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ANNEX 4

Economic Methods for Comparing Alternative Crop Production Systems:

A Review of the Literature

By

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Abstract:

Forty-six recent studies comparing alternative crop production systems are reviewed. Empirical methods are evaluated with respect to profitability, financial stability, and environmental impact criteria. Most studies fail to incorporate environmental criteria sufficiently. Balanced environmental-economic analysis is most likely to arise from integrating biophysical simulation with economic optimization.

Economic Methods for Comparing Alternative Crop Production Systems: A Review of the Literature

Introduction

In response to growing concern over environmental contamination and consumer resistance to food perceived as tainted by pesticides, many farmers and researchers have begun developing alternative crop production systems. Typically, these systems are neither more profitable nor higher yielding than the systems they replace. But they do often result in less contamination of ground and surface waters, less pesticide residue on the marketed product, or better soil quality. Having been designed intentionally to attain these environmental objectives, these systems cannot fairly be evaluated on productivity-based performance criteria alone.

Until recently, productivity-based performance criteria were virtually the only ones considered by economists and agronomists in evaluating agricultural technology. Since World War II, most U.S. crop research has focused on reducing labor requirements and increasing yields per unit of land (Hayami and Ruttan 1985). Economic evaluations of new crop technology have focused on profitability. Yield increases by themselves raise profits, so the only issue was whether the value of the yield increase justified the cost incurred to obtain it.

Three factors complicate comparisons between the new, alternative cropping systems and "conventional" ones: amplified performance criteria, the diversity of the technologies, and multi-product production. Comparisons are most complicated when more than one performance criterion is desired, and when alternative systems excel at different criteria. Different performance criteria must either be transformed into a general index (see, e.g., Higley and Wintersteen 1992; Kovach et al. 1992) or else compared on a one-by-one basis using some dominance criterion (e.g., Bouzaher et al. 1992; Hoag and Hornsby). How closely the technologies are related determines whether or not a "nested" statistical evaluation can be conducted. That is, if one technology is inherently contained within another (such as a lower fertilizer rate within a higher rate) the comparisons are direct and simple. On the other hand, if two technologies are very different, the comparison may be much more complicated (e.g., annual mineral nitrogen fertilization compared with organic soil amendments which may take years to reach an equilibrium level). Most if not all farms are multi-product production units, yet standard economic comparisons treat individual outputs as if they were unrelated. Particular complications arise in determining how to weight joint products when one is a "good" and one or more is a "bad," such that one byproduct inhibits another production process (see Beattie et al. 1974).

In this paper, we review the recent literature on cropping system comparisons. We build on the previous literature review by Fox et al. by identifying important criteria for comparison and developing a typology of U.S. cropping systems that are compared. We proceed to evaluate methods used to compare crop systems with the goal of identifying those best suited for specific kinds of comparisons.

Criteria for comparison

Analytical method used in an economic crop comparison are linked to the criteria of comparison being used. Profitability, stability, and environmental impact are the three classes of performance criteria of greatest interest for contemporary comparisons. Of these three, profitability is the dominant one used in economic comparisons. Stability measures can cover biological/ecological systems as well as socio-economic ones. From a strictly economic perspective, income stability is the measure of interest. This is inherently a dynamic measure, since stability cannot be measured in a single period. However the number of production periods sufficient for a reliable evaluation remains an empirical issue tied to the type of system comparison.

There are many environmental ramifications from any given crop production technology. They may involve air, land, water, and the health and ecology of living organisms. This paper focuses on direct effects from technology implementation on the farm. The effects of interest will vary with the technology, but leading candidates are energy use, soil erosion, chemical leaching, and chemical runoff.

While the profitability and income stability criteria can be applied to virtually all system comparisons of interest, the specific environmental impact comparisons will depend upon the nature of the systems being compared.

Systems and technology types

The economic literature on field crop systems typically starts from a baseline called "conventional," to which are compared systems with reduced levels of tillage, mineral fertilizers, or pesticides. These reductions may range from modest to extreme. The alternative systems may be motivated by an interest in existing technology at reduced input levels, or in a different technology. The latter case embraces such practices as flex cropping and integrated pest management (IPM), which substitute information for physical inputs. Alternative crop nutrition technologies include crop rotations, cover crops, and manure amendments to substitute for mineral fertilizers.

This diversity of alternative crop production systems is best classified according to the primary objective of the alternative system. Most of the reduced input systems are designed 1) to reduce a specific environmental impact, and, sometimes, 2) to reduce costs. Reduced tillage systems are designed to lessen soil erosion. Reduced mineral fertilizer and pesticide systems are intended to cut agricultural chemical release into the environment and/or residues on food. Rotations, cover crops, and IPM, too, have reduced chemical use as their main environmental objective. Flex cropping is primarily a profit-enhancing system, but has repercussions for tillage and chemical inputs as well. More than one environmental criterion may be needed to compare systems, since alternative systems designed to meet one environmental objective (e.g., reduced soil erosion) may be inconsistent with a different one (e.g., reduced chemical leaching) (see Crowder et al. 1985; Painter et al. 1992; Foltz et al. 1993). Ironically, the most elusive system to characterize seems to be the "conventional" benchmark. Since conventional farming practices are always evolving, the benchmarks used are (or should be) typical of common practices in the place and time the research is conducted.

System characteristics important to analysis design

Key system characteristics should guide how performance criteria are measured. The dynamic features of many alternative systems (e.g. rotations, biological, pest control) imply that evaluations should allow time to adjust both for biological changes and for human learning about managing the new system (see Clauson-Wicker 1994; Dabbert and Madden 1986; Hanson et al. 1990; Lockeretz et al. 1978). Resource degradation (e.g. by soil erosion) also occurs gradually, and remedial practices such as conservation tillage and crop rotations that affect its rate of progress have covered several years (Baffoe et al. 1987; Crowder et al. 1985; Goldstein and Young 1987; Helmers et al. 1986; Lesoing and Francis 1993; Sahs et al. 1988; Zentner et al. 1988).

A second important system characteristic is its responsiveness to shocks due to unusual weather, prices or costs. Systems with lower investments in purchased inputs tend to be less susceptible to input price shocks. Some crop systems tend to yield more reliably in the face of unusual rainfall levels (Mends et al. 1989; Sahs et al. 1988; Shearer et al. 1981). Both characteristics affect the income stability criterion, though separating cost, price, and yield effects is analytically important (see Helmers et al. 1986).

The level of aggregation is a third characteristic which will receive only cursory treatment here. Clearly widespread adoption of an alternative system can cause supply shifts, significantly changing price relationships (see Langley et al. 1983; Olson et al. 1982; Knutson et al. 1990).

The environmental resource endowment is a fourth characteristic which needs explicit incorporation into most comparisons. *Ceteris paribus*, systems that reduce soil erosion will have greater benefits on highly erodible soils than on stable ones, or where surface water quality is more highly valued (Faeth 1993). Similarly, heavy soils with poor water infiltration are less likely to allow chemical leaching into groundwater than light, sandy soils (Cox and Easter 1990). Many systems designed with environmental objectives are, in fact, designed for specific environmental resource settings, so these characteristics are important for the design of system comparisons (see McQueen et al. 1982; Schoney and Thorson 1986).

Finally, some cropping systems may have environmental side-effects which diminish their appeal. Examples include organic or low-chemical systems that rely on increased tillage with ancillary increases in soil erosion, or, conversely, conservation tillage systems that rely on increased herbicide use for weed control (Crowder et al. 1985; Dobbs 1994; Zentner et al. 1988). Where such side-effects are important, they merit explicit incorporation into the design of system comparisons.

Methods for comparing systems

The choice of analytical method largely depends on the performance criteria of interest. Table 1 matches analytical methods to performance criteria for the 44 studies reviewed here.

Enterprise budgets are the predominant method used for profitability comparisons. They provide a focus for evaluating the costs and returns of alternative systems (see Table 1 for a list of studies used for this purpose).

Uncertainty about prices and yields in enterprise budgets can be partially accommodated using sensitivity or break-even analysis. Sensitivity analysis brackets a baseline enterprise budget with alternative budgets based on more extreme prices, yields, or costs (e.g. Dobbs et al. 1988; Helmers et al. 1986; Sahs et al. 1988; Westra and Boyle 1992). It provides a means of judging the stability of an outcome under a range of plausible assumptions about risky parameters. Break-even analysis identifies the yield, price, or cost threshold at which enterprise revenues would just equal costs (including opportunity costs)(Hilker et al. 1987; Mends et al. 1989; Painter et al. 1992; Schoney and Thorson 1986). While sensitivity and break-even analysis are based on deviations from typical values, if the probability distribution of the random variable is known, then these analysis can be used to yield rough confidence levels for profitability.

"Green" budgeting is a new approach that includes explicit environmental costs and benefits in enterprise budgets. Although it is applicable in principle to many environmental and health attributes, it has received relatively little use. This is likely due to potential charges of subjectivity. Faeth used off-site social costs of \$0.66 to \$8.16 per ton of soil erosion, based on the regional economic value of water. Higley and Wintersteen estimated environmental costs of pesticides from a contingent valuation survey which they proposed using to calculate (higher) pest management thresholds.

Enterprise budgets are the building blocks for whole farm analysis. Five studies reviewed extended their enterprise budgets to a whole farm analysis (e.g. Dobbs et al. 1988; Hanson et al.; Irwin-Hewitt and Lohr 1993; Klepper et al. 1977; Mends et al. 1989). One useful tool for whole farm analysis is the SMART-FRMS computer-based decision support system (Ikerd 1991). PLANETOR, the whole-farm planning module of SMART-FRMS, allows evaluation of the potential impact of alternative technologies and strategies with farming enterprises. PLANETOR links site-specific farm data with databases on soil and agricultural characteristics to predict environmental risks due to erosion, leaching, runoff, and pesticide toxicity. It also projects financial outcomes, net return correlations, and measures of the balance between farm resource use and requirements. While intended as a planning tool, it can be used to evaluate crop systems for both profitability and environmental risks, though the latter are classified on a rough, three level scale (high, medium, low) (as in Irwin-Hewitt and Lohr 1993).

Linear programming is an optimization algorithm that can be used for multi-period and inter-regional analysis of alternative systems profitability and stability, as well as evaluation of environmental impacts or constraints. In agricultural production economics, LP is most commonly applied to problems of income maximization subject to a set of resource or environmental constraints (e.g., see LP studies used for environmental impact criteria in Table 1). Multi-period linear programming is also used when time is a key factor in the comparison such as comparing rotational impacts on erosion (e.g. Baffoe et al. 1987), or modeling the transition to organic farming (Dabbert and Madden 1986). Another use of LP is in an interregional analysis, such as to evaluate the impact of nationwide adoption of organic practices (e.g. Langley et al. 1983; Olson et al. 1982).

In addition to linear programming, dynamic programming is also used for profitability comparison. Dynamic programming is a mathematical tool for solving multi-stage decision problems. The decision to crop or summer fallow agricultural lands is an example of a multi-stage decision process (see Bole and Freeze 1986; Young and van Kooten 1989). Non-optimizing dynamic simulation is used in another study to determine the long term effect of extending crop rotations (Schoney and Thorson 1986).

Though dynamic programming is used exclusively for profitability analysis, the data that feeds into the DP model often comes from biophysical simulation models which analyze the environmental impact of different cropping systems (see Foltz et al. 1993; Crowder et al. 1985). Linking biophysical process models with economic models is increasingly common. Plant simulation models can be used to predict crop yields under different input levels or moisture data in order to compare the stability of different systems (e.g. Bole and Freeze 1986; Johnson et al. 1991; Taylor et al. 1992).

Approaches to comparing multiple criteria

Where multiple objectives are to be evaluated, two approaches have been taken: indexation, and dominance analysis. The first approach involves creating a weighted index that integrates all objective criteria of interest. Ikerd and the Center for Farm Financial Management took this path in designing PLANETOR, which allows financial outcomes to be compared with three classes of environmental risks. Kovach et al.'s "environmental impact quotient" is an index of pesticide impacts. Higley and Wintersteen followed an index-like approach in using the contingent valuation method to construct "environmental costs" for pesticides based on market costs plus producer willingness to pay for elimination of environmental risks. While indexation is computationally attractive, it is open to criticism for the subjectivity associated with relative weights.

Dominance analysis entails identifying those cases where all objective criteria are at least as good as the dominated alternatives. Van Kooten et al. tackled the environmental valuation problem by constructing a hypothetical utility function based on farm profits and soil quality. They used a stochastic dynamic programming model to calculate a frontier of trade-offs between net returns and soil conservation. Hoag and Hornsby used dominance analysis to construct cost-environmental hazard frontiers which identify the tradeoff between financial cost and environmental hazard for herbicides in southeastern soybeans. Bouzaher et al. used a similar approach to highlight trade-offs between the probability of crop loss and cost of control under a set of alternative herbicide ban scenarios. Carriker used stochastic dominance with respect to a function to identify the risk efficient set of nitrogen fertilization strategies for corn. Two types of risk are associated with each strategy: the variability of net returns and the variability of environmental loading.

Effectiveness of Methods

Most budgeting methods fail to evaluate environmental criteria. Two limited exceptions are green budgeting (Faeth 1993) and break-even budgeting based on meeting an environmental target. For environmental impact analysis, budgets have been supplemented by nonmonetary accounting for an externality such as soil loss (see Ikerd et al. 1993). However, short of dominance analysis, this provides no clear guidance for system ranking. Budgeting methods also miss whole-farm constraints (e.g., workable field time) which may not be limiting at the individual enterprise level.

At the other extreme, biophysical simulation models portray environmental processes in detail but offer no economic basis for evaluating crop systems. To get a balanced evaluation there needs to be some compromise in the level of detail on both financial and environmental sides. The variety of environmental criteria of interest forces focus on key ones (which may result in missing interrelationships) or else indexating multiple criteria.

Few studies have captured dynamic effects, yet these are central to the definition of sustainable systems. Dabbert and Madden made an effort with multi-period LP, but it was founded on a weak base of biological data. Dynamic programming studies have used dynamic environmental state variables, but have not included money-metrics of environmental quality in value functions.

A balanced economic and environmental analysis of alternative crop systems can follow either of two approaches. One is to create a money-metric of environmental impacts (Faeth 1993; Higley and Wintersteen 1992) and put them in the objective function of an optimization model. The other is to treat environmental impacts in an optimization as parameters (Crowder et al. 1985; Johnson et al. 1991), or build efficiency frontiers, such as in dominance analysis (Carriker 1993; Bouzaher et al. 1992; Hoag and Hornsby 1994; Van Kooten et al. 1990).

To do either of these effectively, a minimum amount of data is necessary for any joint micro-economic and environmental analysis of alternative crop systems. First, resource use levels and financial costs are needed, including complete data on all aspects that differ between systems. Second, yield of marketable product should be monitored, including performance under different states of nature and evolution of performance over time. Third, the analysis should include complete data on those environmental parameters that vary significantly across systems.

The money-metric approach has the daunting additional requirement of valuation estimates for reductions in environmental risks. The high cost and potential subjectivity of this last point accounts for the scarcity of money-metric environmental analyses of crop systems. Consequently, the best current analytical techniques link biophysical simulation models to an economic optimization model, usually LP or DP related. However, environmental stability deserves added emphasis in future studies.

Conclusion

Efforts to evaluate jointly the economic and environmental attributes of alternative cropping systems are still relatively immature. The particularity of environmental issues defies general prescriptions for how they should be researched. But system stability and evolution are two areas that deserve more careful study. With care in data collection, existing economic optimization methods linked to biophysical simulation hold the greatest promise for evaluating the tradeoffs among profitability, environmental impact, and stability (both financial and environmental).

Table 1: Classification of literature by performance criteria and analytical methods.

	Criteria		
Method	Profitability	Fin. Stability	Env. Impact
Enterprise budgets	Berardi Chase & Duffy Dobbs (93, 94) Dobbs et al. Faeth Goldstein & Young Hanson et al. Helmers et al. Ikerd et al. Lazarus et al. Legg et al. Lockeretz et al.(78, 81) Mends et al. Moffitt et al. Painter et al. Sahs et al. Shearer et al. Westra & Boyle Young & Painter Zentner et al.	Dobbs et al. Helmers et al. Moffitt et al. Sahs et al. Westra & Boyle	Faeth Ikerd et al.
Break-even budgets	Mends et al. Painter et al. Schoney & Thorson		
Whole farm analysis	Dobbs et al. Hanson et al. Ikerd Klepper et al. Mends et al. Irwin-Hewitt & Lohr	Hanson et al.	Ikerd Irwin-Hewitt & Lohr
Linear programming	Baffoe et al. Crowder et al. Dabbert & Madden Domanico et al. Faeth Foltz et al. Langley et al. Lazarus et al. Lazarus & White McQueen et al. Olson et al. Swinton & Clark Taylor et al.	Langley et al. Olson et al.	Baffoe et al. Crowder et al. Domanico et al. Faeth Johnson et al. McQueen et al. Swinton & Clark
Dynamic programming	Bole & Freeze Johnson et al. Schoney & Thorson Young & van Kooten		
Biophysical Simulation		Bole & Freeze Johnson et al. Taylor et al.	Crowder et al. Foltz et al.
Dominance	Bouzaher et al. Carriker Hoag & Hornsby	Bouzaher et al. Carriker	Carriker Hoag & Hornsby
Index of env. impact			Higley & Wintersteen Kovach et al.

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