# Tree resistance to wind: the effects of soil conditions on tree stability

**P. DEFOSSEZ[a,b], M. YANG[a,b], J.M. BONNEFOND[a,b], D. GARRIGOU[a,b], P. TRICHET[a,b], F. DANJON[c,d]**

a. INRA, UMR1391 ISPA, F-33140 Villenave d'Ornon, France.
Pauline.Defossez@bordeaux.inra.fr
b. Bordeaux Sciences Agro, UMR 1391 ISPA, F-33170 Gradignan, France.
c. INRA, UMR1202 BIOGECO, F-33610 Cestas, France.
d. Université de Bordeaux, UMR1202 BIOGECO, F-33610 Cestas, France

## Abstract

*Wind damage represents more than 50% by volume of forest damage in Europe. Recent evidence suggests that wind damage could double or even quadruple by the end of the century with dramatic consequences for the forest economy and the ecological functioning and survival of European forests. Most trees during storms are uprooted. While a large amount of work has been done over the last decade on understanding the aerial tree response to turbulent wind flow, much less is known about the root-soil interface, and the impact of soil moisture on tree uprooting. This paper investigates at tree scale the effects of soil conditions, such as water saturation during storms, on tree stability. Our analysis is based on (i) the critical bending moment that induces tree uprooting measured from static pulling experiments (ii) the soil mechanical properties as function of climatic conditions measured and modeled from laboratory measurements (iii) new techniques developed for studying the mechanics of tree structure incorporating 3D roots architecture and numerical biomechanics modeling.*

### Keywords : root, failure, soil shear resistance, climatic conditions, tree stability

## 1 Introduction

Forests cover 42% of the land area in Europe and have a wide range of ecological, social and economic functions whose importance keeps growing. Wind damage is the main cause of forest destruction, followed by fire, insects and fungal damage. A recent review on the destructive storms in European forests over the past 60 years shows that storms are responsible for more than 50% of all abiotic and biotic damage by volume to European forests [1]. They shared that the volume of storm damaged trees will amplify as the growing stock and average age of European forests increase. Prediction and mitigation of wind damages are important issues for European forests. After two catastrophic storms in 15 years, questions have arisen concerning the viability of planted forestry. This calls for advances in methods to reduce damage by suitable forest management, including appropriate soil practices (soil tillage, soil drainage, etc.). A key component of all forest wind damage risk modelling is to understand mechanical interactions between the roots and the soil. This paper presents a methodology based on field experiments and numerical simulations, in order to estimate the effects of soil conditions (soil saturation, induration) on root anchorage.

# 2 Materials and methods

Tree anchorage as function of soil water conditions was measured in field conditions. Static tree pulling experiments were used for measuring the critical bending moment that induces uprooting. Experiments were conducted on adult Maritime Pine at three soil water contents: w= 8,6 % ($gg^{-1}$), 13.1% ($gg^{-1}$), 34.5 % ($gg^{-1}$). Tree pulling were performed on 17 adults of 24 m height on a plot located in Aquitaine (France) (44°43'47.5"N 0°44'40.8"W).

The change in soil mechanical resistance as function of climatic conditions was measured and modeled from laboratory mechanical measurements. Our method adapts concepts and methodologies developed in civil engineering for unsaturated soil mechanics to the specificities of forest soils (high porosity, heterogeneity, strengthening by fine roots). To characterize this spatial heterogeneity of soil properties (i.e. porosity, water content, mechanical strength), soil samples was sampled in on three location of the tree plot at three depths above the water table. Soil shear mechanical properties were measured by direct shear tests using a Wykeham Farrance shear testing on soil samples. Measurements were performed as a function of water content on unsaturated soil samples.

A biomechanical model based on the finite element method was used to simulate the tree pulling experiments and examine the impact of soil mechanical resistance. This model was developed to explicitly describe tree anchorage in relation to the main anchorage components, i.e. root system architecture, material properties of roots and soil, and root-soil interactions [2]. ABAQUS 6.13 was used in the study for model development.

# 3 Analyzing the effects of soil conditions on tree stability

Tree pulling data were normalized by the size of the tree following Gardiner et al. [3]: the measured critical bending moment was divided by $h.DBH^2$ where h is the tree height and DBH, the tree diameter at breast height. Field measurements showed that the normalized critical bending moment tends to increase with the soil water content. This is unexpected because the laboratory measurements showed that the shear soil resistance decreases with the soil water content in accordance to literature [4]. The load of the soil-root plate could explain the anchorage strengthening with soil water content. This is examined by using the biomechanical model.

# Références

[1] B. Gardiner et al. Destructive Storms in European Forests: Past and Forthcoming Impacts. Final Report to EC DG Environment. http://ec.europa.eu/environment/forests/fprotection.htm , 2010.

[2] 7. M. Yang, M., P. Défossez, F. Danjon, T. Fourcaud, Tree stability under wind: simulating uprooting with root breakage using a finite element method. Annals of Botany, 114 ( 2014) 695-709.

[3] B. Gardiner, H. Peltola, S. Kellomaki, Comparison of two models for predicting the critical wind speeds required to damage coniferous trees, Ecological Modelling 129 (1), (2000) 1-23.

[4] P. Delage, Y.-J. Cui, Sols non saturés Applications au calcul des ouvrages. Techniques de l'Ingénieur C 303, (2003) 1-27.