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Review article

Review: Wind impacts on plant growth, mechanics and damage

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ABSTRACT

Land plants have adapted to survive under a range of wind climates and this involve changes in chemical composition, physical structure and morphology at all scales from the cell to the whole plant. Under strong winds plants can re-orientate themselves, reconfigure their canopies, or shed needles, leaves and branches in order to reduce the drag. If the wind is too strong the plants oscillate until the roots or stem fail. The mechanisms of root and stem failure are very similar in different plants although the exact details of the failure may be different. Cereals and other herbaceous crops can often recover after wind damage and even woody plants can partially recovery if there is sufficient access to water and nutrients. Wind damage can have major economic impacts on crops, forests and urban trees. This can be reduced by management that is sensitive to the local site and climatic conditions and accounts for the ability of plants to acclimate to their local wind climate. Wind is also a major disturbance in many plant ecosystems and can play a crucial role in plant regeneration and the change of successional stage.

Contents

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1. Introduction

Almost all land plants have to balance five major requirements: first they need to photosynthesis, second they need to transport water, third they need to grow, four they need to reproduce, and last but not least, they need to have mechanical support under static and dynamic loading throughout their lifetime (Fig. 1). One of the major sources of mechanical loading on plants is the wind, which, in turn, has a major impact on plant growth, morphology, physiology and ecology. The subject of plant interaction with the wind has been given a detailed treatment in a number of papers and books [1–7], there have also been discussions of wind loading on plants in other books [8,9], recent reviews of the subject of plant biomechanics have discussed the influence of the wind [10], and there have been reviews of the damaging impact of wind on forests [5,11] and crops [12,13]. However, the overall mechanical influence of wind on land plants has not been discussed together in one place.

In this review paper we focus on the mechanics of the interaction between plants and the wind in order to link the biology of plant growth, development and survival with the physics of wind motion and plant wind loading. Moreover, we deal with both herbaceous and woody plants (which have been often analysed separately) so as to draw attention to general features and traits. This helps to understand how plants have adapted to their wind environment and illustrates the impact wind damage can have on plant communities and ecosystems, and the consequences for commercial forestry, urban trees and farming. We look at modifications to plant cell wall chemistry and structure, the morphology of plant stems and branch structure, plant biomass allocation and plant architecture that resist wind loading. We show that plants respond to the requirement for mechanical resistance to the wind through a comprehensive hierarchical structure from cell wall to the whole plant [14].

We first start with a brief description of the wind in the earth's boundary layer and how this varies depending on factors such as location, topography and the thermal stability of the atmosphere. We then discuss the nature of the wind around plants and through plant canopies, the wind loading on plants and the dynamic behaviour of plants in the wind. In particular we focus on the factors affecting the dynamic response of plants and why this is so important for understanding wind/plant interactions. The focus of the paper then shifts to the impact of wind on tree growth and cell formation and structure. We investigate in detail how modification of plant cell structure and plant biomass allocation during growth counteract the influence of the wind and we discuss how this changes with plant growth stage. Finally, we describe plant damage under wind loading, the different scales of damage from single needle or leaf to individual plants, plant communities and the regional level (Fig. 2). We discuss how plants have adapted to these risks and the economic importance of wind damage. Strategies that have been utilised to reduce wind damage to plants of economic importance are also presented.

This paper does not try to be a substitute for the excellent reviews of the subject of wind and plant interactions [1–3] but rather to focus on the interaction between winds and plants from a mechanical perspective. A glossary of key technical terms is provided in Text Box 1.

2. Wind in the atmospheric boundary layer

2.1. Basic structure of the wind in the boundary layer at the earth's surface

The air in the boundary layer of the earth's atmosphere is in almost constant motion, primarily due to pressure variations created by differential heating of the earth's surface by the sun. The winds generated have very different intensities, direction and persistence depending on the latitude and the meteorological conditions. This is partly due to the rotation of the earth and the balance that exists between the pressure gradient, the Coriolis inertial force and the drag of the earth's surface. The surface drag is negligible well above the surface at a height known as the geostrophic level