16C.5 A COUPLED PHYSICAL-BIOLOGICAL MODEL FOR MAIZE POLLINATION

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1 INTRODUCTION

Controversy surrounding the use of genetically modified crops has led to increased interest in evaluating pollen dispersion, especially for open-pollinated crops such as maize. Previous work has focused mainly on either the biological aspects of pollination or the physical processes affecting pollen dispersion. Efforts to date include estimates of pollen survival in the laboratory (Herrero and Johnson, 1980) and in the field (Raynor et al., 1972; Schoper et al. 1987a, b; Luna et al. 2001). A largely separate line of research has been devoted to predicting the movement of pollen grains in air, treating pollen grains as passive, abiotic particles (e.g., Di-Giovanni and Kevan, 1991; Ashton et al. 2001; Aylor, D.E., 2002 personal communication). Realistic assessment of potential of foreign pollen to produce outcrossing must consider the *interactions* of physical and biological processes. These include the nature of pollen production and shed, the impact of weather patterns on pollen dispersal and viability, and competition between locally-shed pollen and pollen delivered from elsewhere on the wind.

To address this problem we are developing a coupled physical-biological model of outcrossing based on a Lagrangian model of pollen dispersion. There are two specific advantages of the Lagrangian approach: first, the method readily accommodates flow fields of arbitrary complexity; second, each element of the material being transported can be identified by its source, time of release, or other properties of interest. Thus the physical effects of airflow and turbulence on pollen dispersion can be considered together with the biological aspects of pollen release and viability.

2 THE COUPLED PHYSICAL-BIOLOGICAL MODEL

2.1 Overview

The model is a collection of sub-models that couple the physical and biological processes that affect pollen from its production and shed, through its transport in the atmosphere, and finally to its viability at a receptor (here, another plant). A conceptual diagram of the coupled approach is given in Figure 1. The coupled physical-biological model is not yet complete, but several of the components have been developed and are undergoing tests. Current status and results will be presented at the conference. In the following subsections we briefly describe the individual components of the coupled model.

2.2 Meteorological input data

The model is designed to be flexible as to meteorological input data that are used. In most agricultural applications, meteorological data are limited to surface weather variables measured at a single point. We extrapolate such data vertically using similarity theory above the canopy and profile functions given by Wilson et al. (1982) within the canopy. We then assume horizontal uniformity to construct wind, temperature, and humidity fields in three-dimensional space.

Meteorological data can also be input from numerical weather prediction models or operational analyses. As an example, we have used results from the shelter belt model of Wang et al. (2001) to specify the flow field for the Lagrangian model.

2.3 Source submodel

Accurate calculations of pollen concentrations in the atmosphere and pollen deposited at a receptor depend critically on accurate estimation of the amount of pollen produced. Westgate et al. (2002) established quantitative relationships between tassel development and pollen shed. Their techniques revealed that pollen shed on a field scale typically occurred over a period of 10 to 12 days and peaked 2 to 3 days after anthesis. The amount of pollen produced for a typical modern hybrid was about $3x10^{11}$ pollen grains ha^{-1}, corresponding to about $4.4x10^6$ pollen grains per plant. Such measurements allow us to evaluate pollen production on a field scale and thereby define source activity.

2.4 Transport and diffusion submodel

The Lagrangian-stochastic method represents the material being transported as a collection of discrete elements (often called virtual “particles”) rather than a continuous plume. The transport and diffusion submodel follows criteria for validity of Lagrangian stochastic models discussed by Thomson (1987).

Maize pollen grains have a high settling velocity (order 20 cm/s) which strongly affects their dispersion. We adopt a simple method for including the effects of settling, by superimposing a terminal fall speed onto the vertical component of the particle’s motion. Wilson (2000) finds this approach to be adequate in most cases as compared with more complex inertia-particle approaches.

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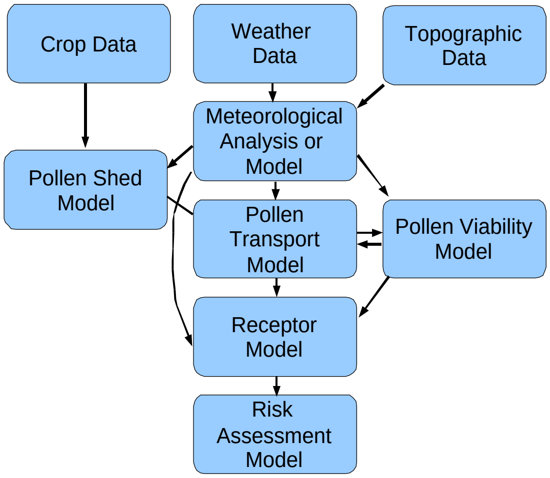

Figure 1: Submodels in the coupled physical-biological model. Arrows indicate the major information flows between submodels.

Results of the pollen transport submodel have been compared to field measurements gathered in a previous project and to results from a standard EPA dispersion model. We are exploring a variety of methods for using predicted virtual-particle locations to estimate the surface pollen burden. The simplest approach is to count the number of virtual particles deposited in each unit area. The main disadvantage of this approach is that large numbers of particles are needed to obtain reliable estimates of concentrations. We are testing statistical approaches such as parametric methods and kernel density estimation techniques that have the potential to yield more robust concentration estimates for a given number of virtual particles, thus allowing fewer particles to be used.

2.5 Pollen viability submodel

The Lagrangian approach allows us to track the physical environment (temperature, humidity, etc.) experienced by each element of the pollen cloud. This is necessary in order for environmental effects on pollen viability to be incorporated into the model. Viability is reduced at high temperatures and low humidities (e.g., Herrero and Johnson, 1980; Luna et al., 2001). Our viability submodel will be based on a pollen aging function that expresses pollen viability in terms of time-integrated temperature and humidity along the pollen trajectory. This aging function will be derived from data obtained during a field study of temperature and humidity effects on maize pollen viability that we performed in the 2002 growing season. These results will be discussed at the conference.

2.6 Receptor submodel

When foreign pollen enters a field, it must outcompete local pollen to achieve an outcross. The outcome of this competition is affected by physical factors (e.g., local pollen density), genetic factors (e.g., pollen-silk compatibility and relative rates of pollen tube growth), and environmental factors (e.g., wind speed and direction, relative humidity, temperature). Luna (2001) reported that for hot, dry conditions no outcrosses occurred beyond 200 m from the pollen source. Receptor plants were not detasselled; thus, adventitious pollen had to compete with a heavy cloud of local pollen. In those experiments it was not possible to determine whether adventitious pollen amount, pollen viability, or failure to compete with locally-produced pollen ultimately controlled the observed level of out-crossing.

Results from our research on pollen shed indicate that a minimum density of pollen shed of about 3000 pollen grains per exposed silk is required to ensure maximum kernel set (Westgate et al., 2002). At lower levels of pollen shed, kernel set decreases dramatically, possibly leading to increased risk of out-crossing.

2.7 Risk assessment submodel

The ultimate product of the model will be a quantitative assessment of the likelihood and degree of outcrossing between adjacent fields. This information can then be used as a component of risk assessment, which must be considered in light of acceptable levels of contamination dictated either by regulatory standards or by market forces.

3 SUMMARY

We are developing a model that couples the physical mechanisms of pollen transport and diffusion with the biological processes involved in pollen shed and viability. The model is designed to be flexible as to the input data that are used and general as to the variety of real-world conditions that can be treated.

The project also will provide the crucial element of field verification to assess the skill and limitations of the model, and components of the model that are most in need of improvement. As noted by Emberlin et al. (1999) most prior studies of pollen dispersion have been performed for narrow ranges of weather conditions, so that it is essential to obtain measurements for verification when a model is applied in a particular environment. The model will be continuously evaluated with results from field studies in realistic applications.

4 ACKNOWLEDGMENT

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