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195 Methodology for Evaluating Soil and Water Management Under Uncertainty

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Introduction

In most of the less developed countries (LDCs), the emphasis to attain self-sufficiency in meeting domestic food and fiber demands has resulted in intensive use of limited agricultural resources, especially land. To meet this objective, even the less productive marginal lands have been brought under cultivation. This exhaustive use of land, particularly in rainfed areas, has resulted in serious problems such as soil erosion and water stress. The loss of organic matter and nutrient-rich top soil adversely effects the water-holding capacity of the land and, in turn, lowers farm productivity. The shortage of available soil water during critical periods of crop growth has severe implications for crops and varieties best suited for production (Colacicco and Setia, 1988).

Evaluation of alternative farming methods is a must since the majority of farmers have scarce resources. To increase farm productivity and to meet family needs for food and fuel, farmers need to make the best use of their limited resources. Though the criterion for investment in new soil and water conserving technologies is to be based on economic evaluation, the financial implications of adopting these technologies requires consideration of farmers' objectives and available resources. The recommended technologies must be appropriate for local physical, social, and economic conditions.

In implementing new soil and water conserving technologies, there is increasing emphasis on having a complementary relationship between conservation and production. For example, adoption of conservation tillage does not only conserve productive top soil and available water and reduce off-site damages, but also results in increased farm income (Crosson, 1981). The new focus to manage soil and water, insects, pests, and disease is to make farmers realize that ecologically and environmentally-balanced agriculture remains productive in the long run, particularly when the short-term adjustments do not significantly reduce profits. This is achieved by means of substituting more management and labor for less fertilizer and pesticides, as well as conserving productive soil and available water. The key to successful achievement of these goals is to identify the appropriate technologies which reduce production cost, on-site and off-site damages caused by soil erosion, meet farmers' expectations, and utilize available resources in the best possible manner while still maintaining or increasing income.

A widespread adoption of new technologies poses some challenges and indirect costs to farmers and the society. During the transition period, there may be a drop in yields and, hence, lower revenue in spite of reduced production costs due to requirements of high managerial skills and strict operating schedules. How farmers perceive the risks in changing and adjusting to new technologies will have a direct influence on adoption. Since new alternatives require more information and a high level of management to substitute other inputs such as pesticides, etc., individuals with high risk aversion and/or limited management skills and labor may be slower in transition. Also, it is becoming clear that future agricultural and social developments will likely place heavy emphasis on conservation and environmental and food quality. Hence, it is important to develop strategies to meet these multiple goals to increase private and social welfare.

It is realized that the total impact of implementing a particular technology or public program is not always known in advance, but decision-makers, including farm managers and policymakers, have to make choices when faced with alternatives. More often than not, the decision analysis is attempted with incomplete information and stochastic outcomes. The analytical procedure followed under uncertain conditions serves to "aid" decision-makers in their efforts to sort through the complexities of their decision problems. Also, to reap full benefits of implementing new and improved technologies, it is necessary to examine the farm, regional, and possibly national level impacts of those systems. An approach of building the analysis from the bottom up may provide useful insights in the successful implementation of a program. If alternative plans are evaluated on their physical and economic merits, it can help farmers in selecting the appropriate technology based on their resources and risk preferences. In addition, it prepares policymakers in facilitating the adoption of that technology and in predicting and dealing with the regional or national impacts. It is quite possible that a change in farming systems may significantly alter input and output markets by changing the demand for crops, inputs, and services. Over time, an increase in income may lead to a rise in demand for consumption goods and services

Table 1. A schematic representation of soil erosion control under risky environment (SECURE) methodology.

STEP 1. Soil Productivity Characteristics Estimation	
Input:	Location, soil type, topography, degree and length of slope, bulk density, erodibility, soil water rate, initial depth of soil layers, nutrient requirement for productivity rebuilding, yield-depth relationship.
Output:	Soil-specific production function and associated soil characteristics.
STEP 2. Crop Yield Simulation (e.g., SOYGRO, CERES-MAIZE)	
Input:	Daily weather data, soil profile properties, soil nitrogen dynamics properties, soil profile initial conditions, irrigation management data, crop management data, genetic coefficients, and crop-specific coefficients.
Output:	Simulated biomass and water balance components at selected phenological stages, harvest (simulated and observed) summary, simulated variables vs time, weather variables and simulated soil water balance vs time, and simulated soil nitrogen variables vs time.
STEP 3. Crop Enterprise Budgets (e.g., CBS, FEDS, MBMS)	
Input:	Crop yields and prices, quantities and prices of inputs such as seed, fertilizer, pesticides, lime, machinery and equipment, drying cost, ownership costs, labor and management cost for crop rotations and tillage methods.
Output:	Net income and total operating cost of each system.
STEP 4. Erosion Control and Soil Water Management (e.g., SSOILEC, CAMPS)	
Input:	Discount rate(s), mean, variance and probability specification for crop prices, crop yields an R-factor (rainfall and runoff factor), covariance between crop prices, covariance between crop yields, crop residue production, yield adjustment due to tillage, mechanical control practice factor, cover and management factor, crop rotation, crop variety, total operating cost, soil types and depths, soil bulk density, length and slope, crop yields at various erosion stages, and existing system.
Output:	Mean and variance-covariance of net income and soil loss for selected management systems adjusted for weather, yield, and product price uncertainties.
STEP 5. Optimum Farm/Region Plans (e.g. Quadratic Programming)	
Input:	Total land area suitable for crop production, land classification, soil loss quota for the farm/region, probabilities of meeting soil loss tolerance level(s), risk aversion factor, mean and variance-covariance of net returns, and mean and variance-covariance of soil loss, taxes, subsidies, conservation regulations.
Output:	Mean and variance of net income for each management system adjusted for weather, yield, product price, and soil loss uncertainties (mean income-variance path).
STEP 6. Policy Analysis	
Input:	Policy controlled variables such as taxes, subsidies, soil loss quota, restrictions on land use, etc.
Output:	Changes in management system(s) and net farm income due to changes in policy controlled variables.

which has important ramifications for overall development in the region. The methodology proposed in this paper can be applied in evaluating micro- and macro-level impacts of adopting selected technologies.

Methodology

The methodology I am proposing is called Soil Erosion Control Under Risky Environment (SECURE). An overview of all the analytical tools applied in this methodology is briefly discussed in this section. As shown in Figure 1, the analysis is divided into two parts, i) technical analysis and ii) policy-decision analysis.

The technical analysis includes site-specific physical and economic characteristics. Physical characteristics take into account information on soils, crop growth and yields, weather, technology, and pesticides. The corresponding economics information consists of total operating costs and net income for each crop enterprise. Physical and economic information regarding each conservation system is linked with the help of a simula-

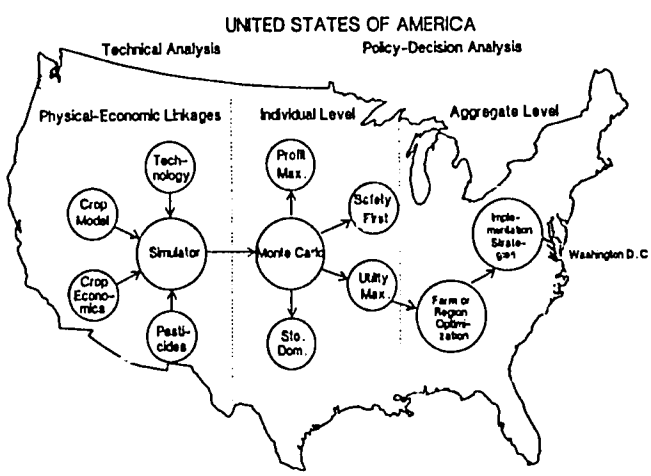

Figure 1. Soil erosion control under risky environment (SECURE) methodology.

tor. The output of technical analysis provides net income, soil loss, variance-covariance of net income, and soil loss for each system due to the stochastic factors identified in the analysis. The results of this analysis provide the foundation for policy analysis.

The policy-decision analysis is conducted at the individual as well as aggregate levels. At the individual level, various conservation systems are evaluated based on selected decision criterion, e.g., profit maximization, safety-first, expected utility maximization, and stochastic dominance to reflect the farmer's perception of risk and his attitudes. Aggregate analysis is conducted with the help of a specially designed quadratic or stochastic programming model to obtain an optimal combination of technologies for a given situation. The programming model is also capable of evaluating the impact of subsidies, taxes, land use restrictions, ownership status, etc., and can be modified to accommodate specific needs. The output of the programming model is utilized to design implementation strategies to know the final outcome to ensure success of the proposed conservation program or project.

A schematic representation of these analyses and various inputs and outputs is presented in Table 1, which shows the steps involved in analyzing soil and water conserving technologies using SECURE methodology. Input and output of analysis conducted at each step is also identified.

Conclusion

An important aspect of the SECURE methodology is to analyze the optimal conservation systems in the presence of weather, output price, crop yield, and soil loss uncertainties for the different risk aversion and soil loss levels. The impact of policy-controlled variables such as taxes, subsidies, regulations, etc. can be traced back to observe the farm as well as aggregate level implications. This can help in identifying the best combination of options to achieve desired goals. Conversely, the consideration of available farm or regional resource base and socio-economic environment will provide aid in designing soil and water conservation programs to ensure their successful implementation.

References

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