AGRICULTURAL METEOROLOGICAL MODELS

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Contents

Summary

This chapter describes agricultural meteorological models, narrowly defined to include only models that simulate meteorological variables that are used in inputs to models that describe agricultural systems that respond to the weather. Both statistical and process models are discussed.

Models are described that simulate the total solar radiation received at the earth's surface and models to simulate the direct and diffuse radiation of the total radiation, visible, and near infrared radiation. Other models include leaf wetness, dew point, evapotranspiration, soil moisture, hourly diurnal temperature, growing degree days, and chilling units. Most of the models use weather inputs that are readily available from current weather observations and climate records. Brief discussions are also included about models that link the microclimate of a crop canopy to atmospheric forcing, and different crop, livestock, insect, and disease models that use weather and climate data as inputs.

1. Introduction

A narrow definition of agricultural meteorological models would limit the models to those that estimate meteorological, canopy, and soil variables that are not commonly measured, and those that model the microclimate of a location based on the forcing of the regional atmospheric conditions. The broadest definition of agricultural meteorological models would include any model that used weather or climate data to evaluate the response of agricultural crops, economically important pests, diseases, and livestock to the atmospheric and soil environment.

This chapter will discuss a) the different modeling approaches in developing agricultural meteorological models; b) models that estimate weather variables that are not commonly measured; c) weather variables computed from measured variables; d) models linking the microclimate to the surrounding atmosphere; and e) models that estimate the response of crops, livestock, insects, and diseases to the meteorological conditions. Application of agricultural meteorological models ranges from evaluation of past weather to forecasting of future weather event effects on crops, insects, or livestock. There will be some overlap with the material presented in this chapter and the material presented in *Computer Models for Food and Agriculture* under the topic chapter *Computer Models for Food and Agriculture*.

2. Approaches in Developing Agricultural Meteorological Models

All models by nature reduce to empirical relationships at some level. Therefore, all models are "statistical" in their development. Generally, some form of regression, either linear or non-linear, is used to relate one or more observed independent variable(s) to an observed dependent variable. The modeling approach is defined by the level at which statistical methods are used to define a relationship, and the number of either statistical relationships or physical principles that are combined to provide the desired model result.

The earliest agricultural models used a statistical approach where crop yield in a region, the dependent variable, was related to monthly temperature and precipitation of the region, the independent variables. During the last half of the 20th century, process models have been developed where yield is simulated based on daily photosynthesis with daily soil moisture, solar radiation and temperature as model inputs. The end result is an estimate of crop yield for a region or field based on a physiological variable rather than crop yield related to monthly weather variables.

2.1. Statistical Approaches

The statistical approach to agricultural meteorological models requires the least amount of data, resources and infrastructure. The simplicity of the statistical models allows them to be used at the farm or regional level with a minimum of training. These advantages are offset by the need to collect weather and biological response data at each location for several years before the model can be used to predict the biological response. As the number of years of data increases, the error associated with the model decreases assuming there is a strong relationship between the independent and dependent variables. The number of years required to develop the model increases as the number of independent variables increases. The minimum number of years of data to develop a statistical model is one more than the number of independent variables. With the minimum number of years, the model has one degree of freedom and represents the relationship between the independent and dependent variables. However, when such a model is applied to an independent data set of the same variables it may fail to accurately predict the response of the dependent variable to the independent variable. As the number of observations increases, the uncertainty of the prediction decreases.

Application to areas other than where the model is developed is problematic because of interactions of other environmental variables that may impact the agricultural system. In the case of agricultural crops, the relationship between the amounts of rainfall received during the growing season will differ by location depending upon the soil texture, water holding capacity, and soil fertility.

A complication of crop statistical models is the change of yield potential as newer hybrids and varieties are developed. The result is a crop model that only includes weather variables, will with time begin to underestimate yields. This requires the model to include a time variable to account for the improved genetics. In addition, management practices change with time, and assuming the new management practices result in larger yields, adjustments must be made for the changing management practices.

2.2. Process Approaches

While the statistical approach is still an important method, the advent of modern computers has resulted in this approach being replaced by more complicated process models. A process model for application to crop growth and development consists of a number of sub-models. In most crop process models there are sub-models that simulate a) soil moisture at a location, b) evapotranspiration, c) photosynthesis response to light, temperature and plant water status, d) respiration, e) partitioning of photosynthates to different plant compartments, and f) plant growth stage. Some models also include sub-models that simulate the plant nutrient uptake and status.

The response of the plants to rainfall or irrigation is reflected in the amount of water in the soil that is available to plants, and the ability of the plants to take up water from the soil. The process models look at the processes of water infiltration, retention, drainage, and uptake by the roots from different soil layers. This contrasts to the statistical models that relate rainfall or irrigation received at the soil surface to final yield or biomass.

Disadvantages of agricultural crop process models include the need for more input data, for example soil characteristics such as texture, infiltration rate, drainage rates, water holding capacity, etc. In addition to a complete description of the soils at a location, the genetic coefficients of the crop being grown must also be developed. Finally, desk or lap-top computers are required to manage the large quantity of weather, soil, and crop inputs to the models, and to run the models. Therefore, process models require more infrastructure and training of users to run the models.

The main advantage of agricultural crop process models is that they can be used anywhere the data required to run them are available. The estimates from these models should more accurately represent multiple locations than a statistical model.

3. Models of Weather Variables not Commonly Measured

Agricultural meteorological models by definition require the input of weather data. Some of these data, such as air temperature and precipitation, are measured on a routine basis at numerous sites throughout the world. Others, such as wind speed and direction, cloud cover, percent sunshine, solar radiation, and barometric pressure, are measured less frequently and most often at major airports or meteorological stations that are manned 24 hours a day. In recent years with the development of data loggers, many of these variables are measured at automated weather stations which are included in mesonets throughout various states and countries.

Historically, only daily temperature and precipitation are available in many of the rural areas of the world. The lack of solar radiation and humidity data requires the use of models developed from temperature and precipitation data to provide estimates of these variables that are needed to run the process models.

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Biographical Sketch

S. E. Hollinger is Senior Professional Scientist Emeritus of the Illinois State Water Survey, Champaign, Illinois. Dr. Hollinger's research included development and use of maize and soybean crop models and field experiments to study the effects of weather on these crop growth and development. His field experiments included the use of mobile rain shelters to study the effects of drought on maize and soybeans at different growth stages, and the use of weather and flux instruments to continuously monitor the energy balance, carbon dioxide and water vapor fluxes from a no-till maize and soybean ecosystem. Although retired, Dr. Hollinger continues to collaborate with scientists at the Illinois State Water Survey studying the effects of weather on crops and the effects of crops on the weather.