STSM - Scientific Report
Cost Action FP1106 (*STReESS*)

STReESS: *Studying Tree Responses to extreme Events: a SynthesiS*

Short Time Scientific Mission (STSM)

Title: Significance of xylem cavitation and tracheid collapse in needles for the drought-induced mortality of Scots pine.

Beneficiary: José M. Torres Ruiz, Institute for Natural Resources and Agrobiology (Seville, Spain).

Host: Prof. Hervé Cochard, UMR-PIAF, INRA-Université Blaise Pascal (Clermont-Ferrand, France)

Period: from 14/01/2013 to 22/03/2013

Reference code: COST-STSM-ECOST-STSM-FP1106-140113-026393

Introduction

According to the cohesion-tension theory, water transport in trees requires a gradient in water potential along the soil-plant-atmosphere continuum (Tyree & Zimmermann 2002). This gradient forces water to move under tension along the vascular system of the plant and, therefore, increases the risk of xylem cavitation (Cochard & Tyree 1990; Sperry & Tyree 1990) or conduit collapse (Hacke et al. 2001). Whereas cavitation events can take place in any plant organ depending on its vulnerability to cavitation (Mayr et al. 2003), the xylem collapse is observed mostly in leaves probably because of the mechanical reinforcement of the conduits in stems or roots (Charra-Vaskou et al. 2012). Both the cavitation events and the collapse of the conduits may finally provoke the tree dieback due to they reduce the hydraulic efficiency of the plant (McDowell et al. 2008).

Drought-related mortality has been observed for Scots pine (*Pinus sylvestris* L.) in several different regions in Europe, although the specific causes of these events remain unknown. Charra-Vaskou et al. (2012) have recently reported for *Pinus pinaster* that the most distal parts of the soil-plant-atmosphere continuum (needles) show low vulnerability safety, limiting the hydraulics of the plant. Their results suggest that, at least for Pinus species, the hydraulic functioning and properties of the needles play an important role in tree survival under severe climate conditions as drought.

Purpose of the STSM

The main aim of this STSM was to investigate if the differences in the mortality rate observed in Scots pines from the same climatic region are related with differences in hydraulic properties (i.e. xylem vulnerability to cavitation and collapse) at needle level. We also evaluated if Scots pines with different mortality rates also showed differences in the annual shoot growth and the number of needles per year among them.

Description of the work carried out during the STSM

This study was carried out in a Scots pine population located at the Poblet nature serve (Prades Mountains, NE SPAIN). The average standing mortality and crown defoliation for this population are 12% and 52%, respectively (Vilà-Cabrera et al. 2011). For this study, we selected an area which shows a standing mortality >20%, so nondefoliated and defoliated Scots pine trees coexist in the zone.

Four primary branches were harvested from each type of pine and both the annual shoot growth and the number of needles per year determined for the last three years.

For determining the vulnerability to cavitation, four primary branches from each type of pine were harvested, covered with dark plastic bags and maintained in contact with water overnight to allow full rehydration. One ultrasonic sensors (150 kHz resonance sensors, R15/C, 80–400 kHz) was attached to a group of 6-10 needles per branch to record ultrasonic emissions (UEs) (Johnson et al. 2009). Saturated branches were then allowed to dehydrate on the bench and the needle water potential (Ψ) was determined with a pressure chamber (Scholander type) in 2-3 needles per branch at intervals while acoustic emission measurements were being made. Once the acoustic activity ceased, the cumulative number of UEs for each Ψ was related to the total number of UEs recorded in each branch for obtaining a vulnerability curve.

For evaluating the xylem collapse, needles from the same branches used for determining the vulnerability to cavitation were collected during the dehydration process (see above) and three-dimensional pictures of their xylem conduits were acquired with an X-ray nanotomograph (Nanotom 180 XS, GE, Wunstorf, Germany).

Description of the main results obtained

Defoliated trees tended to show lower annual shoot growth rates than nondefoliated trees for the three years studied. The number of needles per year tended to be lower in the defoliated trees than in the nondefoliated ones. Unlike nondefoliated pines, the number of needles tended to diminish over the years in defoliated trees.

Although vulnerability curves to cavitation reported a 50% loss of conductivity at similar Ψ for both types of pines, the defoliated trees reached the 100% loss of conductivity at higher Ψ than the nondefoliated trees. Thus, under water stress conditions, the defoliated trees would loss near all their hydraulic conductivity at needle level before than the nondefoliated ones. The lost of hydraulic functioning would reduce the plant whole-plant hydraulic conductance of the defoliated pines and, therefore, the plant transpiration (Sack and Holbrook 2006) that would restrict the plant growth. This would explain the differences in the annual shoot growth and number of needles between both type of pines.

Unfortunately, the quality and resolution of the images we obtained with the X-ray nanotomograph were not good enough for analysing the collapse of the xylem conduits properly. Especially, we did not achieve the contrast necessary to distinguish water in the conduits from cell wall (Fig. 1). Thus, it was impossible for us to determine if the cell walls collapsed or not in needle.

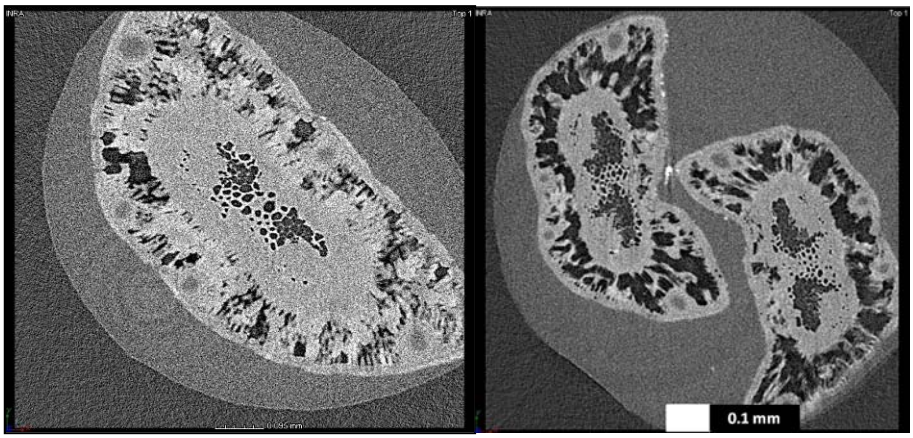

Fig. 1. Transverse sections of Scots pine needles obtained with the X-ray nanotomograph

Future collaboration with host institution

This STSM has provided an excellent opportunity to reinforce the established collaboration between the beneficiary and Prof. Hervé Cochard and his laboratory. In this way, the results obtained during this STSM will promote new collaborations between the beneficiary and both the laboratory of Prof. Cochard and other experienced researchers in plant hydraulics from other institutions. In fact, during this STSM, a research proposal for the European Synchrotron Radiation Facility (ESRF) in Grenoble (France) has been prepared and submitted for evaluating the hydraulic functioning of Scots pine at the needle level by using high resolution computed tomography (HRCT). This novel technique will provide images with enough resolution for evaluating the collapse of the xylem conduits.

Foreseen publications/articles resulting or to result from the STSM

The studies carried out during this STSM were very fruitful according to the results obtained and at least two publications are expected to be published.

Other comments

In parallel to the studies described above, the beneficiary has also obtained images of the xylem of Scots pines at stem level by nanotomography that will allow to evaluate (i) the cavitation spreading in tracheids and (ii) the importance of the cavitation fatigue, if any, in such spreading. Such images are actually being analysed and first results are expected to be obtained during the next months.

Confirmation by the host institution of the successful execution of the STSM

An attestation letter from the host researcher has been attached at the end of this document.

Acknowledgements

Thanks to the STReESS Cost Action FP 1106 for funding this STSM. We also thanks to Prof. Maurizio Mencuccini for his help and advises in this study, and for supplying the plant material from Prades Mountains (Spain); to Dr. Eric Badel for his assistance with X-ray nanotomograph; and to Dr. Katline Charra-Vaskou for helping with the ultrasonic sensors.

References

Charra-Vaskou K, Badel E, Burlett R, Cochard H, Delzon S, Mayr S (2012) Hydraulic efficiency and safety of vascular and non-vascular components in *Pinus pinaster* leaves. Tree Physiol 32:1161-1170.

Cochard H, Tyree MT (1990) Xylem dysfunction in Quercus: vessel sizes, tyloses, cavitation and seasonal changes in embolism. Tree Physiol 6:393-407.

Hacke UG, Sperry JS, Pockman WT, Davis SD, McCulloh A (2001) Trends in wood density and structure are linked to prevention of xylem implosion by negative pressure. Oecologia 126:457-461.

Johnson DM, Meinzer FC, Woodruff DR, McCulloh KA (2009) Leaf xylem embolism, detected acoustically and by cryo-SEM, corresponding to decrease in leaf hydraulic conductance in four evergreen species. Plant Cell Environ 32:828-836.

Mayr S, Cochard H (2003) A new method for vulnerability analysis of small xylem areas reveals that compression wood of Norway spruce has lower hydraulic safety than opposite wood. Plant Cell Environ 26:1365-1371.

McDowell N, Pockman WT, Allen CD, Breshears DD, Cobb N, Kolb T, Plaut J, Sperry J, West A, Williams DG, Yepez EA (2008) Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought? New Phytol. 178:719-739.

Sack L, Holbrook NM (2006) Leaf hydraulics. Annu Rev Plant Biol 57:361-381.

Sperry JS, Tyree MT (1990) Water-stress-induced xylem embolism in three species of conifers. Plant Cell Environ 13:427-436.

Tyree MT, Zimmermann MH (2002) Xylem Structure and the Ascent of Sap, 2nd 538 edn. Springer-Verlag, Berlin, Germany.

Vilà-Cabrera A, Martınez-Vilalta J, Vayreda J, Retana J (2011) Structural and climatic determinants of demographic rates of Scots pine forests across the Iberian Peninsula. Ecol Appl 21:1162-1172.

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

INRA Centre de Recherches de Clermont-Ferrand-Theix — Université Blaise Pascal
U.M.R. PIAF

Dr Hervé Cochard
UMR-PIAF
INRA Clermont-Ferrand
France
Herve.cochard@clermont.inra.fr
+33 (0)4 73 62 44 71

Clermont le 21 Mar 2013

Object: Attestation letter for **José Manuel Torres Ruiz**, Ph.D
Institute for Natural Resources and Agrobiology, Seville, Spain.

This is to attest that Dr José Manuel Torres Ruiz, has accomplished his 10 weeks (from 14/01/2013 to 22/03/2013) visit to my laboratory under the frame of a Short Term Scientific Mission (STSM) - FP1106 COST Action: STReESS. During his stay, José has studied the hydraulics of pine stem and needle with high-tech methods (Ultrasonic acoustic emission, Nanotomography). He collected a very impressive dataset and at least two publications are already planned. His visit was short, but very productive!

Kind regards,

Dr Hervé Cochard
Directeur de Recherches
UMR INRA-PIAF
Clermont-Ferrand, France