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Electrostatic forces in wind-pollination—Part 2: Simulations of pollen capture ☆

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Abstract

During fair-weather conditions, a 100 V m^{-1} electric field exists between positive charge suspended in the air and negative charge distributed on the surfaces of plants and on the ground. The fields surrounding plants are highly complex reaching magnitudes up to 3×10^{6} V m^{-1}. These fields possibly influence the capture of charged wind-dispersed pollen grains. In this article, we model the electric fields around grounded conductive spherical "plants" and then estimate the forces and resulting trajectories of charged pollen grains approaching the plants. Pollen grain capture depends on many factors: the size, density, and charge of the pollen; the size and location of the plant reproductive structures; as well as wind speed, ambient electric field magnitude, and air viscosity. Electrostatic forces become increasingly important as pollen grain charge increases and pollen grain size (mass) decreases. A positively charged pollen grain is attracted to plants, while a negatively charged pollen grain is repelled. The model suggests that a pollen grain (10 μm radius, carrying a positive charge of 1 fC) is captured if passing within 2 mm of the plant. A similar negatively charged pollen grain is repelled and frequently uncapturable. The importance of electrostatic forces in pollen capture is limited by wind, becoming virtually irrelevant at high wind speeds (e.g. 10 m s^{-1}). However, during light wind conditions (e.g. 1 m s^{-1}), atmospheric electricity may be a significant factor in the capture of wind-dispersed pollen.

Keywords: Atmospheric electricity; Electrostatic charge; Electrostatic field; Particle capture; Wind pollination

1. Introduction

The transfer of pollen grains between plants is integral to reproduction for wind-pollinated plants. Following release, the pollen grains are carried by the wind, with most depositing on nearby plants and the ground shortly after release. Successful capture is limited, in part, because the female pollen-capturing structures, called stigmas, present tiny targets (e.g. a few millimeters long) for the minute (e.g. 10 μm radius) pollen grains. Furthermore, the pollen grains tend to follow the wind as it flows around the flowers, passing by the receptive stigmas and avoiding capture (Rubenstein and Koehl, 1977; Shimeta and Jumars, 1991). Adaptations in plant

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morphology that enhance pollen capture should be favored by natural selection.

Electric fields are present in the environment, and wind-dispersed pollen grains are electrically charged (Bowker and Crenshaw, 2006). Consequently, as charged airborne pollen grains encounter the electric fields in the environment around plants they may experience an electrostatic force sufficient to influence deposition. Electrostatic enhancement of capture has been demonstrated in agricultural settings, where purposeful electrostatic charging of pesticides or pollen increased deposition by up to an order of magnitude (Felici, 1973; Law, 1987, 2001; Gan-Mor et al., 1995; Gan-Mor et al., 2003; Banerjee and Law, 1996; Law et al., 1996; Law et al., 2000; Bechar et al., 1999; Vaknin et al., 2000, 2001; Law and Scherm, 2005).

This is the second in a series of two articles exploring the role of electrostatic forces in pollen grain capture under natural conditions. The electrostatic force on a charged wind-dispersed pollen grain is the product of two factors; the electric field at the pollen grain's location and its charge. In the companion article (Bowker and Crenshaw, 2006), we report measurements of the electrostatic charge carried by pollen grains. In this article, we develop a simple model of the natural electrostatic field around plants based on plant size (morphology), location, and the magnitude of the ambient electric field. Then, we use the pollen grain charge measurements (Bowker and Crenshaw, 2006) and the model of the electric field around plants to estimate the electrostatic force on pollen grains and simulate their trajectories as they pass near plants.

During "fair-weather" conditions, characterized by clear skies and light breezes, the atmosphere has a slight preponderance of positive ions, giving the air a small net positive charge (a positive space charge). The space charge is between 10^4 and $10^6\,\mathrm{m}^{-3}$ (Chalmers, 1967). Collectively, the surface of the earth and the plants and animals in electrical contact with it, carry a net negative charge equal to the cumulative atmospheric positive space charge (Fig. 1), even though the ground is defined to have an electrical potential of zero volts. This charge separation generates the "fair-weather" electric field averaging nearly $100\,\mathrm{V\,m}^{-1}$ at the surface of the earth. Globally, a diurnal variation of approximately 20% in the field is present, but this can often be obscured by local effects (Chalmers, 1967). Variation in weather, air conductivity, or the presence of pollution, space charge, or topography can lead to orders of magnitude changes as well as polarity reversals in the local electric field.

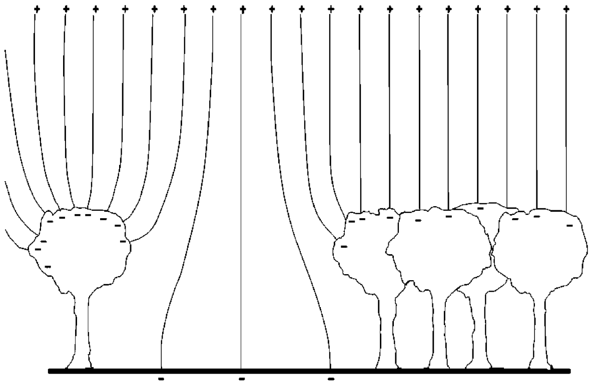

Fig. 1. Electric field lines around a solitary tree, above a forest, and above a grassy field. The lines are tangent to the electric field. The strength of the field is inversely proportional to the spacing of the lines. The lines extend from atmospheric positive charge to negative charge on the ground and on the surfaces of trees. The negative charge is most concentrated on the solitary tree and on the edge of the forest and is nonexistent beneath the solitary tree and within the forest. In the grassy field, between the solitary tree and the forest, the electric field is reduced.

The negative charge on plants is asymmetrically distributed, with charge concentrated on pointed plant features (e.g. tips of branches, edges of leaves, and feathery plant stigmas) that extend above their surroundings. Though not well described, the local electric field around these features derived from the distribution of negative charge is complex and magnified (Maw, 1961a, b, 1963; Corbet et al., 1982; Erickson and Buchmann, 1983; Niklas, 1985; Bechar et al., 1999; Vaknin et al., 2001). The magnification of electric fields around plants is described for electrostatic applications in agriculture, where the electric field forms between a charged spray cloud (of pollen grains or pesticide) and the plant. The electric field around the points of the plant can reach values of several hundred thousand volts per meter (Law, 1987, 2001; Dai and Law, 1995; Bechar et al., 1999). Consequently, the charged spray is often deposited on the points of the plant, as well as on surfaces that generally do not capture particles—such as the underside of a leaf (Erickson and Buchmann, 1983; Law, 1987, 2001; Dai and Law, 1995; Law and Scherm, 2005). Through a similar magnification process, we expect the natural electric field around plants can be many orders of magnitude (e.g. $>100\,\mathrm{kV\,m}^{-1}$) larger than the ambient field (e.g. $100\,\mathrm{V\,m}^{-1}$). A simple model