

ISHS Symposium 2016 "Sensing Plant Water Status" Methods and Applications in Horticultural Science



Book of Abstract 05. – 07. October 2016 Potsdam, Germany



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Heft 90
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ISHS Symposium 2016 „Sensing Plant Water Status“

Methods and Applications in Horticultural Science

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Preface

In horticultural production, water supply is a crucial and, in many cases, a rare resource. In postharvest, water plays an important role considering the quality of produce and sustainable process management. Excessive water losses may lead to unnecessarily reduced freshness, increased waste, and, hence, economic and social problems. Precise knowledge on the physiological role of all aspects of plants water status as well as improved techniques to evaluate water use efficiency and the actual water needs of plants are essential for sustainable horticultural supply chains. Comprehensive understanding of produce water status may also help to optimise postharvest handling during harvest, in storage, and during processing.

The present symposium on SENSING PLANT WATER STATUS will provide a platform to exchange findings on established and new methods - considering the fundamentals of the methodology as well as helpful hints achieved in applications. Various ISHS groups will be involved such as the Commission Irrigation and Plant Water Relations, the Workgroup Water Supply and Irrigation and the Workgroup Water Relations. Main issues will be classical and recent techniques of sensing plant water status, from the cell to the orchard, and their application in horticultural science. Hence, this symposium will bring together researchers from the diverse fields of plant water relations study.

The ISHS symposium on SENSING PLANT WATER STATUS is organized by an enthusiastic group of people of the Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB) in close collaboration with Sascha Oswald and his colleagues from the University of Potsdam, the Humboldt University Berlin, and the Beuth University of Applied Sciences Berlin. It will be held at the Campus Griebnitzsee of the University of Potsdam.

The symposium comprises of three plenary talks, eighteen sessions capturing 49 lectures, in addition > 20 poster will be presented, all covering four major topics 1) *physiological processes*, 2) *quality/process control*, 3) *stress detection*, and 4) *irrigation*. The symposium will provide a wide field for scientists, professionals, and students to present their latest findings and discuss their current work related to basic and applied aspects of all issues of plant water status.

We are very proud to welcome you all in Potsdam and we wish you successful presentations, interesting discussions, and a happy stay in beautiful town.

Werner B. Herppich, Manuela Zude-Sasse, and the entire organizing team.

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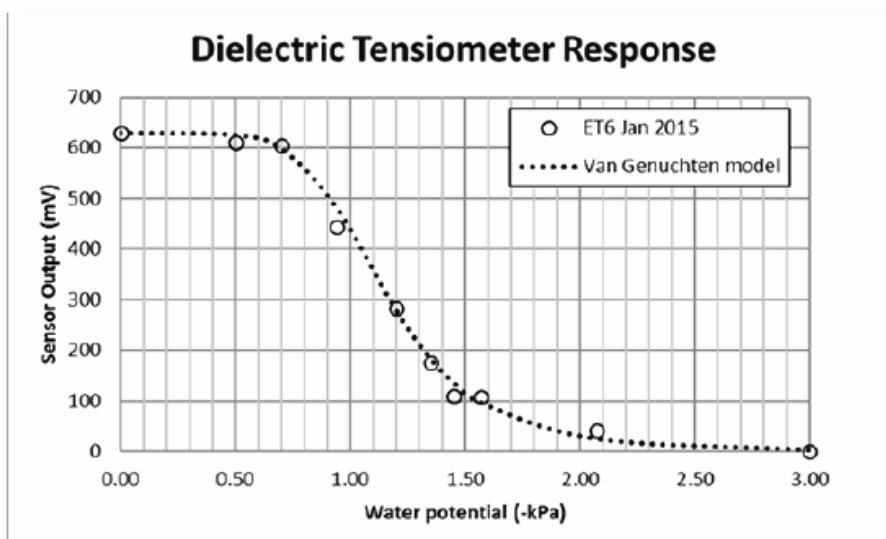
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The **UGT GmbH** develops, produces and distributes measurement and diagnostic technology for soil, water, atmosphere and plants as well as modules for environmental monitoring. We install soil hydrological measurement sites at agricultural, forestal, marsh and water ecosystems as well as monitoring and control stations at landfill sites, mining reclamation areas and non-standard sites.

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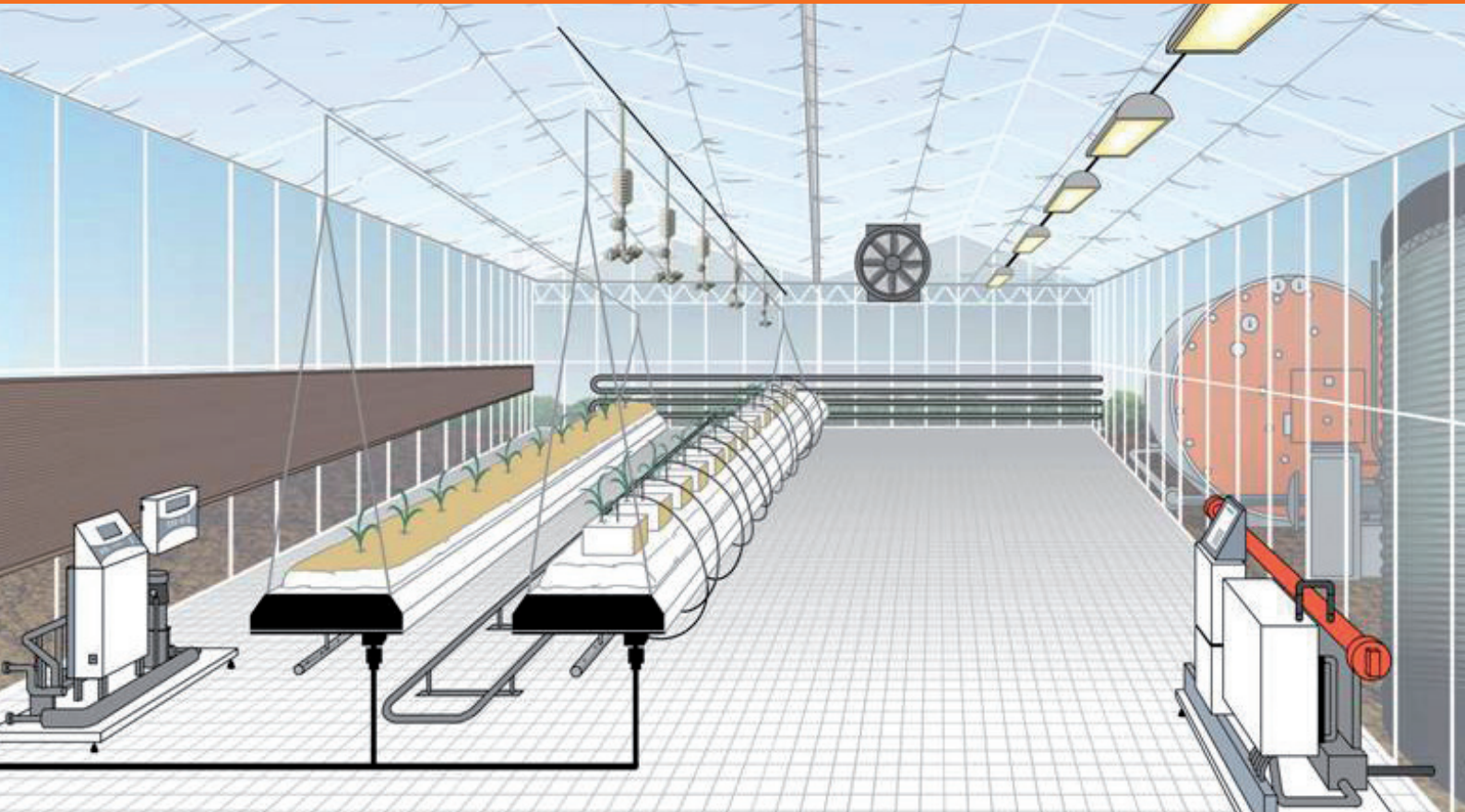
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More than 30 years later, Decagon (decagon.com) is a thriving company where research scientists still work to build what they and their colleagues need to do great research. Our goal: to get the data you need into your hands in the most efficient and accurate way possible.

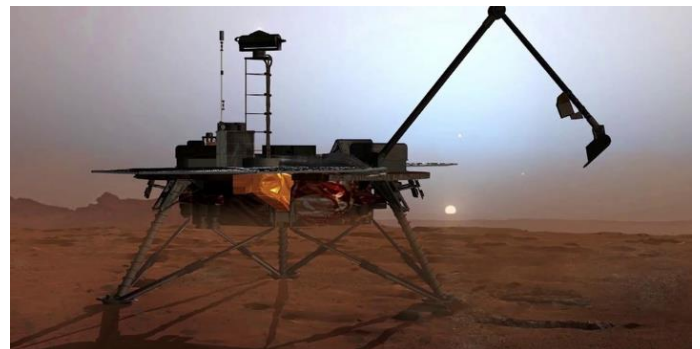
Interesting Decagon Facts:

- Decagon built a thermal and electrical conductivity probe for NASA's Phoenix Scout Lander mission to Mars. The probe successfully gathered thermal and electrical properties data in addition to measuring atmospheric humidity and wind speed.
- Decagon collaborated with horticultural researchers at the University of Maryland and the University of Georgia (among other places) on a 5 year, \$5.2 million USDA grant to increase the efficiency of water and nutrient use by ornamental growers.
- Decagon also makes instruments for the food industry. 80% of the top 100 food companies use Decagon's AquaLab to check water activity in their products.
- Decagon scientists conduct ongoing research both in an on-site soils lab and at several agricultural research sites. They collaborate with outside scientists on research projects and teach the Introduction to Environmental Biophysics course at Washington State University.
- The Grant A. Harris Research Fellowship provides \$30,000 worth of Decagon research instruments to graduate students studying environmental or geotechnical science. Our blog, environmentalbiophysics.org, highlights their research, along with other research topics.
- Decagon is located in Pullman, Washington, USA, home of Washington State University. Decagon also recently merged with the UMS company in Munich, Germany.

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Decagon Employees



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Oral
Session 1 – 18

Sensing and responding to water limited conditions: a combination of both plant and horticultural perspectives

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For both the plant and the horticulturist, it is important to distinguish between measures of water stress on the one hand and plant responses to water stress on the other. Most textbooks on water management typically assert that the objective of irrigation, which is under the horticulturist's control, is to satisfy crop water demand, or that the objective is to maintain soil water availability at some acceptable level. The published literature contains many examples of using plant water stress measurements based on these criteria (e.g., %ETc, soil moisture content, or soil matric potential). However, these measurements are only indirectly related to the real objective of irrigation management. The real objective of irrigation management is to manipulate water availability (typically, but not necessarily, in the soil) so that the plant produces an economic crop, recognizing that crop production is the net result of many independent physiological responses to water. Based on an engineering analogy, the measurement of a relative change in any of these physiological responses (i.e., a change in growth, photosynthesis, yield, quality, etc.) can be considered a measure of physiological strain (analogous to the change in length of a material), whereas measurement of what we believe to be the mechanistic cause of the strain (analogous to the force that causes the material to change in length), is a measure of the stress. In biology it can be difficult to clearly separate cause from effect, but most of the current plant-based approaches to sensing/measuring water stress for irrigation management (e.g., sap flow, dendrometry, canopy temperature) measure the result of one or more physiological process. These approaches can provide a measure of physiological strain when the values obtained are compared to values that would be expected under non water-limited conditions. Similarly, in some horticultural species the water potential of a non-transpiring leaf (i.e., midday stem water potential, SWP) can be compared to non-water-limited (baseline) values. However, SWP alone has also been found to be closely related to many horticulturally and biologically important plant stress responses, without reference to a baseline, and so it appears to be a good candidate for a direct measurement of water stress in plants. SWP is most easily measured using the pressure chamber, which is a relatively robust field method when used properly. However, there are a number of common misconceptions in the literature, and in some cases in operation manuals and current textbooks, concerning the physical basis of function of the pressure chamber and the errors that may be associated with different aspects of methodology. For instance, re-cutting or trimming a petiole or stem after the initial excision from the plant has often been cited as an important source of error, but we have found no evidence for such an error, and little or

none is expected, based on the physics of pressure chamber function. By the same token, protecting leaves from post-excision water loss is often ignored as a source of error, but attention to this factor is critical for obtaining reliable and reproducible values. Other aspects of methodology that have been proposed as limiting the accuracy and reproducibility of pressure chamber values, such as operator subjectivity in judging the endpoint and the need for consistency in the rate of chamber pressurization, have not been found to be of importance once the operator has a clear understanding of the expected behavior of the water that appears at the cut surface when the endpoint pressure is reached. An important assumption common to all measurements of water potential is that the tissue being measured should be in internal water potential equilibrium (i.e., that water potential is uniform throughout). A corresponding practical advantage of measuring the water potential of a non-transpiring leaf (SWP) is that the leaf should always be close to internal equilibrium. Since within-leaf gradients in water potential occur during transpiration and can be substantial, a potential biological advantage of measuring SWP is that the value of water potential obtained should consistently indicate the water potential of the xylem and nearby vascular tissue in most leaves, regardless of environmental conditions. Another recently commercialized system for measuring SWP (directly on stems or on non-transpiring leaves) is the temperature compensated in-situ stem psychrometer. One advantage of these devices is a more-or-less continuous and automated measurement of SWP over time. In most cases these devices have shown diurnal patterns that are consistent with expectations based on diurnal patterns in plant transpiration, and in some cases shown good agreement for different sensors on the same plant and good agreement with pressure chamber measured SWP. However, in most cases, despite what appear to be reasonable diurnal patterns, SWP values obtained using these sensors have been substantially more negative than pressure chamber values, reaching values that are inconsistent with apparent plant health. Some fundamental problems in the basic theory of psychrometer calibration for environmental temperature effects have been identified and solved, giving an error of calibration of about $\pm 0.05\text{MPa}$ when individual psychrometers are calibrated at multiple water potentials and temperatures. However, the source(s) of the additional errors that are associated with in-situ operation of these devices remain(s) to be identified.

Keywords: Methodology, review, sensor, water status

Pilot operation and evaluation of a meteorological data fed water budget model for turfgrass

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In Mediterranean countries –and not only- irrigation consists the major water consumer. In this framework, the development of tools for real time data based estimation of crops' water needs and automatic generation of recommendations for improved irrigation schedules is of great importance. This paper present the evaluation results for a relevant web-based system that covered the whole plain of Arta, Greece (45,329 ha) using data from 6 agrometeorological stations. The system was tested on turfgrass, during the irrigation period of 2015. The reference treatment was a sprinkler irrigation system equipped with a controller that used water budget periods. The other two treatments consisted of a) manually activated irrigation the followed exactly the system's recommendations and b) automatically operated irrigation based on the integral of solar energy at the site, as provided by the system. Irrigation water volume, soil moisture, vegetation growth (cuttings weight) and canopy reflectance were monitored. The latter provided data to calculate NDVI and PRI, which were used as quality indicators. Results showed a significant drop regarding water consumption. For the manually activated system, it was -26.43% and -41.46% for sprinkler and underground drip irrigation, respectively, and for the automatic system -22.32% (only sprinkler irrigation was available). In qualitative terms, no statistically significant differences were found among treatments. These results are very promising as they document the possibilities of a system that uses only the flow meter as locally installed sensor. At the other hand, it strongly depended on the adequate calibration of the system for each situation.

Keywords: irrigation scheduling, flow meter, NDVI, PRI, open source software

A novel dielectric tensiometer enabling precision irrigation control of polytunnel grown strawberries in coir

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The benefits of closed-loop irrigation control have been demonstrated in grower trials, which show the potential for improved crop yields and resource usage. Managing water use by controlling irrigation in response to soil or substrate moisture changes to meet crop water demands is a popular approach but requires substrate specific moisture sensor calibrations and knowledge of the moisture levels that result in water stress or over-watering. The use of water tension sensors removes the need for substrate specific calibration and enables a more direct relationship with hydraulic conductivity.

In this paper, we present a novel dielectric tensiometer that has been designed specifically for use in soil-free substrates such as coir, peat and Rockwool, with a water tension measurement range of -0.7 kPa to -2.5 kPa. This new sensor design has also been integrated with a precision PID-based (drip) irrigation controller in a small scale coir substrate strawberry growing trial, 32 strawberry plants in 4 coir growbags under a polytunnel.

Data presented illustrates that excellent regulation of water tension in coir can be achieved, which delivers robust and precise irrigation control - matching water deliver to the demands of the plants. During a 30 day growing period vapour pressure deficit (VPD) and daily water use data was collected and the irrigation controller set to maintain coir water tension at the following levels: -0.90kPa, -0.95kPa and -1.00kPa for at least 7 consecutive days at each level. For each set-point, the coir water tension was maintained by the irrigation controller to within ± 0.05 kPa, the polytunnel VPD varied diurnally from 0 to maximum of 5kPa over the trial period. Furthermore, the combination of the dielectric tensiometer and the method of PID-based irrigation control resulted in a linear relationship between average daily VPD and daily water use over 11 days during the cropping period.

Keywords: Precision irrigation control, VPD, soil-free substrate, coir

Investigating continuous measures of plant stress for avocado trees to guide irrigation

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Regions with Mediterranean climates regularly experience water shortages due to periodic droughts, which cut availability of irrigation water for agricultural and horticultural production. There is an urgent necessity in such regions for new irrigation strategies to minimize water use. Such strategies currently largely rely on atmospheric measures to determine plant water needs, but plant-based measures are hypothesized to be a better guide for assessing water needs of orchard trees. The aim of this study is to identify plant-based measures of water stress in avocado, *Persea americana*, that can be continuously monitored to guide irrigation decisions. The experiment is conducted in a Fuerte avocado orchard at the Fullerton Arboretum in southern California. Irrigation is mostly kept at a level that meets the trees' demands, but Avocado trees are subjected to temporary drought conditions for two-week intervals, during which several water stress parameters are monitored. The state of water stress is determined directly using destructive measurements of leaf water potentials. In addition, responses to water stress are measured continuously by measuring maximum daily trunk shrinkage (MDTS), trunk water potential via stem psychrometry, volumetric wood water content using frequency domain reflectometry sensors, and sap flow using heat-ratio-method sap flow sensors. Soil water status is also monitored continuously using soil moisture and soil water potential sensors. To determine the best continuous plant- and/or soil-based measures for irrigation scheduling, correlations are assessed between the different continuous measures and discrete mid-day leaf water potentials. Preliminary results show leaf, soil, and trunk water potentials declining after withholding water. MDTS increases with increasing stress, whereas wood water content slightly decreases. These initial findings suggest that using these measures in combination can reliably infer avocado water status to guide irrigation decisions. The study is ongoing through the summer of 2016 and the newest results will be presented.

Keywords: irrigation scheduling, leaf water potential, maximum daily trunk shrinkage, sap flow, wood water content, trunk water potential, soil water potential

Deriving soil moisture threshold from plant water status sensors for irrigation scheduling in clementine trees

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Precision irrigation allows saving water without harming yield and quality by meeting the crop's water specific requirements. Three important parameters to monitor plant water status are the soil water content (θ), the stem water potential (ψ_s) and more recently the leaf turgor pressure (LTP). The aim of this work was to study the relationships between θ and ψ_s during different periods of the growing season in order to define an adequate θ threshold and optimize irrigation in clementine trees. Four clementine trees were equipped with one Frequency Domain Reflectometry probe (FDR) and two plant-based magnetic probes (Yara ZIM-probe) each, located at the east side of the canopy. The Yara ZIM technology measures the pressure (P_p) transfer function through a patch of an intact leaf, which is inversely correlated with the LTP. Midday ψ_s was measured with a Scholander pressure chamber in three leaves of each tree every week throughout the season. Additionally, hourly stem water potential measurements were performed on three days in spring and summer. The selected trees were subjected to three periods of water withholding throughout the growing season. Results show that once the drought cycles started, ψ_s decreased in parallel with θ . These data enabled to set the critical soil water content (θ_{crit}) when ψ_s reached values considered as mild stress for the plants (-1.2 MPa). This θ_{crit} varied depending on the growing period ranging from 24% in winter to 35% in summer. The ψ_s had a good correlation with P_p during the drought cycles with coefficients of determination that reached values of 0.80. In conclusion, results show that the Yara ZIM-probes enabled plant water status telemonitoring on real-time in clementine trees. The soil water content measurement and the use of the Yara ZIM-probes could be an optimal coupling for irrigation scheduling in clementine trees.

Keywords: Citrus, drought stress, leaf turgor, pressure sensors, stem water potential, soil moisture

Irrigation and seed-type effects on tuber yield, culinary attributes, and economic performance of French fry, chipping, and fresh market potato under short growing conditions of the Canadian prairies

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Potato (French fry, Chipping, and Fresh Market) production is a dominant horticultural crop on the Canadian Prairies, and currently valued at \$480 million (40% of Canada's potato production). Suitable cultivars and production practices are required to optimize yield, quality, and economic returns under the prevailing cool and short growing environment. This project examined advanced breeding clones and recently released cultivars of French fry, chipping, and fresh market potato, planted using whole, longitudinal-cut, and transverse-cut seed grown under irrigated and dryland production in comparison to industry standards. The growing season experienced favourable rainfall and temperature that resulted in above average yields. The French fry cultivar 'AAC Alta Strong' produced the highest marketable yield of 61.6 t ha⁻¹, outyielding the industry standard 'Russet Burbank' by 56%. Chipping cultivar 'Vigor' produced the highest yield of 49.6 t ha⁻¹ and out-yielded the industry standard 'Atlantic' by 17%, and 'Snowden' by 39%. Fresh market cultivars and breeding clones produced similar yields averaging 47.4 t ha⁻¹. Irrigation produced higher yields of French fry potato, but had no effect on Chipping or Fresh market types. Cut seed-pieces produced higher marketable yields than whole seed for French fry and Chipping potato, whereas, seed type had no effect on Fresh market yields. Tuber quality attributes were variable among the cultivars/clones. 'CV04144-1', 'Snowden', and 'Milva' produced higher quality French fries, Chips, and Fresh market potato respectively. Tuber quality attributes were similar between irrigated and dryland production for all three market classes. These improvements in agronomic and quality traits translate into significant economic value-chain impact at three levels: producers (lower production cost, increased yield, and contractual premiums for quality attributes demanded by processors relative to the industry standard); processors (higher quality raw material for value-added products - French fries, chips, dehydrated, and canned); and consumers (quality and price).

Keywords: Potato, irrigation, seed type, yield, tuber quality, economics, value-chain

Irrigation and mulching effects on the raspberry leaf temperatures measured by thermal imaging camera

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The paper presents the results of leaf temperature measurements in raspberry orchards, recorded by thermal imaging camera. Raspberry orchards were formed in spring 2014, while the experiment was set up in spring 2015, which was the first yield year. The orchards are located in the south-western part of Republic of Serbia (Ivanjica region). This mountain region is characterized by limited water resources. During the experiment, three irrigation treatments were applied: deficit irrigation (N), deficit irrigation with hay mulch (NM), and rainfed condition (NN). Measuring of the leaf temperature was carried out with thermal camera (FLIR, T335), six times during fruit development. A total of 30 measurements was carried out on each treatment for calculating the average values for leaf temperature. Soil water content was continuously measured by TDR sensors (in the N and NM treatments). Automatic weather data were set up near the experimental field. Results of measurements show the warmest plants were in the NN treatment, followed by plants in the N treatment. The coldest plants are those in the NM treatment. The leaf temperature values for NN treatment are mainly higher than air temperature values, while the N and NM treatments show higher values just in one of six days of measurements. However, soil moisture values reflecting the eventual changes in leaf temperature. The values of soil moisture in the NM treatment were the closest to the field capacity, while the values in N treatment were the closest to the wilting point. A positive impact mulch has to the irrigation water can be assumed according to the experiments' results, and that is very important note for this region. Difference in air and leaf temperature vs. vapour pressure deficit shows linear relationship. The average values of CWSI for N, NM and NN treatments obtain clear differences.

Keywords: deficit irrigation, mulching, thermal imaging, raspberry

From theory to practice - success in implementing drip irrigation in commercial mushroom (*A. bisporus*) cultivation

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In today's practice, mushrooms are watered by spraying systems. To avoid quality damage, watering has to be stopped from the "pin setting" stage until all first flush mushrooms are picked. After the second flush, during the "No irrigation" periods, casing and compost humidity decreases to a level that prevents development of first class mushrooms. This makes it unfeasible to pick the third flush and reduce the profitability of mushroom cultivation. Drip irrigation was developed to overcome these obstacles of the spray watering systems. Since water is applied below the mushrooms it does not cause any quality damage. In the last year, experiments with the new watering system were carried out on three commercial mushroom farms, in three different countries with both the one layer system and the standard six shelves growing technique. Controls were watered conventionally by spraying with water. Special device was developed for the introduction of the drip tube lines into the casing and collection at the end of the growth cycle. With this system, installing drip irrigation in mushroom cultivation rooms became fully automatic. The drip lines can be used for few growing cycles. Drip irrigation kept casing and compost humidity as needed even with 30% reduced thickness of the casing layer. Optimal compost and casing humidity was achieved by a newly developed computerized irrigation controller, with an algorithm that use input from compost and casing humidity sensors and the climate controller. Due to the "water shortage" of the spray irrigated rooms, the second flush mushrooms' mass/size ratio was higher with drip irrigation, i.e. for the same diameter, less but heavier and better mushrooms. This also enables reduction of picking costs. The quality of drip-irrigated third-flush mushrooms was much higher (85% class A) than that of spray irrigated machine-picked mushrooms (0% class A). Increased in relative humidity in the spray irrigated rooms is avoided with drip irrigation, decreasing the energy needs for drying the rooms. Decreased bacterial blotch incidence, due to dryer drip-irrigated mushrooms, also enhanced produce quality. Total higher mushroom quality: 95% class A, as compared to only 79% class A, of the entire yield, using drip instead of spray irrigation increased the entire crop value. These results indicate that introduction of this new technology can improve profitability of mushroom growing.

Keywords: Algorithm, irrigation, mushrooms, quality

Numerical simulation of root zone dynamics of water uptake by drip irrigated asparagus

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Asparagus (*Asparagus officinalis* L.) is a perennial vegetable grown in the north eastern part of Belgium. Asparagus is grown on sandy soils with low water holding capacity. Asparagus has been reported to be sensitive to water stress, with reduced stomatal conductivity and assimilation rate at high soil and plant water potential. On the other hand the root system has been known to be extensive which should permit extracting water from a large soil volume. In 2015 a field experiment was conducted with as aim gaining insight in the root zone dynamics of water uptake by asparagus under four different drip irrigation treatments. Crop development and gravimetric soil moisture observations were collected in four replications. Per treatment one plot was equipped with 6 Watermark granular matrix sensors to observe the variation in soil water potential. In the autumn the Watermark sensors were removed and at the same place root samples were collected to determine the fine root distribution. In total from 117 samples roots were washed from the soil using fresh water. The acquired root distribution, in combination with *in situ* observed water retention characteristics and saturated hydraulic conductivity was fed into the HYDRUS 2D model in order to numerically describe the water extraction pattern of asparagus. With this calculation the relation between soil water potential and plant water status was identified in relation to the subjected drip irrigation treatment.

Keywords: Soil water potential (Ψ_{soil}), soil water content, Watermark sensor, HYDRUS

Predawn water status for irrigation scheduling - Proof of concept for *Asparagus officinalis* L. as model crop

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For an economically and environmentally-sound vegetable production in open field, irrigation scheduling has to meet the demand of yield and quality assurance, resource-efficiency and user-friendliness through automation. Plant-based irrigation scheduling systems are promising approaches which potentially face these requirements. Predawn water status of plants (ψ_{PD}) is a widely used, sensitive indicator for soil drought induced water stress. Since its measurement is not really feasible in practice, irrigation scheduling models exist with parametrized ψ_{PD} , intending to replace its frequent determination. However, the efficiency of ψ_{PD} -based irrigation scheduling systems depends on the accuracy of ψ_{PD} -thresholds initiating irrigation. Thus, the objective of this investigation is to establish how ψ_{PD} -thresholds signaling water stress differ, if determined with physiological parameters (e.g. assimilation rate, xylem hydraulic conductivity, RWC) or with morphological (yield-related) parameters. For proof of concept of ψ_{PD} as irrigation signal, we furthermore aim at evaluating a preliminary ψ_{PD} -threshold in an open field experiment with different irrigation regimes.

Two successive three-year experiments with *Asparagus officinalis* L. cv. Gijnlim were conducted on different open field sites. In the first, asparagus was grown in well-irrigated and non-irrigated plots in sandy loam in Geisenheim, Germany (3 replications, randomized block design). The second consisted of four different irrigation treatments in sandy soil in Ingelheim, Germany (4 replications, randomized block design). ψ_{PD} , gas exchange, plant growth and spear yield were analysed in respect to water supply and a preliminary threshold.

The ψ_{PD} -threshold derived from physiological parameters (-0.15 MPa) lies above those found morphologically. Distinctive limitations of shoot growth and spear yield emerged with $\psi_{PD} = -0.37$ MPa. Thus, ψ_{PD} -thresholds derived with physiological parameters may overestimate asparagus' sensitivity towards drought stress in terms of crop management. Hence, proof-of-concept studies addressing crop parameters are inevitable for using plant water status for irrigation scheduling.

Keywords: drought stress, herbaceous perennial plant, plant-based-irrigation scheduling, predawn water potential, stress threshold

Can plants "sense" irrigation frequency?

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Decreasing the frequency of irrigation may allow water savings without limiting crop yield and/or quality, but many studies have varied both irrigation frequency and irrigation volume. To determine whether irrigation frequency per se affects plant water use efficiency (WUE) and physiological responses to suboptimal soil moisture, greenhouse experiments with containerised plants supplied less water than full crop evapotranspiration (ET), but at different frequencies. Some plants were irrigated daily (in aiming to supply 50% of ET or to maintain a semi-constant soil moisture content, θ) while others periodically received the same cumulative irrigation volume (thus imposing distinct soil drying and re-wetting cycles). In *Pelargonium x hortorum* grown in conventional pots in peat, daily irrigation at 50% ET increased shoot biomass by 15% compared to distinct soil drying and re-wetting cycles. Moreover, daily irrigation increased leaf water potential and decreased leaf xylem ABA concentration at the same θ . In *Helianthus annuus* grown in soil columns in an organic loam, maintaining a semi-constant soil moisture content by daily irrigation increased stomatal conductance and whole plant transpiration compared to plants from which water was withheld (at the same θ). This increased gas exchange was associated with lower shoot xylem ABA concentration and a pronounced inverted gradient in soil moisture (wet upper soil layers, dry lower soil layers). In *Lycopersicon esculentum* grown in soil columns in peat, decreased leaf and root xylem ABA concentration could be partially explained by accounting for water uptake (and ABA export from) from the different soil layers. Moreover, root ABA accumulation was attenuated in frequently irrigated plants due to higher root water potential at the same θ . The significance of these changes in root ABA export in mediating WUE will be assessed by exposing ABA-deficient and wild-type plants to different irrigation frequencies.

Keywords: ABA, root-to-shoot signaling, stomatal conductance, deficit irrigation

Whole-canopy gas exchange chambers to accurately estimate canopy water use of 'Tempranillo' grapevines ('*Vitis vinifera*' L.) under various irrigation regimes in a semi-arid climate

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An accurate estimation of grapevine water use is vital for efficient irrigation water management in vineyards, particularly in regions dependent on the availability of freshwater, and in light of increasing freshwater scarcities in arid and semi-arid regions globally. Using custom-built whole-canopy chambers coupled to a portable infrared gas analyser, we estimated the daily water requirements of mature grapevines (*Vitis vinifera* L. 'Tempranillo') in the field under high environmental demand (vapour pressure deficit) and several irrigation regimes (full irrigation at 100% of crop evapotranspiration or ET_c ; regulated deficit irrigation and sustained deficit irrigation ranging between 30-50% of ET_c). Environmental conditions, soil moisture, and vine water status (midday stem water potential) were measured simultaneously, and ET_c was calculated using the Penman-Monteith relationship for comparison with the whole-canopy measurements. Our results indicate that mature fully-irrigated grapevines in the field use over 30 L of water per day during the peak of the summer. In the same vines, night transpiration represented 32% of the total daily water use, which was not accounted for in ET_c measurements, therefore having implications for irrigation scheduling and lowering canopy water use efficiency (WUE). Canopy WUE was highest early in the morning perhaps due to the relatively higher proportion of diffuse light at that time and, consequently, lower transpiration rates. Daily water use was lower in the reduced irrigation treatments and with negligible nocturnal water loss. Whole-canopy gas exchange chambers built for and used in this study have proven to be a valuable tool for the quantification of plant water use and therefore irrigation scheduling in vineyards.

Keywords: irrigation, water use, *Vitis*, transpiration

Continuous 'in situ' measurements of crop water stress in Shiraz grapevines using a thermal diffusivity sensor

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A new measure of crop water stress (CWS) using a thermal diffusivity sensor was evaluated under field conditions in southern Australia in early 2014 in mature Shiraz grapevines over a two-month period. The trial tracked the correlation between thermal diffusivity (TD) of xylem (sap and tissue) and vapour pressure deficit (VPD) as a measure of CWS. In-canopy VPD measurements were used as a surrogate for atmospheric demand. Matric potential sensors in the soil profile below the vine were used as an independent measure of potential water stress. The TD vs. VPD correlation coefficient was derived from 96 quarter-hourly readings over each day, starting at 6am daily when the vine was expected to have reached hydraulic equilibrium with the soil. Correlation coefficients were around 0.9 under well-irrigated conditions but dropped to around 0.6 before each irrigation was applied. As the soil profile dried over the course of the season and tissue rehydration levels increasingly failed to recover after high-stress summer days where sap flow was low, TD did not correlate as well with VPD. The sensor output closely tracked irrigation cycles.

Keywords: Water stress, irrigation, VPD, sap flow, thermal diffusivity

Water management in Space - monitoring of plant water status in small and closed environments

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The movement of water in, across and out of the plant is a key factor when growing plants as part of a closed regenerative life support system. Under microgravity conditions, it has been proved that transpiration rate of leaves is suppressed by retarding the water vapour transfer due to restricted free air convection. Previous experiments on the International Space Station (ISS) have illustrated the importance of monitoring the water status of plants in space. A frequently reported cause for loss of seedlings due to wilting is technical issues with hardware, which could possibly have been avoided if a better tool for monitoring the water status in plants were available. Currently, experiments in existing growth facilities on the ISS, as well as new hardware are being designed to assess and monitor plant water uptake and transport in microgravity. However, suitable methods for monitoring plant water status in space facilities have proven to be challenging due to the confined environment and the limited volume of available water. Technologies used in previous experiments, lessons learned and future prospects will be presented.

Keywords: irrigation, sensors, relative humidity, monitoring technologies, imaging

Temperature correction of substrate moisture measurements made in coir in polytunnel-grown strawberries

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The aim of this work is to assess the use of temperature corrected soil moisture data to improve the relationship between environmental drivers and the measurement of substrate moisture content in high porosity soil-free growing environments such as coir. Substrate moisture sensor data collected from strawberry plants grown in coir bags installed in a table-top system under a polytunnel illustrates the impact of temperature on capacitance-based moisture measurements. Substrate moisture measurements made in our coir arrangement possess the negative temperature coefficient of the permittivity of water where diurnal changes in moisture content oppose those of substrate temperature. The diurnal substrate temperature variation was seen to range from 7°C to 25°C resulting in a clearly observable temperature effect in substrate moisture content measurements during the 23 day test period. A temperature correction algorithm is presented in this work that has been derived from the Complex Refractive Index Model (CRIM) equation, which was easily calibrated for coir and applied to the substrate moisture and temperature data. The diurnal variations seen with the temperature compensated substrate moisture data now align very well with the expected diurnal water demands of the strawberry plants. To further evaluate the relationship between environmental drivers of solar radiation and vapour pressure deficit with substrate moisture, the temperature correction algorithm was programmed within a GP2 data logger. The GP2 was also collecting solar radiation, air temperature and relative humidity data. The resulting comparison of substrate moisture responses to environmental drivers illustrates a significantly improved correlation with temperature corrected substrate moisture measurements. We conclude that this new temperature correction algorithm addresses the effect of temperature on the relative permittivity of water, which will affect all capacitance based sensor measurements in high porosity soil-free growing substrates such as coir.

Keywords: Substrate moisture temperature correction algorithm, Coir, VPD, Solar radiation

Smart phone tools for measuring vine water status

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Smart phones contain a variety of sensors, which have the potential to monitor the surrounding environment and provide an aid to decision making across a range of industries from medicine through to agriculture. Smart phones have a number of advantages over specialist monitoring systems including ubiquity, price, user familiarity and the ease of implementing updates; they also contain sufficient computing power that the analysis and support software can be contained within the phone.

A range of methods have been developed for the assessment of vine water status – however none currently meet the portability and ease of use requirements for wide scale adoption. A wide range of sensors could potentially be interfaced with smart phones in order to assess vine moisture status. The aim of this project is to evaluate a range of smart phone based tools for measuring vine water status and to develop the most promising tool into a smart phone application that can be easily used by vineyard managers.

Potential systems that are being evaluated include:

- An infrared camera that is integrated into or connected directly to the smart phone and uses established techniques for the analysis of thermal imagery to assess water status
- A portable NIR spectrophotometer that interfaces with the phone and measures reflectance across wavelengths for the calculation of water status indices
- A 3D camera that is integrated into or connected to the phone via WiFi and can use image analysis to assess the shape or orientation of the leaves
- A microscope attached to the smart phone camera or as a separate portable unit that can be used to measure stomatal number and aperture and then calculate stomatal conductance

Most of these systems will rely on the completion of some form of image analysis on the smart phone; therefore, the ability of this analysis to be completed quickly and accurately on the phone will also be assessed.

A trial site with a range of irrigation deficit treatments applied to Chardonnay and Cabernet Sauvignon grapevines has been established in the Riverland of South Australia. Water status measurements from the smart phone based sensors described above are being benchmarked against conventional methods including stem water potential and stomatal conductance.

Keywords: Water Status, Grapevine, Smart Phone, Infrared, NIR, Leaf Imaging, Stomatal Aperture

Stem heat balance method: A new consistent sap flow baseline-correction approach

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A widely used sap flow technique to determine the transpiration and water demand of plants is the stem heat balance method (SHB). Its accuracy depends highly on the correction and calibration of the recorded heat input. Some often applied correction approaches are highly questionable.

We compared the night value subtraction approach (NVS) with direct weighing and measurements on cut plant stems. We found that sap flow directly depends on the water vapour pressure deficit (VPD) at night (no photosynthetically active radiation) and that the constant of the linear regression (VPD vs. recorded heat input) represents the unintended heat loss of the measuring system (fictitious flow).

Our results from an outdoor climbing plant stand show that the measured daily net water uptake is underestimated by up to 33% when applying the NVS correction compared to direct gravimetric measurements (planted lysimeter). In contrary, the physical consistent baseline-correction VPD approach under- and overestimates the net water uptake by only 5 to 10%.

As relative humidity and air temperature should be recorded anyway, the VPD approach can be used to retrospectively improve the quality of the interpretation of already recorded data.

Our results suggest that SHB - sap flow data, which is corrected using the VPD approach gives a reliable estimation of daily transpiration and net water uptake of plants.

Keywords: heat balance, sap flow, vapour pressure deficit

A multi-tool approach for assessing fruit growth, production and plant water status of a pear orchard

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There is very little in the literature concerning seasonal information relating fruit growth to plant water status to yield in horticultural crops. This paper analyses information recorded in 2014 from the end of cytokinesis (early July) on Abbè Fetel trees grafted on four different rootstocks (Farold, Sydo®, MH and MC) grown in the Fratelli Navarra Foundation Experiment Farm, in Ferrara, Italy. Trees were irrigated according to the Irriframe scheduling system designed by the “Consorzio per il Canale Emiliano Romagnolo (CER)” of the Emilia-Romagna Region based on the water balance method. Soil moisture was calculated from the water inputs (rainfall and irrigation) and outputs identified as the crop evapotranspiration (ETc). For each rootstock, three treatments with two irrigation systems (drip and sprinkler) were studied: fully irrigated following the Irriframe scheduling, or 50 and 0 percent of the recommended water volume. Remarkable information of plant development, fruit growth and leaf water status were recorded. In addition, a new approach for measuring plant activity, called IPL index, was undertaken. This index involves chlorophyll fluorescence, carboxylative activity RuBisCo, air and leaf temperature.

In high-quality pear production systems, water management is a must, but growers lack an objective methodology for assessing management decisions. The data collected have been used to provide assistance in management decisions taken by the growers and/or the consultant throughout the season. The goal was to assist the growers in improving the efficacy of crucial decisions along the fruit growth, to help and ensure high production levels without losses in quality. The work presented is also intended as a proof of concept of this methodology, whose satisfactory results signal that it may not be far from large-scale adoption.

Keywords: Fruit Growth, Chlorophyll fluorescence, Tree crops

High throughput image processing with visual programming Rapid data analysis of field data

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Digital plant phenotyping is the complete and extensive measuring of properties, geometry and function in high resolution. With the rise of high throughput imaging systems on laboratory and greenhouse scale, data acquisition using a large variety of sensors in high resolution is quite common and a gap in high throughput data analysis routines can be defined. Especially with the construction of field phenotyping systems carrying a wide range of non-destructive sensor equipment such as RGB-, IR-, hyperspectral- and fluorescence cameras huge datasets have to be acquired, transported, saved to the database, exported and analysed.

An efficient tool LemnaGrid for high throughput and automated plant image analysis has been introduced by LemnaTec GmbH. This software enables the generation of an archetypical processing pipeline. Different single image processing elements containing edge detection, thresholding, segmentation or machine learning algorithms can be connected and represent an image processing pipeline to measure specific parameters of the plant. The single work steps can be evaluated and be adapted to the plant type and the experimental focus. The processing pipeline can be automated to process a huge variety of plant images in high throughput. Applications such as the automated parameterization of shape and colour within RGB images of greenhouse plants as well as for images of microtiter plates within a laboratory application or images coming from a field phenotyping platform are possible. Established processing pipelines can be easily transferred to experiments with a different focus and different plant types.

This work will show a deeper look of the processing of field data coming from the new Scanalyzer Field, a crane based phenotyping platform carrying different kinds of sensors, produced by the LemnaTec GmbH. Observations from a 10mx100m field were processed and analysed using this graphical programming interface. First results were shown for the hyperspectral data analysis regarding its connection between the reflection intensity and the availability of nitrogen.

The image analysis software LemnaGrid (LemnaTec GmbH, Aachen) provides a professional tool that enables the intuitive connection of different image processing algorithms. It is adaptable for different plant types and on different scales from the microscopic scale to the field scale. In this process, the data processing can use different sensor data coming from RGB, 3D, hyperspectral or fluorescence imaging.

Keyword: image analysis, field scale, phenotyping platform

Using sensor-based control to optimize soil moisture availability and minimize leaching in commercial strawberry production in Spain

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Spain is the major strawberry production area in Europe, and ranks fourth worldwide after the US, Mexico and Turkey. The major strawberry production area in Spain is centered in Huelva province (South-western Spain), with over 7,500 ha cultivated with drip fertigation under plasticulture production, in sandy soils with low cation-exchange capacity. Prior research in 2015 with a farmer has greatly increased the efficiency of drip irrigation by pulsing short (15-20 min) irrigation events during the day, increasing yields by more than 20 g per plant, with an increased income of 1300 € ha⁻¹ in 2015. We have implemented the latest soil-moisture sensor-control technology (PlantPoint™, Decagon Devices, Inc.) to see if we can further improve on this efficiency. A sensor network was installed in Nov., 2015 in two production tunnels, one to monitor the pulse irrigation events made by the grower, the other on sensor-based irrigation control. Sensor-controlled irrigation is initiated when the average soil volumetric water content (VWC) decreases below a set-point of 19% that optimizes VWC throughout the 35 cm bed depth. Soil moisture is monitored in each tunnel with three radio dataloggers, each with 10-HS sensors at 10 cm and 20 cm depths in the root zone. One of these dataloggers enables control by averaging the 10-HS sensor VWC readings, and by opening and closing a 12V-DC latching solenoid (Netafim) via a relay on the node. Water applications in each tunnel are also monitored with real-time flow meters. Additionally, soil matric potential is monitored at 10 cm (in the root zone) and electrical conductivity (EC) for nutrient leaching at 35 cm (MPS-6 and GS3 sensors respectively, Decagon Devices). All sensor data is logged and transmitted to a computer and base station on the farm, which is connected to the internet with an air-card modem. All data is integrated into a sophisticated graphical database program (Sensorweb™, Mayim, LLC) that also allows real-time communication with the control nodes to adjust irrigation events, if needed. The Sensorweb software provides micro-pulse (1-5 min) irrigation control capabilities, which further optimizes irrigation water applications. During the first 45 days of control (28 Jan - 12 March, 2016), the grower applied 254,975 L of irrigation water in 1-4 pulses per day, compared to 130,510 L applied with sensor-based control (49% less water). Matric potential in the root zone averaged -10kPa, with minimal leaching of nutrients below 35 cm for the sensor-controlled irrigation. Further increases in irrigation and nutrient application efficiency are likely during the upcoming harvest period (March through May). A full analysis of grower versus sensor-controlled irrigation applications and crop yields will be given for the 2016 season.

Keywords: plasticulture, strawberry, sensor-controlled irrigation, micro-pulse, volumetric water content, soil matric potential

Intra-vineyard variability description through satellite-derived spectral indices as related to water status and other vine physiological indices

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In the Castel del Monte DOCG area, focusing on a vineyard of Moscato Reale (syn. Moscato Bianco), a long time series of Landsat 8 OLI multispectral data ground reflectance calibrated were collected for the period April 2013 – February 2016. NDVI, EVI and SAVI spectral indices were calculated from the available bands to generate indices time series useful to describe, at pixel level (30 x 30 m), local vineyard phenology. The NDWI (*Normalized Difference Water Index*) index was also calculated as proxy of surfaces water content. The vineyard physiological behaviour was explored along different growing seasons looking to integrate satellite-derived information with ground parameters, measured in different vineyard zones, related to vegetative, reproductive, and physiological grapevine activity with special regard to water status, and to berry quality. Correlations between satellite-derived spectral indices and physiological indices, including water status, were individuated.

We found that, at vineyard level, middle resolution multispectral imagery from satellite, if properly acquired and elaborated, is an effective tool for describing physiological behaviour and comparing it among different seasons; moreover, since start data are free, the entire process is economic enough to be consistent with cost and incoming of farms.

Keywords: NDVI, EVI, SAVI, NDWI, ecophysiology

Opportunities and pitfalls in the use of thermal sensing for monitoring water stress and transpiration

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This paper will review recent progress in the development of thermal sensing (both in-field and remotely from UAVs, aircraft or satellites) as a tool for the study of plant water relations and for estimating stomatal conductance and transpiration from crops. Opportunities for future applications in horticulture using both single point sensors and imagers will be emphasised with discussion of the use of field phenomobiles, remotely piloted aircraft systems and fixed sensor networks. Particular challenges limiting the wider uptake of thermal sensing including the treatment of mixed pixels and the use of reference surfaces for absolute estimates of evaporation will be discussed.

Keywords: infrared thermography, stomatal conductance, transpiration, UAVs

Automated sensor-control strategies for drip irrigation of containerized *Chrysanthemum*

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Precision irrigation control of containerized plant material is essential to not only reduce the frequency of irrigation events of plants grown in porous soilless substrates, but also to reduce nutrient runoff to containment ponds and surface water bodies. We are investigating source reduction strategies as part of an integrated national project (i.e. to reduce, remediate and recycle irrigation water, SCRI-Water³). Commercial production facilities are integral to understanding how sensor-based technologies and decision strategies can be implemented at scale. From May through Sept. 2015, two blocks of *Chrysanthemum* in a commercial operation were each monitored with a sensor network consisting of four EM50R (monitoring) and one nR5 (prototype control) nodes (Decagon Devices, Inc., Pullman WA). Five GS1 sensors (per node) were inserted vertically through the side wall of individual 5L (35 cm diameter) containers into the peat-based substrate. The major objectives of this initial study were to (1) understand the variability of the drip irrigation system and soil moisture at various positions in each production block and (2) determine the specific placement of monitoring nodes, to minimize the number of nodes and sensors required for making a good irrigation decision, based upon a set-point substrate volumetric water content (VWC). The VWC set-point for the sensor-controlled (SC) block was set just below container capacity at 39%, so as to not compromise plant size and quality. In addition, minimizing the pulse-time of individual irrigation events (to no more than 4 minutes per pulse) optimized the distribution of irrigation water to all plants within the block, even at the furthest laterals from the solenoid valve. The variability of daily substrate VWC in the grower-controlled (GC) block was significantly greater than in SC block, as the grower typically only irrigated 1-3 times per day (with 15 min irrigations), compared to the SC block which typically irrigated 3-4 times per day (each with three 4-minute pulses). Sensor-controlled irrigation only saved from 9 - 22% of total monthly water applications, compared to GC irrigation (total study savings of 13%), but there were no significant differences between plant canopy dry mass (or canopy volume / number of flower buds) between treatments. This was in spite of GC plants being in water deficit (< 20% VWC) for significant lengths of time each day during August. The experiment will be repeated during 2016, with lower SC set-points (\pm 30% VWC), using only two monitoring nodes (10 sensors) per block. It is apparent that *Chrysanthemum* is more tolerant of low substrate VWC during the day, as long as those periods of temporary water stress do not lead to visible signs of wilt. Lowering substrate set-points should allow us to increase water savings, without any significant effect on production time, or crop quality.

Keywords: container-production, sensor networks, volumetric water content

Determining plant available water to practically implement deficit irrigation strategies in Strawberry production

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A field experiment was conducted at the University of Maryland Wye Research and Education Center in 2015 to study deficit irrigation (DI) in strawberry (*Fragaria X ananassa*) production. A wireless sensor network consisting of nR5-DC control nodes (Decagon Devices, Inc., Pullman, WA) independently irrigated replicate plots, based on soil volumetric water content (VWC) measurements. Soil water retention curves for the study site were developed using a Hyprop apparatus (UMS, Germany); soil matric potential (SMP) values were determined for a control (-30 kPa) and three DI treatments (-40 kPa, -50 kPa and -60 kPa). Corresponding VWC values for the SMP levels were then determined by fitting the Mualem-van Genuchten (1980) model to the soil moisture retention data. These VWC values (36.7%, 33.5%, 32.1% and 30.2%, respectively) were used as threshold values/set-points in Sensorweb™ software (Mayim, LLC., Pittsburgh, PA). Irrigation events were triggered when the average VWC from duplicate 10HS soil moisture sensors (Decagon Devices, Inc.) placed in the root-zone of plants in each plot was lower than the corresponding threshold value. *In-situ* field SMP data for each treatment were measured using MPS-6 matric potential sensors (Decagon Devices, Inc.) in each plot. Daily Irrigation application volumes for each plot were also measured using flow meters (Badger Meters, Milwaukee, WI). Significant decreases in irrigation volumes were observed for the DI treatments, together with decreased fruit numbers and yield, indicating the sensitivity of strawberry plants to changes in plant available water (PAW) within the relatively narrow SMP range imposed in the study. We are repeating the study during spring 2016, to further validate soil moisture and SMP measurements using T8 field tensiometers (UMS, Germany) and more accurately quantify PAW for the control and DI treatments. Understanding responses of strawberry plants to changes in SMP and PAW is essential to identify effective DI strategies, to improve irrigation water use-efficiency and reduce potential nutrient leaching from strawberry production.

Keywords: Strawberry, sensor networks, deficit irrigation, tensiometer, matric potential, volumetric water content

Basis for the fine tuning of deficit irrigation regimes in olive trees based on a novel water stress indicator from sap flow related measurements

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The expected climate conditions in the Mediterranean area demand an increasing use of sustainable water practices in agriculture, such as deficit irrigation (DI). The correct use of the most successful DI strategies, such as regulated deficit irrigation (RDI) requires both a good understanding of main physiological mechanisms involved in the response of plants to water stress, and the use of reliable and sensitive indicators of water stress. Stomatal conductance (g_s) is a good plant-based indicator for irrigation purposes. Besides g_s quick response to increasing water stress, stomatal closure limits photosynthesis and thus, it has important implications for plant function, growth and yield. However, difficulties on monitoring g_s curtails its use for irrigation scheduling purposes. Recently, our research group demonstrated that there is a robust correlation between the changes in sap flux density measured in the outer sapwood section of mature olive trunks and g_s dynamics in the tree canopy, both in response to soil and air water deficit. Stomatal conductance of both sunny and shaded leaves can be reliably estimated from radial sap flux density. A biochemical model of photosynthesis was coupled to the estimated g_s to determine the net CO_2 assimilation rates (A_N) along the season. As expected, our results show that plant growth (leaf area evolution was used as proxy) and yield were highly related to A_N , and our approach was confirmed to be very sensitive to air and soil water deficits. However, our results show that the main determinant of yield was leaf area and not A_N , although both are correlated and markedly affected by RDI. The use of our water stress indicator based on sap flux density appears to be a sensitive tool to schedule a RDI strategy in fruit tree orchards intended to control both vegetative growth and yield by imposing a certain degree of water stress to the trees.

Keywords: sap flow, stomatal conductance, photosynthesis model, yield

Influence of irrigation scheduling using thermometry on peach tree water status under different irrigation systems

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Remotely-sensed canopy temperature from infrared thermometer (IRT) sensors has long been shown effective for detecting plant water stress. To help alleviate water shortage, a field study has been conducted at the USDA ARS San Joaquin Valley Agricultural Sciences Center in California to develop and validate algorithms for determining degrees of water stress and scheduling postharvest deficit irrigation for peach using canopy temperature. The experiment used a 1.6 ha early maturing peach orchard and a total of 18 IRT sensors were used to control six irrigation treatments that included furrow, surface drip, and micro spray irrigation systems with or without postharvest deficit irrigation. During the postharvest period in 2012-2013 and 2013-2014 growing seasons, midday stem water potentials (ψ) of well irrigated trees were maintained at a range of -0.5 to -1.0MPa while ψ of deficit irrigated trees declined to extremely low values. Soil water contents in deeper depths were relatively low in surface drip irrigation than those in furrow and micro spray irrigation plots. Number of fruits and fruit weights from trees under postharvest deficit irrigation treatments were less than well irrigated trees, but no statistical significant reduction in fruit size or quality was found for trees irrigated by surface drip and micro spray irrigation systems ($p < 0.05$). At least 50% of water was saved by using deficit irrigation during postharvest seasons. Our results suggest the feasibility of using IRT to control full and deficit irrigation for early maturing peach trees.

Keywords: irrigation, peach

Effect of variable fetch on flux-variance estimation of whole canopy sensible and latent heat fluxes in a pepper screenhouse

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Knowledge of crop evapotranspiration (ET) is important for accurate irrigation. The area of cultivation under screens has rapidly increased in Israel and worldwide. ET data is well documented for many crops grown in open fields, but for crops under screens or in screenhouses it's rather scarce. Consequently, research on methods to measure and estimate ET in protected cultivation systems has increased. We have shown that the eddy covariance (EC) technique can measure whole canopy ET in screenhouses. However, it requires expensive equipment and complex data analysis; hence it is for research only. Aiming at developing a low-cost and simple method that will be available for day-to-day use by growers, we investigated here the flux-variance method (FV), which is based on high frequency measurements of air temperature near the canopy top by a miniature thermocouple. Air temperature standard deviation is calculated and following Monin-Obukhov similarity theory, sensible heat flux is estimated. Additional measurements of net radiation and soil heat flux allow extraction of ET from energy balance closure analysis. Since air temperature can be measured near the canopy top we hypothesize that fetch requirements can be relaxed relative to those for EC and a relatively small fetch is sufficient for reliable flux measurements by FV.

In the present study, the FV technique was examined in a pepper crop in an insect-proof screenhouse in southern Israel. Five miniature thermocouples were installed above the canopy at various distances from screenhouse edges, providing variable fetch from 30 to 150 m, depending on external wind direction. Measurements of stem sap flow in 10 pepper plants provided data on the latent heat flux. Net radiation and soil heat flux were measured to analyse energy balance closure and an eddy covariance system above the canopy measured sensible heat flux. Sensible heat flux from FV was regressed against reference data from the EC. Results showed that the FV similarity constant, C_T , varied between 3.5 and 4.4 and was independent of fetch. ET extracted from FV and energy balance closure was regressed against values calculated from stem sap flow measurements. Results showed deviations of up to 23% between FV and sap flow based ET, with reasonable coefficients of determination, mostly above 0.56. We conclude that in the insect-proof pepper screenhouse (i) the FV technique was reliable in estimating ET and (ii) C_T was nearly independent of fetch.

Keywords: Evapotranspiration, Eddy covariance, sap flow.

Advanced experimental and modelling methods for better estimation of field capacity, permanent wilting point and the total available soil water in the root zone

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Advanced experimental methods and modelling techniques are now more accessible to researchers. These methods can be used to conduct a more realistic characterization of soil water storage and movement and the availability to plants, in order to enhance the accuracy of simulations that may mimic soil moisture dynamics, calculate the water balance and assess the plant response to water stress. Total Available Water (TAW) in the root zone is commonly defined as the amount of water that can be hold in the soil that is available to plants, that is, the difference between the water content at Field Capacity (FC) and permanent Wilting Point (PMP). If the Soil Moisture Release Curve (SMRC) and the Unsaturated Hydraulic Conductivity Curve (UHCC) can be determined experimentally with high resolution and accuracy, moisture content values could securely be related to water potential and hydraulic conductivity. This provides a new approach to obtain more realistic in-situ values of water content at Field Capacity (FC) and Permanent Wilting Point (PWP), and eventually, relate the atmosphere evaporative demand, plant water status and moisture availability in the root zone. Historically, laboratory, field, and modeling approaches have been used to measure or estimate FC, PWP and available water in the soil. In recent years, a combination of the evaporative and vapor pressure methods has been put together as a bench-top instruments suite (Hyprop[®] + WP4C[®]). This system allows generating, simultaneously, high resolution SMRC and UHCC, with undisturbed and disturbed samples, as well as adjusting different mathematical models to the experimental data. In this work, these curves are used to parametrize Hydrus-2D to simulate the wetted volume under a dripper, obtaining 2D water content and matric potential dynamic values. The derived analysis of the SMRC & UHCC and the 2D soil moisture dynamics allow for a much better estimation of FC, PMP and TAW, in comparison with estimated values from pedo-transfer models.

Keywords: Total Available Water, Field Capacity, Permanent Wilting Point, Moisture release Curve, Unsaturated Hydraulic Conductivity, Soil Moisture

Application in produce quality: Manipulating fruit dry matter content through plant water status

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Handheld shortwave near infrared spectroscopy is used in the Australian mango industry to non-invasively monitor fruit dry matter content (DM) on tree, with a 15% DM recommended for the dominant varieties as a specification on harvest maturity and as a level that translates into a consumer acceptable taste upon fruit ripening (with conversion of starch to sugars). Plant water status is one tool available to a farm manager to influence DM during fruit development. Examples of management manipulations of plant water status to alter the trajectory of fruit DM will be discussed.

Keywords: dry matter, *Mangifera*, NIRS

How to measure stomatal conductance of lettuce leaves via thermography

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Infection of lettuce plants by a soil-borne pathogen such as *Rhizoctonia solani* can result in different response by the plant, e.g. a lower stomatal conductance. Possible explanations for this response might be a reduced water transport capacity from roots to leaves and resulting water stress or a hormonal long range effect caused by the fungus. One way of measuring such changes in stomatal conductance non-destructively can be thermography. In this work, the relationship between stomatal conductance and leaf temperature from thermography is studied. Therefore, lettuce (*Lactuca sativa* var. *capitata* 'Tizian') is grown in standard cultivation substrate. A range of stomatal conductance values is generated by different soil water target tensions between 100 and 800 hPa. Thermographic images are obtained from a VarioCAM high resolution system. Reference values of stomatal conductance are gained from gas exchange measurements using the LI-6400 portable photosynthesis system. To estimate stomatal conductance directly from thermography, additional dry and wet references are necessary to get knowledge about minimum (all stomata closed) and maximum (all stomata with maximum degree of opening) stomatal conductance. Several approaches are conceivable to realize those references. Two strategies are tested here: (a) real plants, which are sprayed with water (wet reference) or sprayed with petroleum jelly (dry reference) and (b) technical references consisting of metal pads painted with a color having the same absorptance as real lettuce leaves. The effect of petroleum jelly is to occlude all stomata, which prevents most of the leaf transpiration. Reference objects are always captured together with the test plant on the same thermal image. The presented outcome of this study will be (a) a correlation between stomatal conductances derived from gas exchange measurements and thermal images and (b) a comparison of real plants and artificial surfaces as reference objects with respect to adequacy, feasibility and effort.

Keywords: lettuce, thermography, stomatal conductance

Drought - challenge of the future for tress and science

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Climate change may foster intensity and duration of drought in southern Germany. Mean annual air temperature would need, in the long term, to increase by about 2°C only, and annual precipitation decrease by 200 mm to prevent persistence of closed-canopy forests. Such fluctuations have occurred sporadically, as e.g. in 2003, when both European beech and Norway spruce distinctly declined in productivity, staying inhibited even for another three years of "regular climate".

Obviously, drought challenges trees – albeit also science, as uncertainty about species-related die-off processes hinders management strategies to reliably provide for silviculture in a warming, water-limited future. Two experimental studies will be highlighted in overcoming knowledge deficits, on (i) reforestation upon wind-throw with juvenile beech, being under light stress and competitive drought by residual spruce trees; and (ii) mechanisms of drought-associated die-off in neighbouring maturing beech and spruce trees through an automated rain exclusion experiment. Explored are extents and complementarity of isohydric versus anisohydric strategies in trees' control of water shortage. Drought response is intermingled today, however, with such to enhanced ground-level O₃ regimes, requiring whole-tree dose assessment. Derivation is demonstrated (iii) to be achievable through sap flow measurement, valuing O₃ impact on productivity and water-use efficiency in interaction with drought.

Will tree performance be driven in the future by facilitation rather than competition? Is "over-yielding" of mixed-species forests relative to monocultures an indication already on resource-poor sites? Understanding of biotic and abiotic interaction principles is inevitable for meeting silvicultural challenges of the future.

Keywords: *Fagus sylvatica*, *Picea abies*, Drought, Competition, Facilitation, Over-Yielding, Ozone Impact

Lysimetry for whole-tree water balance and ‘Sensing’ of effects of plant size, climate and physiological processes on transpiration

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Drainage-weighing lysimeters allow monitoring of water balance components. Whole plant evapotranspiration is affected by plant (canopy) size, weather conditions, water availability, phenological stage, and stress causing factors. Olive (*Olea europaea* 'Barnea') trees were used to demonstrate full tree monitoring of transpiration while alternatively analysing short term drought, salinity and fruit load. Techniques to process accumulated time-course data in order to differentiate between effects of stress-causing factors, tree growth, and weather conditions governing potential evapotranspiration are demonstrated.

The concept of a normalized “effective transpiring canopy area” ($\text{m}^2 \text{ tree}^{-1}$) calculated using actual ET ($\text{L tree}^{-1} \text{ day}^{-1}$) using weight data of whole trees divided by reference ET (mm d^{-1}) is introduced. This results in precise, dynamic measurement of relative plant size. Additional normalization by dividing ETa by canopy area allows determination of influence of physiological processes on water status and consumption.

Results emphasize the value of actual water balance measurement. The feasibility of in-situ use of lysimeters as sensors in the field will be discussed.

Keywords: water balance, evapotranspiration, fruit trees, olive

NIR spectroscopy as a new plant phenotyping technology for static and on-the-go assessment of grapevine water status under field conditions

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In recent years, effective high-throughput phenotyping platforms (HTPPs) have started to be developed, and used in controlled environments to capture detailed, non-invasive information of main agronomical and physiological traits of the plant throughout its life cycle. However, results obtained under restraint scenarios have not replicated under field conditions, as plants experience more heterogeneous situations in the field, including environmental changes and competition from adjacent plants.

In this work, a new plant phenotyping technology, based on NIR spectroscopy is presented and compared with traditional, destructive methods to address a key grapevine trait: the plant's water status. Experimental data were acquired in seasons 2012 and 2015 in three commercial vineyards of Tempranillo, in La Rioja (Spain). NIR spectra were manually acquired with a portable device covering the range of 1600 to 2400 nm in 60 leaves, while on-the-go spectral acquisition was conducted with a NIR spectrometer (1200 – 2100 nm) operating at 30 cm distance from the canopy (both sides were measured), mounted on a quad moving at 5 km h⁻¹. Stem water potential (ψ_{stem}) was also measured and used as reference method. All measurements were carried out in leaves of the mid-upper part of the shoots at solar noon, between 1 and 3 pm. Regression models were built using partial least squares and other data mining techniques. Values of $R^2=0.92$ and RMSE=0.098 were obtained for the prediction of ψ_{stem} using the manual portable device, while R^2 equal to 0.81 and 0.85 and RMSE equal to 1.54 and 1.36 MPa were achieved using the on-the-go acquired NIR spectra from the shaded and sunny sides of the canopy, respectively.

These results are promising and evidence the potential of non-invasive, NIR spectroscopy to become a helpful phenotyping tool to appraise the vineyard water status, either statically or on-the-go, and to become a practical tool to drive irrigation scheduling decisions in viticulture in the short term.

Keywords: water stress, irrigation scheduling, stem water potential, in-field phenotyping

Hydraulic and stomatal factors affecting water transport

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Water uptake and transport are complex processes affected by root hydraulic conductance and water utilization, as mediated by leaf. Arbuscular mycorrhizal (AM) fungi may colonize roots and regulate stomatal behaviour contributing to the overall water economy of the tree. This study test whether AM colonisation has a beneficial effect on total root hydraulic conductance and leaf gas exchange parameters in olive trees both well irrigated and under drought.

Approx. 20 2-year old potted olive trees were inoculated with *Glomus intraradices*, 10 inoculated trees were kept well irrigated (WI) while the remaining were droughted (D) till a value of -2 MPa predawn leaf water potential (ψ). Additional 20 trees were not inoculated and served as control. Hydraulic conductance (K , $\text{kg s}^{-1} \text{MPa}^{-1}$) was determined by a HCFM (Dynamax, Inc. USA) (0.1-0.5 MPa of applied pressure). Leaf transpiration (E), assimilation (A) and stomatal conductance (g_s) was appraised through the LI-6400 (Li-Cor Inc., NE, USA).

Drought in non-inoculated trees induced a decline of midday K from 1.1 ± 0.1 (SE) to $0.9 \pm 0.1 \text{ kg s}^{-1} \text{MPa}^{-1}$, AM fungi maintained K stable or even higher at $1.3 \pm 0.1 \text{ kg s}^{-1} \text{MPa}^{-1}$ (inoculated D trees). A positive impact on hydraulic transport ($\sim 23\%$ increase of K) was also detected in mycorrhizated WI trees. In WI trees, average daily A remained similar in control and mycorrhizated trees ($\sim 4 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$), concomitantly it was registered a significant reduction of E and g_s in mycorrhizated WI trees compare to non mycorrhizated WI. In D trees, a similar response of E and A was detected, while g_s was not clearly affected by AM.

This study revealed that AM may regulate both K and some gas exchange parameters in both WI and D olive trees and that the fungi improved the water use efficiency at leaf scale. It could be concluded that knowledge and improvement of soil biodiversity (including AM) through sustainable practices may be in favour of an optimal water use in agriculture.

Keywords: *Glomus intraradices*, water transport, water stress, mycorrhizas, gas exchanges

Water repellency as a main factor influencing evolution of physical properties of peat and plant development

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Recent studies have shown that growth period largely affected physical properties of substrates, and therefore irrigation management has to be revised according to these changes in order to avoid poor irrigation. This study aimed to analyse the respective effects of root development and irrigation strategies on the physical and hydraulic properties of a peat substrate within a culture of *Rosa x hybrida* 'Radrazz' grown with and without plants during four months, for which watering was managed in three different ways: (1) water potential always maintained at container capacity, (2) irrigation triggered when water potential reached -10 kPa or (3) -30 kPa. Also, another experiment was conducted with another peat substrate with or without wetting agent incorporated, from which irrigation was managed with a minimum -30 kPa threshold, in order to identify the influence of peat wettability on the evolution of physical properties of the substrate and on the plant development.

Root volume, total volume, air and water retention properties, hydraulic conductivity, relative gas diffusivity, and wettability were evaluated at the beginning and at the end of the experiment. The study showed important changes over time, mainly due to the hydric history, leading to large and higher modifications of pore size distribution, tortuosity and wettability as a function of the intensity of the drying/wetting cycles. Changes in wettability, and notably, more hydrophobic properties of the coarser porosity due to its drainage during the drying processes was suggested for explaining the general physical/hydraulic behavior of growing media, and the decrease in shoot dry mass and root content with the intensity of irrigation regimes. Although they were with weaker amplitude to those resulting of the hydric history, positive effects of the root system were shown, increasing pore connectivity, relative gas diffusivity and limiting the decrease in total pore volume, and moreover, limiting the degradation in wettability.

Keywords: wettability, relative gas diffusivity, pore tortuosity, water retention, air filled porosity

Calculating and verifying canopy temperature, stomatal conductance and transpiration from remotely-sensed plant parameters

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Remote sensing of plant canopy temperature has tremendous potential for estimating water and carbon fluxes in plants. Data from continual plant monitoring, whether ground-based or aerial, can be used for estimations of plant water use and stress status. Such data, thus, can allow for plant-based irrigation scheduling (timing and amount required), and yield estimations. Currently, indirect estimations of plant water requirements from soil moisture content involve complex equipment and many steps. Similar determinations from empirical crop coefficients such as crop water stress index (CWSI) may work for producers located near reliable weather stations but have limited applicability under cloudy and windy conditions. Calculating plant water needs from simple and direct plant monitoring methods of canopy temperature and ground cover may provide an effective and less empirical alternative. Here, we calculate canopy stomatal conductance (g_c) and transpiration with the Penman-Monteith (PM) procedure using weather and oblique-angled infrared thermometer (IRTs) data, and compare against g_c and transpiration determined from heat-balance type sap flow gages installed on field plants. We also calculate plant canopy temperature using PM and weather data, and compare against IRT data. Efforts here verify ET calculations determined from PM against ET determined from plant measurements of sap flow.

Keywords: Sap flow, Plant transpiration, Plant ecophysiology, Irrigation scheduling

Sap flow-dendrometer interactions as an avenue for plant drought stress detection

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High-resolution dendrometer and/or sap flow data are widely used as drought stress indicators. We often use these data simultaneously and in combination with a mechanistic plant model to quantify hydraulic functioning and growth of stems. Automated data processing using a cloud service enables instant visualization of water movement and radial stem growth, and real-time plant modelling makes displaying the mechanisms underlying plant responses to drought possible. A central quantity that emerges from this promising measuring-modelling approach is turgor. Turgor, or the positive pressure in living cells, intimately links tissue water and carbon balances through osmotic pressure. It is also the exclusive driving force for cell wall expansion and growth, and controls cell formation, deposition and assembly of new cell wall material. Understanding dynamics in turgor is thus critical to understand growth and drought physiology of plants. Turgor not only decreases with intensified drought as predicted by the Höfler diagram, but also changes dynamically within a day, because living cells act as internal water reserves that are depleted daily and subsequently replenished overnight to overcome temporal imbalances between water loss by leaf transpiration and water uptake by roots. Water released from living cells serves as a buffering system for smoothing abrupt changes in xylem water potential. Vulnerability of a plant to drought stress thus hinges on the interplay between drought-induced cavitation and the capacitive function of the tissues in the stem.

The role of green tissues beneath the bark is often ignored in this intense debate on drought mechanisms, but may have far-reaching implication of how plants cope with water deficit. Refixation of respired CO₂ by photosynthesis in these chlorophyll-containing cells provides carbon locally. This so-called woody tissue photosynthesis has recently been emphasized to become increasingly important under drought, when supply of photosynthate from leaves decreases due to stomatal closure and impaired phloem translocation.

The goal of this keynote talk is to provide an overview of fascinating new findings about the functioning of stems during limited water availability, and the contribution of woody tissue photosynthesis toward maintenance of the functional integrity of xylem in plants. The role of sap flow sensors and high-resolution dendrometers in these new discoveries will be highlighted.

Keywords: dendrometer, review, sap flow, sensor

Effects of mild water shortage on water relations, leaf gas exchanges, fruit growth and vascular flows of two different cherry cultivars

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Cherry trees of the cultivars 'Black Star' and 'Vera' were subjected to two different irrigation regimes: commercial control and 30% reduced irrigation. The daily patterns of stem, leaf and fruit water potentials, leaf gas exchanges as well as fruit vascular flows were monitored before (pit hardening stage) and after (cell expansion stage) veraison. Also, fruit growth was monitored during the whole season and growth rates calculated weekly. In both cultivars, pre-veraison fruit growth was characterized by high xylem and transpiration flows with the phloem accounting for about the 30% of the fruit total daily inflows. At this stage, all parameters monitored were not affected by reduced water supply, except for stem water potential, which showed reduced values in 'Black Star' but not in 'Vera'. At post-veraison, an increase in fruit daily growth rates and in the phloem contribution (reaching up to 70% of fruit total inflows) was recorded in both cultivars. However, 'Vera' showed 40% higher fruit phloem inflows and daily growth rates compared to 'Black Star'. Also, at this stage, the two cultivars showed different responses to reduced irrigation: 'Black Star' showed decreased stem water potentials and afternoon leaf gas exchanges, but no difference in fruit vascular flows and fruit growth, while 'Vera' maintained similar stem water potentials and leaf gas exchanges but decreased fruit water potential, fruit phloem inflow and fruit growth rates. These results lead to conclude that: i) cherry sensitivity to mild water stress increases from pre- to post-veraison; ii) at post-veraison, 'Vera' can be considered more sensitive to water shortage due to its need to sustain higher fruit growth rates compared to 'Black Star'; iii) different sensitivities to water shortage among cultivars may depend both on the amount of resource required by their growing fruit and on the tree ability to decrease stem water potential.

Keywords: Fruit growth, Leaf gas exchanges, Phloem, *Prunus avium* L., Xylem, Water potential

Drought induced cavitation in juvenile beech and spruce trees: which are their water use strategies and margins for embolism repair?

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Shifts in precipitation patterns and increasing temperatures associated with global climate change are assumed to cause widespread decrease in forest area. Water limitation can put at risk the survival of European beech and Norway spruce, tree species of high economic and ecological importance in Central Europe, where droughts are predicted to increase in duration and severity.

When beech and spruce are subjected to drought, there's a need of clarification of: 1) their species-specific water use strategies 2) their capability to recover after drought and the relative mechanisms and factors involved.

In potted beech and spruce juvenile trees, subjected to progressive drought in a greenhouse, leaf water potential, gas exchange, percentage loss of stem conductivity (PLC), stem non-structural carbohydrates (NSCs) have been measured during the drought period and after having resumed irrigation.

Our data: 1) support the hypothesis of a more conservative water use in spruce, limiting water loss and protecting the xylem from cavitation, but an evidence of use of carbohydrates reserves; a more risky strategy in beech, with limited regulation of water uptake and rapid drop in water potentials and related PLC; 2) discuss the extent to which recovery and embolism repair occur and the related involvement of soluble sugars and starch in the stem.

These findings, underline the importance of understanding water use mechanisms of trees, whether used in silviculture or horticulture, as the shortage of water will also increase the significance of water management for horticulturally grown plants. Moreover, NSC content should be taken into account, as also involved in determining productivity, growth, survival and recovery of plants under drought conditions.

Keywords: *Fagus sylvatica*, *Picea abies*, drought, greenhouse, cavitation, water relations, isohydric, anisohydric, recovery, embolism repair, NSC

Morphological adaptation of apple trees due to spatially occurring drought stress

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Precision fruticulture addresses site, or tree-adapted crop management. In the present study, we analyzed the soil's apparent electrical conductivity (ECa) and plant water status in apple production (*Malus x domestica* 'Gala Brookfield'/Pajam1). Our 2-years analysis targeted the spatial characterization of the plant water status.

The experiment was carried out in a commercial apple production with 1180 5-years old trees located in temperate climate, 430 m elevation, with an average precipitation of 906 mm (Prangins, Switzerland, over 30 years). The trees planted in 1 m distance within the row, were covered by hail net in 3.5 m height. The soil texture captures 26% clay, 29% silt, and 45% sand. During the 2-years experiment, treatment with 100%, 50%, and zero irrigation was applied. The soil ECa was measured using an equidistant (0.5 m) Wenner array with the centre at the tree stem using a resistivity meter. Osmotic potential of leaf and stem water potential [MPa] were recorded on 33 trees. Canopy temperature was recorded using FLIR A655sc Infrared camera with 640 × 480 micro-bolometer sensors of LWIR (long wave infrared) spectral range (7.5-13 μm, 0.05 °K sensitivity) and IR (infrared) lens (f = 24.6 mm, 25°). The light detection and ranging, LiDAR, technique was applied using the laser scanner mounted on a tractor to obtain point clouds in side view of the 1180 trees. Fruit quality was measured at the harvest date including the analysis of the chlorophyll pool capturing chlorophyll *a*, *-b*, and pheophytin. Finally, we performed statistical analyses using the statistical package for MATLAB® (R2015B, MathWorks, U.S.) and the free algorithms for spatial analysis.

The soil ECa showed very low variability in the range 0 to 4 mS/m. Based on these values spatial pattern were found in the hot spot analysis (hot spots = 14 and cold spots = 40 spread over all treatments). The CWSI values expressed some variability of spatial pattern (non-significant differences) reflecting irrigation treatments. In the LiDAR readings, the number of hits per tree ranged from 919 to 7261 considering all trees, showing significant ($F=2.61$, $p<0.0001$) differences between non-irrigated and irrigated zones. Fruit pheophytin, a chlorophyll degradation product, was enhanced in drought stress zones.

Keywords: Apple, CWSI, hot-spot-analysis, LiDAR

Sensing of crop reflectance for water stress detection in greenhouses

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Water stress is one of the most important growth limiting factors in crop production. Several methods have been used to detect and evaluate the effect of water stress on plants. The use of remote sensing is allowed particularly and practically suitable for assessing water stress and implementing appropriate management strategies because it presents unique advantages of repeatability, accuracy, and cost-effectiveness over the ground-based surveys for water stress detection. The objectives of this study were to 1) determine the effect of water stress on greenhouse crop using spectral indices and crop temperature readings and 2) evaluate the reflectance spectra using the classification tree (CT) method for distinguishing water stress levels/severity. For this reason, two different irrigation treatments were imposed in tomato plants grown in slabs filed with perlite, namely tomato plants under no irrigation for a certain period; and well-watered plants. Hyperspectral camera and infrared thermography were used to provide remotely plant reflectance and temperature measurements during the periods with the normal or the low substrate water content. Classification tree (CT) was developed to investigate the relationship between the categorical data and determine the variables affecting other independent variables. The advantage of tree-based classification includes that it does not require the assumption of probability distribution, specific interactions can be detected without previous inclusion in the model, non homogeneity can be taken into account, mixed data types can be used and dimension reduction of hyperspectral datasets is facilitated. A large number of vegetation and water indices has been compiled in order to measure plant vigor and other biophysical parameters using the remotely sensed data.

Keywords: hyperspectral imaging, infrared; vegetation index, reflectance index

Xylem tension, lower apoplastic water content and high tissue rigidity improves supercooling capacity during winter

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Olive is an evergreen tree considered highly drought resistant and moderately resistant to low temperatures. Olive tissues do not tolerate ice formation and present supercooling as a mechanism to resist low temperatures. The aim of this work was to evaluate water relations and the mechanisms involved in the frost resistance in five olive cultivars growing in pots during winter and summer in the Patagonian steppe in Southern Argentina. We determined leaf pressure volume curves and measured midday (Ψ_{\min}) and pre-dawn (Ψ_{\max}) leaf water potentials, ice nucleation temperature (INT) and flux density (δ) at the base of the trunk. All cultivars exhibited Ψ_{\min} and Ψ_{\max} significantly lower in winter than in summer. In winter Ψ_{\min} varied between -2.68 MPa and -3.21 MPa, while in summer none cultivars presented Ψ_{\min} lower than -2.1 MPa. Bulk elastic modulus (e) increased in winter in all cultivars. The apoplastic water fraction (AWF) was lower in winter compared to summer in three of the study cultivars. In winter the observed range of leaf osmotic potential at turgor loss point (π^0) was -1.2 to -1.7 MPa, but in summer the range was of -4.1 to -4.7 MPa. During winter INT ranged between -10°C and -13°C, while in summer ranged between -2°C and -6°C. We found strong correlations between INT and Ψ_{\min} , e , AWF and π^0 . Flux density was significantly lower in winter compared to summer. The results suggest that the maintenance of water in an unfrozen state in olive trees during winter is the consequence of the low apoplastic water content, substantially high xylem water tension and tissue rigidity which contribute to improve supercooling capacity.

Keywords: Olive, Flux density, Water potentials, frost resistance

Investigating the relationship between root and soil water potentials to elucidate root-to-shoot signalling responses to soil water deficit

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In the face of changing climate and increasing incidence of extreme weather events, it will be crucial to understand the factors influencing plant resource acquisition and use efficiency. Cultivation of agricultural soils has decreased soil structure, impacting on soil water holding capacity, porosity and soil strength. This may negatively impact plant water uptake and growth, and thence crop yields.

Abscisic acid (ABA) is a phytohormone known to regulate gas exchange and water loss by inducing stomatal closure. ABA is synthesised in response to a variety of abiotic stressors in soil, particularly water deficit. Root water potential is a better predictor of xylem ABA concentration across a range of soil textures than soil matric potential. However, the impacts of soil management practices (e.g. cultivation, compaction, organic matter addition) on the relationship between root water potential and xylem ABA concentration, when texture is held constant, has not been investigated.

A loam-based growing substrate was compressed to three bulk densities (1.1, 1.3 and 1.4 g cm⁻³) in pots designed to fit in a Scholander-type pressure chamber, allowing the water potential of the bulk root system to be measured. After measuring root water potential, additional pressure was applied to collect root xylem sap at flow rates that matched transpirational flow. This allowed accurate determination of ABA concentrations and delivery. Increasing bulk density de-sensitised the relationship between root water potential and xylem ABA concentration. Low bulk density enhanced the increase in xylem ABA concentration as root water potential declined. Further study is required to determine whether changes in soil structure due to management regimes will alter the relationship between root and soil water potential.

Keywords: Abscisic acid, Scholander pressure chamber

Effect of regulated deficit irrigation on vegetative growth and production of apple grown in an open field gully system

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The majority of apple varieties grown in the Netherlands are grafted on rootstock M.9. The vegetative growth of trees on M9 tends to be too high. Still, in many cases irrigation water is applied in the vegetative growth period. Results of experiments in the first or second growth year with apple grown in covered 30 liter pots showed the potential of regulated deficit irrigation (RDI). Maintaining the soil suction level at about 50 kPa during four to six weeks in the vegetative growth period resulted in reduced growth levels of 40 to 50% and no or limited (up to 5%) reduction of fruit weight depending on the number of weeks with water deficit. Reduction of vegetative growth increased the amount and the quality of flowers after pruning in the following winter. Recently a fruit production system was designed and tested to overcome severe soil problems and to increase the application potential of RDI in moderate sea climates. In this system apples were grown in 30 cm wide gullies coated with plastic, with drainage pipes at the bottom and filled with loamy sand, providing each tree approximately 120 liter rooting volume. Results of RDI in the second growth year confirmed the findings of the pot experiments. The improved flowering resulted in increased production without loss of fruit weight in the following year. Repetition of RDI in the third year showed similar effects. The results also showed that increased soil suction levels were needed in later growth years to achieve the same reduction in vegetative growth.

Keywords: Apple, regulated deficit irrigation

Non-invasive analysis of root-soil interaction using complementary imaging approaches

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Plant roots are known to modify physical, chemical and biological properties of the rhizosphere, thereby, altering conditions for water and nutrient uptake. We aim to capture the dynamic processes occurring at the soil-root interface *in situ*.

A combination of neutron (NI), magnetic resonance (MRI) and micro-focus X-ray tomography (CT) is applied to monitor the rhizosphere of young plants grown in sandy soil in cylindrical containers (Ø 3 cm). A novel transportable low field MRI system is operated directly at the neutron facility allowing for combined measurements of the very same sample capturing the same hydro-physiological state.

The combination of NI, MRI and CT provides three-dimensional access to the root system in respect to structure and hydraulics of the rhizosphere. The high spatial resolution of neutron imaging and its sensitivity for water is exploited to analyze the 3D architecture of the root system and the three-dimensional water content in the immediate root vicinity and bulk soil. MRI can yield complementary information about the mobility of water, which can be bound in small pores or in the polymeric network of root exudates (mucilage layer). Additional CT measurements provide information on the pore structure of soil, which is affected by the mechanical interaction of roots and soil, e.g. soil compaction or formation of cracks and macropores.

We co-register the NI, MRI and CT data to integrate the complementary information into an aligned 3D data set. This allows, e.g., for co-localization of compacted soil regions or cracks with the specific local soil hydraulics, which is needed to distinguish the contribution of root exudation from mechanical impacts when interpreting altered hydraulic properties of the rhizosphere. Differences between rhizosphere and bulk soil can be detected and interpreted in terms of root growth, root exudation, and root water uptake. Thus, we demonstrate that such a multi-imaging approach can be used as powerful tool contributing to a more comprehensive picture of the rhizosphere.

Keywords: Imaging, root, sensor, soil

Development of a simple, mobile MRI plant imager

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The application of non-invasive imaging technologies has had a large impact on the study of plant water relations. Magnetic Resonance Imaging (MRI) has made it possible to image the presence of water or the appearance of emboli in the xylem, or to measure, visualize and quantify flow. However, due to the cost, size and specialized nature of the MRI equipment, so far the method has only been applied to plants by a few laboratories world-wide. To make the method more accessible, but also make it available for use in the greenhouse or field, we constructed a basic, mobile MRI imager for plants, maximizing for making it cheap and simple to use.

At the basis of this work was the construction of a mobile 0.25 T, 45 mm gap, C-shaped permanent magnet with a weight of about 16 kg, suitable for MR imaging of objects up to 20 mm diameter. The magnet was fitted with a set of custom built plane-parallel imaging coils, designed for maximum field of view and image resolution, while still offering open access for plant stems. Using a permanent magnet is beneficial due to low purchase and running costs, since neither any power nor liquid gases are required to run it.

In a first demonstration experiment we investigated the effect of drought stress on young spruce and beech trees during a 40 day dry down experiment. Considering the simplicity of the setup and the small size of the magnet, surprisingly highly resolved images could already be acquired with the very first prototype. By means of this data that was obtained weekly over the whole dry down period, insights could be gained on where emboli occur first in the stems of the two species.

Keywords: magnetic resonance imaging, mobile MRI, non-invasive measurement, drought stress, embolism detection

Mobilizing magnetic resonance: sensor like applications and mobile imaging

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Water content and dry matter content are two of the most basic parameters to describe plant performance. Yet, most methods to it are either destructive, or indirect and imprecise. Nuclear magnetic resonance (NMR) does not have these drawbacks. It can be used to quantitatively detect protons in water and organic compounds, and is able to distinguish between liquids and solids. NMR relaxometry thus has become a standard method to measure parameters such as solid fat content or moisture content in seeds – but, until recently, only post-harvest and in a laboratory setting.

In this contribution we present a mobile NMR device that can be used as an on-line sensor, to measure dynamic changes in the water- and dry matter content in the living plant. It currently is suitable for plants of up to 30 mm in diameter, but could be scaled up to 100mm without becoming immobile. The apparatus can be operated in the field, and allows automated, uninterrupted measurements over periods of weeks, with a time resolution of less than a minute. Further, with the addition of a few pieces of hardware, the non-spatially resolving NMR sensor can be used as a fully-fledged small scale mobile NMR imager.

We demonstrate these capabilities by means of experiments on a number of model subjects. In legumes and cereals we used the sensor to measure the diurnal dynamics of leaf water content, as well as diurnal dynamics of grain filling, in response to various osmotic and abiotic stimuli. The method proved surprisingly sensitive and was able to measure water content variations as small as 0.1%. In imaging mode, the durability and utility of a first prototype of the device was proven in the course of a 40 day drought experiment, imaging the trunks of a population of young beech and spruce trees with weekly intervals as they dried down.

Keywords: NMR, MRI, magnetic resonance, imaging, water content, dry matter content, sensor

Observation of water movement in plants by using near infrared spectral imaging and deuterium oxide tracer

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Visual images of water movement through plant tissues will help to understand plant water status and related physiology. To visualize plant water movements, large-scale and expensive devices, such as neutron radiography and magnet resonance imaging, have used so far. In this study, we developed a method to visualize plant water movement by using near infrared spectroscopy combined with deuterium oxide (D_2O) tracer. To examine D_2O can be used as an alternative water tracer in plant systems, we first measured the D_2O uptake speed in rice (*Oryza sativa*) seedling. The average D_2O uptake speed was as small as 70% of water (H_2O) uptake speed. Thus, the different uptake speed between D_2O and water should be taken into consideration when D_2O is used as a tracer. The imaging device consisted of a near infrared camera with a band pass filter. Near infrared images of rice seedlings were obtained for both reflected and transmitted light. The difference in near infrared absorbance between D_2O and water depicted the respective bright and dark areas in the images. The area where water was replaced by D_2O became brighter. For rice leaves the near infrared images for reflected light detected successfully D_2O uptake. On the contrary for roots grown in glass beads the images for reflected light did not detect clearly D_2O uptake because of the disturbance caused by glass bead refraction. Instead, the images for transmitted light detected the D_2O uptake in this case. Our results revealed that the reflected-light image was suitable to visualize D_2O movement in plant stems and leaves whereas the transmitted-light image was suitable in plant roots grown in soil.

Keywords: D_2O , stem, root, *Oryza sativa*

Understanding microstructural deformation of apple tissue from 4D micro-CT imaging

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Water transport in plant tissues is often associated with deformation of the tissues. The ability to visualize and model this deformation is an integral part of better understanding of the relevant parameters involved. Traditional imaging techniques are both time consuming and destructive, this makes them unsuitable for visualizing the tissue deformation process, as both time and environmental conditions are critical parameters. However, even with the use of nondestructive imaging techniques such as X-ray micro computed tomography (micro-CT), visualizing the dehydration process is difficult due to the unstable nature of the samples as well as limitations imposed by accuracy of conventional image reconstruction of deforming objects. As a result, micro-CT images of deforming tissues can often not be processed easily. Here, we applied micro-CT with a novel 4D iterative reconstruction algorithm to more accurately visualize the deformation of apple cortex samples during dehydration such that the deformation process can be quantified.

Outer cortex samples of Kanzi apples of approximately 5 mm in diameter were dehydrated in a controlled environment of 22°C and 30% RH via a interleaved high resolution micro-CT scanning process along with the advanced reconstruction technique to obtain images at 3 µm voxel size. The reconstructed images allowed us to create a time series of high resolution 3D renderings of the changes in the cellular structure of apple cortex samples through the first six hours of the dehydration process. The differential shrinkage rates of the outer and inner cell layers of the samples were analysed, as well as the size and positional changes of cells within the dehydrating samples in reference to the center axis. We expect such quantitative description of cell and cell layer deformation to be useful in enhancing the accuracy of hygro-mechanical models of plant tissues.

Keywords: Apple, X-ray micro computed tomography

Combination of proximal and remote sensing methods for mapping water stress conditions of grapevine

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In the light of climate change impacts on plant physiology, optimising water usage is crucial for crop management. In recent years, optical sensing techniques have been widely spread since they allow the non-invasive evaluation of water stress in a timely fashion. This study combines eco-physiological and optical sensing measurements using a range of platforms, with the aim of testing innovative support systems to farmers for optimising irrigation scheduling. The experimentation, carried out in two vineyards located in Usini and Arzachena (Sardinia, Italy), consisted of four treatments: i) two irrigation treatments applied according to specific leaf water potential thresholds (HIGH and LOW); ii) two reference irrigation treatments (DRY, no irrigation, and WET, irrigation at field capacity). An experimental campaign using the Mikrokopter Okto drone took place on August 2015. The drone was equipped with multispectral and thermal cameras. Since the canopy temperature is an indicator of water stress, crop water stress index (CWSI) values were calculated as the temperature differences between the canopies of the LOW and HIGH treatments and the canopies of the reference treatments. In addition, an automated digital imaging system collected high-resolution vegetation images at daily intervals and the changes in plant colour coordinates (RGB) due to changes in vine phenological stage and water status were detected. The indices obtained from optical sensing observations were then compared with stem water potential, photosynthesis, and fluorescence measurements. Preliminary results indicate that the photosynthesis rate, as well as the efficiency of light use by photosystem PSII, declined under stress conditions and when CWSI values increased. On the other hand, there were no significant differences in efficiency in darkness. This result indicates that the grapevines under our experimental water stress conditions can easily recover their efficiency during the night, activating a defense mechanism that protect themselves from irreversible damages to photosystem

Keywords: Vineyards, Water stress dynamics, Optical sensing technique, Drone, Digital image systems, Ecophysiology, Vine water stress conditions

Integrating thermal surface temperature into Penmanmonteith model for estimating crop water stress and evapotranspiration of an orange orchard in semi-arid region

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This work presents an experimental study and modelling of seasonal actual evapotranspiration (ET_a) of an orange orchard, with drip irrigation, in the semi arid region of Tensift Al Haouz (Central Morocco). The experimental study consists of the measurements of different fluxes (mainly latent heat) exchanged between soil-plant-atmosphere continuum. The modelling of ET_a is based on the modified Penman Monteith equation by introducing a simple empirical relationship between the bulk surface resistance (r_s) and surface temperature (T_s). The proposed model was initially calibrated based on four-years of Eddy Covariance measurements, collected over an orange orchard, and then validated by an independent database collected over four different years. The comparison between measured and modeled ET_a showed that the proposed model correctly estimates ET_a with an error less than 20%. The proposed approach (relationship between r_s and T_s) employed in the Penman Monteith model holds great potential for estimating crop water requirements and crop water stress on an operational basis and at a regional scale, since surface temperature and water status are intimately linked.

Keywords: Evapotranspiration, Penman-Monteith, crop water stress, bulk surface resistance, surface temperature

Relationship between Komatsuna (*Brassica rapa* var. *perviridis*) growth and soil moisture characteristics of a rice-chaff and soil composite in a high-concentration salt solution

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A rice-chaff (75% by volume) and soil (25% by volume) composite (RCSC) is known to prevent root rot disorder under moist conditions and is successfully used in flooding culture of vegetable crops where their deep root zones submerging under water even with salt. The plant survival ratio was significantly higher in RCSC pots (83%) than in normal-soil pots (11%) when salt solutions at concentrations equivalent to that of seawater (3%) were supplied to flooding water. The large water-salt content gradient across the vertical profile of RCSC was caused by its low-capillary features. Furthermore, fresh water was pumped up to the upper layers of the RCSC through hydraulic lift of the roots from the bottom layer. These phenomena may provide a suitable environment for root growth under flooding. We evaluated capillary force and water-retention capacity of three different culture media—RCSC, RCSC prepared using crushed rice chaff (crushed RCSC), and Toyoura sand. The capillary fringe of Toyoura sand was the highest and that of RCSC the lowest of the three culture media, whereas crushed-RCSC had the highest water-retention capacity and Toyoura sand the lowest. We examined Komatsuna growth in a salt solution at concentrations of 2% and 3%. We grew Komatsuna plants (*Brassica rapa* var. *perviridis*) in the three culture media; some plants were grown best in crushed RCSC, whereas all died in Toyoura sand. The high water-retention capacity of crushed RCSC facilitated root growth at the upper layers of the culture media. However, small particles in crushed RCSC increased the capillary fringe, causing the salt solution to rise to the surface and thus some Komatsuna plants did not survive. The low capillary fringe and high water-retention capacity are minimum requirements for plant growth in a salt solution.

Keywords: water stress, salt stress, hydraulic lift, capillary force, root growth

Improving plant water use and performance by collocating and combining in situ and remote sensing instrumentation

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Residential and commercial landscapes are routinely overwatered to ensure plants remain vibrant and visually pleasing. Plant and soil instrumentation, like soil water potential and canopy reflectance, now allow real-time detection of in situ and remotely sensed parameters to better inform models like the classic Penman-Monteith evapotranspiration calculation. However, these approaches are routinely discounted in commercial software offerings, preferring instead simple user-generated model inputs; a choice that has the potential to waste precious freshwater resources. The objective of this study was to combine inexpensive but research-grade instrumentation into an actively managed turf farm to optimize water use and reach a net-zero water loss below zone. The study utilized a three-pronged approach to ensure all aspects of plant growth were considered. Soil water potential and water content sensors were colocated in and below the turf root zone to assess both available and applied water and unutilized water seeping to the ground water. Spectral reflectance of both normalized difference vegetation index (NDVI) and photochemical reflectance index (PRI) were taken over the plant canopy to sense the onset of stress and estimate crop coefficients. And, a microenvironment monitoring station was placed next to the turf to evaluate local meteorological conditions and determine water loss. Results from the ongoing experiment show basic turf management applies water well in excess of plant needs; an expected result. Unexpectedly, collocation of soil sensors provided a rich picture of water availability, soil type, and hydraulic conductivity and has the potential to improve water use models by avoiding user-based inputs. Spectral reflectance measurements proved more challenging as data required intense filtering. Still, key inputs of crop coefficient estimates again offer the possibility of removing this user-generated value. Local ET estimates from the microenvironment monitor showed a much-improved estimate of latent heat flux due to the challenging advective conditions that are common in urban areas. In all, this study shows an exciting opportunity to save scarce freshwater resources using sensor-driven decision-making backed by plant and soil water relations.

Keywords: in situ moisture characteristic curve, plant available water, normalized difference vegetation index, evapotranspiration

Poster Session

Xylem sap flow and water budget of an old beech forest during four years of different drought conditions

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The purpose of the study was the comparison of the hydrological behaviour of an old beech forest stand in three years differing in their meteorological conditions. A warm/dry year (2003) was compared with three other years with cool/wet (2002) or moderate weather (2004, 2005). Investigations were carried out in a 117 years old beech forest in the Northeast German lowlands on sandy soils.

Precipitation, stand precipitation including sap flow, and soil water content were monitored continuously over the whole measurement period. Xylem sap flux measurements were performed during the vegetation period using thermal dissipation probes in different depths in trunks of 10 representative trees. A radial distribution model of the sap flow density pattern was used to compute whole tree and stand transpiration. Increment of stem diameter was measured bi-weekly. Simulations on the water budget were conducted using Biome-BGC in a modified version, which is a process based forest ecosystem model containing a water budget module. Observations were used for model calibration. Simulations resulted in reasonable values compared with observations.

The total canopy transpiration during the seasons 2002, 2003, 2004, and 2005 was 205 mm, 237 mm, 235 mm, and 278 mm, with precipitation sums of 815 mm, 467 mm, 645 mm, and 629 mm, respectively. Reductions of xylem sap flux under summer drought could be assigned to restricted soil water content and were indicated by decreasing stem increment. In the warm/dry year suppressed trees contributed to a higher fraction to whole canopy transpiration of the forest stand. The reduction in transpiration apparently resulted from stomata closure due to an increased vapor pressure deficit, which predominantly affects exposed crown parts. The share of soil water uptake from lower layers was decreased during drought.

Keywords: sap flow, water budget, drought, beech, simulation

Responses of spring wheat to continuous and intermittent drought stress

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Longer drought periods and heavier rainfalls are predicted to be part of future global climate change. In consequence, yields of various crop plants are expected to decrease in the near future. The effects of continuous abiotic stress on plant traits have been well investigated over the last decades. However, still little is known about the consequences of intermittent stress on plants and their interactions with herbivorous insects. In a greenhouse experiment, we investigated the responses of spring wheat (*Triticum aestivum* 'Tybalt') to continuous *versus* intermittent drought stress. Within both water regimes, plants were exposed to different levels of water availability. Plant stress status was assessed *via* chlorophyll fluorescence measurements over time. Morphological parameters and relative water contents were measured at final harvest. Plant responses depended on the magnitude of drought stress and differed between continuously and intermittently watered plants. These drought-induced plant responses might also influence the interactions of wheat plants with their herbivores, thereby further modulating plant performance and yield.

Keywords: crop yield, climate change, drought stress, spring wheat, pulsed stress

Stump sprouts suffer less from drought than seedlings of sessile oak (*Quercus petraea* Liebl.)

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In the presented study we compared young sessile oak of generative and coppice origin in terms of biomass production, transpiration and leaf water potential in relation to water availability. The study was conducted in two sessile oak stands (high forest and coppice), located in the South Moravia, Czech Republic, during the growing season 2015. Sap flow was measured on eighteen seedlings and stump sprouts and analysed with biometric and microclimatic data, including soil water limitations. Leaf water potential was measured simultaneously in two stands, during three full days with contrasting weather and soil water conditions. After the growing season, sample trees were harvested in order to conduct dendrometrical analysis. Inventory data were used to calculate biomass production and to up-scale the sap flow to the whole stand level.

Sprouts had significantly higher height, basal diameter and plant leaf area as compared to seedlings of the same age. This confirmed higher biomass production of sprouts during first years of life. Transpiration of the whole stand was higher in coppice than in high forest during the whole measurement period, despite of its lower leaf area index and stand density. Leaf-scale transpiration was not different in the whole season, however during drought seedlings transpired significantly less. Higher transpiration and leaf water potential of sprouts during drought indicated better water availability and less water stress for sprouts, which resulted in higher biomass production of coppice than of high forest during early development stage.

Therefore, coppice may be an appropriate method of tree regeneration to be adopted on sites characterised by significant water limitations. Moreover, this management system could be beneficial when facing climate changes, as more frequent and severe drought periods are presumed.

Keywords: sap flow, leaf water potential, coppice, water stress, biomass production

Water status measurement in watermelon fruits by using an isopiestic psychrometer

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We measured water status of watermelon (*Citrullus lanatus* (Thunb.) Matsum. et Nakai) fruit by using an isopiestic psychrometer. Distributions of water status in a large size fruit such as watermelon were not investigated frequently. By using isopiestic technique, we investigated the water potential gradients inside watermelons. For this study, we had 2 experiments. In Experiment 1, we considered the changes of water status during fruit growth. We measured the fruit at 0-45 days after pollination. At primary stage, there is no water potential difference between the fruit tissue at the center of the fruits and that near the rind. But at ripening stage, we detected big differences, and the direction of water potential gradient is from the center part to the rind. Turgor of the fruit tissue was almost zero at ripening stage. In experiment 2, we considered the difference of water status between seeded and seedless watermelon fruit. Because seeds might play a role as sink, which induces and accumulates photosynthate for many plant species, water status might be influenced by seeds in a fruit. We also measured the water status for both varieties of the fruit at 0-45 days after pollination. In result, water potentials of the center tissues of and that around seed dramatically decreased as watermelons matured and water potential gradients showed similar pattern whichever fruit contain seeds or not. We will discuss these measurements at the presentation.

Keywords: Isopiestic psychrometer, Watermelon, Water potential gradient

Effects of thermal gradients in sapwood on stem psychrometry

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Water potential measurements are widely considered the gold standard for determining plant water status and drought stress in nature and horticulture. Plant water potentials are routinely measured destructively using Scholander pressure chambers, but that method is labour-intensive and the resulting data are discrete in time. Stem psychrometers allow monitoring plant water potentials continuously, but they are notoriously temperature-sensitive, with a gradient of 1°C between plant and instrument temperature causing a deviation in water potential of up to 8 MPa. To quantify potential effects of thermal gradients in sapwood on stem psychrometry we chose two deeply-rooted chaparral shrubs in southern California as our study systems, laurel sumac (*Malosma laurina*) and toyon (*Heteromeles arbutifolia*). Depending on the time of day, sap ascending from deep roots can potentially be much colder or warmer than the air surrounding a stem, thereby creating thermal gradients at the sapwood surface. These gradients were measured with small thermistors placed at different distances from the exposed sapwood surface, while sapwood water potentials were measured with stem psychrometers. Substantial thermal gradients were detected in both species, in some cases exceeding 0.1°C mm⁻¹, with sapwood temperature fluctuating diurnally from being warmer or colder than the outside air. Effects of these gradients on psychrometric water potential readings were complex and varied with the time of day and the direction of the gradient, causing false readings deviating by more than 2 MPa from correct values determined by concurrent pressure chamber measurements. Attempts to simultaneously measure and correct for these gradients were unsuccessful, but placement of stem psychrometers far away from the stem base largely alleviated the problem by allowing sapwood temperatures to equilibrate with air temperatures. We therefore recommend installing stem psychrometers as far away from the stem base as possible and always compare initial readings to pressure chamber measurements for validation.

Keywords: pressure chamber, sapwood water potential, stem psychrometers, thermal gradients

Xylem sap flow and trunk growth of 5 hybrid clones of rubber tree

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The investigation on growth related with sap flux density of 5 hybrid clones of rubber tree was studied. These clones were bred from the original clones: RRIM600 (female) and RR1105 (male). This study was conducted during June-July 2015 (rainy season) at rubber plantation in the Nong Khai Rubber Research Center, northeast Thailand. The 3 years old of 5 hybrid clones (code 7, 85, 91, 161, 172) were selected and compared with mother clone (RRIM600). The experimental design was randomized completely block design (RCBD) with 6 clones (treatment) and 3 periods (block). The xylem sap flow was measured by the transient thermal dissipation method with Granier's probe. The result showed that the trunk diameter of 6 clones was significantly differed ($P < 0.05$). The clone code 91 was a smallest (3.88 cm) and the clone code 161 (5.92 cm) was a biggest of trunk diameter. The maximum sap flux density had no difference of all clones. However, the tendency of relationship between maximum sap flux density and trunk diameter was a positive trend ($P < 0.05$). It indicated that the high value of transpiration had positively affected to the tree growth.

Keywords: sap flux density, *Hevea brasiliensis*, trunk diameter

Dormant stem water potential responds to cycles of hydration as well as changing environmental conditions in deciduous tree crops

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Pressure chamber measurement of midday stem water potential (SWP) during the growing season has become a practical and widely adopted tool for irrigation management in many annual and perennial crops, but this technique has not been applied to perennial crops during dormancy. Indeed, the reliability of pressure chamber readings on twigs of dormant trees has been questioned due to concerns that a low percent of living tissue and/or a high level of embolism may cause inaccurate results. Psychrometer measurements of water potential are made in the vapor phase and do not depend on the degree of embolism or the percent of living tissue, and hence should be useful in evaluating the accuracy of pressure chamber measurements in dormant trees. Measurements of water potential using both pressure chamber and thermocouple stem psychrometer methods were compared on dormant branches exposed to different levels of hydration in the laboratory. A very highly significant ($P < 0.0001$) linear regression was found between the two methods over a wide range of SWP values (0 to about -2 MPa) in almond, cherry, and walnut, with r -square values of 0.98, 0.91 and 0.90, respectively, and in the case of almond and cherry the slope of the regression was close to 1:1. Field measurements on dormant almonds in two winter seasons with contrasting rainfall showed systematically lower SWP during a dry winter compared to a wet winter, and during a third season, SWP was found to increase in response to a winter irrigation. This evidence strongly supports the validity of pressure chamber measured SWP as a reliable indicator of dormant tree water status, and hence its use as a tool to evaluate the need for winter irrigation in dormant tree crops.

Keywords: stem water potential, embolism

Biospeckle image analysis in frequency domain using Fast Fourier Transform (FFT)

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Biospeckle imaging is a non-invasive technique based on optical phenomenon which occurs during the illumination of a samples surface by coherent light such as laser. The wavefronts of scattered rays interfere with each other and form random, granular patterns consisting of dark and bright spots, visible on the observation plane. The diffraction pattern depends on the geometry of the system, the wavelength of the laser and the aperture of lens of capturing device. Composed of dark and light spots, the speckle pattern is static for a non-living matter. In biological samples, the intensity distribution pattern evolves and fluctuates in time. It was shown that processes such as cytoplasmic streaming, organelle movement, cell growth and division during fruit maturation and biochemical reactions are responsible for certain biospeckle activity. Besides those, the biospeckle fluctuations depend on the chlorophyll and starch content, fungal infections and temperature of the investigated plant sample.

So far, applications of biospeckle technique in agriculture include determination of quality and maturation degree of fruits and vegetables, analysis of seed or detection of plant roots bioactivity changes. In all cases biospeckle activity changed with the state of investigated sample. Currently, the most common and most effective methods of biospeckle activity analysis are the Laser Speckle Contrast Analysis and the method developed by Fujii. These methods are based on a quantitative evaluation of local changes in the brightness of pixels, measuring the biospeckle activity in terms of the amount of changes rather than their dynamics. Recently, novel methods of analysis of speckle time varying patterns based on frequency analysis were introduced. The frequency analysis allows the mapping of activities associated with specific biological or physical processes that only occurs at certain frequencies in the sample.

In the proposed method, the biospeckle activity is determined on the basis of the frequency spectrum of temporal changes of brightness of individual pixels. The resulting spectrum shows the amplitude of the signal components at different frequencies. Initial data pre-processing includes illumination field flattening, background separation, identification and reduction of the local static component of the signal and data normalization. Decomposition of the signal into frequency bands allows studying the biospeckle activity for individual biological processes, including changes in tissue water status. Water transport and cytoplasmic streaming are two possible sources of biospeckle dynamics. Water moving in xylem vessels can cause vibration in the conductive elements and surrounding tissues because of cavitation. Organelles, as well as dissolved macromolecules moving with the flow are acting like scattering centers. Therefore, biospeckle activity seems to be a promising tool for monitoring of changes in tissue water status.

Keywords: Biospeckle imaging, FFT, frequency analysis

New irrigation scheduling device based on CWSI index for orchards

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Crop Water Stress Index (CWSI) has shown to be a good indicator of water deficits in field associated to canopy environmental conditions but has hardly been used in practice because data operating, calculation and its interpretation are not user-friendly for farmers. In this approach, a portable-assembled device with infrared, humidity and air temperature sensors is used to monitor simultaneously T_c , VPD and T_a , respectively. The data were transferred into an Android application via Bluetooth interface to calculate the CWSI index based on verified equations on cell-phone. The lower and the upper limits criterion and the CWSI threshold were obtained for wheat, sugarcane and pistachio tree based on previous investigations. The device can be programmable and it is also able to predict the yield based on water deficit for different growth stages according to research data. The results showed that this technique can be used for precision agriculture and enhancing water use efficiency specifically in arid areas due to easy performance and right irrigation time.

Keywords: CWSI, water deficit, orchards, device, VPD, Irrigation

Physiological and biochemical changes induced by different irrigation strategies in grapevines

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The effects of two different irrigation methodologies, partial root drying (PRD), and deficit irrigation (DI) on grapevines (*Vitis vinifera* L., cv. Mavrodafni) physiological and biochemical parameters were studied using split-rooted potted plants. Five irrigation treatments were applied: fully irrigated (FI) at both parts of the root zone to soil capacity; deficit irrigated (DI50 and DI25) receiving 50% and 25% irrigation water of FI plants, respectively, to the entire root zone and partial root drying (PRD50 and PRD25) receiving 50% and 25% irrigation water of FI plants, respectively, which was successively applied to one and the other part of the root zone. Compared with DI50, PRD50 plants exhibited higher stomatal conductance, sap flow and photosynthetic rate maintaining more favorable plant water status throughout the experimental period. On the contrary, no significant differences in physiological and water relation parameters between PRD25 and DI25 plants were observed, suggesting that irrigation amount could influence different irrigation methodologies effects on plant's performance. Leaf abscisic acid (ABA) concentration at the end of the drought period was significantly higher in DI compared to PRD plants while the opposite trend was evident concerning cytokinins (CKs) concentration. Irrespective the irrigation amount applied, stomatal conductance (gs) in DI plants exhibited the strongest correlation with leaf abscisic acid concentration among the treatments but this relationship was significantly weakened when gs was regressed against ABA/CKs ratio. PRD plant's stomatal conductance was also strongly correlated with leaf abscisic acid concentration but this relationship was markedly improved when ABA/CKs ratio was used. These results imply a more pronounced role of CKs in mediating stomatal responses in PRD plants. In contrast in DI grapevines ABA concentration seemed to dominate stomatal responses to drought.

Keywords: water relations, gas exchange, Irrigation methodologies

Optimizing a sensor-based irrigation protocol for a large-scale cut-flower operation in Southern California

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California and the western United States have been experiencing a prolonged drought since 2012, which led to mandated irrigation water cuts of 25% for agricultural producers in San Diego County, and throughout CA in 2015. Mellano and Company have been using precision drip irrigation and irrigation techniques for over 20 years, but until now sensor-based information has been expensive to gather and difficult for growers to interpret with any degree of confidence. In late 2014, a system of cellular nodes (EM50G, Decagon Devices, Inc.) was deployed in Oceanside, CA, with the intent of providing managers with soil moisture (volumetric water content, VWC) and electrical conductivity (EC) data, to aid in day-to-day irrigation and salinity management decisions. The objective was to achieve the mandated water conservation measures without affecting the yield or quality of the various cut-flower crops grown, many which are long-lived (4-7 year) perennial blocks. To date, more than 15 nodes and sensors in eight different cut flower crops have been deployed in various production blocks. Data are logged every 30-min from GS1 (VWC) and GS3 (EC) sensors at two depths (typically 15 cm and 30 cm) and transmitted by EM50G nodes to a cloud server, four times per day. All data is integrated into a sophisticated graphical database program (Sensorweb™, Mayim, LLC), which is accessible to anyone with an internet connection and access to the password-protected website for the company. In order to rationalize the information that growers receive, a standardized protocol was implemented, starting in 2016. Firstly, VWC sensors are placed at two depths in the crop rooting zone (influenced by crop development and longevity), to understand how irrigation durations are influenced by daily crop water use. An additional EC sensor is typically placed at 45 cm, just below the active rooting zone, to monitor both fertigation events and the build-up of salinity. The intent is to actively manage irrigations without significant leaching, except when salts become excessive. Secondly, the specific field capacity (FC) for each soil is determined after a saturating rainfall event, as an upper threshold for irrigation so that excessive irrigation durations are avoided. A threshold VWC content for each crop and soil type is then set (typically 20-30% of FC). Threshold alerts for the root-zone sensors in each block are created in Sensorweb™, which then texts the cell phone of the irrigation manager, when that set-point VWC is reached. In this manner, growers are able to fine tune irrigation durations (to not exceed FC and increase leaching) and reduce the frequency of irrigation events, according to daily plant water use and crop development. Water savings of about 40% were achieved with Solidago in 2014, and 50-60% for Myrtle through the fall / winter of 2015. In this way, Mellano and Company has been able to achieve targeted irrigation reductions, without compromising crop yield or quality.

Keywords: *Myrtle, Alstroemeria, Ranunculus*, EM50G, large-scale, soil volumetric water content, electrical conductivity

Experimental study of the water balance of the irrigated horticultures in the southern Mediterranean basin

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In southern Mediterranean region water consumption has significantly increased over the last decades, while available water resources are becoming increasingly scarce. In Morocco, irrigation is highly water demanding: it is estimated that 83% of available resources is dedicated to agriculture with efficiency lower than 50%. In the semiarid region of Tensift Al-Haouz (center of Morocco), typical of southern Mediterranean basin, crop irrigation is inevitable for growth and development. In this situation, and to preserve water resources, the rational management of water irrigation is necessary. This objective is one of the priorities of the research program SudMed and the Joint Mixed Laboratory TREMA, installed in Marrakech since 2002 and 2011, respectively.

In these two programs, the scientific approach adopted, to monitor water transfers in soil-plant-atmosphere system, is based on the synergistic use of the in situ data, the satellite observations and the mathematical modelling.

For the in situ measurements, from 2002 to date, seven intensive experiments on dominant horticultural orchards in the region (olive, orange and apricot) were performed, for both drip and flooding irrigation. Focus had been put on the evaluation of the crop's water demand and the partition of water between soil evaporation, plant transpiration and deep percolation. Thus, different terms of water and heat balances exchanged between land surface and atmosphere are controlled with different devices (Eddy Covariance, sap flow system, lysimeter, TDR, heat flux plate, CNR01, thermo-radiometers, ...). Results showed that the water losses by evaporation can reach 28% of water inputs for the flooding irrigation site and are obviously lower (about 18-20% on average) for the drip irrigation sites. Concerning the deep percolation, results are surprising: water losses for the drip irrigation are in the range 29-41% of water input, whereas these losses are between 26 and 31% for flooding irrigation. In the same context, the adequacy of the water supply to the crop requirement was evaluated by using two performance indices: soil depleted fraction and relative evapotranspiration. The result confirms that drip irrigation sprinkles much excessively.

Keywords: Horticultures, semi-arid, water balance, measurement, drip irrigation, flood irrigation

Utilization of reflectance indices to evaluate the impact of grey or recycled irrigation water on *Festuca arundinacea* turf

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The present study investigated the impact of grey or recycled water to the physiological status of tall fescue turf, based on reflectance indices. The study was conducted from May to October 2014 at the Technological Educational Institute of Epirus near the city of Arta, at the northwest coastal area of Greece. It comprised of 9 containers of 2 x 2 x 0.22 m which were filled with loamy sand soil and were irrigated either by tap water (TW) that served as a control, or grey water (GW) or recycled water (RW). All treatments were irrigated using a subsurface microirrigation system which was installed at a depth of 7 cm. Measurements included the determination of volumetric water content (VWC) of the soil using capacitance sensors, turfgrass visual ratings and cumulative clipping's dry weight, normalized difference vegetation index (NDVI) with a multi-spectral radiometer and green turf cover (GTC) using photographs and specialized software. It was found that turfgrass exhibited higher GTC when irrigated with tap water on 2 out of 8 sampling dates while at the end of the study period treated water provided higher GTC values compared with grey and tap water. Nevertheless, GTC remained at high percentages for all treatments during the study, indicating that grey or recycled water were able to provide sustainable growth for the turfgrass. Similarly, NDVI values were higher than 85% for all treatments during the study period and were in accordance with visual quality ratings. Cumulative clippings dry weight was increased in the tap water irrigation treatment compared with grey and recycled water. Based on the findings of the current study, tall fescue can be efficiently irrigated with either grey or recycled water, without affecting either the reflectance indices or its growth and visual quality. In addition a beneficial reduction of biomass production was observed using grey and recycled water that did not have an impact on turfgrass quality.

Keywords: normalized difference vegetation index, green turf cover, clippings dry weight, tall fescue

Response of quantitative and vegetative characteristics of grapevine (*Vitis vinifera* L. 'Askari') to topping time and preharvest irrigation cut-off treatments

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An experiment was arranged as factorial that the first factor included different levels of topping times with 3 levels (after fruit set, un-ripe stage and veraison stage), and the second factor involves the cut-off irrigation treatments on three levels (control, 70, 80 and 90 days after full bloom) in a randomized complete blocks design with four replications in Dena (Sisakht) region during 2013-2015. Quantitative factors included the single berry weight, berry volume, average cluster weight and yield. Also shoot length and diameter were measured. The data, analyzed with statistical software MSTATC and were compared with Duncan test. Results showed that the effect of topping treatment had significant effect ($P \leq 0.01$) on most of quantitative characteristics such as weight of a single berry, berry volume. Effect of cut-off irrigation treatments had significant effect ($P \leq 0.01$) all quantitative characteristics. The interaction of topping and cut-off irrigation treatments showed that significantly effect on the single berry weight, berry volume. Results of mean comparison showed that the topping treatment hadn't significant effect on yield compared to control, but in cut-off irrigation treatment, the yield reduced compared to control. The lowest yield was observed with 70 and 80 days after full bloom. The highest of shoot length and diameter were related to control and non cut-off irrigation treatment and the lowest shoot length was observed with topping treatment in veraison stage and cut-off irrigation treatment in 90 days after full bloom.

Keywords: Askari table grape, Shoot topping, Cut-off irrigation, shoot length, yield

Effects of variations in tuber water status on mechanical properties of radish

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In fresh fruits and vegetables, mechanical properties are very important but complex parameters of produce quality. They are closely related to both the physical and chemical cell wall properties, and to the tissue water status. In any produce, water status, overall tissue structure and physiological product status, all affect various mechanical properties such as elasticity, toughness, strength and others and often to a different degree. In addition, maturation and ripening, senescence or decay, in storage or in retail may affect produce strength and stiffness. Exact knowledge of the effects of the above parameters on mechanical properties of a produce may help to diminish quality losses in fresh vegetables. A better understanding of the physiological basis of water status effects on mechanical properties may also improve minimally processing, prevent unnecessary tissue damage and reduce the risk of pathogen infection. It, thus, can increase shelf life and reduce economic losses of minimally processed fresh products. In particular, tissue elasticity is interdependently determined by water status and cell wall mechanical properties. Short-term changes under unfavourable storage conditions mainly result from a decline in water potential or water volume while cell wall elastic properties remain unchanged. It is known that bruising, splitting or breaking susceptibility of fresh fruits and vegetables may increase at high produce water contents. A positive correlation between relative tissue turgor and cutting energy or elasticity has been found in many produce. Produce development and growth may, however, largely influence these relationships. Comprehensive and systematic studies on these effects on processing related mechanical properties are rare and the published results are equivocal. In the presented study, the acoustic impulse-response technique, force-deformation measurements and cutting-strength measurements were, thus, combined with pressure-volume measurements to study the above interactions in fresh small radish (*Raphanus sativus* L.) as model produce. Radish tubers own a relative simple tissue structure mainly consisting of thin-walled xylem parenchyma. The aim of this investigation was to characterize the fundamental effects of produce development and water status on the elastic properties and toughness of whole intact fresh radish tubers at various developmental stages.

Keywords: Development, mechanical properties, *Raphanus sativus* L., stiffness, strength, toughness

High hydrostatic pressure directly affects cell turgor of fresh produce – evaluation using the cell pressure probe

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High hydrostatic pressure treatments (HHP) are considered as alternatives for traditional chemical preservation to enhance the safety of fresh convenience products. This technique is known to preserve vitamins, pigments, and flavour components but may, e.g., alter the functionality of enzymes or affect the overall tissue structure of produces. Information about the potential impact of HHP on metabolic activity of fresh produce is rare. The few published studies, however, indicated HHP effects on physiological capacity. These effects were highly product specific due to pronounced variations in both pressure sensitivity and stress responsivity. Biomembranes, however, generally seem to be major physiological targets of HHP treatments. Cell turgor inevitably requires fully intact cell membranes. Turgor has important impacts on the fresh appearance of fresh produces, among others, influencing texture. Up to now, there is no investigation available that directly evaluated the effects of HHP treatments on turgor of fresh vegetable tissue. In this study, the pressure probe technique was applied to comprehensively analyse the turgor of red cabbage tissue by directly measuring the hydrostatic pressure of individual cell. The effects of HHP on cell turgor were tested at pressure in the range between 150 MPa and 250 MPa applied to the tissue for 5, 10 15 and 20 min. As pronounced changes in pressure are closely related to those in temperature, the effects of temperature (35°C to 55°C) on turgor also characterised separately. In general, HHP treatments and temperature increases as well as the duration of treatments interactively, pronouncedly and directly affected cell turgor of red cabbage leaves.

Keywords: hydrostatic pressure treatments, cell pressure probe, turgor, temperature

Does increasing tissue water deficit affect postharvest transpiration in radish and carrot tubers?

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In perishable horticultural products, postharvest water losses due to unfavourable storage condition may rapidly result in a complete loss of saleability. The products wilt, become soft, lose their gloss, and change colour; they simply become unattractive. Consequently, minimizing water losses during the entire postharvest chain by optimizing humidity control is essential to maximize quality maintenance. Transpiration properties of different produces and their sensitivity against water deficits are highly diverse. Besides the water vapour partial pressure deficit, the driving force of transpiration, these properties highly depend on structure and thickness of dermal tissues. Potentially, they are also affected by produce water status. Hence, transpiration properties may change during differentiation of products and during storage and shelf life. While transpiration properties of many products are quite well studied, information on interactions between water loss and water status, and the potential dynamics in this relationship during postharvest is scarce. Exact knowledge of these interactions is essential to improve produce specific climate management in storage and in sale, and for a meaningful parameterisation of predictive and control models. The potential relations between water release and water status was evaluated in fresh and stored radish and carrot tubers. Transpiration rates (J_{H_2O}) were determined by repeatedly weighing of tubers during dehydration under strictly environmental control. J_{H_2O} , produce and air temperature and humidity were used to calculate the total surface conductance for water vapour transfer (g_{H_2O}), an indicator of water vapour permeability of dermal tissues. Mean water potentials of intact tubers were measured with a pressure chamber, water potential at tissue levels with a dew-point hygrometer. Pressure-volume analysis was applied to "translate" water potential into its component and in relative water deficits. Neither in radish nor in carrot tubers did g_{H_2O} change during a rapid increase in water deficit under simulated shelf conditions. Although water potential of dermal tissues tended to be more negative than the inner tissue, no pronounced water potential gradient over either tubers was measured. In optimally stored carrots, g_{H_2O} did not change for several months. In contrast, during slow water losses of carrots stored under humid conditions, g_{H_2O} declined beyond a water loss of approx. 4% and finally obtained a more or less constant value at further increased water deficit.

Keywords: surface conductance for water vapour transfer, water potential, pressure potential, water deficit, pressure–volume analysis

Comparing and evaluating ΔT_{\max} determination approaches for Granier-based sapflow estimations on different time scales

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Estimating sapflow using Granier-type thermal dissipation probes requires determining the maximum temperature gradient (ΔT_{\max}) between the heated probe and the reference sensor below. ΔT_{\max} represents a state of zero sap flux, which was originally assumed to occur each night leading to a ΔT_{\max} determination on a daily basis. However, researchers have proven that, under certain conditions, sapflow may continue throughout the night. Therefore alternative approaches to determining ΔT_{\max} have been developed. Multiple ΔT_{\max} approaches are now in use; however, sapflow estimates remain imprecise because the empirical equation that transfers the raw temperature signal (ΔT) to sapflow density (F_d) is strongly sensitive to ΔT_{\max} . So far, this source of uncertainty of sapflow estimates, which is related to the ΔT_{\max} determination approach, has not been quantified. By analyzing the effects of different ΔT_{\max} approaches on sapflow density estimations of three spruce trees, we quantify the uncertainty of sapflow measurements on sub-daily, daily and (intra-)seasonal scales. We show that the ΔT_{\max} determination procedure has a major influence on absolute ΔT_{\max} values and the respective sapflow density computations. Particularly systematic ΔT_{\max} approaches produce synthetic flows that (1) significantly raise absolute sapflow density estimations on the sub-daily, daily and (intra-)seasonal scales, (2) affect sub-daily and daily sapflow density dynamics, and (3) reduce data plausibility in terms of climate feedbacks on the daily scale. We therefore conclude that the use of alternative ΔT_{\max} approaches may be a significant source of uncertainty in sapflow estimations. To improve absolute sapflow density estimations, future research should focus on the development of applicable measuring approaches that allow for absolute nocturnal flow detection and respective recalibration of the Granier formula.

Keywords: Granier, sap flow, spruce tree

Effect of irrigation systems on vegetative growth, fruit yield, quality and irrigation water use efficiency of tomato plants (*Solanum lycopersicum* L.) grown under water stress conditions

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Field experiment was conducted during the two growing seasons of 2012/2013 and 2013/2014, at Bani Salama region, El-Giza Governorate, Egypt, in order to investigate the effect of deficit irrigation (DI) treatments: 100% (control), 85%, 70% and 55% of ET_0 (Reference evapotranspiration) and two irrigation systems: Surface drip irrigation (SDI) and subsurface drip irrigation (SSDI) (20.0 cm soil depth) on vegetative growth, chemical constituents, flowering, fruit yield and quality of tomato plants (Marwa hybrid), grown under sandy soil conditions. Results revealed that DI treatments significantly decreased the vegetative growth, flowering, fruit yield parameters, photosynthetic pigments (chl a, b and carotenoids), leaves mineral content (N, P, K and Fe, %), leaf relative water content (LRWC) and membrane stability index (MSI) of tomato plants, compared to control treatment (100% ET_0). Water stress treatments improved leaves proline content, irrigation water use efficiency (IWUE) and some fruit quality characteristics for tomatoes. Using SSDI system significantly increased plant length, number of leaves per plant, total leaves area per plant, number of flowers and fruits per plant, marketable fruit yield of tomatoes, LRWC and MSI. There were no significant differences observed on the TSS of tomato fruit with both irrigation systems. Regarding the effect of interaction between DI treatments and irrigation systems, the results illustrated that application of irrigation water with 100% ET_0 by SSDI system produced the highest significant vegetative growth, flowering, fruit yield and quality parameters. It could be also concluded that the vegetative growth and flowering parameters, as well as fruit and quality of tomato plants grown under DI treatments (85%, 70% and 55% ET_0), can be improved by using SSDI system.

Keywords: Deficit irrigation, subsurface drip irrigation system, leaf relative water content, membrane stability index, IWUE

Effect of municipal wastewater irrigation and soil texture on vegetative growth and mineral nutrient uptake in *Festuca rubra*

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In order to study the effects of soil texture and municipal wastewater irrigation on the growth characteristics of lawn (*Festuca rubra*) in Yasooj, a split-plot experiment was conducted in a randomized complete block design with three replications, in 2011. The main factor irrigation was in three levels (I₁- irrigation with normal water, I₂- interval irrigation with normal water and wastewater, I₃- irrigation with wastewater during growth season) and sub-main factor soil texture including (S₁-sandy soil, S₂-silty soil and S₃-clay soil). Results showed that kind of irrigation water and soil texture had significant effect on plant height, chlorophyll content, dry and fresh weight of plant and elements absorption. The highest plant height was obtained in plants cultured in silty soil and irrigated with interval wastewater municipal and water. The highest phosphorus, potassium, zinc and iron were obtained in plant irrigated with I₂ (interval irrigation with normal water and wastewater until end of plant growth). Resulting, using wastewater interval with water and silty soil for improvement of lawn *Festuca* in Yasooj landscape is useful.

Keywords: lawn, silty soil, elements absorption, waste water

Physiological regulation of onion dormancy as influenced by pre-harvest irrigation and post-harvest ethylene supplementation

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Onion is one of the most cultivated vegetables with the current global production at 85 million tons per year. Although onion grown for bulb production is cultivated seasonally, the demand for onion bulbs is all-year-round. To meet this demand and ensure continuous supply, the onion industry relies on storing onion bulbs for up to nine months. Bulb re-growth (sprouting) is one of the major causes of storage losses. Continuous ethylene supplementation during bulb storage is known to suppress sprouting. It is hypothesized that sprouting, although a postharvest occurrence, might be regulated by pre-harvest irrigation. However, the interaction between pre-harvest irrigation and continuous ethylene supplementation during onion bulb storage is not known.

Onion cultivars 'Sherpa' (seeds) and 'Red baron' (sets) were planted in John Innes No. 3 compost and grown in the glasshouse for five months. Plants were exposed to differential irrigation from bulb initiation until harvest. The control and test plants were subjected to 100% and 50% replenishment of the control treatment evapotranspiration, respectively. Irrigation was scheduled using soil moisture sensors (ThetaProbe type: HH2 ML2x, Delta-T) and gravimetric methods. Bulbs were harvested at 100% fall-down, cured for six weeks and stored at 1°C. Bulbs were subjected to either continuous ethylene supplementation at 10 $\mu\text{L L}^{-1}$ or air, with three replicates per treatment. Bulbs were assessed for sprout emergence and elongation throughout storage.

The results showed that, pre-harvest irrigation as a single factor did not significantly influence sprouting. However, under continuous ethylene supplementation, sprout elongation was suppressed by a quarter in the bulbs grown under deficit irrigation when compared to the bulbs grown under full irrigation and stored in air.

In conclusion, there is a potential to use deficit irrigation in combination with continuous ethylene supplementation to manipulate the mechanism of sprouting in onion to improve bulb storage qualities.

Keywords: *Allium cepa*, evapotranspiration, dormancy

Sensing for deficit irrigation management of oil olives: integrating stem water potential, fruit water content and trunk diameter changes

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A four-year field trial examining regulated deficit irrigation strategies in olive was conducted on two modern varieties (Barnea and Askal) in Israel. Results from the study implied that water productivity could be significantly increased with little or no effect on yield or oil quality by reducing irrigation during the beginning of the irrigation season in the spring and during pit hardening in the summer. We propose an integrated approach to irrigation scheduling based on stem water potential and fruit water content thresholds. Trunk diameter dynamics were monitored with dendrometers and attempts at calibration to stem water potential and automation of irrigation will be presented. Results suggest that threshold values determined experimentally may not be universally applicable to all places, conditions and seasons. The challenge for continuous evaluation of legitimacy of thresholds and their subsequent irrigation regimes will be discussed.

Keywords: olives, midday stem water potential, dendrometer, fruit water content, irrigation scheduling, thresholds

Rapid drops of soil water content in pot trials affect the prediction of drought tolerance determined in field trials

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Experiments for the assessment of drought tolerance are performed in pots under controlled conditions to achieve high reproducibility. However, for field grown crops, tolerance assessments from pot trials poorly predict field performance. The poor correlation of performance in both systems may result from the small size of the pots, which limits yield under optimal conditions and thus results in an overestimation of tolerance as relative yield under stress. Moreover, small pot size can result in an artificially rapid change in soil water content at the onset of drought treatments compared to field grown crops. The extent of this effect depends on the evapotranspiration rate and thus on the vapour pressure deficit (VPD) of the atmosphere. To overcome these limitations, we conducted drought stress experiment on potato cultivars in large volume-growbags under semi-controlled conditions and compared the tolerance assessed in this system to tolerance rates determined in pot trials under controlled conditions and under field conditions. The change of soil water content after water supply was assessed by continuously measuring the soil water content with Plantcare soil sensors. In parallel, VPD was determined from continuously measured relative humidity and temperature of the atmosphere. We present the variation in decrease rates of soil moisture and VPD in the different experimental systems to decide whether grow bag systems may mimic field trials for drought tolerance efficiently.

Keywords: soil water sensors, pot trials, field trials, drought tolerance

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