81 Integrating Soil and Crop Models for Agroclimatological Analysis

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Introduction

In spite of the rapid advances made in the past 2 decades, world food production will barely manage to keep up with population and demand from now until the year 2000. The exceptionally stable climatic period witnessed by the world over the past 40 years is highly unlikely to continue (Cusack, 1983). Climatic instability will increase the vulnerability of the already marginal areas currently under cultivation in the semiarid regions of Asia and Africa. Integration of information from soils, crops, and the environment is crucial to evolve carefully managed systems of cultivation that make the most efficient use of natural resources.

Progress in Agroclimatological Analysis

Previous agroclimatological analyses are too numerous to list and have ranged from analyzing a single factor such as rainfall to combining multiple data sets from climate, soils, and socioeconomics to develop operationally logical subdivisions for a crop in a country (Carter, 1987). It is difficult to categorize them into well-defined types since the analysis itself was often dictated by perceived needs, data availability and ease of data collection, tools and methodologies available for data manipulation and, most of all, by the evolution of the knowledge base elucidating the interactions between the climate and agricultural systems. For example, rainfall analysis over the past 4 decades progressed from a traditional statistical approach to a more agronomically relevant approach today.

The most common practice in agroclimatic analysis has been to present averages of monthly, seasonal, or annual totals of the parameters of interest derived from long-term weather records. There was an early recognition that rainfall is most properly viewed mainly as a balance between the supply and evaporative demand rather than as supply *per se*. Methodologies initially suggested (Thornthwaite, 1965) that comparisons between average rainfall and potential evapotranspiration (PE) be used to predict moisture availability to crops. In all the above methodologies, the problems associated with interannual variability have been recognized.

The question of variability has been addressed by analyzing yearly totals for a particular period, and estimating from them the amount of rain that can be expected at given probability levels. A unique example of using the probability approach is given by Hargreaves (1971) who developed a "moisture availability index" which is the ratio of PD/PE where PD is the dependable precipitation defined as the expected rainfall at the 75% probability level.

Stern et al. (1982) argued that even with such improved approaches, much of the information that could otherwise be easily generated from daily data is never analyzed. Computer storage is now readily available to easily store and use daily data. As an alternative to many of the direct approaches employed in agroclimatic analysis, Stern et al. (1982) proposed that the seasonal pattern of daily rainfall could be modeled and probabilities of rainfall events could then be derived from the model.

The value of any agroclimatic analysis depends upon its exploitation in an agronomic sense which makes the analysis agronomically relevant. Since most agronomic questions start with decision making pertaining to planting, fertilizer application, weeding, cultivation, harvesting, etc., it is desirable to frame the questions of relevance from the standpoint of cropping sequence as opposed to a monthly calendar. Operations of this nature are based on real time weather events such as the occurrence of a given amount of precipitation, eg., 20 mm of rainfall. Stewart (1985) proposed that indicators be used to forecast seasonal rainfall and then the forecast would be used to guide farm management decisions. Based on the analysis of the relationship between the date of onset of rains and the length of the growing season for 58 locations in the Sahelian and Sudanian climatic zones of West Africa, Sivakumar (1988) proposed the concept of "Weather-responsive Crop Management Tactics". This concept combines the knowledge from the analysis of historical weather data with real-time weather data to make changes in management tactics during the growing season.

Integrating Soil and Crop Models for Agroclimatological Analysis

Agroclimatological analyses of the type described above provide useful information, but integration of this information with soil and crop data is necessary for most applications. Models are useful for the purpose of integration (Nix, 1987). Advances made over the past 2 decades in our understanding of crop/weather relationships led to modeling crop responses to the environment under a wide range of soils, climates, and agronomic management systems. As Nix (1987) explains, models may be simply no more than intuitive judgment-based models based on a set of linked logical statements; a set of statistical equations; or dynamic, process-based simulation models.

Models that integrate soil and crop information for agroclimatological analyses have been developed, e.g., the WATBAL model of CSIRO (Keig and McAlpin, 1974) deals with soil alone.

Since several models are readily available, it is important to ask how one approaches the task of integration. The first step is to carefully define the purpose for which the models are to be integrated for agroclimatological analysis. Initially, this could be defined from the conclusions drawn from climatic data analysis. For example, calculations of the length of growing season from rainfall data could lead to the question of matching crops to the available season length. Then it is important to review the soil, crop, and climatic data available, and the methods of matching these databases, which often dictate the type of model that could be employed. Average climatic data are more readily available and documented than daily weather data and this leads to a clear distinction between crop-climate models and crop-weather models. The choice of a model is also based on the level of accuracy and the scale of application desired.

An example of the use of average climatic data for irrigation planning at individual sites is the Doorenbos and Pruitt (1977) model for crop water requirements. This model could also be employed to estimate loss of crop yield through water stress for specific crops. At the other end of the scale of application of average climatic data is the agro-ecological zones (AEZ) model of FAO (Higgins et al., 1987), which can be used to estimate potential rainfed crop yields on a regional or global scale. The AEZ model combined world soil and climatic data to yield 45,000 unique agro-ecological cells and incorporated elements from other models, e.g., the Doorenbos and Pruitt (1977) model.

It is also important to realize that crop-climate models limit the application to decisions of a "strategic" nature, i.e., those concerning long-term development planning. Intraseasonal variation in weather leads to short-term variation in crop growth and development and these call for "tactical" or operational decisions during the crop growing season. If the purpose is to make tactical decisions during the periods when droughts occur, it is necessary to integrate models that consider prevailing soil water conditions, the sensitivity of the crop to water stress, and crop water requirements in real-time situations. For this purpose, crop-weather models could be used.

A number of crop-weather models are available for these applications. Based on the predominant approach, Baier (1979) classified them into three types: multiple regression yield models, statistically-based crop/weather analysis models, and crop growth simulation models. For real time applications, the latter two types are useful.

Crop/weather analysis models use daily climatic data, soil characteristics, derived variables such as soil water, and observed or estimated crop phenology. Conventional statistical procedures and non-linear regression techniques are used to evaluate the coefficients relating crop response to the input variables. The scale of application could be daily or any interval over which no appreciable change occurs in the crop response. The wheat/weather analysis model developed by Baier (1973) is a typical crop/weather analysis model. A good example of an application of the crop/weather analysis model, under conditions where water is the main constraint for crop production, is the FAO crop forecasting method (Frere and Popov, 1979) which is being used for a number of crops in several regions of the world. This method is based on the computation of a water satisfaction index based upon a cumulative water balance for a given crop on a 10-day scale.

Over the last decade, rapid advances have been made in the development of simulation models. These models attempt to explain, through a set of mathematical equations, the impact of weather variables and soil properties on physiological processes. As discussed earlier, the level of complexity of the model selected depends on the purpose. For agroclimatological applications, early efforts involved the use of a specific crop growth model for examining the effects of variable weather or alternative crop management options such as spacing or plant population on crop responses. However, for some specific applications, two or more simulation models had to be integrated. Krishna et al. (1987) used components of two simulation models, EPIC (Erosion-Productivity Impact Calculator) and SORGF (sorghum growth simulation model), with 20 years of actual climatic data to evaluate the potential of tied ridges (furrow dikes) to increase sorghum production. Their simulations highlighted the importance of year-to-year weather variations on the expected benefits from tied ridging.

Conclusions

Climatic variability and the associated instability in food production in the arid and semiarid regions calls for strategies that employ real-time information on soils, crops, and environment for decision making. Without doubt, we now have the tools, through the explosion of computer technology, to collect, store, process, and interpret soil, crop, and weather data. Soil and crop models provide an effective means to analyze data and summarize results in a user-oriented format. Integration of models for agroclimatic analysis will only hasten the application of agroclimatic information for increasing and stabilizing food production.

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