PN-ABL-550
77720

184 Integrating Biological and Economic Data In Evaluating Dryland Farming Technologies

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Introduction

Development of improved systems for dryland farming is limited by both biological and economic factors. Because dryland agriculture is at the mercy of the weather, the relation of the biological yield distributions and the decision-maker's risk-bearing ability is crucial. Ideally, biological researchers would be guided by a clear knowledge of economic constraints. Likewise, economic analyses should accurately reflect the biological facts. Unfortunately, the integration of biological and economic information is only imperfectly achieved. The objective of this paper is to outline the strengths and weaknesses of the primary techniques used to integrate biological and economic data. Budgeting, regression analyses, mathematical programming, and simulation will be discussed. The discussion will be in terms of expertise required, data requirements, timeliness of results, credibility, and usefulness for various audiences.

Budgets

Budgeting is a very simple model of economic reality. It evaluates certain input-output points by subtracting the costs from gross revenue. Optimization is carried out by choosing the input-output combination that maximizes net profit. Biological information enters the budgets primarily in the form of yields and input requirements. Budgeting can make effective use of data from plot experimentation and other research designed with the linear additive model in mind. This is because both budgeting and plot data focus on the input-output relationship at a limited number of points.

In terms of integrating biological and economic data, the primary shortcoming of budgets is the fact that analysis is limited to a relatively small number of input-output combinations. For example, Ly et al. (1986) evaluated one improved millet (*Pennisetum typhoides*) variety, one alternative planting density, and one level of nitrogen fertilization in combination with the alternative density. They concluded that the improved variety had positive returns at all sites, but that the profitability of increased density and fertilization may be limited to seasons with good rainfall. The results are suggestive of the economics of these agronomic innovations, but leave doubts about the implications of other density and fertilization levels.

Despite its shortcomings, budgeting is still an appropriate tool for evaluating dryland technologies. The economic expertise required to develop budgets is modest. Budgeting fits most common data sources. It is quick, so results can be timely. Budgets are relatively easy to understand. Thus budgets have a credibility that other economic analysis tools lack, because most decision-makers can understand the components of a budget.

Regression Analyses

By estimating production functions, the economics of a response surface can be more thoroughly explored. Calculus and other optimization methods can be used to systematically determine the preferred strategies. Among the problems with response surface estimation are: 1) the choice of functional form can affect economic conclusions, 2) input-output observations are needed all along the response continuum to accurately estimate economic tradeoffs, and 3) the number of potential variables is limited by data and statistical techniques.

The functional form choice problem is evident in the study by Jomini et al. (1988) comparing wealth-maximizing phosphate fertilization strategies for a region in western Niger. The authors used a quadratic and a linear response and plateau (LRP) function. The optimal phosphate levels differed substantially between the two functional form estimates. Regression estimates are at best a crude approximation of the complex biological processes involved in crop and livestock production. The functional form of this approximation should fit the biological facts, but is not entirely determined by biology. The response function is a decision tool. The best response function is one that leads to the best decisions. The form of the response function may be determined by its usefulness in decision making as well as by the biological facts. Thus, Jomini et al. (1988) argue that the LRP function may be preferred even when the quadratic function has better statistical properties. This argument

is based on the upward bias that may occur with fertilizer recommendations based on quadratic functions. The more conservative LRP recommendations are seen as being more appropriate for a developing country like Niger. Further research with the phosphate data suggests that part of the difference between the two functional forms may be due to omitted nitrogen and rainfall variables.

The data demands of regression analyses are rather poorly matched with the usual agronomic plot data. Analysis of variance requires replication of treatments to separate sources of error. Budget constraints usually dictate that relatively few treatment levels are replicated. Thus, much information is available about a few points, but the shape of the production surface between the points is unknown. When using calculus optimization, the curvature of the function is all-important in determining economic results.

At best, regression analyses can provide rough estimates of yield responses. This is primarily because plot data are not well adapted to response surface estimation. However, with the widespread availability of regression software, the time and expertise required to estimate these functions is relatively small. The estimated functions and the economic optimization can be presented in a graphical form that is understandable by a wide range of decision makers.

Mathematical Programming

Mathematical programming can be used to explicitly model the effects of resource constraints, time, and risk on technology choice decisions. These factors can be incorporated in budgeting or response surface analysis, but programming models permit a more systematic analysis of these effects. Biological information can enter programming models either as point input-output coefficients, as in budgets, or as response surface estimates.

Krause et al. (1987) used linear programming to examine the effects of labor and capital availability on adoption of millet and cowpea (*Vigna sinensis*) production innovations. In part, this study grew out of the difficulties in valuing family labor in the budgeting study by Ly et al. (1986). The form of the biological information in Krause et al. (1987) is the same as in the Ly et al. (1986) budgets.

Adesina et al. (1988) evaluated the effect of risk on millet and cowpea fertilization. They used a Minimization of Total Absolute Deviations (MOTAD) model which places a weight on negative deviations from expected results and uses historical data to estimate the deviations. Adesina et al. (1988) used only the traditional unfertilized cropping and one-level fertilization activities.

Programming models require substantial expertise to develop and interpret. Development of realistic models requires substantial information on the farming system, but they can use the same biological information as budgeting or response surface studies. Credibility requires careful validation of the model. If credibility is established, programming models offer a systematic glimpse as to what would happen to the farming system as a whole if a new technology were adopted, or by showing the constraints that limit adoption.

Simulation

In the broadest sense, econometric and programming models, and even budgets, are simulation. They all try to mimic reality. In a narrower sense, the term simulation is usually applied to complex and nonlinear models that do not fit into the other categories. Biological simulation models attempt to mathematically describe the physiological processes of plant and animal growth. The models can integrate biological information from a wide variety of sources: published research, experimental data, and the informal observations of field scientists.

The long-term yield level and variability of millet and cowpea intercrop innovations in Niger are being estimated with simulation models. The simulation model is a modified version of the spreadsheet GROWIT © model developed by Lowenberg-DeBoer and Cherney (1988). The primary modification was designed to account for plant growth stages. In the model, millet and cowpea compete for water and sunlight. Use of the model for economic analysis is proceeding in two ways: stochastic dominance analysis and use of simulation to generate coefficients for programming models. Yield distributions for planting density and fertilization strategies are being estimated with historical weather data for use in the stochastic dominance analysis. Over 50 years of daily weather data are available for many locations in Niger. Weather simulation is an alternative to the use of historical weather data. Use of historical weather data can improve credibility of the results.

Programming models can systematically evaluate a wider range of options than stochastic dominance, but credible programming models require detailed knowledge of the distributions of outcomes. For many crops in the arid and semiarid areas of the world, the statistical distributions of results are virtually unknown, even for traditional production practices. For improved practices, the information on yield distribution is often limited to a few experimental trials. Crops can be simulated over a wide range of environmental conditions to provide better estimates of the distributions. The millet and cowpea model is being used to estimate long-term yield distributions in the Maradi area for use in a discrete stochastic programming model of production and credit interactions.

Effective use of biological simulation in economic analysis requires time, expertise, and cooperation between biological and social scientists. Simulation is data-demanding, but flexible in terms of the type of information that is usable. As in the case of programming models, credibility requires careful validation. Simulation can be used to estimate yield distributions that could otherwise be estimated only after years of empirical work. Simulation can facilitate cooperation

between biological and social scientists by providing a research framework that is scientifically acceptable for both groups of researchers.

Conclusions

Budgeting can provide quick, preliminary estimates of the economic implications of biological technologies. Regression-estimated response surfaces are only rough approximations of complex biological processes, but they can be used to systematically explore a wide range of input-output combinations. Mathematical programming models can be used to analyze the effect of resource constraints, time, and risk on technology adoption, but they do not generally go beyond budgeting and response surface analysis in integration of biological and economic information. The flexibility of simulation permits a more detailed modeling of biological processes and a closer link between the biological and economic processes than budgeting, response surface analysis, or mathematical programming.

Acknowledgments

This research is supported by the U.S. Agency for International Development, Science and Technology Bureau, Technology of Soil Moisture Management Project under USDA PASA No. BST-4021-P-AG-108D-00.

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