Physiological, anatomical and molecular determinisms of water use efficiency linked to drought response in poplars: from leaf level to the whole plant scale

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IUFRO 125th Anniversary congress 2017 - Side event

Seminar "Water use efficiency under drought"

18 September 2017

Centre Inra Grand Est - Nancy, Champenoux, France

Forest ecosystems are ecologically crucial, covering 30% of land area and strongly contributing to global carbon (C) sequestration. In forthcoming decades, global change scenarii predict for many regions a temperature increase coupled with a reduction in summer rainfall. Increased probability of drought episodes is thus expected even in areas usually not subjected to prolonged summer drought. Forest management will have to deal not only with such an unfavourable context for tree growth but also with an increasing demand and usage of woody biomass. Even in forests or plantations, which are presently only exposed to moderate soil water deficits, it will be necessary to **optimize biomass growth per water loss through transpiration**. The ratio between these two traits is known as the whole plant **water use efficiency (WUE)**.

Reduced soil water availability has the potential to, at least, restrict C gain and biomass production and, at worst, to contribute to forest dieback. Tree populations will face environmental changes, which are more rapid than trees generation time, thus reducing their ability to adapt through natural selection. It is therefore essential to better understand the mechanisms of tree acclimation to water deficit and to predict the consequences of such constraint on the forest dynamics, and plantation productivity to better choose forest reproductive material.

This side session of the IUFRO 2017 Anniversary conference in Freiburg will discuss contributions of new advances in

- the understanding of the relationship between WUE and drought responses,
- the processes involved in up-scaling WUE from the leaf to the whole plant level,
- the different methods used to estimate WUE

08:00 - 09:00 Welcome-Registration

08:50 - 09:10 Opening (Didier Le Thiec) - Introduction to the INRA center

Session 1 : WUE at leaf level

09:10 - 09:50 John Marschall, University of Idaho, Center for Research on Invasive Species and Small Populations (CRISSP) : Water-use efficiency at the leaf level

09:50 - 10:15 Fahad Rasheed : Leaf spectral reflectance as a tool for the early water stress detection: a case study in three poplar hybrids

10:15 - 10:40 Théo Gérardin : Within species diversity of transpiration efficiency in two white oak species

10:40 Coffee Break

Session 2 : WUE at the whole plant level

11:10 - 11:50 - Lucas Cernusak, James Cook University, Cairns, Australia : Water-use efficiency at the whole-plant level

11:50 - 12:15 Claire Damesin : Is intra-ring delta^{13}C a good seasonal water use efficiency proxy at the tree level? Studies on temperate species

12:15 - 12:40 Maxime Durant : From the leaf level to the whole plant scale : physiological, anatomical and molecular determinisms of poplars transpiration in response to drought

12:45 Lunch break, Poster Session

Session 3 : WUE at the canopy level

14:00 - 14:40 Belinda Medlyn, (University of Western Sydney, Sydney, Australia) : Water Use Efficiency: from Leaf to Ecosystem

14:40 - 15:05 Andrée Tuzet : Modelling hydraulic functioning of a forest stand to simulate drought stress

15:05 - 15:30 Ettore d'Andrea : Different method to assess water use efficiency in a mediterranean beech forest

15:30 - Coffee Break

Session 4 : Genetic diversity of WUE

16:00 - 16:40 Oliver Brendel, INRA, Champenoux France : Genetic diversity of water use efficiency in forest trees

16:40 - 17:05 Aude Coupel-Ledru : Reduced night-time transpiration is a relevant breeding target for high water-use efficiency in grapevine

17:05 - 17:30 Filippo Santini : Scarce intra-specific variation but substantial spatiotemporal plasticity of water-use efficiency in Pinus sylvestris at its western distribution range

17:30 Debreifing : Jean Marc Guehl

18:00 Closing - Depart for Freiburg or Nancy

Water-use efficiency at the leaf level

Session 1 : WUE at leaf level

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Stable carbon isotopes have been used to estimate water-use efficiency (WUE) of C_3 trees for more than thirty years. This is possible because the parameter that controls WUE is also related to isotopic discrimination. The key parameter is C_i, the intercellular CO_2 concentration. There are, however, at least three leaf-level complications in this story. First, mesophyll conductance, which controls diffusion across the leaf, affects isotopic composition, but does not affect WUE. Second, WUE also increases with tree height and decreases with nitrogen concentration. Third, evergreen leaves continue to gain mass throughout their lives, contaminating the initial isotopic signal. I will describe the magnitude of these complications and suggest means of addressing them.

Leaf spectral reflectance as a tool for the early water stress detection: a case study in three poplar hybrids

Session 1 : WUE at leaf level

Fahad RASHEED [1,2], Sylvain DELAGRANGE [2,3] and François LORENZETTI [2,3]

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The negative impact of water stress on plant productivity has been evidenced many times. However, early detection of low levels of water stress has not received much attention, which can be helpful in sustaining productivity, especially in fast growing plantations. In this study, we tested the sensitivity of various morphological, physiological and leaf spectral traits in detecting low levels of water stress in hybrid poplar clones. The clones were grown under 85% (C), 80% (T1) and 75% (T2) of the soil moisture at field capacity in a green house. During the experiment, we recorded (i) biomass production and allocation in leaves, stem and roots; (ii) gas exchange under controlled conditions, and (iii) vegetation and water indices using leaf spectral reflectance. Results showed that low levels water stress had a significant negative impact on the total biomass accumulated, while biomass allocation pattern, chlorophyll and nitrogen contents, CO_2 assimilation and stomatal conductance remained unaffected. Furthermore, spectral vegetation indices (NDVI, PRI, DVI RVI and SIPI) remained unaltered under low water stress, confirming normal functioning of the photosynthetic system. However, more specific water-stress related indices such as NDWI, WI, SR1 and SR2 were effective in detecting water stress. In this study, we demonstrated that leaf spectral reflectance is a suitable tool for early detection of low levels of water stress.

Keywords
Poplar genotypes, Leaf gas exchange, leaf spectral pattern, water stress,

Within species diversity of transpiration efficiency in two white oak species

Session 1 : WUE at the whole plant level

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Trees are a major component of the biosphere. Covering many regions of the world as natural forests or plantations, they take an important role in the balance of the ecosystems. Recent studies has shown that some of these ecosystems may already be responding to climatic warming and drought, two main consequences of climate change. Such changes have been hypothesized to be able to impact the WUE (defined as the ratio between carbon assimilation during photosynthesis and the stomatal conductance for water at the leaf level) of forest ecosystems. In such context we focused on the diversity of WUE in two major French oak species : *Quercus robur* L. and *Quercus petraea* (Matt.) Liebl. These two species are largely sympatric however with different ecological requirements. While *Q. petraea* is more frequently found on well drained soils and is more tolerant to drought, *Q. robur* is able to survive and grow on poorly drained soils being the result of a higher tolerance to water-logging (Becker et al. 1982). A few comparative studies have described *Q. petraea* as more efficient than *Q. robur* the later having lower values of leaf level WUE (Ponton et al. 2001, Pflug et al. 2015, Thomas et al. 2000) however these results are not consistent in the literature since other studies showed similar WUE between the two species (Parelle et al. 2016, Hu et al. 2013) or even higher WUE for *Q. robur* (Rasheed-Depardieu 2015). Moreover to our knowledge no comparative studies between the two oak species focused on the transpiration efficiency (TE) (defined as the ratio between total biomass production and total water consumption at the whole plant level) have been conducted, leaving a huge gap on the subject. Therefore we addressed the following questions: Do the differences in WUE at the leaf level result in similar differences at the whole plant TE? Which underlying morphological and physiological traits are related to these differences between species but also which traits are driving the within-species diversity? Hence, in a comparative study between the two oak species we assessed different levels of WUE as well as underlying traits for control and drought plants.

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Keywords
Oak, water use efficiency, *Quercus robur*, *Quercus petraea*, drought, stomatal conductance

Water-use efficiency at the whole-plant level

Session 2 : WUE at the whole plant level

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Plant water-use efficiency can be measured at multiple scales and by using a variety of techniques. Destructive measurements of plant biomass production over a period of time combined with measurements of cumulative plant water use over the same experimental period provide a baseline assessment against which more accessible measurements of leaf-level water-use efficiency and stable carbon isotope discrimination can be evaluated. Here, I will discuss relationships among these different measures of water-use efficiency, and the biological implications of information captured at the whole-plant scale. Finally, I will discuss responses of whole-plant water-use efficiency to global change drivers, and to resource availability.

Is intra-ring $\delta^{13}C$ a good seasonal water use efficiency proxy at the tree level? studies on temperate species

Session 2 : WUE at the whole plant level

Elena GRANDA[1], Nicolas DELPIERRE[2], Alice MICHELOT-ANTALIK[3], Florence MAUNOURY-DANGER[4], Stéphane BAZOT[2], Daniel BERVEILLER[2], Anaïs BOURA[5], Chantal FRESNEAU[2], Claire DAMESIN[2]

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Intra-ring $\delta^{13}C$ constitutes a potential tree water use efficiency proxy at the seasonal time step. In this contribution, we synthesize our recent results relative to the functional understanding of the intra-ring $\delta^{13}C$ variations. Our experimental approach focuses on two major European deciduous species : Quercus petraea and Fagus sylvatica. On young oaks, an imposed water constraint induced a clear and rapid increase of $\delta^{13}C$ in the ring built under drought. This result suggests that the effect of water stress in terms of individual WUE is well recorded inside the ring. On mature oaks, the link is less clear. We tested the relationship between the variation of iWUE calculated from latewood $\delta^{13}C$ of the tree rings, and that from the canopy, obtained using flux tower data (Fontainebleau-Barbeau forest, http://www.barbeau.u-psud.fr/) and the simulations from a water, carbon forest balance model (CASTANEA) for the period 2006-2013 which includes years with distinct climate characteristics. We showed that available $\delta^{13}C$air values, temporary stem growth stop and physiological time-lags can induce uncoupling between intra-ring $\delta^{13}C$ and WUE. Moreover, another study, conducted on declining beeches, suggested that the WUE recording in the ring could be altered by reserves, not by their use as previously shown but by their storage via the decrease of ^{13}C available for ring growth. In conclusion, our results highlight that seasonal $\delta^{13}C$ variations could be a good proxy of WUE, but sometimes other drivers could lead to shifts and should be considered. Moreover, a high inter tree variability was found and should be explored to get a better comprehensive physiological understanding of the intra ring $\delta^{13}C$ variations at the individual level.

Keywords
$\delta^{13}C$, ring, seasonal variation, water-use efficiency, flux, reserves

From the leaf level to the whole plant scale : physiological, anatomical and molecular determinisms of poplars transpiration in response to drought

Session 2 : WUE at the whole plant level

Maxime DURAND[1], Oliver BRENDEL[1], Cyril BURE[1], Didier LE THIEC[1]

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As a result of climate changes, the frequency and intensity of drought events is expected to increase in the future. It could in consequence affect the productivity of forest species with a high-water requirement such as poplars. In order to sustain high productivity under low water availability, one approach is to promote genotypes for better water use efficiency (WUE). At the whole plant scale WUE is the ratio of biomass production over the water used but at the leaf scale it is the ratio of net CO_2 assimilation over stomatal conductance to water vapor (gs).Previous studied have found a wide diversity of WUE and a link with gs. These finding suggests the implication of other stomatal traits in the determinism of WUE which could in turn be linked to molecular factors and have an impact on the whole plant water use in the long term. Our objectives are then as follows:
1) Is there differences of stomatal movement dynamics linked to environmental variables (light, VPD) among poplar genotypes and between hydric regimes?
2) Are these differences related to physiological and/or molecular determinisms? If so, what are they?
3) Are these determinisms and their relative contribution to WUE different in controlled relative to natural conditions?
4) How do those determinisms, studied at the leaf scale, contribute to WUE at the whole plant scale?
Experiments in field and controlled conditions are conducted in order to assess differences of photosynthesis and stomatal traits and behavior among genotypes in relation to drought such as the speed of stomatal movement, the stomatal sizes, the elemental content and RNAm content in guard cells during stomatal movement. A process-based model (MAESPA) will enable the integration of multiple level of organization to study the influence of WUE at the leaf and whole plant level.

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Keywords : Water-use efficiency, stomata, upscaling, drought, poplar

Water Use Efficiency: from Leaf to Ecosystem

Session 3 : WUE at the canopy level

Belinda MEDLYN [1]

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Optimization theories for stomatal behaviour have provided significant new insights into water use efficiency at leaf scale. I first discuss and compare alternative optimization hypotheses. In general, optimization theory predicts differences in water-use efficiency across plant functional types. This prediction is supported by water use efficiency data measured at leaf-scale, including estimates derived from instantaneous gas exchange and stable isotope measurements. However, our analysis of eddy covariance data indicates that these differences at leaf scale do not result in differences in water use efficiency at ecosystem scale. I consider possible reasons for this discrepancy between scales and highlight some important future directions for water use efficiency research.

Modelling hydraulic functioning of a forest stand to simulate drought stress

Session 3 : WUE at the canopy level

Andrée TUZET, André GRANIER and Alain PERRIER

A model that couples stomatal conductance, photosynthesis, leaf energy balance and transport of water through the soil-tree-atmosphere continuum have been developed (Tuzet et al, 2017). The aim of this study is to develop a general process model to describe the dynamics of the water flow within the continuum and to better understand the relative importance of atmospheric demand, soil water availability and hydraulic controls on tree water use. In this model, stomatal conductance depends on light, temperature and intercellular CO_2 concentration via photosynthesis and on leaf water potential. Leaf water potential is a function of soil water potential, tree hydraulic resistances and the rate of water flow through the soil and tree. The net canopy photosynthesis is calculated using the detailed biochemical model of photosynthesis proposed by Farquhar et al. (1980). Tree water relations are modelled as an analogue to a simple electrical circuit including plant hydraulic resistances and plant capacitances. Water uptake by roots is controlled by water potential gradient between the absorbing root surface and a cylindrical soil element adjacent to the roots. Water transport from soil to roots is simulated through solution of the Richards' equation. Rainfall interception is calculated using an approach derived from the Liu model (Liu, 1997, Liu 2001).Our results show that early in the season when soil moisture is not limiting, minimum leaf water potential remains almost constant. Later, as soil drying proceeds there is a progressive decrease of minimum leaf water potential. This decrease occurs when the limitation of the water transfer imposed by the soil becomes dominant compared to that of the xylem. The minimum values of water potential reached by the leaves depend on the sensitivity of stomata to leaf water potential. The xylem hydraulic resistance determines the amplitude of diurnal variation of the water potentials when soil moisture is not limiting while the sensitivity of stomata to leaf water potential determines the lower limit of potential reached by the leaves when the soil dries. Then our model is able to explain the contrasting behaviour of many functional types of trees in terms of differing hydraulic resistances and stomatal sensitivities of stomata to leaf water potential. 'Isohydric' trees, which maintain constant minimum leaf water potentials, are expected have high xylem hydraulic resistances and/or high stomatal sensitivity to leaf water potential. 'Anisohydric' trees, which have variable minimum leaf water potentials, are expected to have lower hydraulic resistances and/or lower stomatal sensitivity to leaf water potential.The model reproduces well the commonly observed diurnal variation in transpiration, storage water potentials and capacitive discharge or recharge fluxes under both dry and wet conditions in a stand of European beech. It is able to capture the decrease of relative water content in reservoirs under water stress conditions and their contribution in the transpiration stream, both daily and throughout the season. Depletion of internal water reservoirs delays the onset of stomatal closure in the morning and also limits and regulates the stomatal closure in the afternoon when the climatic demand is high. Trees lose stored water during the day and recover it at night. The presence of reservoirs allows trees to better withstand periods of drought. The model accurately reproduces the seasonal variations of soil water content and leaf water potential. These results are in agreement with those of the comparison between measured and calculated water fluxes. Physical climate processes and ecological processes are closely coupled in the model, which involves important interactions and feedbacks. Capacitive discharge of water into the transpiration stream can buffer fluctuations in xylem tension, thereby diminishing the risk of xylem embolism and hydraulic failure under dynamic conditions. The key conclusion of the paper is that stomatal conductance cannot be modelled using leaf-level processes alone, but must be incorporated into a comprehensive model of water flow from soil through the plants to the atmosphere where various self-regulation are set up to ensure a complete water status equilibrium.

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Keywords

SPAC model, tree hydraulic, tree water reservoir, stomatal conductance, rainfall interception, drought

Different method to assess water use efficiency in a mediterranean beech forest

Session 3 : WUE at the canopy level

Ettore D'ANDREA[1], Carlo TROTTA[2], Alessio COLLALTI[3], Negar REZAEI[1], Andrea SCARTAZZA[1], Giovanna BATTIPAGLIA[4], Pierluigi BOMBI[1], Giorgio MATTEUCCI[5]

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Increasing concentrations of atmospheric CO_2 is affecting the temperature and precipitation pattern driving significant modifications in natural and managed forests (Kirilenko & Sedjo, 2007). In the 21st century, the Mediterranean area might be an especially vulnerable region to global change (Giorgi & Lionello, 2008). Owing to its sensitivity towards low water availability (Ellenberg, 1996) and longer drought periods (Fotelli et al., 2002), physiological performance, growth and competitive ability of beech may be adversely affected by such changing environmental conditions (Peuke et al., 2002), also with a probable strong economical impacts being this species one of the most important in Europe (Geßler et al. 2007). Various definitions of WUE are applied in different scientific disciplines, but the common characteristic is that WUE is always a ratio of carbon gain to water loss (Saurer et al., 2004; Kuglitsch et al., 2008). WUE is dependent by the temporal and spatial scales and can be calculated using different methods (Ponton et al., 2006; Kuglitsch et al., 2008; Peñuelas et al., 2008). Hence, comparative studies of WUE are important for helping to understand how future climate change will affect the carbon and energy budgets of ecosystems (Ponton et al., 2006). In this context we assessed WUE efficiency in a Mediterranean beech forest using five methods. We calculated WUE using cuvette (LiCor 6400) in 8 days of different growing season, $\delta^{13}C$ in tree ring cellulose, eddy covariance technique, 3D-CMCC-FEM and Modis data. The objectives were to compare the different methods and evaluate the effect of environmental variables on intra and interannual WUE.

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Keywords

Water use efficiency, Carbon isotope composition, Eddy covariance, Cuvette, Forest Model, Modis.

Genetic diversity of water use efficiency in forest trees

Session 4 : Genetic diversity of WUE

Oliver BRENDEL[1], Didier LE THIEC[1], Stéphane PONTON[1], Antoine KREMER[2], Christophe PLOMION[2], Catherine BODENES[2], Grégoire LE PROVOST[2]

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Forest trees are organisms which can have very large geographic distributinos and therefore cover a large range of different environmental conditions. In forestry, comparative plantations have been used for a century to compare different provenances of trees for their growth. Such plantations have been used by ecophysiologists to use carbon stable isotopes to screen for variation in water use efficiency, and large population differences have been shown for many species, suggesting a genetic determinism for this traits and perhaps indicating local adaptations. Different crossings (open pollination, half-sibs, full-sibs) can be used to either estimate more precisely the genetic control on this trait (heritability) or to determine the genetic regions (QTL) as well as the genes underlying the observed variation. The running project H2Oak (https://www6.inra.fr/anr-h2oak/) takes this approach for *Q. robur L.* and *Q. petraea (Matt.) Liebl.* Recent advances will be shown and future approcahes will be discussed.

Reduced night-time transpiration is a relevant breeding target for high water-use efficiency in grapevine

Session 4 : Genetic diversity of WUE

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In the face of increasing water scarcity, breeding for higher transpiration efficiency (TE), that is, the biomass produced per unit of water transpired, has become crucial. This could be achieved by reducing plant transpiration through a better closure of the stomatal pores at the leaf surface. However, this strategy generally also lowers growth, as stomatal opening is necessary for the capture of atmospheric CO_2 that feeds daytime photosynthesis.
Here we tested whether reducing transpiration at night when photosynthesis is inactive could substantially reduce water loss without altering growth—a hypothesis that, to our knowledge, has never been genetically addressed in any species. We carried out a genetic analysis for night-time transpiration and TE in grapevine, a major crop in drought-prone areas. A 3-year experiment was conducted on the F1 progeny from a cross between Syrah and Grenache cultivars using a phenotyping platform coupled to a controlled-environment chamber, under well-watered and moderate soil water deficit scenarios. High genetic variability was found for night-time transpiration and 5 QTLs were detected. An experiment was also performed outdoors which confirmed the significance of this genetic variability. We further highlighted a major role of residual stomatal opening at night and a minor, yet significant contribution of the cuticle in determining this genetic variability. Strikingly, 4 of the QTLs detected for night-transpiration co-localized with QTLs for TE. Moreover, genotypes with favourable alleles on these common QTLs exhibited reduced night-time transpiration without altered growth. These original results (Coupel-Ledru et al., PNAS, 2016) open new horizons for breeding plants with lower water loss at night for higher TE.

Keywords
night transpiration, water-use efficiency, growth, stomata, QTL, cuticle

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Scarce intra-specific variation but substantial spatiotemporal plasticity of water-use efficiency in *Pinus sylvestris* at its western distribution range

Session 4 : Genetic diversity of WUE

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Forests play a crucial role in regulating fluxes of carbon and water in the ecosphere. These surface fluxes are closely related to leaf gas exchange physiology varying across spatiotemporal scales and modulated by divergent plant responses to environmental cues. Here we quantified the relevance of intra-specific variation and phenotypic plasticity of intrinsic water-use efficiency (WUEi, ratio of net photosynthesis to stomatal conductance of water) in the most widespread species of the *Pinus* genus (*Pinus sylvestris* L.) growing in the central and eastern Spanish Pyrenees as inferred from tree-ring carbon isotopes. Intra-specific variability of WUEi, evaluated in a provenance trial comprising Spanish and German populations, was very low and relevant only at large (continental) scales. In contrast, phenotypic plasticity, evaluated from natural stands and by tree-ring chronologies, was important at spatial and temporal (inter-annual) levels. Particularly, the extent of spatial and temporal plastic responses for WUEi was about eight- and five-fold larger than genetic variance, in contrast with previous results on other Iberian pines reporting a large intra-specific divergence in WUEi. Spatial changes in WUEi negatively correlated to soil depth, while temporal patterns were mainly driven by summer precipitation. Leaf-level WUEi could be upscaled to ecosystem-level WUE derived from remote sensing data only after accounting for soil water holding capacity. Our findings highlight the necessity to integrate species-specific reactions to environmental changes and accurate micro-environmental conditions influencing ecosystem characteristics when simulating carbon and water budgets at large geographic scales.

Keywords
carbon isotopes, intra-specific variation, phenotypic plasticity, remote sensing, Pinus sylvestris, soil water content, tree rings, water-use efficiency

Combining meteorology, sap flow and eddy fluxes to understand environmental controls of carbon isotope discrimination in in short- and long-lived pools of *Quercus ilex* trees

Poster
Session 2 : WUE at the whole plant level

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We investigated the relationships between δ13C in different C pools of *Quercus ilex*, a broadleaved evergreen tree, and flux tower-derived δ13C input in the Puechabon Forest over the 2003 to 2012 period. The C pools investigated were current and one-year-old leaves, acorns, and early and late wood of the stem growth rings. Weekly variations of ecosystem scale intrinsic water use efficiency (iWUE) were calculated based on estimates of canopy conductance and net assimilation. Canopy conductance was obtained by the ratio of sap flux transpiration and air vapor pressure deficit (VPD). Net assimilation was estimated from gross primary productivity (GPP) minus canopy scaled leaf dark respiration (Rodríguez-Calcerrada et al., 2012). iWUE was finally converted into $\delta^{13}C$ (δ^{13}Cinput) by using weekly values of air CO_2 concentration and air $\delta^{13}CO_2$ for the North Eastern Mediterranean region (using the common Mauna Loa data instead of values obtained in the Mediterranean resulted in significant changes in the pattern and amplitude of the $\delta^{13}C$ signal). Plant water status, and particularly predawn water potential (Ψpd), had a key role on the time course of flux-derived ecosystem iWUE, and we observed the same pattern as the one obtained at leaf scale (Limousin et al. 2010). iWUE ranged from 50 µmol mol-1in the wet periods to a peak at 200 µmol mol-1 for Ψpd between -1.5 and -2 MPa, and then declined linearly with drought until reaching zero for Ψpd around -4 MPa. As a consequence, the δ13C input into the trees exhibited clear seasonal variations. Nevertheless, the long-term integral pool only ranged between -27 and -28 ‰ and the temporal allocation to the different C pools should be better unraveled to simulate the observed $\delta^{13}C$ of the different tissues. Water limitation during leaf growth affected clearly the δ13C of current year leaves. In the same way, $\delta^{13}C$ of early and late wood was marked by the water deficit that occurred during the respective periods of wood growth. However, drought severity in summer didn't seem to have a significant role on the $\delta^{13}C$ of the wood because wood growth is prevented in summer when Ψpd is below -1.1 MPa (Lempereur et al. 2015).

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Keywords

Quercus ilex, $\delta^{13}C$, leaf, ring, seasonal and interannual variations, drought

Impact of nitrogen nutritional status on the dynamics of xylem hydraulic failure and non-structural carbohydrates under moderate and severe droughts in fast-growing trees (*Populus* spp.)

Poster
Session 2 : WUE at the whole plant level

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The mechanisms leading to tree death in response to water deprivation are far from being completely resolved, but xylem hydraulic failure and carbon starvation are regarded as two main causes. However, the role of nutrients in modulating these water- and carbon- associated mechanisms remains largely understudied. Here, we investigated the effects of nitrogen nutritional status on the dynamics of xylem hydraulic failure and non-structural carbohydrates (NSCs) under moderate or severe drought scenarios. Experiments were conducted under greenhouse conditions on two poplar hybrid genotypes showing contrasting stomatal control (*Populus deltoides* × *P. nigra* cv. 'Koster' and *P. trichocarpa* × *P. maximowizcii* cv. 'Skado'). Acclimated 3 months-old cuttings were allocated to six different treatments corresponding to the combination of two levels of nitrogen fertilization (0,5 vs. 10 mM of NH_4NO_3 in a complete nutrient solution) with three levels of water availability (field capacity = control, 20% of field capacity = moderate drought, irrigation cessation = severe drought). Measurements encompassed primary and secondary growth, leaf gas exchange, minimum xylem water potentials, stem vulnerability to cavitation and native embolism, and NSC contents in the leaves and woody compartments (stem and roots).
As expected, nitrogen fertilization stimulated growth and increased vulnerability to cavitation for both genotypes. Trees subjected to irrigation cessation reached the lethal 90% loss of xylem hydraulic conductivity after 15 weeks while under moderate drought native embolism was maintained under 50%. Nitrogen fertilization did not impact significantly the time-course of xylem hydraulic failure, suggesting that the higher vulnerability to cavitation was compensated by other mechanisms such as adjustments in leaf vs. xylem surface areas. Trees growing with a higher N dose showed decreased carbohydrate contents, especially in leaves and roots. When trees had reached 90% of xylem embolism, starch contents were null indicating that carbon starvation may co-occur with xylem hydraulic failure under severe drought. Overall, our first results suggest that nitrogen nutritional status may primarily affect drought response through NSC dynamics and that higher nitrogen availability may be a predisposing factor reducing the ability of trees to cope with recurrent drought events by reducing carbohydrate reserves.

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