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Anticipating and responding to biological complexity in the effects of climate change on agriculture

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The effects of climate change on biological systems are complex. This is particularly apparent for multi-species systems such as plant diseases and plant-herbivore interactions where climate can affect each species individually as well as influencing the interactions between species. Climate change-driven shifts in agricultural patterns and practices add another layer of complexity (Savary et al., Field Crops Res., 2005, 91:263-271). Plant diseases and insect pests have important impacts on agricultural systems; for example, agricultural losses to plant disease are estimated at over 10% (Savary et al., Ann. Rev. Phytopathol., 2006, 44:89-112). Thus, as a first step it will be important to develop an adequate conceptual framework for anticipating the biological complexity of the responses of these systems to climate change. Secondly, an adequate conceptual framework for the effects of different adaptation and mitigation scenarios, with their own complexities, will be needed to evaluate appropriate responses. Our objective is to develop frameworks to help meet this need, and here we outline a modeling structure for these components, with an emphasis on plant disease. The impact of climate, through weather patterns, on plant disease has been studied in detail for several important plant diseases (Garrett et al., Ann. Rev. Phytopathol., 2006, 44:489-509). It is possible to predict with reasonable confidence whether disease will become more or less important within a field as a function of weather variables. However, typical disease forecasting models based on weather do not incorporate larger scale processes or complexities that may lead to higher or lower levels of inoculum availability and pathogen dispersal (Seem, Can. J. Plant Pathol., 2004, 26:274-283). Nor do they incorporate the large effects of increased scarcity of water, labor, energy, and other natural resources on cropping practices and systems. To enhance predictions of responses to climate change, we incorporate scenarios that involve thresholds, interactions, and feedback loops (Garrett, In Global Climate Change and Extreme Weather Events: Understanding the Contributions to Infectious Disease Emergence, National Academies Press, Washington, D.C. 2008). Thresholds may exist such that disease is constrained for some ranges of weather variables and then quickly released from constraint when weather variables shift by a relatively small amount. For example, the Karnal bunt pathogen experiences an Allee effect, or reduced per capita reproduction at lower population sizes (Garrett and Bowden, Phytopathol., 2002, 92:1152-1159). In the case of this pathogen, the reduced per capita success for low populations is due to the necessity of different mating types encountering each other for reproductive success. Insect pests and insect vectors of plant pathogens may experience similar Allee effects. If climatic conditions change such that weather variables are shifted to support populations above an Allee or comparable threshold, the problems caused by the pathogens or insect pests may increase by a greater amount than would have been predicted in a model that ignored this type of complexity. Conversely, if weather variables are shifted to support only lower populations, the decline in the problem may be greater than anticipated. Feedback loops may occur when increases in disease or the abundance of insect pests make some types of management less useful. For example, some types of disease resistance are based on reduced production of pathogen propagules per infection. Within a field removed from other sources of inoculum, this type of resistance would slow epidemics since for every pathogen generation less inoculum would be produced. But in a field networked to other fields where high levels of inoculum are available, the positive effect of this type of resistance within a field may be reduced, leading to higher regional inoculum loads. Other management approaches that similarly rely at least in part on reducing inoculum pressure within a field include sanitation practices such as removing diseased plant tissues and the use of cultivar mixtures or intercropping. We are working to model epidemic interactions across larger spatial scales using a 'disease neighborhood' approach (Willocquet and Savary, 2004). While most models of larger-scale disease risk are based on a point-by-point analysis of risk factors, new models may improve predictions by incorporating the effect of risk levels in neighboring regions (Sparks et al., in preparation). We also envision new epidemic modeling approachs that combine (i) the directs effects of climate change, (ii) the indirect effects of climate change (though rapid agricultural change), on (iii) not one disease, but disease syndromes considered as whole (Savary et al., Ann. Rev. Phytopathol., 2006, 44:89-112). Responses to changes in agricultural risk factors will also need to be addressed at multiple spatial and temporal scales. The impact of increased risk factors will often be greatest for diseases or pests which emerge as important when previously they were minor enough that farmers did not need knowledge or skills to manage them. In these cases, the demands on extension and information networks will be greatest, and inadequate links within these networks will be most apparent. This will be especially true in regions where farmers have lower educational levels and fewer tools in place for accessing information independently.

We are developing models of information networks that incorporate the demands of rapid change in systems and identify nodes where particular attention is needed to make networks resilient to change. The threshold that allows farmers to recover from stress and shocks resulting from climate events and stresses is a function of the types of agricultural production portfolios and other livelihood activities, in their interaction with markets and the environment. Interactions between climate, markets, and changes in agriculture influence the ability of rural households to accumulate or deplete assets, and their ability to incorporate knowledge and invest resources in addressing this changing environment. This is a particular concern in the agriculture of developing countries, where risk reducing institutions are limited or nonexistent. In summary, new models are needed to address changes in agricultural risk factors due to climate change.

Important components of these models will be factors to address biological complexity, such as the incorporation of thresholds, interactions, and feedback loops. These forms of biological complexity will need to be 'scaled up' in models such as those that incorporate 'risk neighborhoods'. Finally, models with these forms of biological complexity will need to be linked with models of information networks and market influences to predict where new demands will be placed on extension and education systems. We will present examples of each of these types of links.