measured 7 days after the beginning of the differentiation (fruit set). Similarly, RDI 2 grapevines showed lower values of gs and Pn 6 days after the imposition of water deficit at veraison. The highest (2.0 kg) and lowest (1.1 kg) yield per plant were measured in RDI 2-Sangiovese-1103 Paulsen and in RDI 1-Merlot-SO4 grapevines, respectively. The RDI 1-SO4 grapevines showed the smallest berries in Merlot, whereas no significant differences were measured among the different combination of irrigation and rootstock in Sangiovese. The threshold of 22 ± 0.5 °Brix, used to establish the harvest date, was reached first by the RDI 2-Merlot grapevines grafted on both 1103 Paulsen and SO4, and after 30 days by the FI and RDI 1 irrigated Merlot-SO4 ones.

Keywords: photosynthesis, rootstock, stem water potential, stomatal conductance, *Vitis vinifera*

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(ROSA Ref. n 14)

Relations between factors affecting water consumption of Vitis vinifera cv. 'Cabernet Sauvignon'

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Skilled water management is considered the main tool for determining grape quantity and wine quality. A comprehensive irrigation method may benefit from incorporating changes in vine water consumption (ETc). Meteorological variables (MV) such as Daily temperature (Tmean), Total radiation (Rn), Relative humidity (RHmean) and wind speed (U2), as well as canopy leaf area (LAI – Leaf area index) all together affect ETc. Our main objective was to study the effects of MV and LAI on ETc. Six drainage lysimeters were constructed within a commercial 'Cabernet Sauvignon' vineyard grown in Meditation climate conditions in Israel. Data were collected during six growing seasons (2012- 2017). The ETc (L per day), was calculated by subtracting the daily water amount collected as drainage from the irrigation amount. In order to determine the relative influence of meteorological and vegetative factors on ETc, a boosted regression trees (BRT) machine-learning algorithm was applied to the time-series dataset, and the relative influence of each predictor on ETc was determined for each season separately. Average seasonal crop evapotranspiration (ETc) was 715 mm per season, while average seasonal calculated reference evapotranspiration (ETo) was 1237 mm per season. Maximum values for the seasonal crop coefficient (Kc) ranged between 0.8 to 0.9, and LAI values were 0.9 to 1.7 m2 m-2. A significant positive multi-seasonal linear correlation ($R2 = 0.66$, $p < 0.0001$) was found between LAI and Kc and may serve as a solid basis of irrigation model for vineyards. The BRT model results showed a pronounced impact of LAI on ETc, with a relative influence range of 62.2 - 86.0% in the different growing seasons. Mean relative influence of LAI, Tmean, Rn, RHmean and U2 were 71.7, 12.5, 9.3, 3.7 and 2.9%, respectively. The findings highlight the predominant role of LAI in determining vine water consumption.

Keywords: crop coefficient, drainage lysimeters, evapotranspiration, leaf area index, Vitis vinifera, water consumption, agrometerology, time series analysis

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(ROSA Ref. n.131)

Calcite silicon-mediated enhanced water stress tolerance in potted Vitis vinifera plants

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Due to climate change, an increase of air temperature and radiation regimes is expected. Plants might suffer from these stress factors causing a decline in morpho-phsysiological traits including photosynthesis, increased leaf temperature and change, berry sugar accumulation that collectively might lower yield and fruit quality. Foliar application of inert materials such as kaolinite clay [Al2Si2O5(OH)] might help to alleviate drought stress impact on plants increasing light reflectance of leaf and in turn reducing canopy temperature. However, the application of silicon has not been adequately explored as drought stress mitigation tool in grapevines. Therefore, the aim of this study was to evaluate the influence of silicon application on leaves of drought stressed grapevine on water relations through mitigation of drought-induced increased leaf temperature. A group of 22 vines were daily irrigated, restoring the daily water consumption, and served as control, at the ALSIA Experimental Station (Southern Italy) while a group of 22 potted (20 L) grapevine were subjected to a 15-day drought period by restoring the 25% of the daily water consumption. 11 drought stressed vines were sprayed with silicon (3% V/V) at the beginning of drought imposition. Stem water potential, leaf gas exchange and chlorophyll fluorescence were monitored early in the morning and around midday before the treatment application and during the experiment every approx. 2-day interval. Results show that in silicon treated vines, leaf/air temperatures ratio is lower than in untreated vines. Only in the presence of a very severe water stress (last two days of measurement) the silicon was ineffective in improving assimilation rate, transpiration, stomatal conductance and water use efficiency, while the treatment shows a significative improvement of these parameters in presence of a medium-severe water stress.

Keywords: chlorophyll fluorescence, micronized silicon, photosynthesis, stomatal conductance, water potential, abiotic stress, *Vitis vinifera*

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Session 8 - Irrigation of annual crops and ornamental plants – open field and greenhouses

Irrigation to crop demand and minimize leaching: how to achieve this mandatory requirement for soil-grown vegetable and cut-flower greenhouse crops in the Netherlands

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Soilless culture is the main cropping system used in Dutch greenhouse horticulture. However, for economic reasons, many cut-flower crops (chrysanthemum, lysianthus, alstroemeria e.g) and some vegetables (radish, leafy vegetables e.g.) are still grown in soil. Moreover all organic crops are bound to 'natural' soil obligatory. Since greenhouse production occurs year-round and at a high level, the amounts of water and nutrients used are much higher than in field crops. However, as irrigation is the only input of water, leaching can be potentially controlled greatly.
The irrigation and fertilisation to the crop demand should be aimed at minimal leaching on best effort basis.To achieve this, the demand of the crop must be estimated, taking into account the variations due to greenhouse type, climate, soil type, growing season, planting date, cultivar e.g. An overview will be given of DSS's that have been developed like the Fertigationmodel, DENAR Aqua Control, the EMMAN3G models, as well as the use of soil sensors (tensiometers, FD-sensors), lysimeters and the estimation of the crop water demand by ET-models.
The main focus will be on the practical implications and consequences of using those tools, aiming at the goal of irrigation tuned to crop demand. As case study, the results of implementation at an organic vegetable grower, a chrysanthemum grower and an alstroemeria grower will be discussed.
The mechanistic ET as well as soil hydraulic models are too complicated for irrigation control. Furthermore, the only possibility for realistic determination of leaching is using a lysimeter, though it provides complicated installation.In conclusion, the fertigation tuned to crop demand will be a learning process for growers and it will result in substantial reduction of the leaching from soil grown greenhouse crops. However, due to its complexity the goal of zero leaching for soil grown crops is beyond reach.

Keywords: WFD DSS Lysimeter Soil-moisture-sensor Chrysanthemum Alstroemeria Tomato Transpirationmodel Fertigation model

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Invited lecture

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Productive and non-productive use of water of common beanunder full and deficit irrigation

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This paper presents the relationship between dry grain and biomass yield of common bean (Phaseolus vulgaris L.) with water productivity (WP gm-2) and water use efficiency (WUE kgm-3). The experiment was set up inStara Pazova, 40 km north of Belgrade, during 2018. Three treatments of irrigation regimes, with tree sowing periods (I - April 16, II - May 30, III - July 5) were monitored. Treatment with full irrigation (F), when 100% is covered by ETc (evapotranspiration), a treatment with deficit irrigation (R) with 80% of the ETc and a treatment with deficit irrigation (S) with 60% of ETc were applied in each sowing period. Automatic weather station was set up adjacent to the experimental plots. Reference evapotranspiration (ETo) was estimated with FAO Penman-Monteith equation using daily data obtained from the station. Crop evapotranspiration (ETc) was calculated as the product of ETo and the dual crop coefficient. The WP values were uniform in all treatments in the sowing period I (15.66 – 15.82 gm-2), whereas WUE values ranged from 1.31 kgm-3 (S) to 1.64 kgm-3 (F). In the sowing period II, the WP and WUE varied most, and were highest in F treatment (16.30 gm-2, 1.58 kgm-3), slightly lower in R treatment (14.89 gm-2, 1.40 kgm-3), and the lowest values were on the S treatment (13.37 gm-2, 1.25 kgm-3). In the sowing period III, highest WP and WUE were on the R treatment (14.79 gm-2, 1.57 kgm-3), followed by F treatment (13.36 gm-2, 1.43 kgm-3), whereas the lowest values are observed in S treatment (12.07 gm-2, 1.27 kgm-3). Least unproductive water use was observed on fully irrigated treatment during the sowing period II (19.98%) and the highest one on S treatment during sowing period I (36.74 %).

Keywords: irrigation, common bean, water use efficiency, water productivity

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Agronomical effects and response of growers in the application of the DSS GesCoN at commercial farms scale

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The results of the application of the DSS GesCoN during the 2018 growing season on six commercial farms for assisting growers in the management of fertigation of the processing tomato crop are reported. The farms were selected within the Capitanata area (Foggia province, Italy) in order to have a representative coverage of all the area, which is a quite large and flat territory where processing tomato cultivation covers about 20000 hectares. To evaluate the effect of the application of the DSS in each farm two plots were selected: one managed according to the daily indications of the DSS and the other one managed according to the empirical procedures followed in each farm. The input of meteorological data into the DSS was carried out automatically and all the communications between the DSS and the growers were performed through the use of smartphones. Results indicate that the application of the DSS allowed a reduction of the seasonal irrigation water volume of about 24%, while the total N fertilizer application was reduced by 7%. Despite these reductions in water and N inputs, total and marketable yield was not affected. No significant effects were also detected on some qualitative parameters of the tomato fruits (dry matter content, titratable acidity, °Brix). Growers followed all the growing season without difficulties in using the DSS and they found all the system very easy-to-use and useful in driving fertigation and in obtaining savings of irrigation water and N fertilizer. After it's first calibration and validation on processing tomato and these preliminary large scale tests, the DSS GesCoN is currently functioning as a service on the platform www.ecofert.it for managing fertigation in processing tomato crop.

Keywords: vegetable crops, decisional support system, fertigation, communication with mobile devices

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(ROSA Ref. n.185)

Commercial yield response of iceberg lettuce (*Lactuca sativa* L. var capitata) to water irrigation at a cool semi-arid climate of Maipo Valley, Santiago, Chile

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In order to unveil the effect of irrigation water applied to the yield and quality of iceberg lettuce cropped at Santiago, Región Metropolitana, Chile, a four treatments drip irrigation experiment was set consisting in a randomize block design with four repetitions. Four pressure compensated types of drippers mounted on a PE plastic 16mm irrigation pipe (20 cm spaced) discharging an equivalent to 1.2 L/h (T1), 2.0 L/h (T2), 3.0 L/h (T3) and 4.0 L/h (T4) were mounted in order to apply different water levels per treatment. The same time and irrigation frequency were applied to the treatments.The crop was established in beds 100 cm wide, with three rows of lettuces spaced at 30 cm between plants, while two drip irrigation pipelines were set by bed. The first repetition run between December 2016 and February 2017 (summer season) while the second repetition of the experiment was performed between March 2018 to July 2018 (autumn winter season). Plants were harvested at commercial maturity and fresh clean mass of the lettuce head was recorded, head diameter, head firmness and the prevalence of diseases in the harvested organ. Soil water humidity and meteorological data was also recorded.Plants of lettuce cropped with low water height (T1) showed the highest rate of head deformity and soft head reaching also the lowest percentage of commercial units. The increment of irrigation water determined an increase of the prevalence of rotten lettuce heads and powdery mildew (T2, T3, and T4). Excess of water applied increases the proportion of soft lettuce heads decreasing the commercial yield. A function of commercial yield response to water applied was set concluding that maximum yield was reached irrigating 169 and 185 mm of water, for the two repetitions of the trial.

Keywords: lettuce, yield water response, commercial yield

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Broomrape (Phelipanche and orobanche spp.) management in Israel using drip herbigation

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The obligate root parasitic weeds commonly named broomrape (Orobanche and Phelipanche spp.) cause severe damage to vegetable and field crops worldwide. In the Mediterranean basin, Egyptian broomrape (P. aegyptiaca), Branched broomrape (P. ramosa), Crenate broomrape (O. crenata) and Sunflower broomrape (O. cumana) are the most abounded and devastating species among broomrapes, parasitizing a wide crop host range including tomato, sunflower, legumes and carrot. The arid and semi-arid conditions in the Mediterranean basin require the use of irrigation system to ensure optimal water supply in the dry spring and summer. Global warming is changing irrigation practices in areas where rains are scarce and flooding irrigation is not possible, thus requiring the use of more sophisticated irrigation systems (e.g. southern Europe, California). We hypothesized that integration of a modeling approach and chemical applications (foliar or delivered by drip irrigation-herbigation) at the soil sub-surface broomrape development phase (pre broomrape attachment and/or post broomrape attachment) will control the parasite and prevent crop damage. In this presentation three protocols for broomrape management at a farm scale, based on this approach will be given: control of P. aegyptiaca in processing tomato, O. cumana in sunflower, and P. aegyptiaca in carrot. A robust thermal time model to predict the parasitism dynamics of P. aegyptiaca in tomato estimates that the first attachment of the parasite to tomato root is observed after 200 degree-days (Tbase=10ºC). Because broomrape seeds germinate throughout the growing season when exposed to tomato root exudates, treatments must be repeated every 200 degree-days. We have developed a decision support system (DSS) 'PICKIT', based on a degree days' model and an integration of soil-applied herbicides for prophylactic treatments, together with POST attachment applied herbicides for P. aegyptiaca control. Soil applied herbicides include pre-planting incorporation (PPI) of 37.5 g a.i. ha-1 of sulfosulfuron, followed by drip herbigation of 4.8 g a.i. ha-1 of imazapic 400, 600 and 800 degree days after tomato planting (facilitating a thermal time model for parasitism dynamics). Imazapic herbigation is applied using low flow drip irrigation, 1.0 l/h, 'Uniram' Netafim, that uniformly delivers the herbicide into the soil. For optimal herbigation, the herbicide must be applied at the last third of each irrigation cycle. Twenty-five experiments at nine locations for field validation of the 'PICKIT' DSS were conducted between the years 2013-2016 in Israel. The use of the DSS lead to effective control of Egyptian broomrape in commercial fields. In high infestation levels yields increased by 40 tons per ha compared to the non-treated control. The same approach i.e. facilitating thermal time model and herbicide applications were used in sunflower and in carrot. Eight large scale experiments examined Herbigation of imazapic to control O. cumana in sunflower confirmed sunflower yield increase of 1.6 tons per ha (~40%). Twenty-five large scale experiments examined foliar application of low glyphosate rate for P. aegyptiaca control in carrot confirmed yield increase by 50% in heavy infested field.

Keywords: Egyptian broomrape, model, parasitism dynamics, herbigation

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(ROSA Ref. n.197)

Assessing the optimal timing of partial root-zone drying alternation in tomato crops under furrow irrigation

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Horticultural production in many countries uses high levels of technology (eg. drip irrigation, soil moisture sensors) which increases not only yield but also resource use efficiency. However, in developing countries horticultural production heavily relies on smallholder farmers that cannot access those technologies. In Ghana, national tomato production cannot match the increasing demand for this crop, especially during the off-season, and there is a need to increase irrigated tomato production. Optimal application of low cost irrigation techniques can increase water use efficiency and therefore increase the land area that can be irrigated during the dry season. Partial root-zone drying (PRD) is a water-saving irrigation technique trialled in different crops including tomato, enhancing crop water use efficiency. Irrigation is applied to half of the root-zone, which is alternated during the period of application. Although crop physiology can explain its superiority over homogenous deficit irrigation at similar irrigation volumes, the timing of alternation is currently applied empirically and its physiological effects are much less known.
To investigate the optimal frequency of alternation in PRD in tomato we carried out a field trial in Kumasi (Ghana) on an improved bush-type cultivar (Petomech) and a controlled environment experiment in Lancaster (United Kingdom) on a miniaturised PRD system using the dwarf cultivar Micro-Tom. Both field and controlled environment trials assessed the effect of three different frequencies of alternation (none, short cycle and long cycle). Long PRD cycles (every other irrigation event in the field) decreased yield compared to shorter cycles or even fixed PRD (no alternation). Since whole-plant gas exchange or plant water status did not differ between alternation treatments, neither during the cycles or upon re-watering in the controlled environment experiment, the physiological mechanisms regulating these responses need to be further investigated.

Keywords: Africa, furrow irrigation, deficit irrigation, gas exchange

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Potential reuse of drainage solutions from three soilless crops grown under Mediterranean conditions

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Fertigation of soilless crops grown in substrate often target at drainage volumes of 30-40% (particularly in summer and in Mediterranean regions). In closed systems the drainage is recycled, being mixed with the new nutrient solution and corrected for the electrical conductivity (EC), resulting in a high water and nutrient use efficiency. In contrast, in open systems (with free drainage) or in semi-open systems (drainage is collected but only partly used for irrigating secondary crops), large amounts of water and nutrients are released to the environment. This study is integrated in the EU Project AgriNuPes (www.agrinupes.eu) and it aimed to assess the potential reuse of drainage solutions from soilless cultivation of tomato, rose and strawberry grown under Mediterranean conditions in semi-open irrigation systems, through quantification of nitrogen, phosphorus and potassium (by colorimetry) and of phytopharmaceutical products. Samples were collected in two points of each system: (i) immediately after passing through the substrates and (ii) in the reservoirs. Drainages obtained from strawberry and rose showed prevalence of N along the system while P was, respectively, 28% and 32% lower in drainages from the reservoirs when compared to drainage from the substrate. In tomato, N was 62% lower in the drainage from the reservoir, but P was rather constant throughout the system. Despite considerable decreases of N and P observed in drainages from different crops, these results indicate good reuse potential through maintenance of large part of the main macronutrients. Moreover, the variation of the content of each nutrient throughout the system stresses the importance of using more precise methodologies in assessing the nutrient profile of the drainages rather than adjusting the solution simply based on EC. Such methodologies will improve fertigation management, which is highly relevant due to increasing water scarcity and to the environmental impact in food production.

Keywords: drainage, fertigation, macronutrients, rose, semi-hydroponics, strawberry, tomato

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(ROSA Ref. n.78)

Water use and evapotranspiration estimates at a California container plant nursery

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The objective was to investigate water use per area and its relationship to reference evapotranspiration at a large-scale container-grown plant nursery in California. Monthly applied irrigation was recorded during 2016 and 2017. Irrigation runoff was captured and measured from impervious material-lined production areas and runoff channels. A runoff coefficient for irrigation volume was developed for periods absent of precipitation two weeks prior to and during those periods. For periods when runoff volume data did not exist, estimated runoff volume was determined by multiplying the runoff coefficient by applied irrigation volume. Estimated runoff volume was subtracted from total applied irrigation volume to estimate total nursery water use. Total nursery water use was divided by the nursery production area to estimate nursery evapotranspiration (ETN). Monthly reference evapotranspiration (ET0) was recorded from two California Irrigation Management Information System (CIMIS) stations, #44 and #240, 19 km and 17 km from the nursery site, respectively. A monthly nursery coefficient (kN) was derived by dividing monthly ET0 by monthly ETN, a similar calculation as crop coefficient (kc). Monthly water use ranged from 6,304 - 69,832 m3 with a mean of 32,066 m3 during 2016 - 2017. Greater monthly water use occurred during periods of higher ET0. Estimated monthly kN at the nursery was 0.21 - 0.56. ETN varied per season likely due to crop selection and total area in irrigated production. Although runoff conduits were lined with impervious material, infiltration and evaporation did occur and accounting for those losses would further reduce kN.

Keywords: nursery, evapotranspiration, irrigation, container plants

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(ROSA Ref. n.5)

Developing an automated leaching fraction-based irrigation schedule for nursery crops

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Container production of woody ornamental crops tends to use high volumes of water and have low water application efficiencies. Leaching fraction (LF) [(volume leached)/(volume applied)*100] is a simple calculation that has been used as a foundation for refining irrigation. However, there is no available system for automating these measurements, which limits the practical application of LF. Therefore, our objective was to develop an accurate sensor to measure container effluent and irrigation volume that, in tandem with a data logger, relay device, and 12 volt solenoids, could calculate LF and automatically irrigate crops. An experimental system was developed at a commercial nursery in Knox County, Tennessee, USA. In each irrigation zone, four leachate sensors and an irrigation sensor were deployed, each using a tipping bucket mechanism to measure volume and a reed switch to communicate individual tips to the data logger. Each day, the program cumulated the leachate and irrigation volumes and calculated the LF for each zone. The previous day's LF was compared to the target LF to calculate irrigation operation time needed to maintain a 15% LF for the current day, and irrigation was actuated accordingly. The LF-based system was compared to the commercial nursery's conventional irrigation schedule, irrigating 2 hours every other day with approximately 1.3 inches (3.3 cm) of water. The experiment was conducted for three consecutive seasons using a new crop of #1 (3.7 L) Juniperus conferta 'Blue Pacific' and J. horizontalis 'Blue Rug' each year. The effect of irrigation treatment on weekly water use, daily leaching fraction, end of season plant biomass, and increase in plant growth were assessed at the end of each growing season using a two-way ANOVA with irrigation schedule and cultivar as the two independent factors. Average weekly water use was reduced 1,094 gallons in the approximately 1200 ft2 production space by using the leaching fraction-based irrigation schedule rather than the grower's standard irrigation practices. Season-long water use was 69%, 63%, and 59% less in 2015, 2016, and 2017, respectively, for the leachate-based irrigation schedule. Daily leaching fraction was less for the leaching fraction-based irrigation treatment than for the control, P-value < 0.0001. In 2015, 2016, and 2017, the average daily leaching fractions were 16% and 73%, 15% and 66%, and 20% and 79% for the leaching fraction-based irrigation and control, respectively. Irrigation treatment did not affect any end of season crop growth measurement.

Keywords: juniper, sustainable, leachate, ornamental, sensor

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(ROSA Ref. n.32)

Optimizing irrigation set-points for the growth and quality of two Chrysanthemum morifolium cultivars in two soilless substrates

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We investigated reducing substrate water availability on the growth and quality of two Chrysanthemum morifolium cultivars 'Chelsea' and 'Ursula', using sensor-based precision irrigation in a greenhouse study. Transplants were grown in 3.8 L containers in either a 80% peat moss:20% perlite (Sunshine LC1) substrate, or a 60% peat:40% wood fiber (WF) substrate, in a randomized complete block design. Three volumetric water contents (VWC) of 45% (Control), 35% (IT1) and 25% (IT2) were selected as irrigation set-points, resulting in different matric potentials (MP) for each substrate. In situ VWC and MP root-zone data were measured with GS-1 and MPS-6 sensors every 5-min using Em50R dataloggers (Meter Group Inc.,). Data were transmitted through a basestation to SensorWebTM software (Mayim LLC., Pittsburgh, PA). WC readings from 4 sensors in each treatment combination/block were averaged every 15 minutes. Irrigation was automatically applied for 15 seconds whenever the average VWC fell below treatment set-points, using nR5control dataloggers (METER Group Inc.) and SensorWebTM software. Irrigation volumes were recorded with flowmeters (Badger Meter Inc., Milwaukee, WI). Plants were harvested at maturity and eleven vegetative, floral and root parameters were measured. No differences among VWC were observed for 'Chelsea' in the WF substrate. However, significant differences in vegetative shoot and floral data were observed for 'Ursula'; VWC below 45% resulted in plants with less vigor. Irrigation volumes were 16.6% and 41.1% less for the WF-IT1 and IT2 treatments compared to the control. In the LC1 substrate, only canopy volume and flower number were significantly different among VWC treatments for 'Chelsea'; only canopy volume was significantly different between irrigation treatments for 'Ursula'. Volume of irrigation water applied was 33.0% and 33.7% lower for the LC1-IT1 and IT2 treatments, compared to the control. Results indicate significant differences in substrate plant-available water and possibly drought resistance between the two cultivars.

Keywords: volumetric water content, matric potential, sensor-controlled, precision irrigation, ornamental, greenhouse

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Posters

Session 1 – Climate and water resource perpsectives: social and economic aspects

Profitability and regional differences of irrigated sweet corn in Hungary

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The cultivated agricultural area is 5.3 million hectares, which is 57.5 per cent of total area of country, providing outstanding opportunities for agriculture. The last decades show more frequent and more severe impact of drought, yet the area with outdoor irrigation system is only 144 thousand hectares, but no more than 100 thousand hectares are irrigated by producers. The increase of irrigable areas would be a huge development opportunity for Hungarian open field plant production. This is even more important in light of the expected negative impacts of climate change in the region. For this reason, the Government treats the spreading and sustainable development of irrigation management, protection and utilization of water resources as a priority, which is confirmed by the 1744/2017. (X. 17.) Government Regulation of Irrigation Development Strategy. As part of the Strategy, the Hungarian Chamber of Agriculture undertook to carry out a survey in the areas with most potential for implementation of irrigation development, i.e. current delimited irrigation network impact area based on 68 surface water bodies. This affected 1.2 million hectares and 43 026 producers. The producers want to irrigate 388.5 thousand hectares from the 1.2 million in the future, of which 120 thousand hectares are currently an area with irrigation system, whereas 268.5 thousand hectares of new irrigation demand appeared. In the largest area of vegetables in the future, producers want to irrigate sweet corn (33.6 thousand hectares). From these 33.6 thousand hectares 9.8 thousand hectares have already had completed irrigation system and 23.8 thousand hectares of new irrigation demand. We made the estimation based on producers' responses, that the future irrigation purpose what economic benefits can be realized. We calculated in detail the profitability indices of sweet corn. The income of dry cultivated sweet corn was between 374.2-598.2 thousand HUF, while it changed between 465.1-862.1 HUF/hectare in case of irrigated sweet corn production. We accounted of different soil conditions and drought zones to the investigation of regional differences of sweet corn's profitability, and we calculated with different years and the territorial variation of yields.

Keywords: sweet corn, profitability, irrigation

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Drip line size selection in micro irrigation design for tree crops: economic and energetic sustainability

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The proper selection of components in an irrigation system can help increase water use efficiency, also reducing costs and saving energy. In the design of drip irrigation systems, characterized by the supply of low water rates, multiple factors are considered: soil type, field length, crop irrigation requirements, distribution uniformity, sector size and number, etc. The present work analyses the criteria for choosing between two different diameters of drip tubing, commonly used in tree crops, considering the technical parameters available and the economic and energetic implications. The analysis considers not only the difference in upfront costs for materials, but also the operation costs, in particular for pumping energy, over the lifetime of the irrigation system. Three scenarios are analysed based on the annual operating time of the system: 400, 600 and 800 hours. Each scenario is applied for the two available diameters of the drip tubing, i.e. 16 mm and 20 mm. The spacing for emitters on the line was chosen at 70 cm, while the effects produced on the system by four different flow rates (in l.h-1) are analysed: 1.0; 1.6; 2.4 and 3.8. The combination of these parameters determines the operating pressure required for the system and the maximum technical length achievable for the dripline. The results of the technical-economic analysis show that an economic advantage is obtained with the adoption of larger diameter lines (20 mm), which increases with extended irrigation time, higher flow rates and longer lines. The maximum advantage, equal to 153 € ha-1 year-1 (+48%), is obtained by combining the long operating time (800 h year-1), the high flow rate (3.8 l.h-1) and the maximum length of the dripline (187 m). Under these conditions, the energy saving is also maximum, achieving a 57.1% reduction in pumping energy consumption, equivalent to 3,874.95 kJ.ha-1 year-1.

Keywords: micro-irrigation, dripline, design parameters, operating costs,orchard irrigation

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Olive yield response to irrigation under climate change scenarios

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Climate change is deemed as a major threat for the sustainability of current agricultural systems. The variety and complexity of ecophysiological responses induced by future climatic scenarios and the tremendous challenge of reproducing those in the field for representative plots and long periods make crop models an appropriate tool to foresee the outcomes of climate change for agriculture. This study assesses the impact of future climatic conditions on the productivity of olive orchards under different regimes of water supply using the process-based model OliveCan. 'Future scenarios' were generated from present weather datasets by increasing temperature by 2 ºC and decreasing rainfall by 20 %, considering a CO2 concentration to 540 ppm, which correspond to predictions by RCP4.5 for the end of the century in many of the Mediterranean areas where olive trees are massively cultivated. According to the model, the increase in atmospheric CO2 leads to a higher water use efficiency that compensate the negative effects of the temperature increase and rainfall reduction in many cases. Hence, our simulations reveal that future climatic scenarios can lead to either lower, neutral or higher productivities in relation to the present depending on the balance of water supply (rainfall + irrigation) and evaporative demand of the orchard.

Keywords: climate change, irrigation, olive tree, water use effiiency

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Water conservation expertise and Involvement Influence plant purchases and enjoyment of U.S. consumers

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As potable water supplies become increasingly strained globally, consumer perceptions and purchases in the horticulture industry will profoundly influence profitability of growers, wholesalers, and retailers. Knowledge or expertise about water conservation, as well as interest or involvement with water conservation measures, should positively influence plant purchases and enjoyment. An online survey of 1543 respondents assessed U.S. consumer's water conservation expertise, involvement, importance, and impact as well as their plant spending and demographic characteristics. Results showed that U.S. consumers who were less interested in water conservation were older, more likely Caucasian, and from smaller households with a lower income. However, subjects who were more interested and knowledgeable about water conservation spent nearly twice as much on plants and related supplies in the year prior to the survey. Findings have important implications for retailers as they should appeal to water-conservers since they are more important plant customers.

Keywords: marketing, survey

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Soil hydrology research platform underpinning innovation to manage water scarcity in European & Chinese cropping systems

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In many areas of Europe and China, crop production is already water-limited and will be more so in the future due to climate change and to increased competition for water from other sectors of society. This is recognized by comprehensive EU and Chinese initiatives. There is a need to adopt innovative tools to deal with water scarcity at the farm level and integrate these within the entire agro-ecosystem (catchment or community scale). Investments in soil and water conserving technologies and improved agronomic techniques must be balanced against their costs, by accounting for their impact on other key agro-ecosystem services essential for long-term sustainability and demanded by society: soil conservation, soil organic carbon and drainage/runoff water quality. To achieve the aims of SHui (Soil Hydrology Research Platform Underpinning Innovation to manage Water scarcity in European & Chines cropping systems), we present some aspects of specific objectives: First how o develop and propose integrated water management strategies for optimizing crop yields and key agro-ecosystem services in cereal-based rotations and tree crops at different spatial scales based on sustainable intensification under different environmental and social conditions in EU and China. Furthermore, we consolidate a network of long-term experiments within agricultural systems in EU and China for research and, training and exchange of technical information. Coordinating a trans-disciplinary stakeholder approach on a farm and regional scale, the socio-economic team will supplement technological and irrigation related scientific findings with the economic, environmental and social (including gender) dimensions, enhancing sustainable development. We will work with an adapted cost-benefit analysis of best management on-farm strategies developed within the project. An efficient strategic framework for regional and local allocation of soil and water resources will be developed. Finally we coordinate and disseminate economic analyses for policy makers and land users using participatory approaches.
Keywords: soil hydrology, cost benefit analysis, water management, sustainable water use

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Session 2 – Non conventional water use: saline and urban wastewater

Feasibility of tertiary treated wastewater reuse in the irrigation of grapes and olives

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The increased global water demand is causing strong stress on natural water resources, and implies the need of alternative ones. In this view, treated wastewater is increasingly considered a potential source of water, rather than a waste. In recent years, several studies about treated wastewater reuse for irrigation confirmed the feasibility of this practice. Nevertheless, water reuse still meets hesitation in potential users, mainly for incomplete information about the characteristics and potential benefits of reclaimed water. The project MeProWaRe (WaterWorks2014, Water JPI cofunded call) was aimed at encouraging treated wastewater reuse through an integrated strategy for the irrigation of vineyards and olives groves. MeProWaRe introduces an innovative methodology towards water reuse specifically addressing well defined types of crops, agronomic practices, and water constraints that are typical of Mediterranean countries. The idea is to highlight the positive relationships between water reuse, plants growth and crops productivity with specific reference to the Mediterranean area. To obtain this, reuse practices were made more easily acceptable to stakeholders through their direct participation in the implementation of the proposed methodology. Experimental activities were carried out at three demonstration sites in Portugal, Spain, and Italy. The present study focuses of the Italian case study of Acquaviva delle Fonti (Puglia, South-Eastern Italy), where the adoption of tertiary treated effluents form the local municipal wastewater treatment plant was evaluated by monitoring their quality over time. The proposed strategy included the possibility of blending the treated effluent with the conventional source (well water), and the results showed the effectiveness of the tertiary treatment based on gravity disk microfiltration and UV disinfection to obtain water suitable for unrestricted irrigation. The possibility of adjusting the dilution ratio of the two water sources according to the nutrient content of the treated effluent and the phenological needs of the crops was also evaluated.

Keywords: crops irrigation, water reuse, wastewater treatment, olive trees, grapevine

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Process energy analysis for the agricultural reuse of industrial wastewaters

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Today, it is well known that there is a growing deficit in the traditional water resources, in terms of quality and quantity. This is mainly due to the agriculture, industrial and urban development, which, in turn, causes a deterioration in the quality of surface and underground water and a resulting increase in wastewaters treatment costs.
What would happen if the huge quantities of wastewater deriving from domestic, agricultural and industrial use, that are daily discharged into the environment, were considered a precious resource rather than a heavy burden? Nowadays the search for sustainable solutions focuses on optimizing the use of natural water resources and on integrating alternative water resources, such as the so-called unconventional waters (purified wastewater or rainwater drainage). Although many international organizations promote the practice of reusing wastewater as an incentive for sustainable development, according to Agenda 2030 SDG's, up to now there are few concrete experiences in this sector. In this work, in collaboration with Feem (Eni Enrico Mattei Foundation) and Biomedical Campus University of Rome, the design of a pilot plant for the reuse of industrial wastewater has been carried out. The pilot plant allows the production of different types of water at various levels of purity that can be reused in:

- the agricultural sector to irrigate green areas and crops for bioindustrial purposes, but also for recreational or sport activities;
- the industrial sector to treat industrial wastewaters and for cooling circuits, boilers and various technological cycles;
- the civil sector to wash the urban roads and to feed heating and cooling cycles;
- the pharmaceutical sector to produce drugs and to feed the related pharmaceutical processes;
- the laboratories analysis;
- the food sector;

Finally, a process energy analysis is proposed to create a calculation list capable of determining an energy equivalence between the different plant processes, considering the possible uses for the different types of water produced.

Keywords: wastewater reuse, agriculture, climate change, energy, sustainable development

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Interactions of fertilizer and chemical sanitizing agents in water

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The objective was to quantify interactions between fertilizers and chemical sanitizing agents. In order to measure decrease in active ingredient level of four oxidizers, sodium hypochlorite, chlorine dioxide, and two commercial activated peroxygen products were added to either NaCl or 17-1.8-14.1 at 100 mg.L-1 N solutions, with and without iron-ethylenediaminetetraacetic acid (FeEDTA) at 1 mg.L-1 Fe. Activated peroxygens did not decrease in concentration. Chlorine dioxide and sodium hypochlorite decreased more in the macronutrient solution than NaCl, but was not affected by FeEDTA. A second experiment evaluated interaction of Cu at 2 mg.L-1 from either copper nitrate salt or copper ionization with different iron chelates [no chelate, FeEDTA, or iron-ethylenediamine-N,N'-bis(2-hydroxyphenylacetic acid) (FeEDDHA)], and solution pH levels (4.0, 5.5, 7.0, and 8.5) in a 17-1.8-14.1 nutrient solution. Free copper in the absence of iron chelate decreased when pH level was 8.5 compared with lower pH levels, particularly for Cu from copper salt. Copper reacted with iron chelates at all pH levels, presumably by substituting the chelated iron, with Cu from copper salt less stable than copper ionization as free copper. A third experiment evaluated the effect of all six sanitizing agents described above on concentration of FeEDTA and FeEDDHA. Copper from both salt and ionization sources at 2 mg.L-1 Cu reduced the concentration of both FeEDTA and FeEDDHA, by 0.1 to 0.8 mg.L-1 Fe after 1 h. Activated peroxygens reduced FeEDDHA concentration by up to 0.8 mg.L-1 after 1 h and 1.3 mg.L-1 after 24 h, but had less effect on FeEDTA (up to 0.3 mg.L-1 decrease after 24 h). Chlorine dioxide at 0.5 mg.L-1 and sodium hypochlorite at 2 mg.L-1 did not affect iron concentration from either chelate. Given the many complex reactions that occur, it is important to regularly measure sanitizing agent concentration under local irrigation conditions.

Keywords: activated peroxygens, chlorine, chlorine dioxide, copper ionization, sodium hypochlorite, water treatment

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Remediation of phytopathogen contaminants from irrigation runoff using floating treatment wetlands

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Irrigation runoff is an alternative, supplemental source of water for specialty crop producers. The presence of phytopathogen contaminants in runoff limits grower willingness to reuse water as phytopathogens can directly impact crop health. Treatment technologies are available to manage other contaminants of concern (e.g., nutrients and pesticides), but little information is available about the efficacy of biologically-based treatment systems to remediate phytopathogen contaminants. Growers need this information to help them make informed decisions with regard to selection of technologies to enhance management of irrigation runoff. We evaluated the efficacy of floating treatment wetlands to mitigate phytopathogen contaminants present in simulated production runoff by performing both microcosm scale and pilot scale experiments. During the microcosm scale, Phytophthora susceptibilityscreening evaluations in 2016 and 2017 we exposed Pontederia cordata and Agrostis alba to five species of Phytophthoraanddetermined that neither plant species was susceptible to infection by the species of Phytophthora evaluated nor served as an asymptomatic host. We performed pilot-scale experiments in summer 2018 with the same plant species established in floating treatment wetlands. The presence of both plant species slowedPhytophthora propagule movement through the water control structure in contrast with experimental units that had no plants present. These preliminary data show promise for phytopathogen remediation, as slowing water and thus contaminant movement is the primary means by which remediation occurs, permitting biological and physical parameters to influence the survival of phytopathogen propagules within treatment systems. Further plant evaluations will aid in design and installation of plant-based treatment technologies, tailoring plant selections to site specific remediation targets.

Keywords: Phytophthora remediation, Pontederia cordata, Agrostis alba

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(ROSA Ref. n.73)

Are farmers willing to use urban wastewater for irrigation? Results from a survey to Apulian irrigators

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In many regions already affected by structural water scarcity, reuse of treated wastewater is claimed to be a real solution to alleviate increasing water demand while mitigate groundwater depletion.
Although technological progress ensures that recycling is safe, the total volume of treated wastewater reuse in Europe is a tiny percentage of the treated effluent. Water reuse projects may fail for various reasons. One is the lack of popular support, because the perceived risk of poor water quality leads to problems with acceptance. Therefore, farmer's acceptance is crucial to foster reclaimed wastewater reuse in agriculture.
Farmers' acceptance of urban wastewater reuse was investigated in Apulia region, southern Italy. A sample of 250 irrigators was used to carry out a choice experiment (CE), by which preferences for wastewater reuse in agriculture were elicited. Moreover, average payment that farmers are willing to pay for wastewater was assessed.
As a whole farmers' acceptance of wastewater for irrigation is fair. Nevertheless, few respondents are reluctant in using reclaimed wastewater. On the other hand, large share of farmers would pay less than current tariff for conventional irrigation water sources. With greater relevance, findings pointed out that farmers' preferences for wastewater use are affected from groundwater management policy.
On the base of results, some policy implications can be discussed aimed to foster wastewater reuse in the Mediterranean regions.

Keywords: urban wastewater, farmers' acceptance, willingness to pay, choice experiment, Mediterranean regions.

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Physiological changes of grapefruit trees irrigated with saline reclaimed water combined with deficit irrigation detected by multispectral images

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We report the results of an experiment using multispectral images and physiological data at leaf level to evaluate the physiology of adult grapefruit trees irrigated during 13 years with saline reclaim water (RW) and transfer water (TW) with different irrigation strategies: control (C) and regulated deficit irrigation (RDI). Multispectral data were acquired by an airborne flight using a fixed-wing unmanned aerial vehicle while concomitant measurements of photosynthesis net (A), stem water potential (SWP), leaf total chlorophyll content (Chl T) were taken in a commercial orchard located in the Southeast of Spain at 12.00 GMT on October 4, 2018. Results suggested that Chl T content were significantly reduced by RW (34.5 and 31.4% for RW-C and RW-RDI, respectively). Plant water status was also affected: SWP and A decreased by RDI strategy, and mainly in RW-RDI. Regarding the relationships with spectral data, Chl T was significantly correlated with R (Red) wavelength (R2=0.41, p2=0.36, p2=0.76, p2=0.47, p.

Keywords: Chlorophyll, citrus, gas exchange, near infrared, reflectance, stem water potential, water stress.

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Preliminary assessment of using nitrates and potassium probes for sustainable management of fertigation with reclaimed water in citrus

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The saline reclaimed water has a high macronutrient concentration and toxic salts for the plant, so in this kind of water an efficiency management of fertigation is necessary in order to avoid an excessive leaching of the nutrients and harmful effects for the plant. In this sense, the main objective of this study is to evaluate the absorption efficiency of nitrates and potassium for the crop. The experiment was conducted on a plot of adult grapefruit trees (Citrus paradisi Macf., cv. Star Ruby) located at Molina de Segura, Murcia. Two different water sources were used. The first one was pumped from Tajo-Segura Canal (transfer water, TW), and the second one was pumped from Molina de Segura tertiary wastewater treatment plant (reclaimed water, RW). Both treatments were irrigated to fully satisfy the crop water requirements (100% ETc). The nitrate and potassium in the soil solution was monitored continuously with probes which measure the concentration of each nutrient. The results indicated that the concentration of nitrate and potassium in the soil solution is different between water sources (in RW is being 5 times more than in TW). Besides, the plants irrigated with saline RW are showing a high concentration of both nutrients in the soil solution, respect to the plants irrigated with TW (5 and 2.5 times more for nitrates and potassium respectively). This study allows us to understand the dynamic of absorption of both nutrients, which was different according to this, showing that RW plants presented a double K absorption respect to TW plants, indicating a mechanism of alleviate saline toxic effects. On the other hand, these novel data open news perspectives on the sustainable management of saline RW with high nitrogen concentration in citrus crops, avoiding the unwanted nitrate leaching, this being a potential contaminant of aquifers.

Keywords: saline treated wastewater, nutrient absorption, leaching, irrigation practices

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The potential role of arbuscular mycorrhizae fungi and mixed substrate in the physiological and agronomical behaviour of tomato plants irrigated with saline reclaimed wastewater

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The use of reclaimed wastewater could be a valuable water resource to irrigate crops. However, reclaimed wastewater may contain high concentrations of salts among others, and thus appropriate cultural practices are required. In this greenhouse experiment, we evaluated the role of the arbuscular mycorrhizal fungi Glomus iranicum var tenuipharum and a mixed substrate (a combination of a traditional agricultural soil with a specific substrate for horticultural crops) on the physiological and agronomical response of tomato plants (Solanum lycopersicum var HULK F1) irrigated with saline reclaimed wastewater. Therefore, eight treatments were applied in the plants during 20 weeks, as a result of a factorial combinations of soil type used (agricultural soil or mixed substrate) (S, M), mycorrhizae application (absence or inoculation) (-M, +M) and irrigation water (control water and saline reclaimed water) (C, S). Saline reclaimed wastewater caused an accumulation of toxic ions in leaf tissues during the last weeks of the experiment. Salinity also decreased leaf water potential and leaf gas exchange. As a consequence, some fruit quality parameters was negatively affected. Nevertheless, the application of soil mixed favoured the uptake of beneficial ions and water through the roots, which consequently improved the plant water status, gas exchange and quality of fruits. On the other hand, despite the fact that arbuscular mycorrhizal fungi needed a few weeks to stablish in the roots, they were able to improve some physiological parameters at the end of the experiment, such as gas exchange. The incorporation of these practices might be a novel approach to improve water productivity and quality of tomato irrigated with saline reclaimed wastewater and in commercial farm conditions.

Keywords: Glomus iranicum, crop system, water relations, yield, quality, salinity

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(ROSA Ref. n.119)

Agrichemical remediation from runoff water using bioreactors

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Bioactive concentrations of agrichemicals in runoff pose a threat to receiving water-bodies and may render captured runoff water unsuitable for recycled irrigation. In an effort to reduce contamination in runoff, whether prior to environmental discharge or re-use as irrigation water, treatment systems such as woodchip bioreactors and adsorptive media reservoirs have been investigated for their ability to remove nutrients and pesticides. Bioreactors are systems that harness microbially-mediated processes such as denitrification to remove agrichemicals. Agricultural runoff is diverted into a reservoir filled with woodchips – an inexpensive, sustainable carbon source for bacteria – and passed through at a rate sufficient for bacterial reactions; whereas, adsorptive media reservoirs filled with substrates such as expanded clay and shale aggregates have charged surface sites where phosphate and certain pesticides can be bound. A series of studies were conducted in order to elucidate the effect of hydraulic retention time (HRT), the total amount of time a unit volume of water spends within the treatment system, as well as the effect that the presence of pesticides may have on the efficacy of these treatment systems. When a HRT of 3 days was studied, nitrate concentrations in excess of 70 mg/L were consistently reduced to below 1 mg/L using woodchip bioreactors, and phosphate concentrations over 2 mg/L were effectively removed using expanded shale aggregate, with the efficacy of both treatments conserved in the presence of the insecticide chlorpyrifos. When an HRT of under 25 minutes was investigated, nutrient remediation was minimal; however, the pesticides bifenthrin, chlorpyrifos, and oxyfluorfen were capable of being reduced by up to 75%. When operated under different HRTs, water treatment systems such as bioreactors and sorptive media reservoirs have the capacity to remove eutrophication inducing concentrations of nutrients, as well as reduce the amount of pesticides in recycled irrigation.

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(ROSA Ref. n.72)

Tolerance and physiological response of young *Ficus carica* L. plants irrigated with saline water

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Preliminary results were obtained in an experiment carried out on 2-year-old potted fig (Ficus carica L., cvs. Dottato and Brogiotto) plants to evaluate the effect of saline water on plant water status, leaf gas exchange and fruit growth. Plants were irrigated for 7 weeks (three days a week) with pure water (Control) or saline water (T100) at 100 mM NaCl concentration. Stem water potential (SWP), stomatal conductance (gs) and net photosynthetic rate (Pn) were measured at 4, 27 and 47 (53 for SWP) days after the beginning of salinization (DABS). Fruit diameter and fruits number per plant were measured at 5, 14, 21 and 41 DABS. Significant differences in SWP were already evident between treatments 4 DABS and lasted until the last date of measurement (53 DABS). The highest and lowest values of SWP were measured at 53 DABS in Dottato Control (-0.5 MPa) and Dottato T100 (-1.7 MPa), respectively. Significant differences in gs, Pn and intrinsic water use efficiency (iWUE) between treatments were evident in all dates of measurement, with the exception of Pn at 4 DABS. Differences in gs, Pn and iWUE between cvs. Dottato and Brogiotto were observed at 4 (Pn, gs and iWUE) and 27 (iWUE) DABS. No significant differences were found between treatments regarding the fruit diameter and fruits number per plant. The highest and lowest increase in fruit diameter was measured in Dottato Control (7.9 mm) and Brogiotto Control (2.9 mm) plants, respectively. The highest decrease in fruits number per plant at 41 DABS, with respect to the initial (5 DABS) measurement, was measured in Brogiotto T100 plants (-57%), followed by the Brogiotto Control (-50%) and Dottato T100 (-9%) plants, whereas a slight increase in fruits number per plant (+5%) was showed by Dottato Control plants.

Keywords: fruit growth, net photosynthetic rate, salt stress, stem water potential, stomatal conductance

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(ROSA Ref. n.90)

Session 3– Evapotranspiration, irrigation requirement and modeling

Evapotranspiration and crop coefficients of micro-irrigated pistachio orchards grown on non-saline and increasingly saline soils in the San Joaquin Valley of California

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In California, pistachio is grown on about 133,550 ha and generates a total production of 450,000 Tons and an economic value of about $1.5 Billion. Pistachio is rapidly expanding on salt-affected areas thanks to its economic profitability and salt tolerance. Water use information commonly used in California for scheduling irrigation on pistachio were developed in an earlier study (1985) in a sprinkler-irrigated orchard, but nearly all pistachio orchards are currently micro-irrigated. Unfortunately, not much information is available to growers on the actual water use of pistachio grown with micro-irrigation and on saline soils. To fill this knowledge gap, a three-year field study (2016-2018) was conducted to determine the actual evapotranspiration (ETa) and crop coefficients (Kc) of commercial pistachio orchards grown on non-saline and increasingly saline soils with drip irrigation. ETa was determined with the residual of energy balance method, using a combination of eddy covariance and surface renewal equipment to measure the sensible heat flux density. The percentage of photosynthetically active radiation (fPAR) intercepted by the tree canopies was also measured along the crop seasons. At the non-saline orchards, ETa averaged 50 mm/week during June-July. The fPAR ranged from 75% in the non-saline orchard to 25% in the high-saline area of the salt-affected orchard, whereas ETa decreased from 45 to 35 mm/week (10-30%) as salinity increased. In the non-saline orchard, Kc reached 0.80 from mid-April to mid-May, peaked to 0.90 from mid-May to mid-July, and then decreased to 0.80 and to 0.50 during August and September, respectively. In the saline orchards, Kc was 0.40 in April, between 0.60 and 0.80 from May to mid-July, and decreased to 0.25 in October. The newly developed water use information could allow growers improving resource efficiency of pistachio production in California.

Keywords: residual of energy balance, Pistacia vera, water use, irrigation, canopy cover

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Microclimatic drivers of leaf and tree transpiration and water use efficiency for low to high canopy cover irrigated apple orchards in two production regions of South Africa

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Irrigated apple production in South Africa is facing increasing competition for scarce water resources. Daily and seasonal transpiration of well-irrigated trees is dynamically driven by microclimatic factors in interaction with stomatal responses. These dynamics possibly differ between production regions with contrasting climates, between orchards with varying canopy cover, and between cultivars. A better understanding of these drivers in low (non-bearing) to high (full-bearing) canopy cover apple trees can contribute to improved irrigation practices and greater water use efficiencies from planting to maturity. This study, conducted from 2014-2017, investigated the water use and its microclimatic drivers in six 'Golden Delicious' and six 'Cripps Pink' orchards of varying ages/sizes in two winter rainfall production regions of the Western Cape: the high altitude interior Koue Bokkeveld (KBV) and the coastal Elgin-Grabouw-Vyeboom-Villiersdorp (EGVV). The full study included detailed quantification of tree and orchard water use using sap flow sensors, eddy covariance evapotranspiration (ET) measurements, and ET modelling, as well as measurements of leaf level gas exchange and tree water relations. In this paper we present an analysis of the most important relationships between microclimatic factors, transpiration rate, stomatal conductance, water use efficiency (WUE) and water potential at leaf and tree level. Contrasting relationships were identified between trees of differing canopy cover and between the two production regions, but not between the two cultivars. The solar irradiance, air-leaf vapour pressure deficit (VPDleaf) and leaf temperature (Tleaf) were the key factors at leaf and tree level. We conclude with practical recommendations and further research needs.

Keywords: canopy cover, climate, transpiration, vapour pressure deficit, water use efficiency

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(ROSA Ref. n 26)

Estimating the spatial variability of water needs using soil ECa, rooting depth, and fruit developmental stage in sweet cherry orchard

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In the future, agriculture has to produce more fruit with less water. Therefore, irrigation management must be adapted to the actual water needs of fruit trees aimed at more sustainable irrigation scheduling. In semi-humid climate, spatially resolved analysis of water deficit was carried out in a sweet cherry orchard (Prunus avium L. 'Regina'). The meteorological data was recorded daily by a weather station. The apparent soil electrical conductivity (ECa) was measured at field capacity with a Wenner array. Furthermore, in 20 locations with varying ECa, the root depth was measured to contrast the field-uniform root depth commonly used in water balancing according to FAO guidelines. The actual evapotranspiration was estimated daily considering the coefficients of crop, soil water stress, and soil surface evaporation in low, mid, and high ECa. Consequently, two ETa cases and subsequent water balance were compared for ECa regions: Kc timing according to FAO and field-uniform root depth of 1 m (WBRF), and, second, considering the Kc timing according to the measured fruit developmental stage and root depth (WBRD).
The total available water content in the root zone correlated positively with the ECa (r= 0.68). In parallel, EC-a- correlated negatively (r= -0.72) with the root depth pointing to the adaptation capacity of the trees, which may partly compromise the spatial variability of soil water content. The WBRF revealed 11.45 mm more water use compared to WBRD, in low ECa regions during harvest. Despite the fact that no water stress was depicted by the two models in high ECa areas, WBRD differed approximately 28.6 mm from WBRF during harvest period. Consequently, the adjustment of water balance considering the rooting depth and fruit developmental stages can lead to more sustainable fruit production in cherry orchards.

Keywords: apparent soil electrical conductivity, irrigation management, Prunus avium L. 'Regina', water deficit, Wenner array

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(ROSA Ref. n.122)

Surface energy flux measurements over a drip-irrigated young almond orchard

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Irrigated almond orchards are fast extending in the past few years in arid and semiarid areas of the Mediterranean basin with limited water resources. A good knowledge of the almond crop evapotranspiration (ETc) becomes then crucial for a correct irrigation strategy. A study was conducted during May-October 2018 in a ~14 ha young almond (Prunus dulcis (Mill.) D.A. Webb) orchard in a semiarid location in Central Spain. The objectives of this work were: a) quantify the water use of drip-irrigated young almond trees under no soil water limitations; b) determine the crop coefficient (Kc) values for young almond trees cv. Lauranne; c) parameterize Kc as a function of fractional canopy cover and vegetation indexes obtained by remote sensing techniques. With this with a net radiometer and a set of soil heat flux plates. Data of the different terms of the energy balance equation were stored every 15 min, and then averaged at an hourly and daily scales. A footprint analysis was first carried out to ensure the validity and representativeness of the turbulent flux measures within the field boundaries. A lack of closure in the energy balance equation around 30% was observed. This imbalance was corrected by applying both residual and Bowen ratio techniques, and recalculating sensible and latent heat fluxes. When this systematic underestimation of heat fluxes was corrected following the residual closure approach, seasonal almond ETc measured was 506 mm, resulting an average daily ETc value of 2.78 mm day-1. Maximum Kc value of approximately 0.72 was reach in August, coinciding with maximum canopy cover values and high evaporative demand. Linear relationships were established between Kc and both, canopy cover and the vegetation indexes.

Keywords: eddy covariance, surface energy balance, energy closure, footprint, crop evapotranspiration

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(ROSA Ref. n.120)

Evapotranspiration of a rainfed sweet cherry orchard in Eastern Free State, South Africa

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Evapotranspiration measurements of fruit trees can assist in improving irrigation scheduling, and consequently for sustainable water resources management of orchards. The purpose of this study was to assess how evapotranspiration and precipitation variability are influencing harvesting dates of sweet cherry (Prunus avium L.) trees. The study was conducted in Eastern Free State, South Africa in a 25 year old rainfed sweet cherry orchard over two extremely dry seasons (2017/18). The reference evapotranspiration (ETo) were computed using the Penman Montieth equation. Measurement of crop evapotranspiration (ETc) rates where done using the Open Path Eddy Covariance system (OPEC). The latent (LE) and sensible (H) heat fluxes data were selected according to the footprint analysis and to the energy balance closure error. The total amount of rainfall received on 2018 was higher compared to 2017, however the monthly average ETo estimation has shown an increase from 2017 to 2018 by 12 mm, while the rainfall in the same period declined by 37 mm. Below normal rainfall was observed during the two periods as compared to the long term mean rainfall of the area. The ETc for October and November ranged between 2.18 - 2.13 and 2.62 - 2.36 mm day-1 for 2017 and 2018, respectively. The ratio of H/LE increased from 0.97 to 2.13 in 2017 and 1.23 to 2.38 in 2018 while the relationship between ETc and ETo decreased from 0.30 to 0.20 in both growing seasons. The harvesting date for 2018 was delayed by one week (started on 24 October) as compared to 2017. Therefore, there is a need for supplementary irrigation in the sweet cherry orchard during the early stage of fruit development when experiencing below normal rainfall with frequent increase in heatwaves.

Keywords: growth stages, harvesting, evapotranspiration, irrigation, fruit development

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(ROSA Ref. n.105)

Assessing evapotranspiration of mountain foothills agriculture in the south Mediterranean region using scintillometry and thermal infrared satellite data. Case of the Rheraya catchment, Morocco

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The estimates of the evapotranspiration (ET) at the basin scale are of crucial need for climate studies, weather forecasts, hydrological surveys, ecological monitoring, and water resource management. In the Tensift Bassin (central of Morocco), ET is largely investigated over the plain area using differents devices and models, however, this component still currently not very known over the montains regions. Most published ET often relied on temperature-based or radiation-based estimates which are extremely unreliable, particular in mountain regions. In the present study, the issue of using a Two-Source-Energy-balance model (TSEB) driven by the LANDSAT data for estimating evapotranspiration over Tahnaout site has been investigated. This site consisted of a mixed of arboriculture, wheat, corn, alfalfa, follow and bare sol. Flood irrigation is particularly used using runoff water that occurs as a result of melting fallen snow. The heterogeneity related to the vegetation canopy and changes in topography, generates a large variability of evapotranspiration fluxes which limit the use of local scale measurements device such as the eddy covariance system (EC). In this context, a Large Aperture scintillometer (LAS) was installed over a transect of about 1.4 km to measure the convective fluxes. It is a device that obtains path-averaged surface fluxes over several kilometres and is relatively cheap and easy to maintain.
The LANDSAT-7 and LANDSAT-8 data used as inputs for the TSEB model such surface temperature, albedo and emissivity, were firstly aggregated based on the values of LAS footprint. The results obtained by comparing the evapotranspiration values simulated by the TSEB model and measured by the LAS showed good consistency (R = 0.72, RMSE = 52.4 Wm-2). On the other hand, TSEB slightly underestimates the sensible heat flux but the comparison remains acceptable (R = 0.65, RMSE = 75.5 Wm-2). Keywords: remote sensing, TSEB, evapotranspiration, Landsat, latent heat flux.

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(ROSA Ref. n.63)

Slope, aspect and row orientation effects on crop coefficients

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Considerable literature is available on crop coefficient (Kc) values, but little information is published on how energy-limited crop evapotranspiration (ETc) and Kc values are affected by growing crops on hillsides or with different row orientation. In California, both north-south (NS) and east-west (EW) row orientations are common for citrus, and winegrape vineyards are commonly grown on hillsides, so research was conducted to determine effects of those physical factors on ETc and Kc. Under deficit irrigation, the measured actual evapotranspiration (ETa) is often lower than ETc due to water stress effects on canopy development and stomatal closure. Each half hour, ETa was determined measuring net radiation (Rn), ground heat flux density (G), and sensible heat flux density (H) to calculate the latent heat flux density as: LE=Rn-G-H (MJ m-2 HH-1). Both sonic anemometers (eddy covariance) and thermocouples (surface renewal) were used to determine H. The half-hourly ETa (mm) was calculated as: LE/2.45. Daily ETa was calculated by summing the 48 half hourly ETa values. Daily Ka were calculated as ETa/ETo, where ETo is the standardized reference evapotranspiration for short canopies. Vineyard ETa was higher on south facing slopes during spring and fall, but there was little or no difference during late June through July when the north slope received more direct solar radiation early and late in the day. Differences in ETa were clearly related to variation in direct solar radiation onto on the slopes. In most cases, the EW row citrus orchards had higher ETa and Ka values than the NS row orchards. Since the study area has mostly low wind speeds, the alteration in ETa was attributed to differences in light interception over the day rather than to aerodynamic differences that might occur in locations with higher wind speed.

Keywords: surface renewal, evapotranspiration, irrigation, Citrus, orange, winegrape, vineyard

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(ROSA Ref. n.84)

Modelling root-zone soil moisture from observed and simulated fluxes

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Root zone soil moisture (RZSM) is a key information for quantifying the soil and plant water status and therefore the crop water requirement, especially in semi-arid regions such as the Haouz plain (center of Morocco). As a preliminary study on modeling the RZSM, a model was developed to simulate soil moisture at 0-30 or 0-50 cm deep from various components of the surface water budget: irrigation, precipitation, evapotranspiration, capillarity, vapor diffusion and deep percolation. These water fluxes were derived from direct field measurement or simulated by a two-source energy balance model (TSEB). In particular, we compared two in situ measurement techniques for estimating surface water fluxes, which determine the RZSM. The first one was based on lysimetric measurements. This system had been installed in a 3 ha organic raspberry field near Chimbarongo (Chile) during the 2014-2015 agricultural season. The other was based on the measurement of turbulent fluxes by the Eddy covariance system. The latter had been installed on a 4 ha wheat field in a modern irrigated zone (R3) in the Haouz plain during the 2002-2003 agricultural season. With these data sets, we achieved to simulate the RZSM with an acceptable accuracy at the station scale (RMSE = 0.025 m3 m-3 for wheat and 0.019 m3 m-3 for raspberry). Temporally, the dynamics of the RZSM is consistent with meteorological and anthropogenic forcing, and precisely follow in situ data during dry periods. The use of TSEB model allows simulating the vegetation transpiration rate and any crops water stress. These preliminary results are hopeful to go forward by coupling the RZSM model with remote sensing data (Landsat-7/8, Sentinel-1 and Sentinel-2) at high-spatiotemporal resolutions.

Keywords: Soil moisture; water and energy balance; evapotranspiration, lysimeter. TSEB.

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(ROSA Ref. n.59)

Evaluation of the reduction of non-beneficial evaporation losses with an anorganic mulch structure (Tree hog) in a commercial citrus orchard in the Western Cape, South Africa

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The Western Cape, South Africa, has been identified as a region to be seriously affected by climate change (Midgley et al., 2014). Being a winter rainfall region, the commercial production of fruit crops necessitates irrigation. In 2018, the worst drought experienced in 100 years placed a renewed focus on water savings. The introduction of various commercial devices, e.g. T-Pee®, Tree Grow and Tree Hogs (TH), with water saving claims, came as no surprize. This paper evaluated the contribution of TH as abiotic mulch in reduction of non-beneficial water use (soil evaporation) in a commercial Eureka lemon orchard in Robertson, South Africa. The orchard was divided into two irrigation blocks of 0.5 ha each. TH were installed on each tree in one of these block (January 2016), after planting in October 2015. Each tree was irrigated with a micro-sprinkler. Various physiological parameters were monitored from January 2016 to December 2018, using 10 single tree replicates per block. Irrigation volume applied was monitored with a flow meter in each block. Plant-based physiological parameters indicated no stress in spite of severe reduction of irrigation volumes in the TH treatment. Stomatal conductance and stem water potential was significantly higher for the control than TH treatment in 2017 and 2018. Increases in tree height, stem diameter and canopy diameter were recorded in the TH treatment in the 2018 season. Block differences in actual evapotranspiration (ET) and ETdeficit were evaluated using satellite derived data (FruitLook.co.za). ET from the control and TH treatments were similar in the 2016/17 and 2017/18 seasons, with increased differences from October 2018 (Control ET exceeding TH ET). Differences in ETdeficit between treatments were typically less than 1mm/week, indicating no increased stress in the TH compared to the control. For certain instances the ETdeficit of the TH exceeded that of the control.

Keywords: citrus, evapotranspiration, flow meters, plant physiology, stem water potential

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(ROSA Ref. n.12)

Total evapotranspiration of apple trees with drip irrigation in high density orchard

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Due the changes of technologies of apple growing – introduction of dwarf rootstocks in orchards, the importance of irrigation increased in Latvia. At the Institute of Horticulture the first trial with apple trees on dwarf rootstocks related to influence of irrigation and sawdust mulching was performed only in 1997. Effectivity of drip irrigation to the productivity increase, fruit quality changes, tree development, etc. was evaluated in climate condition of Latvia, too. In period May – September of 1998 – 2007 there was the total evapotranspiration of apple tree roots area of irrigated apples and perennial grass cultivated between rows estimated using method of soil layer balance. Several methods of evapotranspiration calculation were compared. In climatic conditions of Latvia, where irrigation is required mainly as an additional soil moistening measure due to the uneven distribution of rainfall, calculation method, where the apple tree and partly the grassland in its root area provides total evaporation only from the optimal moistened soil area, is not really feasible. In the observation period the total evapotranspiration was 2.7 – 3.0 mm or 4.1 – 4.9 litres per day in average of season depending on calculating scheme. In July of 2001 maximum of the total evaporation calculated (5.3 mm per day). In September of 1998 minimum of the total evaporation estimated – 0.9 mm per day.

Keywords: Malus, grassland, soil layer balance, root area, dwarf rootstocks

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(ROSA Ref. n.111)

Estimation of soil surface evaporation in commercial pistachio orchards of Iran; the case study of Yazd province

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Iran is the world's largest pistachio (Pistacia vera L.) producer, with a total cultivated area of 429,535 ha in 2017. The high tolerance of pistachio tree to the soil water and salinity along with its promising economic gains are the major reasons for development of this crop to many parts of the country. Most of Iranian pistachio orchards are located in central parts, which are mainly identified as arid, saline and water scarce regions. Surface irrigation (furrow and basin) is the conventional irrigation method of these pistachios, in which soil evaporation is the most non-beneficial use of water which does not contribute to the productivity. The present study was aimed to estimate soil evaporation as well as pistachio evapotranspiration in surfaced irrigated commercial pistachio orchards of Yazd province, located in central part of Iran. While Bear-Lambert method was used to determine the soil evaporation contribution, the satellite-based SEBAL approach was employed to estimate the pistachio actual evapotranspiration on a spatio-temporal distributed basis. In addition, the results of Beer-Lambert method was validated with evaporation measured through monitoring of soil moisture contents. The results showed that soil evaporation rate occasionally reaches to around 3.1 mm.day-1 and its contribution ranges from 5 to 27 percent of pistachio evapotranspiration (averagely 17 percent). This variation is mainly due to tree canopy, soil moisture content, soil texture and growth stage. Soil evaporation contributions can be reduced by employment of soil surface mulching methods, reduction of wetting area or introduction of subsurface drip irrigation systems. Soil surface scratching a few days after irrigation is another option for evaporation reduction in these commercial pistachio orchards.

Keywords: SEBAL, Landsat 8, LAI, beer-lambert law, surface irrigation.

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Session 4 – Water relations, soil and plant water stress assessment

Growth and yield of apple as affected by different irrigation levels at various phenological stages using drip irrigation system in North Himalayan region of India

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Increased world population mandates a more efficient use of land and water resources for agriculture as International Water Management Institute in their Macro-level estimate, reports that one-third of the world population would face absolute water scarcity by the year 2025. Irrigation plays a vital role in crop production and is considered as an important aspect of orchard management. A very high percentage of orchards in India and particularly in Jammu and Kashmir state are on seedling rootstocks and are bereft of any irrigation facilities and rainfall is the only source of moisture. Consequently, water is not available to the plants during their critical stages of growth, leading to poor yield and fruit quality. Therefore there is a need to shift to high-density plantation using spur varieties and dwarfing rootstock along with the installation of drip irrigation system. Putting this in view, an experiment was performed on five year old apple var. Super Chief Sandidge on M9T337 grown at a spacing of 1.5 × 3 m (2222 plants/ha) to study the effect of different levels of irrigation at different phenological stages on vegetative growth and yield of apple for the year 2017 and 2018. Thirteen different treatments were given which comprised of three different levels of irrigation regimes (100%, 75% and 50% volume of class A pan evaporation coefficient) which were applied at four different phenological stages (Flowering and fruit set, Fruit growth stage, Pre-harvest stage and throughout the season) along with a control (only rainfed). Overall results indicated that level of irrigation as well as the plant developmental stage has a significant impact on growth and yield of plant. The results revealed that irrigating trees at 100% ETc and 75% ETc throughout the season produced optimum yield and also resulted in increased vegetative growth in comparison to other treatments. Further it was observed that stressing tress at any phenological stage significantly affected fruit yield.

Keywords: irrigation regimes, apple orchard, drip irrigation, phenological stages

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(ROSA Ref. n.184)

Different indicators reveal dynamics of physiological limitations to water uptake in Pistachio under long-term salinity

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A better understanding of limitations to tree water uptake under long-term saline conditions is key issue for optimizing orchard's water management. In a field study on micro-irrigated pistachio in California, stem water potential (ΨSTEM), trunk diameter variations, and the ratio (A/LE) of the aerodynamic contribution (A) to latent heat flux (LE) were used to characterize the major effects of soil salinity on tree water uptake and growth. Actual evapotranspiration (ETa) for non-saline and salt-affected pistachio orchards was measured using the residual of energy balance method. Results highlight a strong seasonality of salinity effect on pistachio ETa, which was correlated with different stress indicators depending on the growth stage. The period from leaf-out to mid-July was characterized by stem growth. In this stage, the maximum daily shrinkage (MDS) was the most sensitive indicator of salt stress with values of about 75 µm/day for saline and 40 µm/day for non-saline sites. The ΨSTEM decreased from about -0.7 to -1.3 MPa and was slightly higher in the non-salt-affected trees; the A/LE ratio was similar between sites (~0.4). The early season showed a "preferred window" for pistachio to perform at maximum potential, which makes the salt affected trees more "responsive" to environmental conditions. Soil osmotic limitations were highlighted by the indicators tested. The second stage (from mid-July forward) showed interruption of stem growth and flattening of the MDS at about 50 µm/day for both non-saline and saline sites. The ΨSTEM decrease stopped and values were higher in the salt affected trees; the A/LE strongly decreased to 0.05 for saline sites. During the late season, stressed trees are more "isolated" from the environment, and stomatal closure was mainly limiting water use for the saline sites. Overall, the presented data provide useful information to pursue a more integrated irrigation management of pistachio under long-term salinity conditions.

Keywords: stem water potential, dendrometers, stress, evapotranspiration, Pistacia vera

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(ROSA Ref. n.172)

Floral developmental failures and ovary size variability in field-grown olive trees under water deficit

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In the olive tree, Olea europaea L., flower development constitutes an extensive process which requires two to three months, and includes elongation and branching of the inflorescence axis and the formation of the individual flowers. Container experiments, where water deficit is more easily controlled, have shown reduction of and compensation among parameters such as inflorescence number, flower number, perfect (hermaphroditic) flower number and percentage, and ovule development, related to the timing of the deficit period. With the aim of observing the effect of water deficit in field-grown mature trees, inflorescence and flower development, including histological preparations, were observed in 'Picual' olive trees following a winter of severe drought. Sampling of 25 inflorescences around each tree was carried out, inflorescence structure and flower gender observed, and ovule development and ovary size evaluated in histological preparations of pistils. Inflorescence and gender quality parameters were reduced. Ovary size varied widely, with ovaries distributed in two distinct groups according to size. In the majority of the larger ovaries, 3 or 4 of the total 4 ovules were well differentiated, showing a high potential for fertilization and subsequent fruit set and development. In the small ovaries, however, ovule development was poor, with only 5-10% showing sufficient development to permit fertilization. These observations affirm the necessity of sufficient water in early spring during inflorescence and flower development, and also indicate that inadequate floral development for satisfactory fertilization and fruit set may occur but not be easily visible. The presence of two ovary populations may represent an evolutionary mechanism to provide a few high-quality ovaries to assure sexual reproduction.

Keywords: Olea europaea L., pistil abortion, flower quality, ovule differentiation, imperfect flower

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(ROSA Ref. n.43)

Transpiration reduction as an answer to water stress: models versus measurements for irrigated olive trees in South Portugal

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The so-called stress functions, allowing quantification of transpiration or evapotranspiration reduction as an answer to water stress (stress coefficient, Ks), are a useful tool for irrigation scheduling. It is known that Ks depends on several variables and parameters, such as evapotranspiration rate, root patterns/density and soil properties. However the most common Ks models with practical applicability do not include some of these factors and the experimental work on this matter is not abundant. A well-known model proposed in FAO 56 manual uses two parameters: the allowable depletion (p) and the available soil water (AW) in root zone, the input variable being the soil water depletion (SWD). The model considers adjustments in p, for the evapotranspiration rates. We discuss the application of this model in natural conditions. Two studies were conducted in Alentejo, South Portugal (2010_11 and 2017), in one intensive and one super intensive olive orchard (Olea europaea 'Arbequina'), drip irrigated. Transpiration reduction was measured using sap flow sensors, by means of the so-called Granier technique, where one point is heated permanently and the increase in temperature downstream is quantified, to express the importance of convective heat and mass transfer (sap). In both experiments Ks was obtained as a function of SWP and of predawn leaf water potential (PLWP). The experimental relationships are compared with literature and modelling outputs. For both experiments, the Ks FAO 56 model only can be well adjusted using parameters such as p= 0.05 and AW = 350 mm. The suggested p in that manual is 0.7. Furthermore, for those soils, anisotropic canopy and small wetted area (drippers), 350 mm is much more than first approach estimates would suggest. The results are discussed, in relation to the resilience of olive trees and the role of the root system size in these irrigated trees.

Keywords: Olea europaea, modelling, Alentejo, roots, irrigation scheduling

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(ROSA Ref. n.75)

Apple rootstock affects scion physiological responses to water limitations

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Water availability is one of the major limitations to plant productivity, and it regulates the distribution of plant species around the world. The capacity of plants to tolerate fluctuating environments involve morphological and physiological changes in short and long-term. Enhancing water use efficiency in crop plants is a key component to sustainable increase agricultural productivity and therefore meeting the increasing food demand in the coming decades. The objective of this study was to determine how rootstocks and water-limited conditions affect tree biomass distribution and physiological features in 'Honeycrisp' apple. A completely randomized design experiment of 'Honeycrisp' on four different rootstocks; G41, G890, M9-T337, and Bud9, was planted at WSU-TFREC Sunrise Orchard in Rock Island WA USA in 2016. Trees were drip irrigated daily using emitters of 3.78 L h-1 spaced 30 cm apart and fertilized using standard commercial practices. Drought treatments consisted of keeping trees under 50% of field capacity and were applied in 2017 and 2018 immediately after petal fall and maintained throughout the growing season for 90 days. Physiological measurements to determine water use efficiency (WUEi), mid-day stem water potential and shoot growth were monitored bi-weekly. At the end of the experiment, trees were destructively harvested, and trees biomass distribution was recorded. Results on WUEi showed a rootstock effect only in 2017 where Bud9 and M9 were the most efficient on water use. Shoot growth showed for both years that G890 had the highest growth. Below ground biomass was reduced by water limitations for trees grafted on G41. For above ground biomass, G890 and well-watered trees were significantly higher. Even though trees under drought received 85% less water than untreated trees during the growing season, G890 showed to be more responsive to water limitations because of its active growth throughout the season in contrast to more dwarfing rootstocks.

Keywords: water use efficiency, honeycrisp, drought, vegetative growth, biomass

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Improving water productivity of avocado (*Persea americana* Mill.) var. Hass by using a reinforced plastic cover over the canopy at Petorca Valley, Region of Valparaíso, Chile

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To improve the productivity of irrigation water applied on avocado var Hass, a reinforced plastic cover was built over the canopy of an adult orchard established at Petorca Valley, Región de Valparaíso, Chile. Two treatments, each representing 7000 m2 of surface, were compared to unveil the effect of the plastic cover on the evapotranspiration loss of the orchard (T0: without plastic cover and T1: with plastic cover).
During 2016/2017 and 2017/2018 seasons crop evapotranspiration (ETc) in both treatments was recorded, evaluating two seasons of tree physiology, microclimate and yield affected by the treatments. The avocado orchard was irrigated at 100% ETc replenishment while soil water content was monitored by using FDR sensors at three soil depths: 20,40 y 60 cm. Air temperature and relative humidity was also recorded at 5 heights by HOBO sensors. Crop evapotranspiration were measured by an Eddy Covariance tower (T0) and by Surface Renewal analysis (T1). Plant water status was evaluated by xylem water potential (xwp), chlorophyll fluorescence (Fv/Fm) and stomatal conductance (gs). Additionally, phenological stages were monitored periodically while the activity of pollinators was also recorded under the two different treatments.
In general, under the plastic cover (T1) ETc dropped by roughly 15%; minimum air temperatures increased between 1 and 2°C higher under the plastic cover, while maximum temperatures increased in 4 °C, approximately compared to the orchard without plastic cover (T0). Relative humidity increased by 10%, while solar radiation decreased 27% without affecting photosynthesis. Flowering stage during season 2016/2017 occurred slightly faster inside the plastic cover (T1) than under Control treatment (T0), while during 2018/2019 season no differences on phenological stages were observed. The use of plastic cover allowed to improve water productivity from 0,7 Kg/m3 (T0) to 1,0 Kg/m3 (T1) with a consequent energy saving for water pumping for the irrigation system.

Keywords: Plastic cover, avocado, water productivity

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(ROSA Ref. n.53)

Nocturnal and diurnal grapevine transpiration. Relationship with meteorological parameters

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An experiment was carried out in a semi-arid area of Spain (Albacete) with the objective of quantifying the daily transpiration (nocturnal and diurnal) of grapevine cv. Tempranillo during 2012. Measurements of transpiration were taken in a weighing lysimeter; the soil surface was covered with a waterproof canvas to avoid the evaporative component of evapotranspiration. The sample frequency was 1 s, and a mean value was recorded with a datalogger (CR10X, Campbell Scientific) every 15 minutes, which allowed for measuring the transpiration every quarter of an hour. The results show values of night transpiration between 3% and 35%. With the objective of quantifying the effect of different meteorological parameters on transpiration, air temperature, relative humidity, wind velocity and solar radiation were measured with an automated weather station located over a reference grass surface less than 100 m from the vineyard lysimeter. The work shows the relationship between the different parameters measured.

Keywords: lysimeter, night transpiration, air temperature, air relative humidity, wind speed

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(ROSA Ref. n.163)

Canopy conductance of Hazelnut orchards appeared relatively insensitive to different irrigation regimes

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Hazelnut (Corylus avellana L.) is one of the most appreciated nut crops by the food industry, which lead to create new extensive plantations in extra native sites. Despite that, our knowledge about the ecology of the species and its responses to water availability are still limited. Available data show the species to be shade-tolerant (saturation point about 300-400µmol m-2s-1). Because its stomatal conductance strongly decreases in condition of VPD > 15hPa, hazelnut can be also defined as very sensitive to atmospheric evaporative demand (drought avoider). Therefore, we investigated the effect of different irrigation regimes: we hypothesized that a limited response in terms of stomatal conductance (and thus on carbon assimilation and yield) should occur when the soil water availability increases.

We monitored six hazelnut trees cv. Tonda Gentile delle Langhe (TGL) during two growing seasons in San Sebastian, Chile. We measured all climatic parameters, sap flows and soil water content on two irrigation treatments: T100 and T200 respect to the local standard.

Our results showed that the response of sap flow to VPD remained relatively constant in the two treatments, and that the daily pattern of canopy conductance was slightly higher in treatment T200 (+15%). Treatment T200 had a more pronounced increase of canopy conductance at lower values of VPD (< 15hPa). However, for higher VPD values, the canopy conductance did not differ, showing a strong stomatal closure.

Our results suggest that hazelnut has a relatively rigid stomatal behavior, which largely depends on the atmospheric evaporative demand but less from the available water in the soil. This must be taken in to account when predicting the potential productivity in warm and dry sites.

Keywords: Tonda Gentile delle Langhe, irrigation, sap flow, nut crop, vapor pressure deficit

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(ROSA Ref. n.158)

Water-yield relationship in the cultivation of strawberry

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In recent years, the amount of land allocated to agriculture has been decreasing because of rapid urbanization and construction, etc. This means a decrease in the land used for agricultural production. On the other hand, there has been a decrease in the available water resources as a result of global warming and climate change in the world. Moreover, due to the global climate change, the pressure on these scarce resources is increasing, and the quality of water resources is decreasing accordingly. As a result, one of the main objectives in plant production today is to investigate the possibilities of producing more agricultural products with the use of these limited soil and water resources. For these reasons, investigation of the relationship between the different irrigation levels for different plant species and water-yield relationships under different irrigation application techniques has become a necessity. Under the traditional irrigation practices, many studies have been carried out in the fields, gardens and greenhouses in Turkey and other countries. However, the number of researches related to irrigation in the cultivation of the strawberry plant is very limited in the relevant literature. In this article, the reaction of the strawberry plant under different irrigation levels is discussed. In addition to other factors, irrigation application is an important issue in increasing the yield value of fruit and vegetable cultivation. Therefore, the response of the strawberry plant under different levels of irrigation water is extremely important because water is one of the scarcest natural resources in today's world.

Keywords: irrigation water, water scarcity, yield, deficit irrigation.

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(ROSA Ref. n.143)

Adaptation mechanisms to water scarcity of two almond cultivars from different origin countries

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Climate change is making the Mediterranean Basin particularly vulnerable to water scarcity and desertification. Under this conditions it is crucial to study the plant adaptation mechanisms in order to choose the most appropriate cultivars and the related agro-practices. The aim of this work was to study the behavior of two almond cultivars of different origin: Filippo Ceo (Italy) and Texas (America) managed according to the principles of Dry Farming Practices (DFP) in a high water demanding environment. The trial was carried out in an experimental farm with an almond germplasm collection located in the Southern Italy (Apulia Region). The germplasm collection included more than 300 cultivars assuring an effective cross-pollination of Texas. In 2015 and 2016, during fruit growth season, fruit surface conductance (cmh-1), fresh weight (g) and fruit size (mm3) were measured. In 2016, from April to July (3 times during the day), leaf net photosynthesis (Pn), stomatal conductance (gs) and leaf transpiration (Tr) were monitored. In both years, fruit surface conductance was higher in Texas than in Filippo Ceo, with an high water use, and a theoretical low drought tolerance, of the foreign cultivar in comparison with the local one. Productivity and fruit quality were higher in Filippo Ceo than in Texas. Interestingly, Texas showed higher Pn and gs than Filippo Ceo, in correspondence of warmer periods. In almond the fruit growth period is very short and susceptible to water scarcity. The limiting factor for Texas could be the high water demand for fruit transpiration rather than for leaf functioning. However this divergent behavior of source and sinks organs should be investigated deeper in the future.

Keywords: transpiration, fruit surface conductance, gas exchange, productivity

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(ROSA Ref. n.117)

Irrigation levels and abscisic acid application effects on pomological characteristics of strawberry

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In this study, the effects of four different irrigation regimes (IR125, IR100, IR75 and IR50) and Abscisic Acid application (ABA use and control) effects on some pomological characteristics (Total Soluble Solid, fruit firmness, fruit weight, pH, colour characteristics) of strawberry (Fragaria x ananassa cv. Rubygem) were evaluated under Spanish type high tunnels which Turkey is the fourth producer in the world. ABA, was applied three times starting from March to May via foliar application, as 20 µmol L-1. From the initiation of the treatment to the end of the trial, a total of 552, 447, 342 and 237 mm of water were applied to treatments IR125, IR100, IR75 and IR50 respectively. In addition to the increase in the yield of strawberries with increasing amount of irrigation water, the average fruit weight also increased significantly from 16.86 (IR50) to 27.64 g (IR125). ABA aplications also effects positively to the fruit weight with increasing 6%. As expected, the amount of Total Soluble Solid (TSS) increased significantly with decreasing irrigation water. The ABA aplication had positively effect on TSS, and the value varied between 7.8 and 8.4%. Even if the effect of irrigation levels and ABA aplication on the fruit hardness is insignificant, it is determined that the increasing irrigation water and ABA has a positive effect on the hardness of the fruit. Furthermore, the pH of the fruit juice decreased with the rise of the irrigation water and no significant effect of ABA were detected on pH. Consequently, the most effective agricultural application with consedering pomological factors IR125 with ABA aplication is quite accepteble. However, it is important to evaluate this judgment economically in order to be offered to the producer.

Keywords: Mediterranean region, quality, taste, yield

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(ROSA Ref. n.103)

Can foliar anthocyanins help Prunus saplings to alleviate water stress effects?

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The aim of the study was the evaluation of the biochemical and physiological responses of mature leaves to a severe PEG6000-induced water stress in saplings of two morphs of Prunus cerasifera (clone 29C, greenleaved, GP, and var. Pissardii, red-leaved, RP), to elucidate a possible role exerted by anthocyanins. After 20 days, the reduction in photosynthetic rate was of 41% and 35% in GP and RP, respectively, as compared to controls. In both the morphs, the decrease was attributable not only to stomatal closure but also to a strong reduction in actual PSII photochemical efficiency, as measured in terms of chlorophyll a fluorescence. Leaf sugar metabolism was also studied: a consistent accumulation of glucose, sucrose and sorbitol was observed in both the morphs already after 10 days of stress; however, the increment was steeply in GP than in RP. In addition, differently to GP, in RP starch content decreased after 10 days of stress.
It is conceivable that a part of C assimilated was invested into anthocyanin synthesis and this, in turn, brings to a lower accumulation of soluble sugars, so to partially explain the lower values of intercellular CO2 concentration observed in RP leaves at the end of the experiment.
This study does not report differences between morphs, in photosynthetic rate and photoprotective responses to water stress but provides an in-depth analysis of the relationship between sugars metabolism and anthocyanin content in leaves.

Keywords: anthocyanin, chlorophyll fluorescence; drought; gas exchange

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(ROSA Ref. n.97)

Influence of the environmental conditions under hail nets on efficiency of irrigation and fertilization in ´Golden Delicious´ apple trees

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Optimal irrigation and fertilization management is one of the objectives of precise agriculture. The aim of this study was to analyze the variability of the irrigation and fertilization efficiency according to the environmental conditions in young apple orchard. During 2015–2018, the three years old trees of apple cultivar ´Golden Delicious´ were grown as modified slender spindle with regular thinning of fruits by hand. The treatments, differently managed by drip irrigation and fertilization, were analysed according to the use of grey hail nets and use of replant sites. The full irrigation and fertilizer doses proved to regulate the proportion between vegetative growth and fruit production in apple trees. The change in environmental conditions, mainly lower light transmittance and wind speed, as well as higher soil water content, connected with the use of hail nets may alter the intensity of vegetative growth and fruit production modifying the water use efficiency and the efficiency of the fertilization management on replant soils. With decreased intensity of the effect of replant soil, apple trees rise their tolerance to water stress. On sites with less evidence of replant soil problems it seems that the concentration of applied nutrients becomes more important for the fruit yield than the particular irrigation or fertilizer rate.

Keywords: Malus domestica Borkh, growth, yield, water deficit, replant soil

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(ROSA Ref. n.98)

Session 5 - Sensing technologies relevant to the precision irrigation

Plant and soil water status indicators for irrigation scheduling in young lime trees

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In Mediterranean regions water scarcity make necessary an efficient irrigation management. The use of physiological water indicators for irrigation scheduling could be interesting because it would increase the water use efficiency. In this sense, the objective of this study was to evaluate the capability to detect water stress of different plant and soil water status indicators. The experiment was conducted on a plot of young limes trees (Citrus latifolia Tan., cv. Bearss) cultivated in open-air ridges and in a clay-loam soil at a field station of CEBAS-CSIC in Murcia (Spain). The trees were submitted to two treatments: Control (drip irrigated at 100% ETc) y Stress (water withholding). Soil water status was determined by monitoring soil water content (SWC) with capacitance probes and soil matric potential (SMP). Plant water status was assessed by measure of stem water potential (Ψstem) with a pressure chamber, gas exchange with a portable photosynthesis system, and canopy temperature (Tc) with infrared temperature sensors located above the tree crown. From the beginning of the stress period a progressive decrease in both soil water status parameters was observed, while a delay was noted in Ψstem in stressed plants. Gas exchange showed a decrease in response to water deficits but with a high variability. In stressed plants, canopy temperature showed values above air temperature during most part of the day with maximum values observed around solar noon and similar values to that of the Control trees during the night and late afternoon. Real time soil water dynamics at the plant root zone provide the necessary data for irrigation automation. The combined use of soil water content and matric potential is proposed as threshold values for automation irrigation: SWP for starting irrigation and SWC for stopping irrigation. This is a sound basis for improving precise irrigation management.

Keywords: plant water status, precise irrigation, soil water content, water deficit

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(ROSA Ref. n.130)

A plant-based index for plant water status detection and irrigation scheduling in pear 'Abbé Fetel': first results on the use of the IPL index

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Water is the most important factor affecting fruit production and quality. Under the threat of climate change, making irrigation effective and efficient is a pivotal issue. This study reports preliminary results on the use of the recently developed, plant-based IPL index for detecting leaf photo-assimilation and scheduling irrigation. This index considers leaf fluorescence variables, RuBisCo activity, leaf and air temperature, which are easy and quick to measure. This rapidity allows a high number of measurements, strengthening the representativeness of data. The trial was carried out on pear 'Abbé Fetel' grafted on quince 'Adam' rootstock and trained as slender spindle. 100(T100),50(T50),25(T25)and0%(T0)oftheestimatedevapotranspiration were supplied during the whole season. A "Dynamic" (DYN) treatment was added to the static ones, in which water was provided according to the IPL values. When IPL for DYN was lower than that for T100 irrigation was supplied, restoring IPL to values similar to those of T100. Results suggested that IPL was reliable. DYN reached the same productivity of T100 (45.1 t ha-1, 41 tonnes of which with a diameter >65mm) but using 56% less water than T100; irrigation water use efficiency (IWUE) was 61 grams of fruit fresh matter per litre of water supplied (g L-1) versus 24g L-1 of T100. Water use efficiency was 13.3 and 9.63 g L-1 in DYN and T100, respectively, when also rain water supply was considered. Although further tests on other species and sites should be performed, these first results suggest that the IPL index could be a promising tool for easy, effective plant stress detection and irrigation scheduling.

Keywords: photosynthesis, temperature, model, precision agriculture, water use efficiency

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(ROSA Ref. n.112)

A tool for simulation of water storage and infiltration capacity of agricultural soils depending on carbon management practices

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The objective of the on-going project Carbonagrisoil is to raise awareness of farmers and policy makers about the importance of organic carbon in agricultural soils (SOC) in combating soil desertification and degradation. To pursue this objective the project aims to develop a web-based tool for quantification and simulation of four ecosystem services (ES) related to SOC at farm level and at landscaper level: support to water cycle, erosion resistance, climate change mitigation, support to nutrient cycle.
The three year project will be finalized in November 2020.
To date quantification of ES was performed through the use of the biogeochemical model APEX (Williams et al. 2000), which let to simulate the impact of agricultural management practices on carbon, nitrogen and water cycle in the agro-ecosystem. The input data required by the model were collected for Apulia and Basilicata regions in Southern Italy, as pilot application, for land use, climate and soil type. Calibration and validation of the model was performed on 62 measured samples. A set of management practices were modelled which can influence the storage or loss of carbon in agricultural soils are: tillage practices, use of organic amendment, crop residues management, use of cover crop, irrigation practices.
The Major results obtained by now are: the individuation of a certain number of homogeneous soil climate unit, the calibration and validation of APEX model on measured samples, the development of baseline maps of ES, the design of the user interface of the web-based tool Carbonagrisoil.

Keywords: sustainable management practices, soil organic carbon, web-GIS, simulation, ecosystem services
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(ROSA Ref. n.190)

Deepfield connect, an innovative decision support system for crops irrigation management under Mediterranean conditions

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The irrigation management, in the Mediterranean region, represents an important technique useful to reach sustainable yield and improve the quality of the crop. The use of decision support systems and water saving techniques has gained importance during the last decades mainly in arid and semiarid countries where water is considered a precious resource. DeepField Connect by BOSCH is an innovative tool able to support farmers in irrigation management and consists of three main parts: hardware (sensors, device-to-web-data logger and thermo-hygrometer), algorithm and graphic use interface (app). This system is based on GIS analysis, which represents the most innovative and functional tool for such studies, which provides a mapping of soil hydrological characteristics at the regional level. We used, as a reference, soil data analysis obtained at Regional level from the ACLA II Project. In this way, the system creates an interactive mapping system, matching each point of the Apulian surface, in particular, the texture composition of the soil and the values of the hydrological constants (wilting point, WP and field capacity FC), for irrigation planning. These data are integrated with the recharging point (RP) a value calculated for the main regional irrigated crop which represents the level of soil moisture that, together with FC, represent the range of plant-available water. Besides, this tool provides different irrigation strategies such as deficit irrigation or complete restitution of evapotranspiration losses, according to farmer needs. DeepField Connect by BOSCH transmits the data via the Bosch Cloud to the smartphone. This allows to keep track of fields at any given time and to provide assistance in: when to irrigate and which irrigation volumes to use. This intelligent system can be considered as the application of one of the best practices that the agricultural sector can implement to improve its environmental performance and contribute to sustainable food production.

Keywords: moisture sensors, water use efficiency, water saving, precision agriculture

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(ROSA Ref. n.178)

Polyphenolic and sugar profiles in leaves from two apple cultivars grown with and without irrigation

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The aim of this work was to compare sugar and polyphenolic profile in leaves of the two apple cultivars, 'Golden Delicoius Rainders' (GDR) and 'Granny Smith' (GS), with and without irrigation. Both cultivars were grafted on the rootstock M9, planted in 2012 as maiden trees with planting distance 3.3 × 0.9 m. One plot (0.2 ha) was irrigated with 7-10-day intervals from June 1st until end of August as much as the amount of water consumed from the field capacity. The other plot (0.3 ha) was without irrigation, having just rainfall during the whole year. Orchard managements was similiar for both plots. The averages of annual temperature, relative humidity, and total precipitation were 13.9 °C, 64 %, and 508 mm, respectively. The total yields in 2017 for the irrigated trees were 55 t/ha for GS and 65 t/ha for GDR, and 30 t/ha and 35 t/ha for the unirrigated trees, respectively. Leaves were picked from the middle section of all twig types in July The leaves, picked in triplicates, were dried and analysed for polyphenolic profile using ultra-high pressure liquid chromatography and high-performance anion exchange chromatography (HPAEC) was used for sugar analysis. Total phenolic content (TPC) was determined by Folin-Ciocalteu assay. The most abounded sugars in the leaves were glucose, fructose, sorbitol and sucrose. In leaves from unirrigated trees, higher levels of stress sugars such as trechalose, turanose, melesitose were found too. The most abundant polyphenolics in apple leaves were phlorizin, followed by quercetin-3-O-rhamnoside, quercetin-3-O-galactoside and phloretin. Leaves from stressed trees had higher level of polyphenolics then those with irrigation. TPC; vanilic, ellagic, procatehuic acid, aesculin and eriodictyol, were higher in leaves from unirrigated trees for both cultivars and positions of leaves, while caffeic acid and rutin were higher when trees were grown without irrigation. This study showed that both apple cultivars had similar metabolic reaction to drought, while long fruiting and non fruiting shoots were under the highest stress under non-irrigated conditions.

Keywords: Malus domestica Borkh, yield, drought stress, leaves, chemical composition

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Application of automatic irrigation system (IRRIX) to water management in nectarine commercial farm

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The application of scientific knowledge to routine on-farm irrigation practices is the key to a real improvement in the efficiency of water use in irrigation. However, this knowledge transfer can be complicated and costly when it requires the integration of different sources of information, with a sound technical basis. The development of software systems that allow the combination of the water balance by estimating the Evapotranspiration of crops (ETc) with humidity sensors from the soil or plants, to be readjusted, at each phenological moment, water doses and irrigation strategies can be a good system for more efficient management of crops. The objective of this study was using the IRRIX system to automatic irrigation management in a commercial farm. The automated irrigation system was carried out by emulating the criteria of the farm's technical staff, applying regulated deficit irrigation strategies. The trial form FETINNOWA showcase activity, was conducted during 2018 in a specific area of "Finca El Chaparrito" commercial farm belongs to the company Haciendas Bio SA, Badajoz (latitude 38 ° 56'13.59 "N, longitude 6 ° 45'21.98" W, datum WGS84), Spain over Kaysheet variety early maturing nectarine (1.5 ha), planted in spring 2009 at a spacing of 5x3 m, in an east-west row orientation. Irrigation management was carried out by IRRIX system with the combination of a crop model, corrected with the information of a set of soil moisture sensors. The amount of water applied with the automated system was significantly lower (30%) than with the technical criterion: during the pre-harvest period maintaining a similar water status and with a moderate deficit in post-harvest, with lower values of stem water potential. The results obtained in this work demonstrate that the automated system offers an affordable opportunity to improve the efficiency of water use on the farm.

Keywords: water scheduling, deficit irrigation, smart irrigation, fertinnowa project, DSS

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(ROSA Ref. n.18)

A microtensiometer sensor to continuously monitor stem water status in woody plants - design and field testing

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Water is one of the most critical limitations to growth, productivity, fruit or nut quality and profitability in fruit crops. Irrigation is a large user of water resources, thus optimizing the management of water resources is also critical. Measuring plant response to soil water, rainfall and irrigation is the key to optimal water management. To do so, we have developed and tested an inexpensive, electronic, large-range, continuous-reading water potential sensor for embedding in the trunks of woody plants to monitor stem water potentials. The sensor is a microelectromechanical system (MEMS)-based microtensiometer that can measure plant stem water potential continuously with a high degree of precision. The sensor chip has the same principle as the common soil tensiometer, but with a much smaller volume and 100-200 times greater range. Its advantages include unprecedented range of detection, low power consumption, small size, low cost due to micromanufacture and easy to incorporate in sensor networks. The sensor chip is integrated with associated data handling, logging and wireless transmission for online monitoring. Challenges include engineering the sensor for long-term continuous measurement; optimizing easy installation and insulation methods and materials; and learning how different species and varieties react to the embedded sensor. The microtensiometer has been field tested in potted and field-grown apple, grape and almond. Current designs and methods have given very good results with high correlations to stem potentials by pressure chamber in multiple crops. The ability to monitor plant stress with the microtensiometer will be a valuable tool for precision irrigation programs, research, and modeling. Scalable microtensiometer arrays in conjunction with wireless networks and remote sensing offers the potential to provide continuous, high-resolution data to optimize irrigation and water resource management for sustainable crop production.

Keywords: stem water potential, sensor, fruit crops, nut crops, irrigation, drought stress

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(ROSA Ref. n.87)

A comparative study of irrigation scheduling based on morning, daylight and daily crop water stress index dynamic threshold (CWSI-DT) in apple trees

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Precise irrigation scheduling requires accurate monitoring methods of water stress. Crop water stress index (CWSI) is a good indicator of water stress in fruit trees. A previous CWSI based on a dynamic threshold (CWSI-DT) was developed using midday (between 13:00 and 15:00) measurement. Here, we compared morning, daylight and daily (24-h) averages of CWSI to assess their effectiveness on irrigation scheduling. Also, we testified their sensitivity to changes in soil water content (soil water deficit and soil water potential). In the 2018 growing season, ground-based thermal and other measurements were conducted in four different commercial apple orchards under arid conditions in Washington State. There were 3 trellis systems (V, vertical, and traditional), 3 apple varieties (Golden Delicious, Fuji and Honeycrisp), 2 IRT orientations (45 degrees, and nadir view) and one orchard was completely covered with shade cloth (sunburn protection). In some of these locations, soil water status ranged from fully watered to severely stressed (low deficit to high deficit). We used soil sensors and IRTs to monitor both canopies and soil with several replications. The CWSI used here was theoretical and apple specific. CWSI morning averages showing the highest sensitivity. The preliminary analysis showed that there was a good correlation between theoretical CWSI averaged over late morning hours (10-11am) and soil water deficit, also between theoretical CWSI and soil water potential. The latter correlation was slightly higher.

Keywords: CWSI, apple trees, dynamic threshold

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(ROSA Ref. n.81)

Plant growth as an indicator for irrigation practices

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Adapting irrigation according to plants requirement can improve significantly growth process and lower the costs of water and fertilizers. Interaction between plants growth analysis combines with drain measurement is presented. DrainVision system recently developed by Paskal Group, monitors irrigation and drainage accurately and can be connected to controller and used an algorithm to optimize the irrigation scheduling. The system can be connected to Plant Growth Analysis System (PGA)as a component of irrigation strategy involving plant growth. The PGA developed earlier by Paskal, weighing continuously the plant weight, filtering and transmit growth data. At present, most common irrigation strategies use radiation level as a major factor for irrigation scheduling, and the drainage provides some indication on improper irrigation. In soilless culture, irrigation scheduling is an important task, as water and nutrients must be applied frequently and precisely, due to the low volume and limited water holding capacity of most substrates. The present research studied the relationship between water content in the root system and plant growth. An algorithm for optimal irrigation application was developed and implemented. In these experiments various irrigation regimes were applied and plants growth was hourly and daily recorded. An algorithm developed in order to adjust leaching fraction according to the desired water content in the root zone. Irrigation timing controlled by the algorithm enabled to keep the desired water content in the substrate. The DrainVision system provides the capability to control water content. Integration between PGA and DrainVision systems will provide deeper (better) insight of water availability and plant-growth relationship.

Keywords: irrigation practices, plant growth analysis, precise irrigation

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(ROSA Ref. n.94)

Decision support systems shape new strategies to manage irrigation of orchards in a climate change context

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Almonds are produced almost exclusively in California were water shortage is becoming more and more pregnant. While almond trees can withstand water stress, this crop is still a huge consumer of irrigation to maintain a high level of yield. In order to ensure water saving, the Almond Board of California is pushing forward a Strategic Deficit Irrigation (SDI). Growers apply a fraction of orchard evapotranspiration during specific development stages to limit the growth of vegetative parts while minimizing the impact on almond productivity. Compared to a fixed amount of water each year, this method has the benefit to save water while maintaining a high level of yield, prevent some diseases and favor uniform timing of hull split for harvest.

In this work, we used a simple water budget model to help growers implement a SDI strategy throughout the season. This formal approach has been coupled with a mechanistic model of soil-plant-atmosphere initially developed and successfully tested on vineyard (Vintel®). This model allows us to access hidden physiology variables like Stem Water Potential (SWP) in the tree throughout the season.

We demonstrate that a DI strategy needs to be carefully tuned to a specific orchard in terms of soil and tree development to have some benefits: limit the amount of water while keeping the tree above high stress levels. Furthermore, our model helps us explore what will happen to this orchard in the context of climate change. We show that relying on SDI won't have the capacity to adapt fast enough and future management plans will have to rely directly on SWP. However, the level of measurements needed to pilot irrigation, especially in a non-uniform orchard is too strenuous to prove feasible which justify the use of models such as ours to integrate various knowledge and sensors information in a comprehensive irrigation management plan.

Keywords: precision agriculture; crop modelling; irrigation scheduling; strategic deficit irrigation (SDI); plant physiology; stem water potential; soil water capacity

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(ROSA Ref. n.21)

Development of linear models to estimate vine water status usingspectral indices

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The measurement of stem water potential (Ψstem) has been suggested as an excellent tool for monitoring water status in drip-irrigated vineyards. However, its practical application is limited because of the high cost and time-consuming measurement. As an alternative, the use of spectral indices (SI) is proposed, which has been reported as a good predictor of plant water status in a non-invasive way. The aim of this study was to identify the relations between the Ψstem and several SI in a drip-irrigated vineyard growing under semiarid conditions. Both Ψstem and SI were measured at midday using a pressure chamber (model 1000, PMS Instrument Co., Corvallis, Oregon, USA) and a portable spectrometer (SVC HR-1024i, USA), respectively. Using this information, 74 spectral indices were calculated based on visible (VIS), near-infrared (NIR) and shortwave infrared (SWIR) spectra. In addition, linear regression analyses were performed to determine the relationship between SI and Ψstem. The results indicated that there were significant linear correlations between Ψstem and SI with values of R2 ranging between 0.05 and 0.67. The highest values of R2 was observed for the linear regression between Ψstem and photochemical reflectance index * chlorophyl index (PRIxCI). This regression was developed using values of Ψstem from -0,53 to -1,44 MPa.

Keywords: hyperspectral indices, linear model, stem water potential

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(ROSA Ref. n.166)

Estimation of vineyard water status using infrared thermometry measured at different positions of the canopy

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The use of remote sensing technologies in the form of thermal sensors has become a potential tool to estimate vine water status. The Crop Water Stress Index (CWSI) incorporates thermal information along with climatic data to estimate the degree of plant water stress. It can be calculated through different methodologies and subsequently relate it to stem water potential measurements (Ψstem). In this regard, the aim of this study was to evaluate the CWSI based on leaf energy balance for computing vine water status of a drip-irrigated vineyard (Vitis vinifera cv. Cabernet Sauvignon). The vineyard is trained on a vertical shoot positioned system and located in the Pencahue Valley, Maule, Chile. Meteorological data and canopy temperature were measured during 2018-2019 growing season. Canopy temperatures were measured from the north, south and top of the vine canopy with an infrared thermometer (Apogee MI-2H0) and climatic information was obtained from an automatic weather station (AWS). Results indicated that there is a significant linear correlation between CWSI and Ψstem with r2 ranging from 0.24 (top of the canopy) to 0.59 (north side of the canopy). These results open up the possibility of using thermal sensors as a tool to remotely estimate vine water status.

Keywords: Crop Water Stress Index (CWSI), thermometry, stem water potential

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(ROSA Ref. n.165)

Estimation of soil moisture from UAS platforms using RGB and thermal imaging sensors in arid and semi-arid regions

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Soil moisture is a connective element between the Earth's surface and atmosphere and is influential on various climatological processes. Surface soil moisture is a key component for addressing energy and water exchanges and can be estimated using different techniques, such as in situ measurements, and remote sensing. However, in situ measurements are prolonged, labor intensive, costly, and limited to discrete measurements in point scale, which is rarely capable in demonstration of moisture fluctuations in the soil profile and its relation with other processes. On the other hand, current high spatial resolution satellite sensors lack the spectral resolution required for many quantitative remote sensing applications, which is critical for heterogeneous covers. RS based on Unmanned Aerial Vehicles (UAVs) represent an option to fill this gap, providing low-cost approaches to meet the critical requirements of spatial, spectral and temporal resolutions. The present research gives a description on generating high-resolution remote sensing products using a rotary wing UAS equipped with thermal imaging sensor in an agricultural field. We carried out two survey during the day and night time with a DJI Phantom 4 Pro over an agricultural field in the northeast of Iran. Firstly, we examined how vegetation indices such as Normalized Green Red Difference Index (NGRDI), Green Leaf Index (GLI), Visible Atmospherically Resistant Index (VARI) and Excess Green Index (ExG) vary in this field over different soil textures and vegetation covers via the RGB camera. Secondly, soil moisture values were retrieved from the FLIR Tau2 thermal camera operating in the wavelengths of 7.5-13.5 Mm. The soil moisture values obtained from the UAV were evaluated with the surface soil moisture values measured from a Campell TDR100 in a 9*7 grid. This study demonstrates the potential of UAVs in providing high-resolution thermal imagery along with quick turnaround times in vegetation and soil moisture monitoring in agricultural fields.

Keywords: remote Sensing, surface soil moisture, thermal imagery, UAVs

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(ROSA Ref. n.156)

Preliminary real-time monitoring of the sap electrolyte concentration inolive tree through an in vivo sensor

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Precision farming targets include the synchronisation of plant nutrient demand and soil mineral availability. For that purpose, soil, plant tissue and soil solution analysis are currently adopted. However, these methods are time consuming hence not suitable for precision farming. Sensors for in vivo measurements of sap ion concentrations are increasingly developed focussing both qualitative and quantitative information. This study tested the quantitative response of an organic electrochemical transistor (OECT) termed Bioristor to variable sap flow rates in olive plants. A Bioristor is composed by two threads made of a biocompatible fibre acting as channel and gate of the transistor, both functionalized with a specific polymer. The sensor response (R) is evaluated as being proportional to the electrolyte concentration of the plant sap and sap flow rate. Bioristor were inserted across the trunks of six 2-year old olive plants. Daily water consumption rates of olive trees were measured gravimetrically. Values of R were continuously recorded for 13 days. In order to test the quantitative response of R to variable sap flow, 3 trees were subjected to drought stress by completely withdrawing the water under the assumption that such a drought imposition is influential on sap flow. The remaining 3 plants were regularly irrigated. In drought stressed trees the sensor response R progressively declines during the drought stress and correlates with the reduction of daily water consumption (R2 ranging from 0.83 to 0.98). The results support the reliability of the OECT sensor toward a real-time and in vivo monitoring of ion concentrations/sap flow rates in tree plants for water management in phenotyping measurements being scalable, non-destructive and potentially high throughput.

Keywords: Organic Electrochemical Transistor (OECT), bioristor, xylem sap, *Olea Europaea* L.

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(ROSA Ref. n.150)

Monitoring fruit daily growth indicates the onset of mild drought stress in apple

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This work tests the possibility to monitor fruit growth as a potential physiological indicator for tree water status and productive performance in apple, for potential implementation in decision support systems for irrigation scheduling. Starting from 10 weeks after full bloom (WAFB), a wide range of plant water statuses was induced in a "Gala" apple orchard by applying different shading (with red-50%, white-50%, and black-20% nets) and irrigation levels (severe-SS, moderate-MS and no-NS stress). For each net*irrigation treatment combination, midday stem water potential (mSWP) was assessed weekly, while fruit diameter variations were continuously monitored using automatic fruit gauges, from 10 WAFB until harvest. Leaf gas exchanges were also monitored at 14 and 16 WAFB. As expected, the different net*irrigation treatment combinations widely affected mSWP, leaf gas exchanges and fruit growth. On all dates of measurement, leaf gas exchanges were tightly correlated with mSWP, while daily fruit growth showed significant but weaker correlations with mSWP. In all cases, these relationships indicated the onset of drought stress below the threshold of about 1.2 g fruit-1 day-1, which corresponded to mSWP below -1 MPa. Almost no correlation was found between mSWP and the other parameters derived from the fruit daily growth pattern (midday, maximum and minimum absolute growth rates (AGR) and fruit shrinkage). Based on these results, we can conclude that, although fruit daily growth rate is not related to mSWP as tightly as leaf gas exchanges, it represents a promising physiological indicator to be implemented in a decision support system for irrigation scheduling. Specific fruit growth thresholds indicating the onset of drought should be defined, depending on the orchard conditions and productive target.

Keywords: irrigation scheduling, physiological indicator, water relations, fruit growth, decision support systems

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(ROSA Ref. n.149)

Soil scanning and remote sensing for precision irrigation managementin pear orchards

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To evaluate whether soil EC scanning and remote sensing techniques can yield useful information for precision agriculture including precision irrigation, two commercial pear orchards were monitored monthly from April to August 2018 using RGB, multispectral and thermal camera's on drones. Soil EC was measured using a EM38-mk2 sensor. Simultaneously, several parameters such as soil moisture, chlorophyll content, shoot length, and fruit yield and quality were evaluated in the field. Statistical analysis of soil scanning, remote sensing and crop data indicates that soil EC, soil moisture and fruit yield correlate with each other. Moreover, certain crop indices derived from remote sensing data can potentially be used as a proxy for plant drought stress and thus, for variable or zonal irrigation management. In 2019, additional data will be gathered to confirm the correlations observed in 2018. In 2017, a similar but restricted test was performed with drones to monitor a pear orchard with a gradient in nitrogen fertilisation doses and induced drought stress. As a reference to the drone data, soil water tension was measured in the field using Watermark sensors. The induced drought stress resulted in an a lower fruit yield. When the trial was repeated in 2018, a significantly higher number of small fruits was observed for the stressed compared to the non-stressed trees. The relatively high number of fruits might be a result of the 2017 drought stress treatment. Whether crop indices derived from the drone data reflect plant drought stress needs to be further evaluated in 2019. The relevance of these findings for precision irrigation management will be discussed.

Keywords: soil scanning, remote sensing, precision agriculture, precision irrigation

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(ROSA Ref. n.147)

Possibilities to determine of the soil water content

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The most basic and most important applications in plant production are the application of irrigation water. Irrigation applications are very sensitive because the soil which is an environment for plant growth is not homogeneous in every part and depth. The soil has a very heterogenic structure depending on the location and depth. This leads to difficulties in the application of irrigation water to the root area of the plant. A successful irrigation application depends on the precise and accurate measurement of the water content in the soil. Basically, direct and indirect measurement methods could be used to find out the soil water content in the plant root region. The method of direct measurement is based on sampling some spoilt and an intact soil; which is exhausting, laborious and time-consuming. In addition, in the direct measurement method, the measurement of the soil water content requires at least one day because the soil samples are stored in the drying oven. However, soil water content could be measured more quickly with indirect measurement methods. However, a limiting factor in the indirect measurement methods is that the accuracy of the devices and/or instruments used may be low. In this article, the possibilities of determining the water content in the plant root area are discussed because the most basic issue in a successful irrigation application depends on the most accurate measurement of the water content in the soil.

Keywords: water scarcity, water harvest, soil water content

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(ROSA Ref. n.145)

Irrigation of grape and pomegranate by using soil sensors

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The use of sensors can play a key role for scheduling irrigation in orchards and vineyards managed according to precision agriculture techniques. Among soil and plant water indicators, midday stem water potential (Ψstem) is considered as one of the most stable, reliable and accurate plant water status indicators for irrigation scheduling for many fruit tree crops. However, measuring Ψstem is a destructive and labor-intensive method which requires equipment (Scholander pressure chamber) not easy for a 'fast' monitoring of tree status. The Ψstem in commercial orchards and vineyards can be measured by also using a pump-up device which is portable and easier to use but for values only up to -20 bar. The soil matric potential (Ψm) is another indicator used for irrigation which can be easily automated with dataloggers and soil sensors and data can be used for real time monitoring of soil water status. The trial was conducted in 2018 at the experimental station 'P. Martucci' of the University of Bari 'Aldo Moro' – DiSSPA (Fruit Tree Unit). The two indicators (Ψstem and Ψm) were applied in the repositories of grape and pomegranate during the irrigation season, from June to August 2018. The two varieties used in the trial were Primitivo and Vkusny, for wine grape and pomegranate, respectively. The Ψstem values for pomegranate ranged between -8.5 and -16.2 bar, whereas for grape from -3.8 down to -9.5 bar. The lowest values were recorded in July when the higher temperatures were reached. The Ψm was measured at both 25 and 50 cm and values were kept higher than -40 kPa during the growing of the fruits. In grape, only after veraison Ψm fell below -100 kPa at 50 cm. In the case of pomegranate, values of Ψm resulted >-500 at the end of July when irrigation was withhold for some days. A linear association between Ψm mean values at 25 and 50 cm and Ψstem was found for grape with R2 of 0.87. In the case of pomegranate, the linear association between Ψm at 25 and 50 cm and Ψstem was also found with R2 of 0.76. Since Ψstem is a reliable indicator of the water condition of a plant but acquiring data is time consuming, the possibility of using an equation with Ψm data could be a useful tool for the management of the irrigation in orchards and vineyards.

Keywords: stem potential, matric potential, datalogger, remote sensor, leaf

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Field-testing of a Decision Support System (DSS) integrated with plant/soil sensors to optimize irrigation management in kiwifruit in Italy: the issue of model parameterization

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Kiwifruit is sensitive to water deficit throughout the growing season and possible restrictions in summer easily affects fruit size and yield. On the opposite, excessive water supply in poor draining soils is often associated with severe problems of plant decay. 'Regulated deficit irrigation' during specific fruit growth stages can be used to control fruit quality (e.g. dry matter content) which is related with 'premium quality' programs and long-term storability. Therefore, 'precise' irrigation management is required under conditions of increasingly limited water availability and climate change.

Decision Support Systems (DSS) are promising tools to support the irrigation management in the context of precision farming, and advances in digital technologies enable for an 'easy' data access by means of mobile devices. In Italy, a private company developed BluleafTM DSS to support irrigation scheduling based on the modelling approaches suggested by FAO-56 and FAO-66 I&D Papers. The computation of daily crop water balances requires local weather data and setting of site-specific parameters (soil, crop, irrigation) that significantly affect model results: however, the integration of different types of soil and/or plant sensors in the framework of the DSS is very helpful to 'calibrate' model parameters thanks to the 'real-time' feedbacks received from the cropping system.

In recent years, several farmers adopted the BluleafTM DSS for the irrigation management of kiwifruit under different pedoclimatic conditions. This paper briefly analyses field data and observations collected during 2017-18 for relevant case-studies, with specific reference to: i) the estimated crop evapotranspiration for different types of orchards (age, variety, canopy cover); ii) the comparison between DSS and farm strategies in terms of irrigation scheduling and seasonal volumes; iii) trends in soil water content and/or fruit growth rate as measured by sensors; iv) results in terms of yield and fruit quality that could be related with differences in water regimes.

Keywords: DSS, sensors, model parameters, precision orchard management, precision irrigation

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Optimizing sampling protocols for estimating irrigation usage with regional monitoring

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Regional irrigation monitoring can be conducted to help quantify the average irrigation application over time, for example to assist regional water supply management. One inexpensive automated method to estimate this uses a datalogger and pressure switch connected to drip irrigation systems to measure operation time. Two main sources of error affect this measurement; the sampling error of the population of irrigated farms in the region, and the measurement error of using operation time since actual emitter flow can differ from design flow. Both errors can be reduced by increasing the sampling size; the latter error can also be reduced by performing site-specific calibrations of drip system performance. However, resources for conducting such calibrations compete with resources for increasing the total sample number. Data from a recent irrigation assessment in California vineyards along with data on drip system testing results was used to develop a model to help predict the optimum allocation between the total number of sites sampled and the number of sites receiving additional in-field calibrations, with the goal of minimizing the total error. The main input variable of the model was the cost of conducting the in-field calibration of the drip system; the main output variables were the total number of sites sampled and the number of sites that received calibrations. Fixed variables were the cost of each automated measurement device (US$150) and the total budget available (US$15,000). The model output indicated that if the in-field calibration of the drip irrigation system can be accomplished for US$83 or less per site, then this should be done at all sites even though the total sample size is reduced. If the cost of the in-field calibration exceeds this value, then no calibrations should be done as more benefit is achieved by devoting the limited budget to maximizing the sample size.

Keywords: irrigation, monitoring, vineyard, water supply, sample size,

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Correlating remote and terrestrial water status indices in a nectarine orchard

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Accurate measurements of the plant water status are becoming essential for precise irrigated agriculture, especially in semi-arid regions where water resources are limited. This work aimed to study the feasibility of precise irrigation scheduling based on real-time soil water content (SWC) assessed by traditional discrete plant water status indicators compared to other based on multispectral and thermal indices taken from unmanned airborne vehicles (UAVs). The experiment was conducted in a nectarine orchard applying two irrigation treatments: Control (CTL), irrigated to ensure non-limiting water conditions (100% of crop evapotranspiration) and automated irrigation (AUTO) based on threshold SWC values, with capacitance probes, allowing a slight water deficit during the postharvest period. Plant water status was determined by stem water potential (Ψstem) and gas exchange measurements. Two airborne flights were conducted twice on a typical summer day, using a fixed-wing UAV. From this, Normalized Difference Vegetation Index (NDVI) and canopy temperature were obtained. At soil level, AUTO treatment registered a mean soil water deficit of 15% with respect to CTL. A significant mean reduction of 0.25 MPa in the values of Ψstem in AUTO treatment was observed respect to CTL treatment, corresponding to a plant moderate water stress situation. Gas exchange parameters were slightly lower in AUTO treatment. However, no significant differences were detected in UVA's indicators between irrigation treatments. The results showed that care should be taken using UVA's indicators to assess water deficit in deciduous fruit trees with a heterogeneous tree cover, in favour of the traditional plant-soil water status indicators. AUTO treatment applied 43% less total irrigation volume than CTL with no yield penalty, so that the use of real-time threshold SWC values could be a promising irrigation strategy for clay-loam soils in Mediterranean areas endangered by climate change.

Keywords: canopy temperature, Normalized Difference Vegetation Index (NDVI), plant water status, precise irrigation, soil water content

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VISCA - An integrated climate application for decision support system in vineyards

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Since 1950, weather records have shown an increment of temperature and a reduction of precipitation in the main viticultural regions in Europe. The Intergovernmental Panel on Climate Change (IPCC) forecasts maintenance of such tendency together with an increase of extreme climatic events (heat waves, droughts or flooding). The VISCA multi-platform integrates a climate service with a decision support system (DSS) based on local monitoring of weather and physiological variables together with end users' specifications, thus providing useful information for the implementation of medium- and long-term mitigation strategies. This platform provides a user-friendly interface together with the orchestration via a centralized web-based platform, of external processing modules to provide weather forecasts, phenological predictions, and irrigation recommendations. The time resolution of the weather forecasts varies from seasonal (6 months) to bi-weekly (14 days), and daily; with a spatial resolution of 0.7 x 0.7 degrees for the seasonal, 0.5 x 0.5 degrees for bi-weekly and 0.012 x 0.012 degrees for the daily weather forecasts. The main phenological events (from bud break to veraison) are predicted through a thermal time model, adapted to be able to run with seasonal variables. The dynamics of fruits maturation, i.e. accumulation of soluble solids is predicted using a process-based carbon balance model. Irrigation needs are computed with the soil water deficit approach, i.e. depth of water required to bring the soil to field capacity. Bi-weekly weather forecasts and phenological predictions are used to obtain crop evapotranspiration applying the dual crop coefficient approach. The tool is being validated at three demo sites located in Italy, Spain, and Portugal. Preliminary results show good predictability of the main phenological events and of plant water requirements. The validation experiments will continue until 2020.

Keywords: climate service, decision support system, grapevines, climate change

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An electronic Decision Support System to determine risk-based, site-specific fitness for use of irrigation water

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Agriculturists often evaluate the fitness for use (FFU) of a given water source for irrigation. Water resource managers need to know what water quality should be in order to maintain successful irrigation in a specific area. The need for a risk-based, electronic assessment of irrigation water quality that also considers site-specific factors, lead to the development of the DSS presented here.
The DSS operates at two tiers to assess the effect that water quality constituents may have on soil quality, crop yield and quality (including human health effects) and irrigation equipment. A number of 'Suitability Indicators' divide these effects further into sub-components. The user-friendly colour coded DSS output displays the FFU of water as being 'ideal', 'acceptable', 'tolerable' or 'unacceptable'. Help files provide information regarding current state of knowledge for suitability indicators and the calculating procedures used in the DSS. Tier 1 assessments provide generic, conservative guidance regarding the effects of water quality constituents. These assessments assume, e.g. no dilution of irrigation water by rain, instant equilibrium between water constituents and soil, and crops that are generally sensitive to water quality constituents. The guidance provided at this level resembles that provided by currently published international water quality guidelines. Tier 2 assessments are more rigorous and used to assess whether the FFU of a water could improve when site-specific conditions are considered. These assessments employ a scaled down version of the Soil Water Balance (SWB) model to dynamically simulate the interactions between irrigation water constituents and the soil-crop-atmosphere system over periods of 10 to 50 years, in order to quantify the probability and severity of a specific effect occurring. Default model parameters allow the user to select an appropriate weather station, soil texture, crop, irrigation management approach, and irrigation system, in order to consider site specificity.

Keywords: irrigation water quality, crop quality, crop yield, decision support system, soil quality.

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(ROSA Ref. n.118)

A new automated station for water status monitoring in grapevines

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Climate change scenarios together with the increasing request of sustainable products push the irrigation sector towards always more efficient use of natural resources. This is particularly evident for the vine sector of the Mediterranean areas where there is a growing interest by farmers for technologies and knowledge for a better irrigation management. In this paper, an automated platform for assessing the vineyard water status is described. It is capable to estimate the water status through the use of a set of mini sensors placed on the grapes. The platform includes also a weather station and a surface renewal system for estimating actual evapotranspiration. All of the data are automatically sent and analyzed by a remote server and results are returned to the farmer in near real time, giving useful and user-friendly information for the irrigation scheduling.

Keywords: water potential; water stress; drought; water deficit

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(ROSA Ref. n.109)

Mapping of deep percolation using remote sensing over irrigated area in the Haouz plain (Marrakech, Morocco)

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The objective of this study is to estimate the spatial deep percolation (DP) by combining remote sensing data and SAMIR (Satellite Monitoring of IRrigation) tool. DP was derived as the residual component of the water balance at the root zone.
The computation of the water budget requires climatic data (reference evapotranspiration (ET0) and rainfall), land cover, crop coefficient derived from Normalized Difference Vegetation Index (NDVI), and hydrodynamic soil parameters such as soil moisture at field capacity and wilting point.
The main component of the water balance is the evapotranspiration which is spatialized based on the FAO-56 approach and the relationship between crop coefficient and NDVI.
The developed approach has been tested over an irrigated area in the Haouz plain during the agricultural period (2011-2012). The Results showed that DP amount follows water supply fluctuations (Irrigation provided by ORMVAH and rainfall). The high values of DP are observed during heavy rainfall in March by recording values around 36, 27 and 20 mm for the beet, wheat and olive trees, respectively. While for the rest of the season from April to June, the vegetation cover was exposed to high water stress due to the mismatch of water supply.

Keywords: deep percolation, water balance; FAO-56 model; remote sensing; SAMIR

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(ROSA Ref. n.64)

Automation of drip irrigation in almond and apple tree plots considering the sources of variability that affect humidity sensors

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The most usual method to determine irrigation needs is based on the water balance. However, especially in horticulture, the different components of the balance present some uncertainties. An alternative method is to schedule irrigation automatically using soil moisture sensors. A practical problem with soil moisture sensors is the high variability between repetitions installed in equivalent locations in the same plot, being very sensitive to local variations in soil texture, presence of coarses, roots, macro pores and soil compaction. In addition, drip irrigation produce wet bulbs below the drippers, affecting little or nothing the rest of the soil. The aim of this paper is to understand the soil water dynamics in a context of localized irrigation to help interpret the sensor measurements for making irrigation decisions.

This work focuses in two drip-irrigated orchards, one with almond grown in ridges and the other, an apple orchard with different tree sizes. In both cases, sensor-based automation by the IRRIX web tool was compared with manual scheduling by an expert.

IRRIX gathered soil water and weather data from the field, interpreted them according to the established seasonal plan, filtering anomalous data and weighting each sensor according to its representativeness and made daily irrigation decisions. The performance of IRRIX, using humidity sensors, was satisfactory because the sensor feedback, allowed adjusting the irrigation doses to the precise requirements at each moment and each place.

IRRIX was as effective as human programming, but more efficient, since the programming was automated and was able to manage the irrigation in an unassisted way throughout a season.

Keywords: automation irrigation, precision irrigation, humidity sensor, variability, almond tree, apple tree

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(ROSA Ref. n.7)

Analysis of some key features of a web tool for automated sensor-based irrigation scheduling in horticultural crops

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In spite of the advances in the understanding of water requirements of horticultural crops, their practical usage for scheduling irrigation in commercial orchards is hindered by the labor effort in gathering data, processing them and making routine decisions. Automated tools for irrigation scheduling should close the gap between academic knowledge and actual irrigation practices in farms. Nevertheless, the design of a proper irrigation tool for horticultural crops is not trivial, since it has to deal with a variety of discontinuous canopies, localized irrigation, concerns with fruit quality and often with limited water allocations. This contribution describes the key features in the design of IRRIX, a web tool for automated sensor-based irrigation scheduling which has been tested in a range of crops, including greenhouse tomato, apple, almond, nectarine, plum and olive orchards. The basis for the scheduling algorithm is a combination of water balance and feedback from soil sensors, where the water balance contributes its reliability and capacity of anticipation, while sensors allow to fine tune the model to the precise scenario of each irrigation sector. In addition, IRRIX brings a seasonal perspective of the irrigation management, integrating in the day to day adjustment of irrigation doses both the information derived from the sensors and the adherence to a seasonal plan. To enhance its robustness, the interpretation of soil sensor data includes rating the reliability of each sensor on a daily basis, which allows discarding automatically unreliable sensors before they could affect the decision making. The tool updates on a daily basis the irrigation doses on the irrigation automata and may operate almost unattended for the whole season. Meanwhile, the role of the user focuses on occasional supervision of data already digested by the tool and minding for alarms that may warn of anomalies in the irrigation setup.

Keywords: automated irrigation scheduling, precision irrigation, web platform, irrigation model, irrigation control loop, interpretation of soil water sensors, IoT

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(ROSA Ref. n.50)

Leaching fraction and soil salinity status of surface irrigated pistachio orchards in Yazd Province, Central Iran

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Salinity of irrigation water is a major limitation to agricultural production in many parts of the world. In these areas, both water and salts are added to the soil when it is irrigated. Excessive salts in the root zone will not only reduce plant water uptake, but also may affect its growth and productivity. Under such circumstances, proper irrigation management practices can reduce the adverse effects of salinity on plant production. Of which, Leaching Fraction (LF), or the fraction of applied water that passes through the entire rooting depth and percolates below, is of great importance that should be properly managed in saline condition. The present study was aimed to evaluate the irrigation management of saline waters used for pistachio production in Yazd province, located in central part of Iran. For this purpose, twenty-four commercial pistachio orchards were selected. Over the growing season, soil samples were collected from the pistachio root zone (0-120 in 30 cm intervals) and analyzed for electrical conductivity of paste saturation. In addition, water samples provided and analyzed for electrical conductivity (ECiw). To collect the beneath root zone drainage water and determine its electrical conductivity (ECdw), a funnel-shaped Wetting Front Detector device (WFD) installed in the 120 cm soil depth of the representative orchards. The Leaching Fraction (LF) was calculated by dividing the ECiw by the ECdw. The results showed that the averaged root zone salinity varied from 3.4 to 21.2 dS.m-1. While the irrigation water salinity ranged from 1.2 to 16.6 dS.m-1. ECe variation was mainly due to ECiw, irrigation depth and interval as well as leaching fraction and tree evapotranspiration. Depending on the plant growth stage and irrigation management, the estimated LF averaged around 26 percent and it varied from 17 to 59 percent. In the case of constant irrigation depth and interval over the growing season, acceleration of pistachio evapotranspiration rate in the middle of growing season decreased the soil water content and consequently, reduced the LF values. So, the observed salinity buildup at nut filling period was attributed to higher evapotranspiration rate and should be managed by irrigation interval or depth. New technologies such as pressurized irrigation systems or optimization of existing traditional irrigation methods may be suggested for this case.

Keywords: pistachio, salinity, LF, ET, WFD

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(ROSA Ref. n.71)

Computation of satellite-based single crop coefficients time series for drip-irrigated apple (*malus domestica* b.) trees

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The climatic change is significantly affecting on irrigation water supply in countries with Mediterranean agro-climatic conditions such as Chile, main supplier for apples in southern hemisphere, being necessary to develop a decision-making tools to optimize water sustainability in apple production (WP; kg/m3), maintain adequate yields of high quality and considering the protection of environment. Thereby, an accurate prediction of single crop coefficients (Kc), a component of consumptive crop water use (ETa), is critical for proper irrigation management of drip-irrigated apple trees grown in Central Valley of Chile (35°25' LS; 71°23' LW; 189 m.a.s.l). In this study the METRIC (Mapping EvapoTranspiration at high Resolution with Internalized Calibration) model was applied to analyze in time series the spatial and temporal variability of Kc of a drip-irrigated apple orchard during three growing seasons (2012/13, 2013/14 and 2014/15). Using Landsat 7 ETM+ and Landsat 8 OLI satellite images we analyze the behavior of the model with and without modified parameterizations of the aerodynamic roughness length, soil heat flux and leaf area index compared to those values obtained from an eddy covariance (EC) system installed above apple trees. Results indicated that METRIC estimate Kc with a r2 of 0.54, a RMSE of 0.07 and MAE of 0.04. Major disagreements were observed in months that present part of soil surface wet and weeds growing between rows. Finally, Kc and ETa maps at different spatial and temporal scales for main phenological stages were developed and demonstrate the practical use in site specific irrigation management.

Keywords: energy balance, evapotranspiration, apple orchard, remote sensing

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(ROSA Ref. n.153)

Evaluation of a two-source model to estimate vineyard evapotranspiration using UAV-based thermal images and meteorological data

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A field experiment was carried out to implement the Shuttleworth and Wallace (SW) model for estimating vineyard evapotranspiration (ETv) using thermal images from an Unmanned Aerial Vehicle (UAV) and meteorological data. The vineyard (cv. Cabernet Sauvignon) was drip-irrigated and located in the Pencahue Valley, Maule Region, Chile (35°25´ LS; 71°44´ LW; 90 masl). For this study an UAV was equipped with an infrared thermal camera (FLIR/TAU-2) in order to obtain surface temperatures at a very high resolution (6 cm × 6 cm) during 2018-2019 growing season. Meteorological variables and surface energy balance components were measured at the time of the UAV overpass. The performance of the SW model was evaluated using measurements of ETv obtained from an eddy correlation system. In addition, estimated values of latent heat flux (LE), net radiation (Rn) and soil heat flux (G) at the time of the UAV overpass were compared with ground-truth measurements from a four-way net radiometer and flux plates, respectively. Results indicated that SW model estimated ETv with errors of 8%, root mean squared error (RMSE) = 0.44 mm day-1 and mean absolute error (MAE) = 0.28 mm day-1. Finally, instantaneous values of LE, Rn and G were computed with errors of less than 24% and with values of RMSE and MAE of less than 55 W m-2. Results demonstrated that a thermal camera placed on an UAV could provide an excellent tool to estimate the intra-vineyard spatial variability of Rn, G, LE and ETv over the vine canopy and soil surface between rows.

Keywords: unmanned aerial vehicle (UAV), vineyard water consumption, remote sensing

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Water savings via a web-based irrigation decision support system

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Friendly Fruit is a Climate-KIC funded, 3 year project focusing on apple and strawberry, with the goal of identifying, testing and transferring to growers good horticultural practices able to improve sustainability of production. With a budget of € 1.8 million, it involves growers, commercial entities, and research outfits in several European countries. Within the project, one action focuses on methods to improve water irrigation management by using soil water sensors, climate models, cloud based decision support systems (DSS) and the Internet of Things. Soil water content sensors have been installed in commercial farms in France, Spain and Italy, which are connected via the Cloud and provide data used by a DSS to schedule irrigation. The project uses as benchmark to assess the effectiveness of the irrigation applied a commercially available fruit size forecasting service. In the present configuration, the project is comparing two irrigation scheduling systems (in-house and cloud-based). The in-house is based on the operator's personal experience or evapotranspiration estimation. In the first year of the project (2018) the system was deployed and tested, and irrigation scheduling was initiated. Preliminary results for France show a 449 m3 ha-1 reduction in irrigation between Aug. 1st and Oct. 10, i.e. a 30% savings. The system allowed to discover a partial clogging of the pipes in the Italian site, due to very clay soils, which had gone unnoticed and prevented correct delivery of irrigation volumes. The data for Spain are still under evaluation.

Keywords: decision support systems, soil sensors, Climate KIC, apple

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Session 6 - Tree crop irrigation management (drought and fruit quality)

Subsurface drip Irrigation and ICT for the innovative irrigation water management: application to citrus crop (*C. reticulata* cv. Tardivo di Ciaculli)

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Subsurface drip irrigation (SDI) is considered one of the most efficient irrigation systems because it allows the optimization of crop water productivity maximizing, at the same time, farmers' economic benefit. However, to take full advantage of SDI systems it is necessary to prevent emitter obstructions caused by root intrusion, as well as to apply water saving strategies, such as regulated deficit irrigation (RDI). Regarding the first aspect, manufacturers are claiming different techniques to protect emitters from root intrusion, such as mechanical barriers, addition with different chemical compounds into the emitter itself or chemicals into irrigation water. On the other hand, application of RDI strategies during specific periods of vegetative growth makes it necessary to control soil/plant water status in order to identify appropriate irrigation scheduling parameters (timing and doses) and to increase water use efficiency. In this direction, new sensors associated with information and communication technology can allow, in the real time, the remote monitoring of soil and plant water status, avoiding tedious and time consuming field data collection. Objectives of this ongoing research are: i) to identify precise and automatic irrigation scheduling parameters in a citrus mandarin orchard (C. reticulata cv. Tardivo di Ciaculli) under SDI system, based on the monitoring from remote and in real time of the soil-plant-atmosphere system and ii) to test different anti-root agents settled in the same emitter model. Moreover, to reduce the total amount of applied water, RDI was applied, in half of the orchard, during the phase II of fruit growth. Integrated sensing methodologies, supported by Internet of Things and cloud computing technologies, together with a suitable communication infrastructure, were used for the continuous monitoring of soil water status with "drill & drop" sensors (Sentek, Stepney, Australia) and climate variables by means of a Spectrum weather station. Scholander chamber observations were additionally used for the assessments of orchard's water status through weekly predawn and midday stem water potential measurements. Data collected during the first season allowed to identify the threshold of soil water content below which crop water stress occurs, which resulted variable, for the investigated soil, from about 0.20 and 0.25 cm3/cm3.

Keywords: subsurface drip irrigation, ICT, irrigation water management

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(ROSA Ref. n.187)

Performance of sweet cherry trees growing in pots in a controlled environment

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Sweet cherry trees grown in small pots in unheated greenhouses are one of more advanced way of producing fruits. The soil volume is limited and the supply of water and minerals has to be much more precise. Three years old feathered trees of 'Regina' and 'Kordia', both grafted on the dwarfing rootstock 'Gisela 3 and 'Lapins' /G5 were planted in 35-L pots in March 2017. The growth medium was a mix of 1/3 each of the substrates - black peat fiber, coco peat fiber and expanded clay. The trees were trained as a central leader tree (spindle). The distances between the pots were 0.7 × 2.25 m (1.58 m2/trees). Fertigation supply was installed using drip irrigation to each pot with two drippers. Three levels of electric conductivity (EC) in the water were given (0.7-1.30-1.90) with the following ratio of the different macro elements: Total nitrogen (100), phosphor (21), potassium (187), calcium (184) and magnesium (66). Each pot was given from 0.5 l with fertigation up to 3 l at midsummer depending of light regime and leaf areas, i.e., matching the evaporative demand of the trees with about 10 % overflow in the pots. The frequency per day of given fertigation varied from 2 (April) to 10 (mid-summer). The EC levels and the mineral contents were analyzed from the drips and the overflow from the pots during the season. The trees blossomed in end of April and fruits were harvested second and third week of July with 'Lapins' as the earliest followed by 'Kordia' and 'Regina'. Average temperatures for the months April, May, June and July were 9.6, 16.2, 15.0 and 17.7. The EC- levels increased from the overflow mainly due to higher level of nitrates. All macro elements in leaves were within the optimal recommended range during the season. The year after planting 'Lapins' /EC 1.9 gave the largest yield (5.6 kg per tree) and 'Regina'/EC 1.3 the smallest (0.9 kg per tree). Generally, the fruit quality traits were high. However, increasing level of EC reduced to some extent the fruit sizes, percentage of soluble solids, the flavour and delayed the maturity.

Keywords: fertigation, fruit quality, greenhouse, high density, Prunus avium L., yield

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Assessing drip irrigation system performance in a blueberry crop to improve the water use efficiency and productivity within the water-energy-food-nexus

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A drip system evaluation performance was done in a blueberry (Vaccinium corymbosum L.) commercial crop of 10 years in Concordia, Entre Ríos province, Argentina. Crop is planted in rows each 3.5 meters and plants in the row each 0.75 m. The drip system includes two drip irrigation tubes per blueberry row, with drippers each 30 cm. of 1.1 liters per hour at a pressure of 11 meters of water head. Roots of blueberry are very shallow, that characteristic combined with sandy soils of the area with very low water holding capacity, requires the application of very low quantities of water in each irrigation application. The objective of the experiment was to measure the current flow of the drippers of the 10 years old system, in 400 points of the 25 has system, obtaining 1) Uniformity Coefficient of Christiansen (1942) (CU), 2) Uniformity Coefficient of Application of Keller and Karmelli (1984) (CUa), 3) Uniformity coefficient of the minor quarter of Pizarro (1996) (CUqm), 4) Total Distribution Efficiency of Holzapfel (2008) (EDT), 5) the Wetting Time in Drip Irrigation (WTdi) and 6) the Recession Time in Drip Irrigation (RTdi) of Pannunzio (2016). Results showed that EDT is the better tool because includes the design and management criteria of the system, the characteristics of the better irrigation scheduling for the crop including particularities of the soils of the area and the implications of slopes and kind of drippers selected in WTdi and Rtdi.

Keywords: drip irrigation management, design criteria, irrigation efficiency, water management, water footprint, blueberry

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Substrate moisture effects on growth, yield and fruit quality of strawberry (Fragaria X ananassa)

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The effect of substrate moisture on the growth, yield and fruit quality of strawberry (Fragaria X ananassa) cultivars 'Chandler' and 'Sweet Charlie' was investigated in a randomized complete block design experiment inside a greenhouse. Plugs were transplanted to 3.8 L pots filled with commercial substrate (Sunshine Mix LC1, Sungro Horticulture, Agawam, MA) composed of 75-85% peat moss and 15-25% perlite on volume basis. Moisture release curve for the substrate was developed using Hyprop device (METER Group Inc., Pullman, WA) to correlate volumetric water contents (VWC) with corresponding matric potentials (MP). Four substrate VWC levels of 40% (control), 30% (DI1), 20% (DI2) and 15%(DI3) were selected as treatment set-points, corresponding with MP values of -4.3, -13.8, -36.7 and -63 kPa, respectively. GS-1 soil moisture sensors (METER Group Inc.,) were inserted in three plants per plot and VWC was recorded on a 5-minute basis using Em50R data loggers (METER Group Inc.,). Data was transmitted to SensorwebTM software (Mayim LLC., Pittsburgh, PA) and averaged on a 15-minute basis. Plots were independently irrigated when the average VWC dropped below the corresponding set-point for each treatment. Irrigation treatments were started at four weeks after transplant and were maintained for the duration of the study. Destructive harvests conducted for fall and spring growth analysis and after final harvest showed significant effect of irrigation treatments on plant growth parameters for both cultivars, with DI2 and DI3 treatments resulting in plants of less vigor. DI2 and DI3 also resulted in significantly lower total yield, with decreased irrigation application compared to control and DI1, and hence non-significant increases in water-use efficiency. Differences in all fruit quality parameters were not significant. Understanding how plant growth, yield and fruit quality respond to decreasing substrate moisture availability is critical to devise efficient irrigation practices for strawberry production in various production systems.

Keywords: deficit irrigation, substrate, matric potential, volumetric water content, strawberry

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(ROSA Ref. n.54)

Testing three strawberry cultivars for reduced water demand in the mid-adriatic area

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Strawberries cultivation systems generally requires high amounts of water supply, especially in some phases of the cultivation cycle. New strawberry cultivars with lower water demand are now requested to reduce input in the cultivation process, to reduce costs, to save this precious resource and increase adaptability to changing climatic conditions. With the aim to study the effect of different water supplies on three strawberry cultivars, the yield and fruit quality of "Cristina", "Romina", and "Sibilla" grown at reduced water restitution (80% and 60%) were compared with the full (100%) restitution of water lost from restart of growth to fruit ripening. To monitor the response to these treatments, vegetative, productive, and qualitative parameters were detected in 2018 harvest season. The water reduction affected in different manner the three cultivars, with "Cristina" and "Romina" resulting the most adaptable to these resilient conditions. In particular, with 80% water restitution, "Cristina" and "Romina" did not show negative effects on plant production, while "Sibilla" showed reduced amount of yield. The vegetative parameters of the three cultivars were not significantly affected by the different water regimes. Similarly, fruit quality of the three cultivars was not altered by water reduction, even if a positive trend of sugar and acid content was detected with decreasing water restitution. The results confirm the importance of genotype rusticity for reducing water use in strawberry cultivation systems. All the cultivars are able to maintain regular plant development, at any water regime, but only "Cristina" and "Romina" are able to maintain a good yield even at 80% of water restitution. The research will continue to identify other new cultivars even with higher resilience to water limitation.

Keywords: water stress, plant yield; fruit quality; soluble solid; titratable acidity

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(ROSA Ref. n.146)

Irrigation of apples in a humid climate in wet and dry years

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An irrigation field experiment was conducted from 2015-2018 at 3 commercial apple farms in southern, western and northern New York State, USA and at the Geneva Experiment Station of Cornell University. At each site we managed irrigation quantity using a modified Penman-Monteith transpiration model (Cornell) We assessed tree growth and tree stress, and crop yield, fruit size and fruit quality (flesh firmness and sugars) with irrigation and no irrigation. In 2015 in Geneva the cumulative water balance showed that water supply from rainfall was sufficient to meet water requirement by the tree for the whole season, whereas in Southern NY, water requirement exceeded supply from rain from August through October. In 2016 both at Geneva and in Southern NY, water balance showed that water requirement exceeded supply from rain from June through October. In 2017 both in Geneva and southern NY, water supply from rainfall was sufficient to meet water requirement by the tree for the whole season, being the highest cumulative rainfall values of the last three years. In 2018 both in Geneva, northern NY and Southern NY, water supply from rainfall was sufficient to meet water requirement by the tree for the whole season, being the second highest cumulative rainfall values of the last three years. At Geneva we did not detect differences in stem water potential between irrigated and non-irrigated trees in 2015, 2017 or 2018 but significant differences were observed in 2016. We consider that tree stress starts with stem water potential values below about -1.6 MPa. Trees in Northern NY and Western NY did not reach this stress level in any of the three years of the study.

Keywords: stem water potential, modified Penman-Monteith, apple, irrigation

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(ROSA Ref. n.169)

Effects of the application of water stress controlled technique on productive, qualitative and nutritional parameters on a late peach cultivar

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The peach tree is one of the most cultivated tree species in the Marche Region. Recently also in central Italy there are problems of water availability for agricultural purpose. For this reason a study focused on the introduction of the controlled water stress technique in a high density commercial peach orchard has been conducted, located in the Valdaso area (FM) Marche Region. Irrigation control was carried out through the introduction of tensiometric probes for the measurement of soil water potential.
The 3 theses applied are: full irrigation (100% of irrigated restitution with respect to the field water capacity); moderate stress (80% refund); intense stress (60% refund). The test was carried out on a late peach cultivar nectarine 'Tarderina' (Prunus persica L. Batsch) grafted on GF677 rootstock, and the stress was applied during the second phase of fruit growth.
The productive, qualitative parameters were collected during 2017 and 2018 harvest years, while nutritional parameters of the fruit were measured only in 2018 harvest season. The tests showed that the irrigation treatment affects the total production of the plant, the fruit size, the firmness of the pulp and the skin overcolour.
Water stress clearly affects the nutritional parameters of the fruit. In particular the 60% refund resulted to promote the Antioxidant capacity and Polyphenolic content.
The results obtained are useful to the company for an efficient planning of the irrigation management and for reduce the water use.

Keywords: tarderina; fruit weight; fruit firmness; antioxidant capacity, polyphenolic content; GF677 rootstock

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(ROSA Ref. n.141)

Evaluating irrigation practices of two olive orchards in a water-scarce environment in Cyprus

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Limitations on irrigation water resources in the Mediterranean require the improvement of water use efficiency in agricultural areas. Monitoring and understanding farmers' practices could improve irrigation practices. The main objective of the study is the evaluation of current irrigation practices in two olive orchards in Nicosia district, Cyprus. The first olive orchard is located in Deftera community; it is a mono-varietal orchard, with 15-year-old 'Koroneiki' trees. The second orchard is located in the river plain in Peristerona community. It is a mixed cultivation with different olive varieties; 17-year-old 'Koroneiki' trees were selected for this study. Cultivation practices, such as irrigation, pruning, tillage are different. Soil moisture and meteorological conditions are monitored in both sites. In July 2018, temperature reached 40.5 ° C in Deftera and 41.1 ° C in Peristerona, whereas minimum temperature for the same month was 15.7 ° C in Deftera and 17.3 ° C in Peristerona. Reference evapotranspiration from June to December 2018, was 664 mm in Peristerona and 718 mm in Deftera. In both sites irrigation started in April – May. Low precipitation in the winter months resulted in water stress in late February, a sensitive growth period. Fifteen irrigations were given in Deftera and nine irrigations in Peristerona. Irrigation intervals were generally 12 to 15 days. Soil moisture observations indicated that irrigation applications exceeded the field capacity of the root zone, in both sites. Field capacity was estimated at a volumetric soil moisture of 30% in Deftera and 26% in Peristerona. Discussion with the farmers took place, who agreed to reduce irrigation amounts per application and irrigate more frequently. It is expected that new irrigation schedules wil decrease water loss and increase irrigation water use efficiency.

Keywords: Koroneiki, soil moisture, climate, soil conditions, participatory research

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(ROSA Ref. n.138)

Effects of a severe one-season water shortage on survival and yield in almond

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The cultivation of the almond tree in Spain is currently undergoing a revolution. Production intensification, as it has been done in California in the past, is taking place with new orchards being planted with modern varieties and high tree densities under irrigation. In some regions, where water shortage is a structural problem, there are in some years drastic reductions or even no water availability for irrigation. No data are available of long-term effects on almond production of drastic irrigation reductions in one season induced by a severe drought. In 2017, an experiment of one season irrigation reduction was made in a mature orchard of almond cv. Guara on GF-677 rootstock, with three treatments: Control, fully irrigated; Deficit, 25% of control; Rain fed, no irrigation. In 2018 all treatments were restored to full irrigation. Even though almond is considered a very drought resistant species, almost all trees died (98%) by dehydration caused by the long severe water stress period in rain fed treatment. Besides, water stress negatively affected yield. Kernel weight was affected the year of the drought, with reductions of 34% in the deficit treatment. Also pre-harvest stress increased the number of hull tights, almost 100% of the harvest in deficit treatments. Additionally, the number of nuts per tree was affected the following year in the D treatment, when the irrigation was restored, with a decrease of 17%. In this work it is argued that there is a need to determine water stress thresholds to the minimum irrigation that avoids almond tree death.

Keywords: drought management, almond survival, water stress threshold

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(ROSA Ref. n.134)

Long-term summer pruning in peach trees: is it an advisable cultural practice?

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Summer pruning (SP) in fruit trees is based on the ability to control tree vigour and carbon allocation in the shoots, through alteration of the apical dominance and light distribution in the canopy, reducing the needs for winter pruning (WP). The issue addressed in this work deals with the effects of SP on vegetative growth, yield and fruit quality, along with plant water status of extra early-maturing peach trees during four consecutive growing seasons (2012-2015). Trees were drip irrigated in Mediterranean conditions of Murcia (Spain) in a clay-loam soil. Two pruning treatments were imposed: winter pruning (WP), which was carried out during the dormancy (December) in order to maintain the vase tree architecture, and a summer pruning (SP) consisted of the elimination of the water sprouts just after harvest (May). Plant water status indicators were assessed by midday stem water potential (Ψstem) with pressure chamber. Canopy tree cover (TC) was obtained with zenithal imagen analysis. The percentage of effective shade was estimated with the TC and the solar angle of the measure day. Yield and fruit quality were evaluated at each pick of harvest. Fruits were separated in the field by manual calibration into 7 fruit diameter categories. Total pruning of SP trees was on average 12 kg per tree (dry matter) slightly higher than WP trees, being the contribution of SP nearly 35%. TC was significantly lower in the SP treatment, which resulted in an improvement in the plant water status of about 0.15-0.30 MPa with respect to WP trees in summer, leading to a reduction in water consumption during periods of high evaporative demand. No significant differences were detected between WP and SP in the yield components studied. Summer pruning can be considered a sensible cultural practice to mitigate the drought effects in early-maturing peach trees, maintaining yield.

Keywords: canopy cover, fruit quality, plant water status, pruning, Prunus persica, yield

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(ROSA Ref. n.126)

Irrigation strategies for citrus trees – a farm scale comparison for a Greek and an Italian area

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This work is part of LIFE+AGROCLIMAWATER project. The main objective of the project is to promote water efficiency, in the frame of climate change, through the development of water management adaptation strategies in Crete - Greece and in Basilicata – Italy. The common crop cultivated in both areas is citrus and the irrigation method used is microjet irrigation. In the Italian region, irrigation water comes mainly from surface water resources (dams). Irrigation in Italy, in cases of water sufficiency, takes place at regular intervals (daily basis) maintaining soil moisture in the upper layers (up to a depth of 30 cm) at steady levels for optimal production. In contrast to the Greek region, where irrigation water comes mainly from groundwater and water availability is limited, citrus irrigation is carried out on a weekly basis with the aim of satisfactory distribution of the soil moisture throughout the soil profile up to the depth of 60 cm. Comparing the efficiency of these two different water management strategies for citrus crops, where good agricultural practices that enhance water utilization efficiency are applied, the Water Use Efficiency (WUE), the Water Footprint (WF) and the related WF Blue component as indicators were estimated and compared at farm scale between Crete and Basilicata regions.

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(ROSA Ref. n.92)

The influence of water deficit and rewatering on flower bud morphogenesis in young apricot trees (*Prunus armeniaca* L.)

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In deciduous fruit species, as well as in apricot, floral bud initiation, differentiation and organogenesis take place during the summer season that precedes anthesis. A number of factors (environmental conditions, cultural practices, abiotic stresses) have been identified as important triggers able to modify the regularity of floral differentiation. The water availability represents a crucial key factor, particularly under Mediterranean climates characterized by long drought periods.
The aim of this investigation was to assess the influence of summer water deficit and re-watering treatments on floral morphogenesis, growth and quality of flower buds in apricot.
Trials were carried out over 2-annual cycles on potted two-year-old trees (cv. 'Portici') grown at the research station of University of Pisa.
Plants were divided into three uniform groups: the first one was watered daily maintaining soil water content around 90% of field capacity, whereas second and third ones were subjected, in June or July, to a 30 days of imposed water deficit followed to re-watering.
In order to determine the evolution of floral bud differentiation, prior, during and after the imposed water stress, histological analyzes were carried out. From autumn to spring, qualitative traits of flower buds (growth, anomalies) were also analyzed. Midday stem water potential was used to determining water status and leaf gas exchanges were measured during trials.
Both water stress periods affected the floral differentiation leading to a temporary shutdown. The plants stressed in June were able to recover the development of meristematic apices already after two weeks from the regular re-watering, while those stressed in July showed a strong delay up to the end of summer. As a consequence, variations in bud size and flower anomalies were observed.
Results confirm that water stress may play an important role for flower bud differentiation and development influencing the quality of flower buds.

Keywords: floral differentiation, bud growth, bud quality, irrigation, leaf gas exchange

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(ROSA Ref. n.115)

Evolution of quality parameters in cv. Angeleno (*Prunus salicina* L.) under different irrigation strategies

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Regulated Deficit Irrigation strategies in stone fruit orchards can reduce the supply of irrigation water below the water needs of the crop with a reduced impact on the harvest. However, many of the studies carried out have detected changes in the characteristics of the fruits harvested. The objetive of this study is to evaluate the effect ofthese strategies on the fruit ripening processof the Japanese plum cv. Angeleno. A field experiment was stablished for 5 years (2009-2014), with 3 irrigation treatments: Control, covering crop water needs; DI-20-60, a moderate water deficit coinciding with the phase II of fruit growth with a repplied of 20% of the Crop Evapotranspiration (ETc) and 60% of the ETc in Post-harvest; DI-0-30, with 0% and 30% of the ETc in the Phase II and Post-harvest respectively. In the first three years of the trial, the duration of the stress period was approximately 60 days and was halved in the following two years

The extended water stress during phase II promoted changes in the fruit ripening process during phase III about the Control. These modifications were more evident when the period of stress was more severe: they were more pronounced in the DI-0-30 treatment compared to DI-20-60. The stressed fruits remained smaller than those of the Control, with higher soluble solids content and lower acidity and firmness, for the same sampling date. As a consequence, deficit irrigation caused an advance in the harvest date and fruits with different characteristics. With a less prolonged period of stress (2013 and 2014) the differences between treatments were annulled. The yield was similar or slightly lower in the Control treatment along the five years. Deficit irrigation strategies can have a greater scope than improving the efficiency in the use of water or reducing crop costs, but also they can be an effective instrument to modify the characteristics of the fruit, adapting them to the tastes of consumers.

Keywords: Ripening process, regulated deficit irrigation strategies, japanese plum, water stress

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(ROSA Ref. n.20)

Efficiency of irrigation and fertigation in mature period of apple orchard

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In the largest part of fruit production regions where apples are grown on dwarf rootstocks the irrigation is applied as a standard practice. In Latvia most of orchards have no irrigation due to 667 mm of annual precipitation in average (permanent observations) and comparably low evapotranspiration. The productivity of commercial orchards is low due to insufficient available water in soil especially during periods important to generative development of apples. The water deficiency is caused mostly due to the shallow and compact root system with disproportionally large canopy that is typical to the vegetative propagated rootstocks widely used in the apple orchards. The aim of the investigation was to evaluate the efficiency of irrigation and fertigation in mature apple orchard with cultivars 'Auksis', 'Zarya Alatau' and 'Spartan' on dwarf rootstocks with tree density 1666 trees per 1 ha in condition of Latvia, Dobele. The drip irrigation system was established ten years after planting of trees. The single drip line per row used with dripper distance 38 cm and transmittance 2.0 L/h providing additionally up to 1039 mm (in 2012) of water by irrigation depending of season (precipitation and temperature). During period 2007 – 2018 the calculated productivity obtained larger in irrigated/fertigated area – in average 33.5 – 34.4 t/ha. Providing the additional water, the increase of productivity was at least by 5.1 – 6.0 t/ha in average compared to the area without irrigation. Some effect by cultivar differences were observed as well. At the sometime the size of fruit differs insufficiently providing additional water in the root zone of apple trees. As well as the statistically provable influence of additionally provided water to the growth of apple trees was not found.

Keywords: Malus, drip irrigation, precipitation, dwarf rootstocks, fruit size, growth

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(ROSA Ref. n.113)

Evaluation of variable rate irrigation systems in California almond orchards

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Micro-irrigation systems have greatly improved water and nutrient use efficiency in California orchards in recent decades. However, water resource depletion has resulted in regulations that will sharply reduce allocations for perennial tree crops operations across the state. With less water available, water use efficiency must be improved to maintain yields and profitability. Efficiency may be improved by designing variable rate irrigation (VRI) systems to account for soil spatial variability that influences water movement in the rootzone and tree uptake. A trial was established in a 7-year old almond block comprised of a 50-50 mixture of nonpareil and wood colony in Tulare, California, USA to evaluate VRI improvements in water use efficiency. The VRI system (Netafim, USA), a grid of thirty-six 0.4-hectare sub-irrigation zones, was established on approximately 15 hectares, beginning operation in 2019. Another 15 hectares has the original irrigation system and serves as the grower control. Irrigation system distribution uniformity and average application rate were determined for each of the VRI zones as well as for the control plots. Baseline data including stem water potential, canopy photosynthetically active radiation (PAR), NDVI, tree circumference, height, percent shaded area, tree volume index, harvest yield, and soil infiltration rates were used to identify similar sub-zones. Irrigation schedules for sub-zones have been condensed into six variable rate management areas. Weekly irrigation schedules for each management area are determined based on on-site determined evapotranspiration (ETc) (Tule technologies, USA), with adjustments in response to stem-water potential physiological measurements, rootzone soil moisture, and weekly changes in NDVI imagery. Continued annual yield measurements, ground and aerial based plant physiological measurements, water and fertilizer application monitoring, and energy use will be tracked to document the potential resource conservation and economic benefits of variable rate irrigation systems in almond orchards.

Keywords: variable rate irrigation, soil spatial variability. water use efficiency

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(ROSA Ref. n.110)

Deficit irrigation applied in a peach orchard under Mediterranean climatic conditions in Portugal

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In the region where this study take place, in the center countryside of Portugal, the availability of water is poor, so the efficient use of the water in agriculture activity have a so much importance. The irrigation patterns in two peach orchards located at the region Beira Interior, south of "Gardunha" Mountain, and the effect of different amount of irrigation in the gross production and fruits quality were evaluated. The soils where are located the peach orchards are Cambisoils and Regosoils, majority deep and well drained. The topography of this region is plane or gently sloped, and the climate is characterized by typical Mediterranean conditions. The experiment was conducted in 2016, in two different orchards, and included three treatments correspondent to three different flow rate per tree: 8, 12 and 16 l/hour. The soil moisture was evaluated periodically with a FDR probe (DIVINER 2000), and the water balance included the water supply by rain and irrigation and the crop evapotranspiration. At harvest crop production, pulp firmness and percentage of total soluble solids were evaluated. There were no significant differences between treatments in the average production per tree. However, in one of the orchards production increased with the volume of irrigation. In the same orchard, the pulp firmness decreased with the increasing water supply. Total soluble solids had decreased with the increasing water supply in both orchards, probably as a consequence of the dilution effect due, directly, to the water incorporate in the fruits, or, indirectly, to the larger fruits produced by the more irrigated trees. In general, in the treatments used in this study as well as in the farmer's practices, the supplied water was in deficit, but the farmers tend empirically to follow closely the evolution of evapotranspiration.

Keywords: Mediterranean climate, deficit irrigation, peach tree, production, percentage of total soluble solids, pulp firmness

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(ROSA Ref. n.108)

A near-hydroponic open field drip irrigation system improves young persimmon trees performance and water use efficiency

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A recent study by Rubio-Asensio et al. (2018) showed that it is possible to adapt the hydroponic culture system to an already established nectarine orchard. In this research, we evaluated the effects of installing coconut fiber substrates bags either laying on the orchards surface or buried into the soil on a newly established persimmon orchard. The experiment took place in Murcia (southeastern Spain) under semi-arid conditions and with drip irrigation. Tree growth and leaf water and nutrient relations were determined during the first 4 seasons after tree planting. Compared to a Control treatment with conventional drip irrigation, and for similar irrigation water application, trees growing with the substrate bags had increased vegetative growth and in the third season up to 40% higher yield. In the fourth season, there were not statically significant differences in yield among the evaluated treatments, but fruit fresh weight was increased by 21% in trees with coconut fiber bags. During the course of the experiment, substrate bag root colonization was monitored, determining that root growth was favored by the installation of the coconut fiber substrate bags. During some part of the seasons, trees with the substrate bags, had improved water status compared with the Control treatment which could explain the improved tree performance. The near hydroponic technique could be an option to improve persimmon tree performance during the first years of the orchard establishment. Further research is needed to optimize fertirrigation frequency of application and longer term studies are needed to further demonstrate a cost-benefit advantage of the innovative technique here investigated

Keywords: coco fiber substrate; hydroponics, tree nutrient status, midday stem water potential

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(ROSA Ref. n.99)

Influence of different water stress strategies applied to olive trees on the fruit size and oil production

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The relationship between productivity and amount of water applied by irrigation in olive tree has been widely studied before in different conditions and areas where water is the limiting factor. Several years of work are required to obtain reliable data of the yield and production quality of olive trees under different deficit irrigation management. However, it is complicated to determine the influence of the irrigation directly on the fruit size due to the big variability of the canopy volume and the fruit load of different treatments within the same season.

A long-term field experiment is conducted in an adult olive grove in Cordoba (Spain), on 'Manzanilla de Sevilla' cultivar, with a density of 408 olive trees/ha (7x 3.5m). In the first year, trees of the different treatments were initially homogenous having identical canopy volume and similar number of fruits per tree. The experiment was designed in randomized blocks with four repetitions for each treatment: 1)100% ETc following water balance method (FAO, 1998), 2) Controlled Deficit irrigation with medium water stress (CDI1), 3) Controlled Deficit irrigation with severe water stress (CDI2) 4)Rainfed. Leaf water potential was measured every two weeks and it was used to determinate the irrigation dose for treatments 2 and 3. The measured parameters were: leaf water potential, growth of shoots, evolution of the weight and the oil content of the fruit during the season. Production and oil yield were measured at harvesting. The application of different amount of irrigation water showed a straight effect on enhancing the productivity per hectare of the olive tree. In fact, the amount of water applied through irrigation during water stress events affects mainly the fruit size and the oil content but leads to a higher yield in kg in terms of production when it is increased although the water use efficiency decreases.

Keywords: olive trees, deficit irrigation, leaf water potential, fruit growth, water use efficiency.

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Enhancing water use efficiency in irrigated agriculture through variable rate drip irrigation: the case of a pear orchard in northern Italy

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Few studies applying Variable Rate Irrigation (VRI) by means of drip systems are described in the literature, even if drip irrigation is the best irrigation strategy for orchards. In the agricultural season 2018, the effectiveness of variable rate drip irrigation was demonstrated in a pear orchard of about one hectare located in Lodi (NUTRIPRECISO project; RDP-EU, measure 1.2.01, Lombardy Region). Through the use of an Electro-Magnetic Induction sensor (EMI) pulled by a Quad, soil electrical conductivity field maps were obtained, and two homogeneous Management Zones (MZs) were identified by applying statistical techniques. A soil profile was opened in each MZ, soil core samples were collected from the soil horizons, and soil water content at the field capacity and wilting point were laboratory-measured. For each MZ, the Available Water Content (AWC) in the rooting depth was computed and used to obtain the Irrigation Prescription Map (IPM). Based on the IPM, a drip irrigation system characterised by three sectors was designed and realized: two sectors supply water to the two MZs, while the third one, whose function is to show the 'reference irrigation management', covers a lateral strip of the field in which both soil types are present. In the first two sectors, drip lines were optimized in terms of spacing between drippers and dripper flow rates according to the soil types. In the third sector, the most common drip lines used in orchards were installed. A wireless sensor network including one soil water content probe for each sector was used to fine-tune the frequency and duration of irrigation events in the first two sectors; in the third sector irrigation was supplied following the farmer's habit. Drip VRI allowed to reduce the pear orchard water consumption of about 50% compared to the 'reference irrigation management', without losses in yield and product quality

Keywords: precision agriculture, variable rate irrigation, homogeneous management zone, drip irrigation, proximal soil sensing, water use efficiency

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(ROSA Ref. n.74)

Evaluation of an operational participatory system for irrigation recommendations - case study for kiwi crop in Greece

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In Greece –like many Mediterranean countries- irrigation is by far the major water user. In this framework the development of operational tools that support decisions and provide recommendations aiming to improved irrigation management is of great importance. In this study the web-based participatory system for irrigation management (http://arta.irrigation-management.eu/, the system hereafter) that operates at the plain of Arta (NW Greece) is evaluated. The evaluation was performed for the case of kiwi fruit, an evolving crop for the area which is characterized by significant water requirements. Water usage and soil moisture were continuously monitored using water meters and capacitance sensors respectively in three typical orchards of *Actinidia deliciosa* 'Hayward', during two irrigation periods. The system, provided real time forecasts for soil moisture and generated recommendations for future irrigation events, based on the outcomes of a model that follows the principles of FAO's paper 56. The model takes into account: (a) measurements of weather parameters from agrometeorological stations in the area; (b) soil, crop and irrigation system parameters; (c) time and volume of the actual irrigation events and (d) weather data forecasting. The soil moisture time series that were produced by the system's model were compared to those measured by soil moisture sensors in the three orchards. The differences were small and it was found that following the system's recommendations could lead to 30-65 fewer irrigation events and 33-74% less water usage per year compared to the typical practice in the area.

Keywords: water requirements, micro-sprinkler, efficient irrigation, DSS

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Overcanopy irrigation in apple orchard: a two-year study on the microclimatic, physiological and productive effects

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The efficacy of the evaporative cooling induced by overcanopy irrigation management was tested in 2017 and 2018 on a commercial "Fuji" apple orchard placed in Medelana (Ferrara, Italy). Trees were subjected to two irrigation regimes: drip irrigation (DRI) or, between July and August, when the hottest period of the growing season occur, supplemented by overcanopy irrigation (OCI). Water potentials and leaf gas exchange measurements where performed, soon after and the day after OCI, twice along the growing season. Within day fruit growth, leaf and fruit temperature and microclimatic parameters where monitored for the entire experiment. No difference was found in leaf/stem water potentials, or leaf gas exchanges before and after OCI while were improved on the OCI day if compared to DRI. Fruit growth modified its pattern only on the OCI treatment day, with higher rates all day long, but no clear effects was found in the following day. Leaf, fruit temperature and microclimate within the treatments were only different on OCI during the irrigations and few hours later. Yield and quality data show no difference between the two irrigation managements. The OCI practice enhances water use with no effect on the apple production and quality resulting in more resources applied per ton of fruit, likely a result related to the hot and humid climate of the Ferrara province.

Keywords: tree physiology, precise fruit growing, orchard management, heat waves

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(ROSA Ref. n.17)

Apple fruit quality improved by means of shading

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This work wants to highlight the improvement of apple fruit final quality by means of shading. In season 2016 a standard black anti-hail net (20% shading), serving as control, and three photoselective nets (red, blue, white, 50% shading), were used to cover 6 trees each, in a Rosy Glow apple orchard. In season 2017, in the same orchard, but on different selected trees, the same standard black anti-hail net and three photoselective nets (red, blue, white, 20% shading), were used to cover 6 trees each. The total eight light environments were compared for final fruit quality traits. From June to October, both seasons, meteorologically speaking, did not differ, except for relative humidity (2016 was more humid than 2017). Significant differences arose for maturity, Brix°, total acidity, Brix°/total acidity ratio and HUE°. More shading led to higher Brix° and lower total acidity, whereas the colour of the nets influenced maturity and HUE°. The white nets anticipated harvest and lowered HUE°, whereas the blue nets tended to delay the first and increase the latter. Firmness, relative dry matter and starch content remained the same among the eight treatments. To further confirm these findings, more studies are needed, however these results suggest a strong potential for commercial purposes.

Keywords: orchard, protecting systems, light intensity, light quality, objective measurements.

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Response of juvenile plantain (Musa AAB) to irrigation

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Plantain provides food security and income for about 90million Nigerians. Hitherto grown as a rainfed crop in southern Nigeria, climate change has accentuated drought stress during the dry season, causing significant yield loss of plantain. Adoption of irrigation for mitigating the effects of drought stress has not been hitherto adopted by growers. Thus, between February and July 2016 a potted experiment was conducted in the screenhouse of the Department of Agronomy, University of Ibadan, Nigeria to determine the amount of irrigation water required to redress drought stress in plantain. Sprouted false horn plantain cv. Agbagba bits grown in 4.5kg of sandy loam received irrigation rates of 125, 250, 500 and 1000 mls water/plant/week. The irrigation rates were assigned following a completely randomised design with four replicates. Observations were made on vegetative growth and soil moisture status for 16 weeks. Gravimetric moisture content of the soil due to irrigation ranged 0.3-3%, 4.0 – 8.0%, 8-18% and 20-38%, respectively. The effects of irrigation on vegetative growth were insignificant during the first four weeks of application. Thereafter the growth parameters differed in their response to irrigation. The effects of 250, 500 and 1000 mls water/plant/week on plant height and canopy diameter did not differ significantly, but they all produced significantly ($P<0.05$) shorter plants and plants with smaller canopies than application of 125 mls water/plant/week. The effects of 500 and 1000 mls water/plant/week on number of leaves, leaf area and total dry matter accumulation did not differ significantly ($P>0.05$), but they produced plants with significantly larger values of these growth parameters than plants irrigated with 125 mls water/plant/week. Based on the response of leaf area and total dry matter accumulation, application of 500mls water/plant/week which maintains soil moisture content between 8 and 18% is recommended for juvenile plantain during dry spells in southwest Nigeria.

Keywords: food security, Nigeria, soil moisture stress alleviation

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The response of pear tree and fruit growth to the water stress applied during different growing stages of pear tree

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Water deficit irrigation can effectively inhibit the vegetative growth of pear trees, maintain or increase the pear fruit yield and fruit quality, save irrigation amount and improve irrigation water use efficiency. The study was conducted in experimental orchard in Beijing Academy of Forestry and Pomology Sciences to investigate the influences of water deficit applied in different stages on the growth of pear trees and the fruit yield. The experiment included five treatments: control, the full irrigation during the whole growing stages; T1, the moderate water deficit irrigation applied during the vegetative growth stage and full irrigation applied during the other stages; T2, the severe water deficit irrigation applied during the vegetative growth stage and full irrigation applied during the other stages; T3, the moderate water deficit irrigation applied during the fruit enlargement stage and full irrigation applied during the other stages; T4, the severe water deficit irrigation applied during the fruit enlargement stage and full irrigation applied during the other stages. The results indicated that the water deficit irrigation applied during the vegetative period significantly decreased the shoot growth, but had no obvious negative impacts on the fruit growth and final fruit yield. Because the shoot growth were more sensitive to water stress than the fruit. The fruit yield were significantly decreased by the water stress applied during the fruit enlargement stage, but no significant differences in vegetative growth were detected between the control and the water deficit irrigation applied during the fruit enlargement stage. Though the vegetative growth was sensitive to water stress, the shoot growth ceased after June and the water stress in fruit enlargement stage had no impacts on the shoot growth. However, the fruit rapidly grown during this stage, thus the water stress applied fruit enlargement stage damaged the fruit growth and decreased final fruit yield.

Keywords: pear tree, water deficit irrigation, full irrigation, vegetative growth, fruit growth

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(ROSA Ref. n.19)

Evaluation of subsurface drip irrigation emitters on a split-root container-grown citrus rootstock (citrange carrizo)

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Among irrigation systems, sub-surface drip irrigation allows obtaining values of water use efficiency higher than 90%. However, when emitters are installed below the soil surface, root intrusion can represent the main cause of emitter occlusion. To prevent this phenomenon, manufacturers normally use herbicides which could have deleterious effects on plant growth. Objectives of the paper were: i) evaluate the effectiveness of different anti-root agents settled in the same emitter model and ii) identify their possible effects on the growth of a commonly adopted citrus rootstock (citrange Carrizo). Five different anti-root agents were tested rows of 8 trees planted in split-root containers in which half volume was irrigated with standard emitters, while the other with the emitter containing the anti-root agent. A control treatment (C) was also tested. The following root growth inhibitors were examined: copper (Cu), cyanamide at two concentrations (CY1, CY2), and two different herbicides (R1, R2). After one year, new vegetation and root development were measured, as well as the change in the flow rate-pressure head relationship, q(h), and the possible presence of roots inside the emitter. Experiments evidenced similar tree growth among treatments and the absence of effects on root growth produced by the anti-root agents. It was observed that in the control and in four of the five anti-root agents, intrusion occurred even after one-year experiment. The roots presence interested 100%, 67%, 48%, 33%, 33% of the examined emitters with average length of 7.2, 6.55, 5.63, 5.8, 8.7 cm respectively for CY1, CY2, C, Cu and R1, whereas it did not interest treatment R2. Roots intrusion affected the q(h) relationships, causing the complete clogging of some of the emitters in C and CY1, with reductions of the average flow rates ranging between 2%(Cu) and 31% (CY1) and a substantial increase of the coefficient of variation.

Keywords: sub-surface drip irrigation; anti-root agents; Split-Root Container; clogging emitters; root intrusion; citrus rootstock

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(ROSA Ref. n.24)

Irrigation of intensive olive groves in the Mediterranean environment with different water regimes on two different soils - I: Effects on yields, water use efficiency, vegetative behaviour and water status of the crop

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Although a renewal of Italian olive growing is underway with the introduction of the VHD (very high density) cultivation system, well over one million hectares of olive groves in Italy are intensive (high density), of hundreds of different cultivars, with a long life ahead and represent the point of strength of Italian olive oil industry with their very incredible range of sensorial profiles. At the same time, the FAO Earth and Water Division, then the UN, calls for modern agriculture to produce more with less water. Two experimental trials have been carried on in intensive olive groves with quite different soils, one shallow and silty, based on tufaceous-calcareous rock, and the other was a deep and silty-loamy. Compared water regimes were a dry control and two irrigated with restitution, 50 and 100%, of the watering volume required to restore the full crop evapotranspiration (TWR), monitoring the water status of the wetted soil by means of tensiometers located at different depths. Only for the deep soil there were also an additional treatment resembling local farmers behaviour in irrigating olive (TF). Main results remark that: (i) shoot growth did not significatively differ among water regimes; (ii) leaf water potential decreased from the best water regime to the dry control; (iii); TWR showed a very significant increase of yields, particularly different in terms of drupes (much higher in the deep soil) but higher and much more similar in terms of oil beween the two soils, and interestingly TF had lower performance respect TWR; (iv) respect what reported by some Authors, we found always an increase of the oil content in TWR, although somewhat reduced on the deep soil; (v) with the irrigation management adopted we found seasonal irrigation volumes widely different between years but not so different between soils.

Keywords: Olea europaea L., irrigation volume, irrigation frequency, tensiometers, oil yield, shoot elongation

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Irrigation of intensive olive groves in the Mediterranean environment with different water regimes on two different soils - II: Effects on carpological parameters and technological and qualitative characteristics of the oils

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Reasons of primary importance in supporting the positive trend of worldwide per capita consumption of EVOO (extra virgin olive oil), begun more than thirty years ago, are quite certainly the numerous benefits on the human health recognized in the EU by three health claims awarded by the EFSA (European Food Safety Authority). In two experimental trials carried on in intensive olive groves with quite different soils, in addition to vegetational, agronomical and physiological parameters reported in another paper, some carpological parameters and qualitative characteristics of oils have been determined and discussed in the present paper. Compared water regimes were a dry control and two irrigated with restitution, 50 and 100%, of the watering volume required to restore the full crop evapotranspiration (TWR). Only for the deeper soil there were also an additional treatment resembling local farmers behaviour in irrigating olive (TF); low frequency and high volumes). Results remark that: (i) the flesh:pit ratio grew passing from the dry control to the restitution of 50% and 100% but the highest value was obtained with TF; (ii) TF, was able to modify the shape of drupes increasing their roundness, interestingly for the table olive industry; (iii) at harvest, irrigation determined a better oxidative condition, mainly due to a light reduction of acidity and a significative reduction of oil oxidation indexes; (iii) under increasing seasonal irrigation volumes, the percentages of oleic acid enhanced, while that of stearic, linoleic and linolenic acids decreased; (iv) it seems that water deficit conditions may increase the percentage of linolenic acid of olive oils over the maximum allowed under the EU regulations for EVOO although they have excellent quality; (v) opposite to what the main part of Authors reported, we observed an increase of the content of total phenols in the TWR respect to the dry control.

Keywords: Olea europaea L., pulp:pit ratio, fruit shape, phenolic content, fatty acid composition, linolenic acid

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(ROSA Ref. n.49)

Session 7 – Vineyard irrigation: grape and wine quality

Application of an innovative plant biostimulant to increase water use in crop production

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Water is one of the most important resources for agriculture and for most human activities. Agriculture consumes 70% of the entire available water globally, and crop production is limited by water scarcity more than any other environmental stress. In this context, innovative agricultural practices and technical solutions, such as the use of plant biostimulants (PBS), are needed to produce "more crop per drop".
The use of PBS to improve plant productivity under limiting environmental conditions is increasing in the contemporary agriculture. This work reports the effect of a new PBS formulation on water use in grapevine (*Vitis vinifera* L.) and tomato (*Solanum lycopersicum* L.) plants.
A group of 10 potted plants per species were kept under reduced irrigation (RI) for approx. 20 days. Half of these were treated (10 L/ha) with a PBS (RI-PBS) at 0, 7 and 14 days after the beginning of irrigation reduction. Leaf gas exchanges (LI-6400), biovolume and water use efficiency (WUE) were determined through imaging (Scanalyzer 3D system LemnaTec GmbH).
Leaf gas exchanges measurements showed that stomatal conductance (gs) of PBS treated grapevines and tomato plants was maintained in the range of 0.2 and 0.3 mol H2O m-2 s-1 respectively, while for the RI plants the gs values were approx. 50% (grapevine) and 30% (tomato) lower than that of RI-PBS. This suggests that the PBS allowed a high carbon gain at leaf scale.
The image analysis conducted at plant scale confirmed the ability of PBS to improve WUE approx. 40% (for both species) in plants under reduced irrigation.
In conclusion, this study demonstrates that the application of specific PBS formulations increased WUE, which might sustain improved crop water productivity. A biostimulant-based approach is therefore proposed to reduce unproductive water losses and maintain healthy, vigorously growing plants in cropping systems under sub-optimal water availability.

Keywords: plant phenotyping, gas exchanges, grapevines, tomato, biostimulant

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(ROSA Ref. n.182)

Differences among two grapevine cultivars in their response to pre and post veraison water deficit

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A field experiment, set up in a private vineyard located in Alghero (Sardinia) and planted in 2000, was carried out over two seasons on Vitis vinifera L. cvs Cannonau and Cabernet sauvignon in order to compare pre-veraison and post-veraison water restrictions on vine performance and fruit composition. For cultivars under observation, during the vegetative and productive season, were analyzed both the chemical characteristics of the musts and berry texture analysis, as well as yield and its components. A randomized block design was used to study the follow treatments: NI (non-irrigated), FI (full irrigated), LD (late deficit, irrigation supply until veraison) and ED early deficit, irrigation supply after veraison). Main results showed that Cabernet sauvignon is more sensitive to water stress. However, in both cuiltivars, the irrigation treatments affected yield and must quality. As aspected, sugar content and total anthocyanins were higher in stressed vines. Regarding LD and ED tratments, the water supplied before and post veraison promoted a better must composition on Cabernet sauvignon and Cannonau respectively. Skin thickness have shown a different evolution during the berry ripening among the cultivars.

Keywords: irrigation strategy, cannonau, plant water status, grape berry phenolics, varietal diversity

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(ROSA Ref. n.168)

Is it possible to increase the soil water retention after irrigation? A practical experience in a table grape vineyard

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The surfactants, also called 'wetting agents', are commercial products that increase water infiltration in the soil, and improve water distribution uniformity as well as its stay in the topsoil, helping to avoid water losses.
The aim of this work was to test the effectiveness of an agricultural surfactant in keeping the water around the root-zone in order to evaluate the possibility to save water during the irrigation season and improve its efficiency especially in sandy soils.
The trial was carried out in the years 2016 and 2017 in a vineyard (surface: 2 hectares) grown in a sandy loam soil and located in Palagiano (40°35'N 17°03'E, 39 m asl, Taranto province, Southern Italy), on Vitis vinifera cv 'Sugraone' B. grafted onto Vitis berlandieri x Vitis rupestris 140 Ru rootstock.
The technical experience carried out in two seasons, highlighted that the wetting agent was able to keep water in the first soil layers, where the root density is higher, generating in this way the following practical effects:
increasing the time between one irrigation loop and the next, which means saving water per season;
improving the soil water holding capacity in the sandy soil;
improving the fertigation efficiency by reducing mineral leaching.

Keywords: wetting agents surfactant, Vitis vinifera, lysimeter

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(ROSA Ref. n.136)

Yield and berry composition of Tempranillo grapevines exposed to deficit irrigation applied at different phenological stages

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The correct use of deficit irrigation (DI) in viticulture for wine production represent an effective tool to improve berry composition at harvest. However, these effects are strongly dependent on the phenological stage when DI is applied and on the level of water stress induced. If water stress is too severe, berry composition is negatively affected. Severe water stress conditions can easily occur in vineyards located in dry areas when irrigation is withhold. Hence, the aim of this experiment was to study how withdrawing irrigation at two different phenological stages affected fruit yield and berry composition in a dry region. The experiment was carried out in Raimat (Lleida, Catalonia, Spain) on Tempranillo grapevines. The experimental design was a complete randomized block design with three treatments and four blocks. Treatments were the following: a DI treatment in which vines received 0% of calculated evapotranspiration (ETc) between fruit set and veraison, whereas 100% of ETc was replaced with irrigation during the other phenological stages (hereafter PRE-DI treatment); a DI treatment in which vines received 0% of ETc between veraison and harvest, whereas 100% of ETc was replaced with irrigation during the other phenological stages (hereafter POST-DI treatment); a control treatment in which vines received 100% of ETc throughout the growing season (hereafter C treatment). Between fruit set and harvest, PRE-DI and POST-DI treatments allowed to save 41 and 45% of water applied with irrigation. Both DI treatments induced moderate water stress conditions (midday Ystem decreased down to values between -1.5 and -1.3 MPa) in the phenological stages when irrigation was withhold. Harvest date was anticipated by PRE-DI treatment compared to POST-DI and C vines. PRE-DI induced a decrease in berry growth and fruit yield at harvest. POST-DI did not affect berry anthocyanin concentration at harvest.

Keywords: quality, stem water potential, pre-veraison DI, post-veraison DI

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(ROSA Ref. n.129)

Effects of soil water availability and leaf area on transpiration rates of grapevines

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Physiological indexes related to plant gas exchanges can be used to monitor water status of vines at different level of water stress. The aim of this study was to assess how plant transpiration changes under variable soil water availability and to relate these changes with the stomatal functioning of grapevines. Vine water transpiration was measured by mean of compression load cells, able to continuously detect small (few grams) weight changes of 9 vines grown in pots. Vines were characterized for their total leaf area (ranging from 1 to 3 m2 vine-1) and exposed to cycles of water stress (no water supply for 6 days), followed by water application. Soil evaporation from the pots was prevented. Assessment of water loss by transpiration during stress cycles were combined with measurements of key environmental variables, leaf water potential and leaf gas exchanges. Independently from the canopy size, non-stressed vine followed a transpiration pattern similar to that of vapor pressure deficit (VPD), showing a maximal transpiration rate, normalized for the vine leaf area, of 0.170 kg m-2 h-1, occurring just after daily maximal VPD was reached. Stressed vines had lower maximal transpiration rate (0.135 kg m-2 h-1), which was partially uncoupled from the VPD daily pattern. Stomatal conductance (gs) measured at noon was reduced by 50% (~250 mmol m-2s-1) when stem water potential (Ψstem) was -0.8 MPa and reached values close to zero when Ψstem was around -1.4 MPa. No correlation was found between gs and predawn leaf water potential (Ψpd) when the latter was above -0.2 MPa (no-stress condition). Below that threshold, gs progressively reduced at decreasing levels of Ψpd, reaching values below 50 mmol m-2s-1. Overall, Ψstem correlated better than Ψpd to gs, pointing out the use of the former as proxy for assessing vine water stress level according to vine physiology.

Keywords: Water stress, leaf transpiration, stomatal conductance, stem water potential, leaf area

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Irrigation scheduling using continuously monitored data of soil volumetric water content

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Multiple depth capacitance sensors, capable for continuously measurements of soil water content at different depths, were used for on-farm cotton and grapevine irrigation scheduling. Soil water content data were combined with concomitant measurements of microclimatic parameters as well as plant's hydrodynamic (leaf water potential) and physiological parameters (gas exchange) during four successive drying cycles which were consistent of a well watered control and un-watered treatments in which no irrigation was applied. Indices derived from continuous soil water content measurements were correlated to plant's physiological and hydrodynamic parameters in order to identify threshold values capable the assessment of the onset of water stress in plants. Protocols, based on these indices, were developed and assessed for their ability to ensure the maintenance of plant physiological performance. Results indicated that these protocols could be effective for irrigation management optimization assuming the same species and similar cultivars are grown in given soil types.

Keywords: cotton, irrigation, grapevines, soil water content

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(ROSA Ref. n.66)

Effect of forcing vine regrowth to delay the crop cycle on canopy productivity and crop water needs of a wine vineyard in southwestern Spain

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In the Mediterranean vineyards, the delay of the crop cycle can provide more favorable conditions for the ripening of the fruit. Forcing vine regrowth through the pruning is an aggressive but effective technique to achieve this but, its consequences must be carefully evaluated taking into account the current and subsequent years. A field experiment was established during two years (2016 and 2017) in a vineyard of "Tempranillo" in Extremadura (southwestern Spain). The technique was conducted by hedging growing shoots to seven nodes and removing leaves, summer laterals and cluster just after anthesis (F1) and about 20 days later (F2). The vines grown under conventional practices were the Control. Crop forcing delayed harvest 23 and 58 days in 2016, and 41 and 61 days en 2017 for F1 and F2 respectively. Therefore, it caused displacement and shortening in the crop cycle about the control as well as modifications in the architecture of the plant and the location of the clusters. These changes affected the canopy productivity about the intercepted radiation, leaf photosynthesis, biomass production along the crop cycle, the yield and its components. Although crop forcing decreased grape production in both treatments, total aerial biomass decreased in F1 but increased in F2 about the Control. Total crop water needs remained similar in Control and F1, although with a shift in the period of highest consumption. However, F2 had lower evapotranspiration as consumption lower in the period of higher evaporative demand.Throughout these two years, this technique has proved useful in modifying grape production conditions, both in relation to weather conditions and in the architecture of the plant canopy and the distribution and characteristics of the bunches.

Keywords: biomass production, photosynthesis, yield, grape characteristics

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(ROSA Ref. n.29)

Vermentino and Cagnulari adaptation responses to the regulated deficit irrigation strategy managed with stem water potential watering thresholds

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Recent years of drought in Sardinia have led to productive problems, not only in rainfed vineyards but also in those irrigated with the most diffuse on farm supplemental irrigation strategy. An optimized production could be obtained with the adoption of regulated deficit irrigation strategy (RDI). RDI can be managed by applying watering thresholds based on the measurement of stem water potential (SWP), even if not all the varieties are suitable for SWP evaluation. Moreover, quality of grapes production could be oriented, depending on the water stress levels induced on plants according to the oenological objectives. Two experiments were carried out in order to evaluate the adaptation of Vermentino and Cagnulari varieties to RDI managed with SWP watering thresholds. These three years experiments were set up with a randomized blocks design where each plot was replicated three times, considering two RDI treatments, differentiated by the induced water stress level (moderate stress and severe stress) as controlled variability factor. The second goal was to evaluate if the different water stress levels imposed by treatments could affect grape quality production in such a way that grapes can be potentially addressed to different oenological objectives. Both varieties resulted suitable for the RDI irrigation management based on SWP watering thresholds. The two different stress conditions induced by RDI treatments were recorded on physiological and productive parameters measured. In particular, each RDI treatment produced grapes suitable to obtain different style of wine in both varieties. Especially in drought years, from both varieties it is possible to improve the on farm irrigation management by applying RDI strategy managed with the SWP irrigation thresholds to obtain an optimal production compatible with programmed oenological objectives.

Keywords: vineyards, stem water potential, irrigation strategy, water stress

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(ROSA Ref. n.10)

Quantifying table grape vineyard water use and water use efficiency through transpiration and evapotranspiration using sap flow measurements and FruitLook remote sensing data

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In South Africa all commercial table grape production is under irrigation. The aim of this project was to establish a range of water use efficiency (WUE) values for table grape production in SA. The study, conducted on Crimson Seedless over three seasons, included a WUE field trial on four blocks in the Hex River Valley, as well as a WUE survey, including 18 commercial blocks, representing all five SA table grape production regions. WUE were calculated based on water used for irrigation, evapotranspiration (ET) and transpiration (T). For the field trial blocks, FruitLook Actual evapotranspiration (ETFL) www.fruitlook.co.za) values, as well as ET values calculated as the product of the reference crop evapotranspiration (ETo) and published crop coefficients, were obtained. Sap flow (transpiration) measurements were performed in two of the field trial blocks. Phenological stages, yield and grape quality were also recorded. Total water used for irrigation (per ha per season) varied from 4 598 m3 to 18 634 m3. WUE and blue WF based on irrigation volume, varied from 0.44 to 4.96 kg/m3 and 202 m3/kg to 2267 m3/kg respectively. WUE based on ET values of blocks included in the field trial, varied from 1.72 kg/m3 to 3.03 kg/m3. For both field trial blocks where transpiration was calculated, the WUE based on transpiration was similar (4.8 kg/m3). The seasonal volume of water used for transpiration can be considered as an indication of the minimum water requirement for a table grape vineyard and ranged from 5 036 to 8 960 m3 under the conditions of the trial, while the calculated ET values of the corresponding trial blocks were 8 960 and 10 080 m3 respectively. Comparing irrigation applied with water used through ET and T, results indicated that water applied exceeded the water consumed during all phenological stages. It is recommended that stem water potential measurements should be used to establish "refill lines" for the degree of plant available water depletion allowed before irrigation is applied

Keywords: Table grapes, water use efficiency, blue water footprint, evapotranspiration, transpiration, sap flow, irrigation, Crimson Seedless.

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(ROSA Ref. n.202)

The effect of overhead netting on water utilisation and soil water content of a table grape vineyard

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The use of hail netting as a requirement for the successful cultivation of table grapes is an accepted practice in the northern summer rainfall region of South Africa. Recently there has been a growing interest in cultivation of table grapes under netting in the Western Cape and the Lower Orange River area. The purpose of the trial was to obtain parameters, which can be used for irrigation scheduling of table grape vineyards under netting and thus the effect of overhead netting on water utilisation and soil moisture contend was investigated. A six-year-old vineyard at the ARC's experimental farm at Roodeplaat (25°35'South; 28°21'East, 1164 m above sea level) was used. Vines of four Vitis vinifera L. scion cultivars grafted onto Jacquez clone 5/8/4 were planted (3,0 x 1,8 m spacing) on a Hutton soil and trained onto a Trentina trellis with black hail netting (20% shade effect, with a diamond mesh size of 8 x 8 mm of high-density polyethylene filament and lint). Irrigation was applied by micro jets and scheduled according to crop factor adjusted evaporation rates using a Class A evaporation pan. Standard viticultural practices were applied during the growing season. The trial was laid out as a combined split plot randomised block design. Every cultivar block was laid out as a randomised block design. Hail net treatments were allocated completely randomized within each cultivar block, with four replications. Netting (20%) decreased transpiration rate (-4.0%) and evaporation (-15.5%) significantly. Leaf temperature decreased significantly under hail netting, whereas ambient temperature was only slightly lowered. Gravimetric water content of the soil decreased under netting. The increased leaf water potential and leaf water content, as well as the lower transpiration rate, evaporation and soil water content under netting, indicate that irrigation requirements under netting are reduced compared to conditions of direct sunlight.

Keywords: table grapes, overhead netting, water use, soil water content, transpiration, evaporation.

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(ROSA Ref. n.203)

Session 8 - Irrigation of annual crops and ornamental plants – open field and greenhouses

Driptape clogging and poor irrigation performance: the patented dripline providing a solution allowing durable supply uniformity even in the case of low filtration

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The world's demand for clean water for human consumption is increasing exponentially, relegating lower quality water for agricultural applications. The widespread use of drip irrigation systems has increased annually in an attempt to reduce water use and improve yield. This does not come without the challenges faced using dirty water. Traditional drip tape does not have a high resistance to dirty water and it is easily clogged, resulting in poor irrigation performance. Also filters are often not used due to the added expense, or are simply not available to the farmer. EXXtreme tape™ is the Irritec-patented unstoppable light dripline with continuous flowpath and with the most extended filtration surface in the world. It is an evolution of the world renowned Irritec tape especially designed for "difficult waters", as it allows irrigation with less purified or less filtered water. EXXtreme tape™ has two continuous filtering barriers along each side of the flowpath, allowing the filtered water to flow through the two continuous lateral supply channels. These interconnected channels, common to all emitters, distribute filtered flow with constant uniformity, regardless of the position of the emitter. Since the filter of eXXtreme tape™ is 20 to 50 times longer than traditional drip tape, the risk of clogging is proportionally reduced and the product works uniformly, until the complete occlusion of the filters. Therefore, perfect emission uniformity is achieved until the end of the season. During laboratory testing carried out by the Center for Irrigation Technology, Fresno, CA, 70 mesh sand media was applied to eXXtreme tape™ and it did not experience any occlusion. Therefore, we can say that 120 mesh filtration may be sufficient for eXXtreme tape, rather than 150 mesh filtration applied to traditional tape. Also, the product potentials have been confirmed during customer tests carried out in Italy and in Peru. Considering it has durability and resistance to plugging, in many cases eXXtreme tape™ may be reused for more than one season. Last but not least, the longer life eXXtreme tape™ compared to the traditional product allows a 28% reduction in the amount of plastic laid on the field and a reduction of approximately 0.34 kg of CO2 emissions per hectare of cultivated land due to the plastic reduction.

Keywords: drip irrigation, driptape clogging, durable supply uniformity; Corresponding author: research@irritec.com

Patent owner: Irritec S.p.A.

(ROSA Ref. n.186)

Two seasons of deficit irrigation of processing tomato in Hungary

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Successful processing tomato production is possible only under irrigated conditions on its production area. Water savings can be achieved if we apply smart irrigation strategies such as deficit irrigation. We cannot reach the potential maximum yields this way, but soluble solids content will rise and provide better fruit quality. The goal is to reach adequate soluble solid (SS) yields and save irrigation water. Open field experiments on clay-loam soil were conducted with UG812J F1 in 2017 and 2018 under different water supply levels. Irrigation water amounts were calculated by AquaCrop. 50% (I50) and 100% (I100) of potential evapotranspiration (PET) were compared to unirrigated control (C) in both years and 75% of PET (I75) was added to the experiment in 2018. We measured the biomass, fruit yield, SS content, SS yield and water use efficiency (WUE) of tomato. The highest biomass (126,37 t ha-1) and marketable fruit yield (103,74 t ha-1) were reached in 2017 in the I100 treatment and the control reached the highest SS content (6,14 °Brix) in 2018. Significant differences were found between treatments in marketable fruit yield, SS content and SS yield in 2017 but not in WUE. Differences were not significant in several cases in 2018. Water supply affected the biomass, marketable fruit yield, SS content and SS yield significantly according to the results of the two years. The highest coefficient of determination was found between the SS yield and water supply (R2=0,93). The weakest relationship was between SS content and water supply (R2=0,73) caused by the low SS content in the I100 in 2018. There was no significant difference between the SS yield of the I75 and I100 treatments in 2018. Thus, the same level of SS yield was reached while 25% of irrigation water was saved.

Keywords: soluble solids, water saving

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(ROSA Ref. n.155)

Agronomical, physiological and water use efficiency changes of lettuce in response to deficit irrigation regimes

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Deficit irrigation occurrence while maintaining acceptable yield represents a useful traits for lettuce production wherever irrigation water is limited. Lettuce (Lactuca sativa L.) cv. Corsica was grown in the field from May to July in order (1) to investigate the daily and seasonal evapotranspiration (ETc) of lettuce using drainage lysimeter, (2) to determine the crop coefficients (Kc) values and (3) to study the effects of deficit irrigation on growth, yield and water use efficiency (WUE). Treatments were: well-watered treatment receiving 100% of ETc (C), water-stressed treatment receiving 80% of ETc (WS1), water-stressed treatment receiving 60% of ETc (WS2), water-stressed treatment receiving 40% of ETc (WS3). Lysimeter measured crop evapotranspiration (ETc) totaled 422 mm, for total irrigation period of 81 days. Seasonal evapotranspiration (ET) of lettuce treatments, varied from 351 mm in the WS1 treatment to 305 mm in the WS2 treatment and 259 mm in the WS3 treatment, while in the control ET totaled 397 mm. Increasing irrigation deficit reduced the vegetative growth parameters (plant height, leaf number and leaf area index) with deficits WS2 and WS3 significantly worse than the control treatment. The highest yield was recorded in C and WS1, with no significant differences between treatments followed by WS2, while the lowest value was recorded under the severe water stress treatment. A yield response factor (ky) value of 1.17 was determined, and lettuce was found to be sensitive to water stress. The highest values of water use efficiency (WUE), was recorded on WS1 (18.8 kg m-3), followed by the C (17.8), WS2 (16.3) and finally WS3 (15.5) treatment. Applying 80% of ETc resulted in water saving, with the least yield reduction, making more water available to irrigate other crops, and thereby considered optimal strategies for drip-irrigated lettuce in the semi-arid climate.

Keywords: crop coefficient, deficit irrigation, evapotranspiration, Lactuca sativa L., water use efficiency

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(ROSA Ref. n.151)

Evaluating the responses of Ghanaian rice varieties to alternate wetting and drying and continuous flooding

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Rice is a major staple food worldwide and constitutes a major economic activity for smallholder communities. In Ghana, increasing rice production to meet domestic demand is an important step to achieving food self-sufficiency, but this must occur with more efficient water use. This research investigates the opportunities to develop and optimise water-efficient irrigation techniques for African rice varieties

The experiment used a split-plot design with three replications per treatment. The main plot was irrigation type (alternate wetting and drying [AWD] and continuous flooding [CF]) and the sub-plots were nutrient (High nitrogen [HN] and Low nitrogen [LN]) and genotype (improved variety cv. CRI-AgraRice and local variety cv. Viwornor). The AWD treatment was applied throughout the entire cropping cycle and irrigation was carried out when water level has dropped to about 15 cm below the surface of the soil. The improved variety was developed by CSIR-Crops Research Institute. Although alternate wetting and drying (AWD) decreased yield of the local variety compared to continuous flooding (CF), yield of the improved variety was independent of irrigation treatment. Thus combining an improved genotype with a water-saving irrigation technique maintained grain yield while supplying circa 30% less water. Whether this technology package is attractive to smallholder rice-farming communities will be evaluated.

Keywords: AWD, water-saving irrigation, genotypic selection, Africa

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(ROSA Ref. n.133)

Controlled deficit irrigation ' effects on growth and water relations of (*Daucus carota* L.) tubers

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Regulated deficit irrigation (RDI) comprises controlled reduction of irrigation during certain phases of plant development, accepting minor yield reduction but maximising net returns. To optimise RDI, plant response-based irrigation scheduling may be essential. For this the knowledge of plant reactions to soil water regimes is indispensable. In field trials (randomised block design, 3 repetitions), 'Nanthya' carrots (F1-hybrid) were grown at 20 %, 40 %, 60 % and 80 % field capacity (determined by TDR sensors), yielding soil water contents of 5.1 ± 0.2 %, 6.2 ± 0.8 %, 10.1 ± 0.5 % and 11.2 ± 0.2 % (controls). To guarantee constant controlled soil water contents, plastic rain shelter (76 % transparency) were applied. Plots were irrigated if necessary. Treatments started 23 d after sowing (DAS), first sampling was 91 DAS, while final harvest was 106 DAS. On each date, fresh and dry mass, water content, water potential, osmotic potential, turgor and stiffness of carrot tubers were analysed. Tuber fresh mass (n = 20 carrot per treatment) was higher at high water availability only at the 1st sampling, but not at the final harvest. Here, water regime did not affect yield. At this time, tuber water potential was lower than at the 1st sampling and Y was also lower at low soil water availability (20 %, 40 %). Similar results were obtained for the mean osmotic potential. These variations partially resulted from osmotic adjustment (at 1st harvest) and from a lower tuber water content at the final sampling. The generally higher modulus of elasticity at this date indicated water volume-independent cell wall-stiffening, i.e. elastic adjustment. The presented results point out that moderately reduced (by 20 %) irrigation of carrot does not affect its yield, while pronounced water shortage may induce physiological adjustment.

Keywords: elastic adjustment, modulus of elasticity, osmotic adjustment, osmotic potential, stiffness, turgor, water potential, yield

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(ROSA Ref. n.124)

Small´ potato production: cultivar and agronomic practice influence on yield and tuber size distribution

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Growing demand for 'Small' potato for the fresh market has resulted in increased production of 'Small' potato in North America. Commercial-scale 'Small' potato production requires suitable cultivars and appropriate agronomic practices. A 2017 study conducted at Canada-Saskatchewan Irrigation Diversification Centre examined, four potato cultivars (AC Peregrine Red, AAC Hamer, Milva, Operle), two seed-piece spacings (15, 20 cm) and three top-kill timings (10, 11, 12 weeks from planting) under dryland and irrigated (60% Field Capacity) production. The dryland crop received 110 mm rain and the irrigated crop received an additional 193 mm of irrigation through overhead sprinklers. Harvested tubers were graded into 'Small' (20-25, 25-30, 30-35, 35-40 mm) and 'Table' (>40 mm diameter) size categories. The dryland and irrigated crops averaged similar 'Small' (± 6-7 t ha-1) and 'Table' (18 t ha-1) grade yields. Operle produced the highest 'Small' grade yield (dryland-10 t ha-1; irrigated-11 t ha-1) and lowest 'Table' grade yield (dryland-14 t ha-1; irrigated-15 t ha-1). AC Peregrine Red produced the lowest 'Small' grade yield (dryland-3 t ha-1; irrigated-4 t ha-1) and highest 'Table' grade yield (dryland-20 t ha-1; irrigated-22 t ha-1). Yield rankings of various cultivars were similar for the different tuber size grades under both dryland and irrigation. Under irrigation, 15-cm seed-spacing generally produced higher yields of the different size categories than 20-cm spacing. However under dryland, seed-spacing had no effect on yields of all tuber size categories. Ten-week top-kill produced 7 t ha-1 'Small' and 12 t ha-1 'Table' grade yields under dryland, and 8 t ha-1 'Small' and 14 t ha-1 'Table' grade yields under irrigation. Delayed top-kill (12 weeks) resulted in an 11% loss of 'Small' grade yield under dryland and a 20% loss under irrigation. However delayed top-kill produced 100% higher 'Table' grade yield under dryland and 64% higher under irrigation.

Keywords: potato, solanum tuberosum, creamer, baby potato, spacing, irrigation

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(ROSA Ref. n.102)

Influence of irrigation schedules on Radicchio production in north-eastern Italy

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An experiment was set up in Mirano (45°30'45"N, 12°5'58"E, north-eastern Italy) to test the effect of two irrigation schedules on Radicchio "Rosso di Treviso" (Cichorium intybus L., rubifolium group) production. The trials were conducted during the 2013-2017 production seasons. An irrigation system with low-volume mini sprinklers was used. Two different treatments were tested: * a low-frequency irrigation schedule (about 14 mm of water every 4 days); * a high-frequency irrigation schedule (about 7 mm of water every 2 days). Water volumes were selected to avoid water logging, runoff and deep percolation, maintaining at the same time an adequate moisture level in the root zone. Irrigation was suspended during rainy periods. Total water volumes were the same in both treatments with an average of 134 mm of water used each year throughout the cropping season.
Radicchio was transplanted at the beginning of August (with a plant density of 6.41 plants m-2, row spacing of 0.6 m and in-row spacing of 0.26 m) and harvested in October-November. Sample areas were set up to measure the weight of marketable heads of each treatment (underweight, rotten and flowering heads were considered non-marketable).
Results of 5-year field trial (from 2013 to 2017, except for 2014 due to extremely rainy weather) showed no significant differences on Radicchio marketable yield with 26478 ± 828 kg ha-1 (average ± standard error) in the high-frequency irrigation treatment, and 24609 ± 1008 kg ha-1 in the low-frequency treatment. Marketable yield was significantly different among the years, with 2015 being the most productive year (28829 ± 826 kg ha-1) and 2016 the least productive (20396 ±714 kg ha-1).
Considering the experiment was performed on multiple years (under different weather conditions), we suggest adopting the irrigation schedule with the frequency that best suits the farm management needs, as no clear yield differences were reported in our field trial.

Keywords: chicory, crop production, irrigation efficiency, sprinkler irrigation

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(ROSA Ref. n.22)

Response of melon (*Cucumis melo* L) var. Honey dew to four levels of irrigation at Cachapoal Valley, Region de O'Higgins, Chile

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Irrigation treatments consisting on four levels of water were applied to melon var. Honey Dew cropped at Rengo, Región de O'Higgins, Chile. Four drip irrigation treatments were set in a randomize block design with four repetitions, using compensated drippers mounted on a PE plastic 16mm irrigation pipe (20 cm spaced) discharging an equivalent to 1.2 L/h (T1), 2.0 L/h (T2), 3.0 L/h (T3) and 4.0 L/h (T4), applying the same time and irrigation frequency to the treatments.
The crop was established in beds 100 cm wide, reaching a plant density equivalent to 8.930 pl/ha and 10.416 pl/ha, for the seasons 2016/2017 and 2017/2018, respectively, recording soil water humidity and meteorological data. Both repetitions run between November and February, during summer season of the Southern Hemisphere. Fruits were harvested at commercial maturity, while equatorial fruit diameter and fruit weight were measured, recording the prevalence sunburn in the harvested organ. Pulp pressure and total soluble solids were also recorded in the fruits.
Fruit diameter was affected by irrigation treatment for both repetitions. The smallest equatorial fruit diameter was reached by plants irrigated at the lowest water level (T1). Treatments T3 and T4 showed similar fruit diameter. For both seasons, plants watered by T1 and T2 yielded fruit with lower average weight showing also higher incidence of fruit sunburn compared to T3 and T4. Finally, fruits of plants receiving T4 irrigation treatment were not statistically affected in yield nor fruit weight.

Keywords: melon, water yield response

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(ROSA Ref. n.67)

Biofilm management in irrigation lines and hydroponic lettuce solutions using sanitizing chemicals

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The objective was to evaluate the effect of four sanitizers, including hydrogen peroxide plus peroxyacetic acid (H2O2), quaternary ammonium chloride (QAC), sodium hypochlorite (Chlorine), and d-limonene (Limonene) products on (A) biofilm control within mist irrigation lines, and (B) biofilm and plant growth in hydroponic lettuce cultivation. Two greenhouse experiments were run for objective (A) where sanitizers were dosed into a nutrient solution and delivered with each irrigation through a mist propagation system. In the first experiment, with either clear water, a nutrient control (100 mg L-1 N) or nutrient solution plus either H2O2 (54 mg L-1), QAC (5 mg L-1), Chlorine (2 mg L-1) or Limonene (350 mg L-1), with 16 replicated irrigation lines per treatment. Biofilm mass per unit of internal pipe area was 0.1 mg cm-2 for tap water, increasing to 1.82 mg cm-2 with the nutrient control. Limonene (0.43 mg cm-2) resulted in less biofilm than any treatment containing nutrient solution other than QAC (1.0 mg cm-2). Biofilm growth was greater in the second irrigation line experiment than in experiment 1, with 10.2 mg cm-2 of biofilm in the nutrient control. Biofilm reduction compared with the nutrient solution was observed in QAC (8%) and H2O2 (9%), but Limonene (at a reduced concentration of 32 mg L-1) and Chlorine did not reduce biofilm. In the lettuce hydroponics experiment, the four sanitizing treatments did not lower biofilm mass in hydroponics compared with the nutrient control. Plant dry mass was reduced at the H2O2 high dose of 149 mg.L-1 (8.2 g)compared with nutrient solution (14.3 g) and plant evapotranspiration was reduced at both levels of H2O2 (30 or 149 mg.L-1). Overall, a low continuous dose of a residual sanitizer is unlikely to provide adequate biofilm control under conditions that strongly favor biofilm growth, and dosage is limited by phytotoxicity.

Keywords: fertigation, clogging, limonene, chlorine, quaternary ammonium chloride, hydrogen peroxide

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Influence of irrigation on effectiveness of nematicides for management of Columbia root knot nematode on potatoes

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In the Pacific Northwest of the United States of America, the Columbia root knot nematode, Meloidogyne chitwoodi, causes significant yield reduction and significant numbers of blemished and unmarketable potato tubers. An entire field can be declared unmarketable when as few as five percent of the tubers are found to be blemished. The influence of irrigation on nematicide effectiveness and distribution in the soil profile was demonstrated in two field trials conducted in a silty clay loam soil with 12 percent organic matter. Plots were 0.9 m wide by 18 m long arranged in a randomized complete block design with four replicates per treatment. Nematicide applications were injected into drip irrigation tubing with a piston pump. Treatment effectiveness was monitored via tuber yield and blemish and soil nematode populations. At harvest, tubers were divided into blemished and unblemished groups. Within these groupings, they were graded into the following categories: greater than 227 g, 113 to 227 g, less than 113 g, and culls (tubers unsuitable for market due to growth deformities not caused by nematodes). Tuber yield, grade, and the percent of each grade with nematode blemish were determined. Nematode population levels were determined from soil samples taken pretreatment and at harvest. Each sample was composed of ten 2.5 cm diameter cores to a depth of 30 cm. Nematodes were extracted from soil using a modified semiautomatic elutriator and sugar flotation technique. Drip irrigation applications of metham sodium, 1,3-dichloropropene, oxamyl, and sodium tetrathiocarbonate applied in different volumes of water showed greater effectiveness with increasing volume of water.

Keywords: irrigation, nematode, nematicide, potato, root knot nematode

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Simple and spatial approach to optimise water irrigation and cereal yield in the semi-arid areas

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The objective of this study is to develop a simple and spatial approach, based on remote sensing data, to optimize water irrigation and cereal production (dry matter DM and grain yield GY) in the semi-arid areas. The proposed method is based on the three efficiencies model of Monteith (1972). It consists of converting of solar radiation to the DM by the climate (ec), interception (ei) and conversion (econv) efficiencies. The proposed method combines the maximum of both ei and econv (noted eimax and econvmax) into a single parameter denoted emax, calculated as a function of cumulated growing degree day (CGDD). Also, the stress coefficient Ks, which affects the conversion of the absorbed solar radiation to the biomass, was derived from the surface temperature or the FAO-56 water balance at the root zone. In addition, the expression of Ks has been improved to optimize water irrigation amount and cereal production. It has been shown that the value 0.7 of Ks is considered as a suitable threshold for triggering irrigation in semi-arid areas. Otherwise, the developed method proposes a variable Harvest Index coefficient (HI) for partitioning the dry matter developed, between straw and grain. Since the ear apparition, the evolution of HI is derived from CGDD whereas, the final harvest Index (HI0) is estimated from the maximal value of Normalized Difference Vegetation Index (NDVI).).
The developed model has been calibrated and validated on both semi-arid regions (Haouz in Morocco and Kairouan in Tunisia). The obtained results showed a good agreement between observed and estimated DM and GY values. Average values of R2 and RMSE are about 0.98 and 0.35 t/ha for DM and 0.98 and 0.19 t/ha for GY, respectively.

Keywords: cereal, yield, dry matter, grain, remote sensing, stress coefficient, semi-arid areas

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Irrigating based on container capacity conserves water with minimal effect on crop quality

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Ornamental crop production depends on maintaining adequate moisture levels for plants, which can be particularly challenging when grown in containers. Irrigation is oftentimes applied daily via overhead impact sprinklers; however much of the applied water lands on non-crop areas. Furthermore, indiscriminately applying irrigation on a daily basis may unnecessarily consume limited water resources, lead to excessive nutrient leaching from containers, and generate substantial quantities of surface runoff. In an effort to apply water more judiciously, alternative methods of irrigating - such as micro-irrigation - can apply water directly to crops with enhanced precision, while using moisture sensors quantifies the conditions within the container substrate, allowing improved decision making on the irrigation volume required. At the Michigan State University Experimental Nursery, four ornamental taxa (Cornus sericea 'Farrow', Hydrangea paniculata ‘Limelight’, Rosa x'Meipeporia', and Spiraea japonica 'SMNSJMFP')were grown in #3 containers with either a 85:15 (V:V) pinebark:peat moss substrate or a 80:20 pinebark:coir substrate and subjected to one of three irrigation treatments. A control of 19 mm per day applied via overhead sprinklers was compared with two water conserving irrigation treatments: overhead irrigation and micro-irrigation spray stakes, both utilizing substrate moisture sensors to apply water daily to return containers back to capacity. Irrigation volume applied was recorded throughout the growing season, in addition to crop growth index, container substrate pH and electrical conductivity, with root and shoot dry weight measured at the termination of the study. At seasons end, irrigating based on DWU and spray stakes yielded water savings of 50% and 75%, respectively, with no or minimal reductions in growth due to treatments. The use of sensors and micro-irrigation technologies in nursery production is capable of producing plants of equivalent quality while conserving substantial amounts of water.

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Effect of peatmoss amended pine bark on water dynamics within a nursery container and weed growth on the substrate surface

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Container nursery substrates are composed primarily of softwood tree bark, with pine (Pinus taeda) bark being the predominant type used in the central and eastern United States. Sphagnum peatmoss is one of the most commonly used amendments, and is often incorporated at rates from 10% to 40% of the substrate volume. Sphagnum peatmoss can hold up to 20 times its weight in water, and thus is often used to increase the water holding capacity of pine bark substrates. Little is known about how sphagnum peatmoss, and other substrate components, affect weed establishment or herbicide efficacy in nursery containers. The objective of this research was to determine how pine bark substrate amended with sphagnum peatmoss affects creeping woodsorrel (Oxalis corniculata) germination in containers. Black nursery containers (12 L vol.) were filled with either 100% pine bark, 80 pine bark : 20 peatmoss, or 60 pine bark : 40 peatmoss (v:v). All substrates were amended with a commercial formulation of controlled release fertilizer. After potting, half of the containers were treated with 2.24 kg/ha ai pendimethalin and the other half were left untreated. Containers were seeded with 40 creeping woodsorrel seed the day following herbicide application. Air space decreased and water holding capacity increased with increasing peatmoss level when considering the bulk container. However, moisture characteristic curves showed that moisture level on the substrate surface was similar regardless of substrate type. Substrate type had an inconsistent and relatively minor effect on creeping woodsorrel numbers. Among containers treated with pendimethalin, weed counts were similar in all substrate types.

Keywords: moisture characteristic curve, herbicide, weed control

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Effects of a simulated heat wave on growth and eco-physiology of seedlingsin *Quercus ilex* L. and *Arbutus unedo* L.

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Drought-induced mortality of seedlings and young plants is critical for the assessment of forest vulnerability in Mediterranean environments where increasing frequency of extreme events, such as heat waves, are expected. Many Mediterranean shrub and tree species show very plastic responses to fluctuating climate parameters in adult plants due to physiological adjustments, as well as to the occurrence of structural hydraulic traits (throughout the whole root-stem-leaf system), which allow adaptation and survival under limiting conditions. However, compared to adult plants, seedlings and young plants are more vulnerable to environmental constraints. Species-specific sensitivity to stressors during the early stages of seedling establishment are expected to affect vegetation dynamics and forest productivity. Within this framework, there is increasing interest in understanding if, how and to what extent, saplings are able to tolerate prolonged water deficit combined with high temperature regimes. The aim of this study was to evaluate the effect of a simulated heat wave (prolonged water stress combined with high temperatures) on growth and eco-physiological behaviour of one-year-old plants of Quercus ilex and Arbutus unedo. The experiment was conducted under a plastic tunnel where rooted cuttings were transplanted in April and subjected to two irrigation treatments (100% and 50 % water reintegration). After 115 days, irrigation was suspended for three weeks (maximum registered temperature), and later restored. Mortality, plant growth (including plant height, morphological parameters, biomass) and eco-physiological traits (e.g. leaf gas exchange, plant water potentials and photochemistry) were analysed. Although in both species, pre-acclimation to water shortage allowed better surviving capability, they showed different adaptation mechanisms. Understanding the behaviour of young tree and shrub species under severe fluctuations in climate parameters furnishes useful information for the management of not only natural ecosystems but also urban green areas.

Keywords: plant growth, drought stress, plant water potential, leaf gas exchange

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Examining the potential to reduce nursery crop fertilizer rates with a leaching fraction-based irrigation schedule

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An automated irrigation system based on leaching fraction was used to produce #1 container size (3.7 liter) oakleaf hydrangea (Hydrangea quercifolia 'Snow Queen') in 2016 and 2017 using two fertilizer rates in order to determine if nutrient inputs could be reduced. Crops were produced using either the grower's conventional irrigation system that applied 1.3 inches (3.3 cm) of water in a single irrigation event every other day or a newly developed system that irrigated daily to maintain a 15% leaching fraction. The grower's standard fertilizer rate or a reduced rate (75% of the grower's standard rate) were used. At the end of each season growth metrics: height, widest width, growth index [(height+widest width+width perpendicular to the widest width)/3] and increase in growth were recorded. Additionally, in 2017 the Virginia Tech Extraction Method (VTEM) was used to measure the electrical conductivity and pH of container effluent during the growing season. In 2016, final plant height was 40.4 cm and 48.6 cm for 100% and 75% fertilizer rates, respectively, in the leaching fraction-based irrigation zone and 47.3 cm and 46.7 cm for 100% and 75% fertilizer rates, respectively, in the conventional irrigation zone. In 2017, final height in the leaching fraction-based irrigation zone was 56.9 cm and 57.5 cm for 100% and 75% fertilizer rates, respectively, and 47.2 cm and 56.9 cm for 100% and 75% fertilizer rates, respectively, in the conventional irrigation zone. Container leachate electrical conductivity was 0.56 and 1.3 mS/cm, 0.24 and 0.35 mS/cm, and 0.56 and 0.53 mS/cm on the first 3 data collection periods for the standard and leaching fraction-based irrigation treatments with the 100% fertilizer rate, respectively. An irrigation system predicated on achieving a 15% leaching fraction is proposed as a practical way that nursery producers can reduce fertilizer inputs and limit nutrients in runoff without sacrificing crop growth.

Keywords: hydrangea, water use, nitrogen, leachate

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(ROSA Ref. n.31)

A comparison of irrigation-water containment systems and management strategies, to ensure water security in two ornamental operations

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Water security in ornamental production operations is vital for maintaining profitability and can involve expensive, complicated treatment systems and skilled management to assure water quality and plant health. Two irrigation recycling systems and site-specific management strategies were studied in a greenhouse and field-production nursery operation. The greenhouse operation grows multiple cycles of floral and herbaceous crops annually. Precision irrigation is achieved with a combination of automated irrigation systems. The operation contains and recycles about 75% of its water through a system of underground cisterns, a recycling pond and a newly constructed slow sand filtration (SSF) system. Captured rainfall and groundwater wells supplement irrigation water as a last resort. Plant pathogens were qualified and quantified and the fate of paclobutrazol was quantified throughout the treatment-train after applications to plants in 2018. Pythium and Phytophthora spp. were found throughout the water treatment-train, but were significantly reduced after SSF. Paclobutrazol was found in return water, even after the SSF treatment in concentrations which may affect sensitive species. The second nursery propagates cuttings, grows field-grown trees and supplies containerized plants to landscape operations. Water is supplied by a series of containment/recycling ponds, capturing rainwater and irrigation runoff and supplemented from a well with limited output. Water quantity is an issue, but water quality has also had negative economic effects. Recycled water is treated with chlorine gas before being applied to plants via overhead and micro-irrigation systems. Plant pathogens were qualified and quantified in the recycling ponds. Several non-virulent species of Pythium and Phytophthora were found in ponds, but were eliminated after chlorine treatment. The two nurseries have employed very different water treatment systems based on their access to water, irrigation methods, topography and capital investment. This study can serve as a model for determining management strategies for ensuring water security in different ornamental operations.

Keywords: ornamental plants, irrigation, growth regulators, pathogens, water quality

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Effects of a biostimulant for the use in fertirrigation on processing tomato regarding the main biometric and production parameters, in controlled and field conditions

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In order to obtain information on the effects of the biostimulant Idrogrena® in processing tomato crop, in 2018 two experimental tests were carried out by Horta Srl: one in a controlled environment (tomato cultivated in pots in green house) and one in open field conditions.
In the controlled environment experiment, Idrogrena® was applied at two different levels of water regime: 100% and 30% restitution of the evapotranspiration of the crop.
In the field test Idrogrena® was applied following the fertirrigation advices provided by the DSS (Decision Support System) pomodoro.net® developed by Horta Srl.
The results of the test in the controlled environment have shown an important effect of Idrogrena® on: i) chlorophyll content; ii) root Index, iii) plant height and iv) plant precocity.
The results of the field test also highlighted the quantitative and qualitative advantages of using Idrogrena® in fertirrigation through drip systems.

Keywords: processing tomato, fertirrigation, biostimulant

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Reducing agrochemical movement in container crops by irrigating based on container capacity

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Container nursery production depends on frequent, often daily, irrigation in order to produce a quality crop. Irrigation is commonly applied through overhead impact sprinklers, where a substantial portion of applied water falls on non-target areas and may be lost to runoff or soil infiltration where it is capable of transporting nutrients and pesticides off-site. Methods in which to irrigate more efficiently, such as using moisture sensors to apply the correct amount of water and micro-irrigation to apply water directly to crops, have been used to reduce the quantity of water used in nursery production, as well as the volume of water lost. In a series of studies conducted at the Michigan State University Experimental Nursery, water conserving irrigation technologies were compared across 16 individually controlled production zones, with each zone constructed to direct runoff water and soil infiltrated water to respective collection tanks. The volume of water applied and the quantity of water lost to runoff/soil infiltration, were recorded throughout the growing season, with samples collected for agrichemical analysis. Three rounds of pesticide applications - each comprised of an herbicide, an insecticide, and a fungicide - were applied at the ornamental label rate, with samples collected from the runoff/infiltration tanks over a 16 day period following application. Water conserving irrigation technologies were effective in reducing the volume of water applied, as well as the quantity of runoff and infiltration water lost. Through the use of these technologies, the movement of certain pesticides was reduced, allowing more time to degrade in-situ. Nursery crop production is faced with concerns over water resources – both the quantity used/available for irrigation and the quality of water leaving production sites. The use of water conserving irrigation technologies may allow growers to address these issues without sacrificing crop quality.

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On-the-go Automatic Resistivity Profiler (ARP©) mapping as a basis for modelling crop precision irrigation strategies

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Mapping of permanent soil properties may be a key for planning precision irrigation based on soil spatial variation. Among geophysical methods ARP is less prone to drift and variations in depth sensitivity. This work aims at comparing uniform and differential irrigation strategies through crop modelling on the basis of soil variability assessed through ARP mapping.
Automatic Resistivity Profiler (ARP © Geocarta - Paris) was used for mapping electrical resistivity (ER) at three soil depths (50, 100, 200 cm) in Southern Italy (40°36 49N; 15°18 07E). Soil texture calibration was conducted on six areas and TAW (total available water) was calculated with the Saxton and Rawls (2006) pedotransfer corrected for gravel. The ISAREG model (Teixeira and Pereira, 1992) was applied to each soil area. Weather inputs were daily data for 15 years (1999-2013). Simulations were conducted on drip-irrigated Tomato (Lycopersicon esculentum L.), and sprinkler-irrigated Alfalfa (Medicago sativa L.) and Sorghum (Sorghum bicolor L.).
In the 6 zones increasing ER corresponded to increasing coarse soil fraction content and decreasing TAW ranging from 216 to 121 mm over 200 cm depth and from 120 to 66 mm at 100 cm. Differential irrigation of each area according to its own TAW up to 100 cm allowed to save an average of 20% of water without yield losses compared to uniform irrigation using average TAW. Differences in texture and consequent ranges in TAW and modelled crop response to irrigation found along our range of ER confirm the value of resistivity mapping for precision irrigation planning where ER is a proxy for relevant variables.

Keywords: precision irrigation, sensors, automatic resistivity profiler

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