3.6. A LAGRANGIAN STOCHASTIC SIMULATION MODEL FOR EVALUATING CROSS FERTILIZATION IN MAIZE

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1. INTRODUCTION

The extensive adoption of genetically modified crops has spurred the need to quantify movement of genetic traits in the environment due to pollen flow and cross fertilization. Cross fertilization between varieties of a species can result in outcrossing and the subsequently formed hybrids may express traits from either parent (e.g., when yellow seeds occur on normally white-kernel ears of maize). A Lagrangian stochastic (LS) model was developed specifically to examine maize pollen transport in a maize canopy with a goal of evaluating pollen-mediated gene flow (PMGF) on seed purity in hybrid seed production fields.

2. THE MODEL

The two major barriers to PMGF are spatial and temporal separation of the pollen source and receptor plants (Aylor et al. 2003, Halsey et al. 2005). The extent to which PMGF can occur depends on several factors including: 1) pollen transport between plants and survival of pollen (Aylor 2004) in the atmosphere, 2) deposition of viable pollen grains on receptive silks, 3) the probability that any particular pollen grain will successfully out-compete other pollen deposited on the same silk to complete the fertilization process, and 4) the degree of temporal congruence of male and female flower development (e.g., maize tassels and silks). These processes were incorporated into a model for PMGF, which is described briefly below.

The spatial part of the model is framed in terms of pollen flow between a single source and a single receptor (SS-SR) plant; this includes the case of pollen transport between a source (tassel) and receptor (silk) on the same plant, potentially resulting in self fertilization. The resultant PMGF for pollen flow between blocks of plants was obtained from the basic SS-SR model by mathematically integrating over all of the possible transport events between the source and receptor plants of interest.

The pollen transport function was calculated using a Lagrangian stochastic (LS) particle trajectory simulation model. The basics of the LS model have been described previously (Aylor and Flesch 2001, Aylor et al. 2003, Aylor 2005, Boehm and Aylor 2005, Aylor et al. 2006, Boehm et al. 2008).

3. THE EXPERIMENT

The model was used to analyze maize outcrossing data in which yellow-seeded (Y) maize and white-seeded (W) maize was each planted in spatially separated blocks (Fig. 1 bottom). Outcrossing percentage, χ, was determined by separately counting the number of yellow, N_Y, and white, N_W, kernels on individual ears in each row

Fig. 1. Maize ears of the white kernel variety (top panel) harvested at various distances from blocks (bottom panel) of yellow kernel corn.

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of the white-seeded type (Fig. 1 top) using the formula $\chi = 100 \times N_Y / (N_Y + N_W)$. Data were obtained from two planting arrangements: In Planting 1, Y and W maize plants were planted alternately in a series of contiguous blocks, each containing a different numbers of rows (Fig. 1). The planting arrangement yielded pollen source to receptor plant distances ranging from 1 to 53 m. In Planting 2, four blocks (two white and two yellow) were planted adjacent to one another in a checkerboard pattern. In this case, source to receptor distances were from 1 to 27 m. Flowering of the two varieties overlapped almost perfectly, except that the Y variety was about one day ahead of the W variety in Planting 1.

4. MEASURED and MODELED OUTCROSSING

The modeled patterns of χ are shown in Fig. 2 for Planting 1 (top) and Planting 2 (bottom) by variations in color, where red corresponds to 95-100% and violet corresponds to 0-5% Y kernels on W ears. Attention here is restricted to row-average values of χ, which result from using a mechanical row harvester and, therefore, are the values of practical agronomic interest. The LS model results were highly correlated with the observations and generally gave good agreement with the average outcrossing percentage observed in each W row. For Planting 1, the relationship between predicted (Pred) and observed (Obs) values of outcrossing was given by Pred = 0.65 x Obs + 0.14 (r^2 = 0.92), while for Planting 2, the relationship was Pred = 0.98 x Obs + 0.01 (r^2 = 0.96). The agreement for Planting 1was less good than for Planting 2 and arose mainly from the comparisons made for the single and double rows of W corn surrounded by several rows of Y corn, where the outcrossing percentage was consistently under predicted.

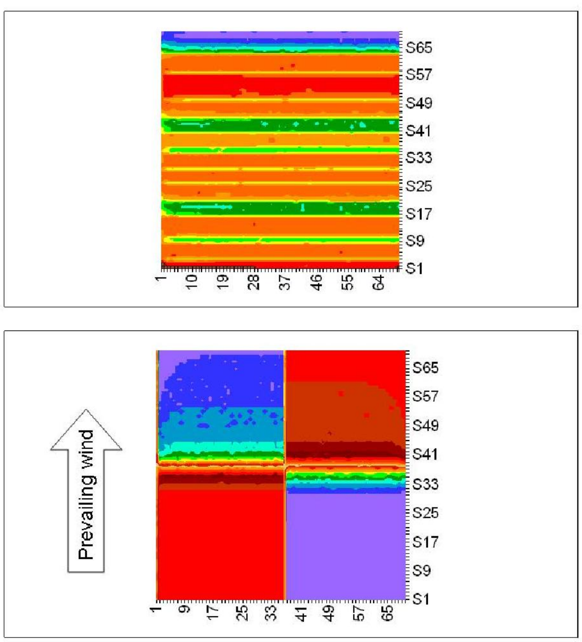

Fig. 2. Modeled patterns of outcrossing in maize planting 1 (top) and in planting 2 (bottom panel), where red represents a high level (95 to 100%) and violet a low level (0 to 5%) of outcrossing.

5. SUMMARY

The LS model predicted reasonably well both the magnitude and the general shape of the outcrossing curves. However, it must be emphasized that a) the model contains some adjustable parameters (particularly with respect to partitioning of pollen release at various wind speeds during the course of a full pollination season) and b) the model uses a feasible but, as yet, unproven fertilization rule for connecting pollen transport and deposition to gene flow. It has been argued (Gustafson et al. 2006) that, since outcrossing depends on so many highly complex and interacting factors, practical problems are best approached empirically. It seems hard to argue with this assertion at the present stage of model development. However, a main strength of the combined modeling and experimental approach presented here is that it has the potential to efficiently examine PMGF for a wide array of conditions and planting schemes and to help guide the process of experimental design. Since the model yields a physically-based interpretation of the effects of distance and border rows on outcrossing potential, it promises to have utility for analyzing or designing studies of cross pollination in maize and other wind-pollinated species.

6. ACKNOWLEDGEMENTS

This work was supported in part by Hatch Funds; by the Cooperative State Research, Education, and Extension Service, U. S. Department of Agriculture, under Agreements 2001-52106-11528 and 2004-33522-15044; and by a grant from Pioneer Hi-Bred International, Inc.

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