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WHOLE-FARM MODELING FOR ASSESSMENT OF DRYLAND TECHNOLOGY

R.D. Ghodake and J.B. Hardaker

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
ICRISAT Patancheru P.O.
Andhra Pradesh 502 324, India

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ABSTRACT

This paper has been prepared as a methodological contribution to the research project 'Assessment of Technology Options Available to Semi-Arid Tropical Farmers.' Examination of the characteristics and problems of semi-arid tropical agriculture leads to the conclusion that there is a need to develop technology that is appropriate for transfer to farmers in the region. There is also a need for methods of assessing technologies. Because of the integrated nature of dryland farming systems, this assessment needs to be performed in a whole-farm framework. Of the methods of whole-farm planning available, mathematical programming (MP) models, especially those that account for risk, are most appropriate for this purpose. However, in the absence of suitable computer facilities, budgeting methods can be used. Implementation of an MP approach to whole-farm modeling requires the construction of a suitable model incorporating a relevant objective function, appropriate activities, and constraints on those activities. The assessment of technologies using this approach can provide information useful in agricultural research, extension, and policy-making.

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WHOLE-FARM MODELING FOR ASSESSMENT OF DRYLAND TECHNOLOGY*

R.D. Ghodake and J.B. Hardaker†

INTRODUCTION

The main thrust in all the dryland technology developments is to produce technologies that will be acceptable to the majority of farmers and that will achieve improvements in the overall socioeconomic conditions of small landholders and landless laborers. These implicit considerations of equity and efficiency lead firstly to recognition of the importance of the farmer and his farm as the primary target of technology development. Secondly, macro level implications of technologies must be carefully evaluated against socioeconomic goals. Therefore, it is essential to provide feedback about transfer feasibility and potential consequences of technologies to agrobiological scientists and research policy makers. Information on transfer feasibility will enable research scientists to modify and redesign technologies, if necessary, while research policy makers need feedback on technology consequences to improve the allocation of research resources. Development policy planners also need to be informed of probable consequences of technologies to enable them to formulate suitable policies.

In the above contexts, the role of assessment of technologies before they are considered for transfer becomes crucial. In fact, technology assessment forms an integral part of technology development and transfer. The assessment techniques used must be sufficiently comprehensive to yield correct inferences about the consequences and desirability of assessed technology. These techniques should account for the farmer's decision making environment including his resource base, degree of skill, objectives and goals, attitude towards risk, risk bearing ability, as well as the institutional and social systems within which he operates. An ideal assessment approach should also enable the consequences of technologies to be judged against policy objectives. Thus, the approach should encompass all possible direct and indirect effects and implications of the technology.

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†Economist, Economics Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru P.O., Andhra Pradesh 502 324, India, and Head, Department of Agricultural Economics and Business Management, University of New England, Armidale, NSW 2351, Australia, respectively. The authors would like to thank J.G. Ryan, N.S. Jodha, T.S. Walker, and V.S. Doherty for their comments and suggestions on an earlier draft of this paper.

This paper therefore attempts to discuss and to establish the merits of whole-farm modeling approach in assessment of dryland technologies. The approach is being presently employed at ICRISAT to assess technology options available to semi-arid tropical farmers. To start with some of the methods used for assessment of technology are reviewed. The appropriatness of the whole-farm modeling approach is discussed. Major techniques of whole-farm modeling are outlined to judge their suitability for the purpose of technology assessment. Finally, the role of whole-farm modeling in assessment of dryland technology is emphasized.

ASSESSMENT OF TECHNOLOGY

Two types of procedure for assessment of agricultural technology are commonly used at present and are performed at two or more stages. The first type is generally adopted by the technology designer himself during the initial stages of development and depends mainly on criteria of technical efficiency. The second type of assessment is performed either jointly by technology designers and social scientists or by social scientists alone. In this section we shall examine these two types of assessment methods and shall try to establish the merits of the whole-farm modeling approach for assessment of dryland technology.

Assessment by Technology Designer

The assessment procedure followed here is generally inherent in the design of the experiment for technology development. Control options representing existing technology and other relevant technology options are included in experiments and are then used for comparison purposes to establish the relative merits of the new and old technologies. Typical technical efficiency criteria, such as output per hectare, output per unit of input or output stability are measured over a sufficiently long time span to capture the contributions of time-specific factors and also at different locations to reflect the effects of site-specific factors. Then, with the help of suitable statistical techniques, the technologies are rated for relative performance.

Thus, the major focus in this type of assessment is generally on technical efficiency in terms of output potential and stability. The overall target of the analyst at this stage is to see that the technology being developed meets certain specified technical criteria related to the needs of the farmer and so will be potentially

acceptable to him.[1] Strictly technical efficiency criteria, however, fail to account for the value of the output produced by the technology in relation to the value of the costs of achieving that output. On-farm testing, an important component of technology development, is considered a step further in recognizing some of the potential difficulties in the way of transfer of technology.

Partial Budgeting

This is a commonly used approach for assessment of agricultural technology by research designers and social scientists. Extra costs and extra returns of the technology being assessed are considered to arrive at net benefits over and above the local technology of comparable type. The economic criterion of returns net of variable costs is used to rank the various technologies compared. This method is called partial budgeting and, as we define the term,[2] it does not embody consideration of indirect and interactive effects of assessed technology when viewed in a whole-farm planning environment. It serves as an initial approach to arrive quickly at broad pictures of relative costs and returns of various technologies. The approach has merit in comparisons of directly substitutable technologies which have similar requirements of basic resources such as land, fixed capital assets, family labor, etc. For example, under certain conditions new seed technology can be substituted directly for existing seed technology or modified interrow spacing can replace traditional spacing without inducing any significant change in basic resource requirement patterns.

In the partial budgeting approach it is assumed that the farm consists of a superstructure of enterprises, resting on a 'foundation' comprising fixed resources of land, fixed capital, and entrepreneurship. Working capital (cash), family labor and animal power may be included as part of this fixed foundation. Thus, for budgeting calculations, the costs of basic resources are omitted as it is presumed that the enterprises can be varied within quite broad limits without affecting these costs. However, use of this approach for assessing dryland technologies has some severe limitations.

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1. The multidisciplinary research approach at the stage of technology design recognizes potential absolute constraints that are likely to affect the transfer of technology. For example technologies are evaluated for output quality and low input criteria to recognize consumer preferences and resource restrictions, respectively.

2. The term 'partial budgeting' appears to mean different things to different people. Some interpretations would bring it within what is here defined as a whole-farm approach (Rickards and McConnell 1967).

First, partial budgeting resembles a 'top down' approach to technology development since it does not involve any detailed consideration of the circumstances of individual farms. Many of the input-output coefficients and prices are taken to be given and comparisons may be confined to a limited range of technology options. However, on an individual farm the consequences of introduction of a new technology may be very pervasive, affecting many aspects of farm organization and methods. Further, the level of resource availability may pose a serious constraint to technology adoption while input-output coefficients and prices may vary appreciably from farm to farm. Collectively these factors can dramatically alter the results of technology assessment.

In partial budgeting it is usual to assume that fixed resources like land, fixed capital, etc., have zero prices. However, in the real world, these factors do have some costs, measured as opportunity costs, i.e., the values of these factors in the best alternative uses to which the farmer can assign them. Although the farmer's supply of these resources may be constant, the demand for them will vary considerably over the farming year so that their opportunity costs may vary widely from month to month, and even from day to day. Thus, omitting land and other fixed resources from costs and returns analysis, or pricing these inputs at arbitrarily fixed prices, will almost always cause inaccuracy, unless the technologies being compared use these resources with the same intensity over the same period of time.

For various reasons relating mainly to transport difficulties and immobility of resources, market prices for some farm inputs and outputs may be poor reflections of their true economic values. Indeed, for some items, such as family labor, animal labor, land and crop byproducts, no effective market may exist in the village. In such situations the opportunity cost principle must be employed to achieve realistic evaluations of technology. But here again the partial budgeting approach does not permit appropriate opportunity cost values to be determined. Even in cases when prices of purchased materials are available from markets, the evaluation is not straightforward. The actual cost of purchased material depends upon the opportunity cost of the farmer's cash, which depends in turn upon the availability of cash and its alternative uses in different periods of the year. These considerations become too complex to be incorporated in partial budgeting.

A still more crucial and complicated aspect surfaces when one wants to evaluate technologies for conformity with an individual farmer's objectives. Farmers may have more than one objective. Such objectives could be net return maximization, gross return maximization, risk minimization, meeting subsistence needs, etc. In the case of dryland agriculture in developing countries where the majority of farmers is of subsistence or semi-subsistence type, valuation of farmers' objectives becomes very complicated and such issues are difficult to handle with partial budgeting.

Village or regional-level restrictions like institutional infrastructure which in general determine levels of common resources, market infrastructure determining levels of active commercial markets, land-labor-credit market linkages, and availabilities of extension services all have a vital role in technology adoption and have to be accounted for in evaluating technologies. But again partial budgeting ignores all such considerations.

Another major disadvantage of partial budgeting for dryland technology assessment is that it provides limited scope for accounting for risk in the technology outcomes. Typically the analyses yield single-valued measures of net benefits, possibly supplemented by some simple sensitivity analysis. This is unsatisfactory for two reasons. First, most farmers are risk averse and their adoption decisions will be influenced by the distribution of outcomes, not just the average or most likely value. Second, because of interactions between technologies, and through the operation of the law of diminishing returns, riskless analysis using expected values can overestimate the mean net benefits.[3] In brief, the riskiness of technology combined with risk aversion of farmers is important in determining the level of technology adoption.

Any technology assessment process is not complete unless the post adoption consequences are ascertained to be set against policy objectives. Such objectives could be achieving more equitable distribution of income from technology, biased gains favoring small landholders and landless laborers, reduction of unemployment, increased self-reliance, greater national output and income, etc. Here again, the partial budgeting approach is hardly adequate for the purpose.

The above discussion leads to two main conclusions. Firstly, very often technology assessment can best be attempted in a whole-farm context. Secondly, evaluation of technology options and valuation of limiting resources need to be done simultaneously. Hence, in order to make realistic evaluations of agricultural technology, an approach is needed which will simultaneously value the production factors available to the farmer and evaluate technologies with due consideration to the farmer's objectives and also to the institutional and social systems within which he operates. Such an approach can also be used to assess short and long-run consequences of technologies in terms of social costs and benefits and macro level planning objectives (Swindale 1980). Whole-farm modeling approach for assessment of dryland technology is discussed in the next section.

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3. Thus, if the output of activity X is an intermediate product used as an input for activity Y, and if the yield of X is variable due to weather or other risk factors, the mean output of Y will in general be less than that estimated using the mean yield of X.

WHOLE-FARM MODELING

The approach of whole-farm modeling is primarily based on a concept of a farm as a system (Barlow et al. 1980). In this regard the definition of a farm system as agreed by the Workshop on Farming Systems Research at the International Agricultural Research Centers is very relevant.

> A farm system or whole-farm system is not simply a collection of crops and animals to which one can apply this input or that and expect immediate results. Rather it is a complicated interwoven mesh of soils, plants, animals, implements, workers, other inputs and environmental influence with the strands held and manipulated by a person called the farmer who, given his preferences and aspirations, attempts to produce output from the inputs and technology available to him. It is the farmer's awareness of his immediate environment both natural and socioeconomic that results in his farm system. (Technical Advisory Committee, Consultative Group on International Agricultural Research, 1978a, p. 5).

The place of the whole-farm approach in technology development and transfer is illustrated in Figure 1. The need for technology is established on the basis of existing levels of output, levels of income, resource use patterns and environmental factors. The technologies being developed are evaluated with the whole-farm modeling approach which considers social structure, institutional infrastructure, extension base and market infrastructure under which the farmer makes his farming decisions. The approach also accounts for farm resources, present technologies, degree of skill, and attitude of the farmer, his objectives and goals, etc. The outcomes of such assessment in the form of output, income, risk employment, etc., are then used to judge the acceptability of the technology to farmers and also to judge conformity with policy objectives. In the process, limiting factors and key constraints are identified which help to suggest required revisions in technology or policy so as to alleviate such constraints.

This approach could be termed a 'bottom up' approach for assessment as it simulates a farmer's behavior (though it does not directly involve the farmer at the grassroot level) in terms of his goals, skills, attitudes and preferences and also his physical environment in terms of farm resources, institutional infrastructure, alternative technologies, etc. The desirability of the bottom up or whole-farm approach to dryland technology assessment is consistent with recent thinking on needed reorganization of farming systems research (Binswanger et al. 1980), and with the 'farming families' approach recommended by Gilbert et al. (1980). This approach does not substitute either the technology testing at experiment stations or the on-farm testing of technology. In fact these are complementary in the sense that indications received and coefficients generated through these processes are valuable in developing realistic whole-farm models.

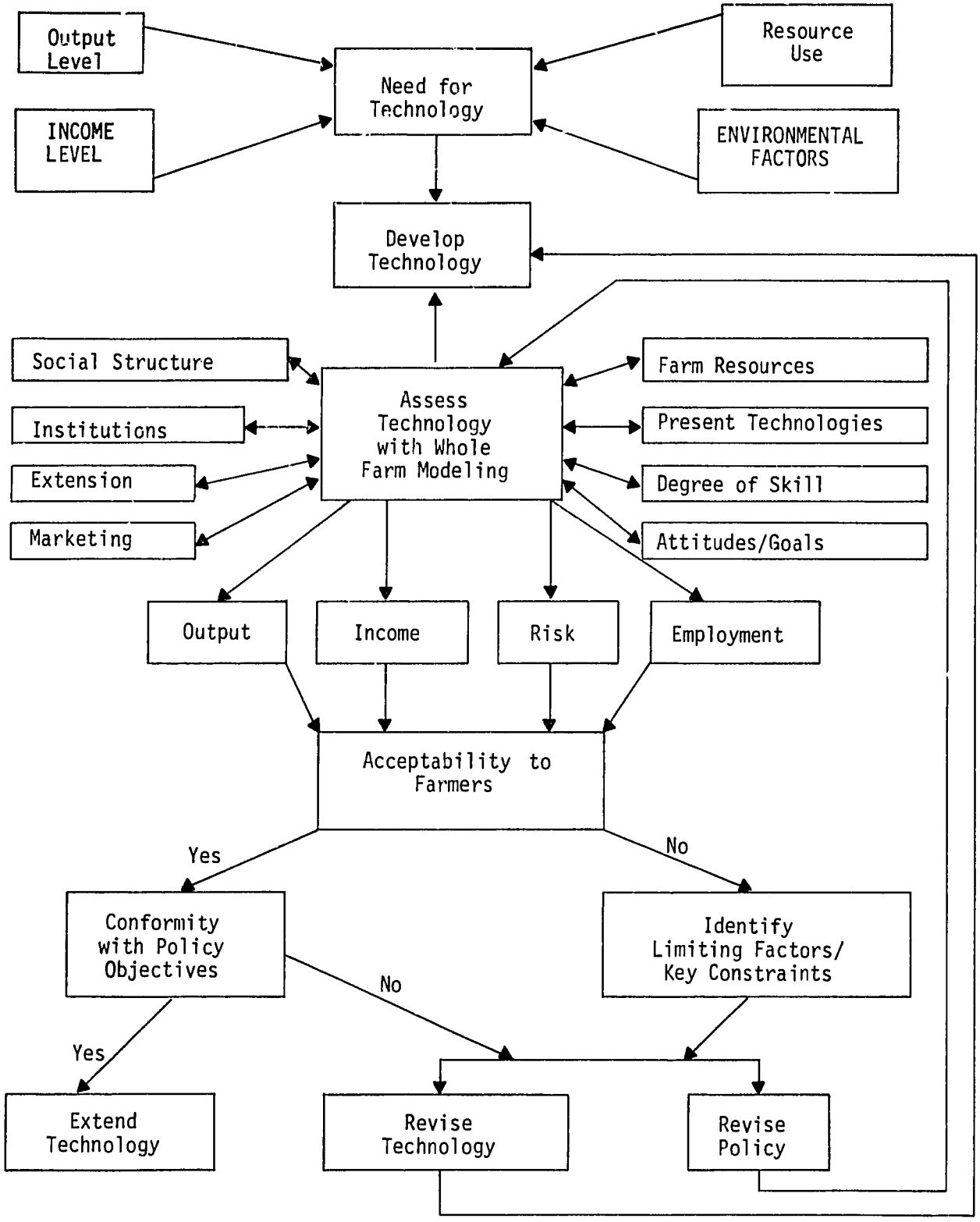

Figure 1. Technology assesment with whole-farm modeling

In addition to climatic and biological complexities in drylands, the farming environment is further complicated by imperfections in different factor-product markets. For example, both resource base and the social status of a cultivator can decide his access to factors of production and can influence family labor participation in the rural labor markets. Objectives and goals of farmers depend not only upon their preferences but also upon their attitudes towards risk and upon their risk perceptions. Imperfections arise due to interlinkages between land-labor-capital markets. With relatively sophisticated and complex techniques, many of these issues can be rationalized and incorporated in whole-farm models.

In brief, the whole-farm modeling approach can evaluate a technology or a package of technology in the context of all the farmers' economic activities, including his other agricultural enterprises and his household and off-farm operations, thereby assigning imputed values for resources available to the farmer with due regard for their actual availability and for the demand which exists for them. Because of its broader context, the whole-farm modeling approach also can give indications of possible impacts of technology adoption on major policy variables like employment, distribution of income gains, social costs and benefits, etc. Thus, the whole process of optimal technology selection and measurement is performed within the complete framework of a defined farm-household model, taking into account interrelationships among all production processes through their dependence on common resources.

In emphasizing the merits of the whole-farm approach, it should be recognized that these advantages are only bought at the cost of a considerable increase, compared with partial budgeting, in the complexity of the analysis. While whole-farm modeling can permit more complete account to be taken of the farm circumstances and relationships that impinge on the technologies being assessed, these circumstances and relationships must first be identified, quantified and incorporated into a suitable model. Moreover, it must be possible to use the model to arrive at an evaluation of the particular technology. In the next section some whole-farm models which can be used for assessment for dryland technologies are evaluated.

COMPARATIVE EVALUATION OF WHOLE-FARM MODELING METHODS

There exists a wide range of methods of whole-farm modeling that can be used to assess technologies. Reviews of these methods are available elsewhere (Hardaker 1979).[4]

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4. For more details on these methods and their applications see Dillon and Hardaker 1980; Barnard and Nix 1973; Anderson, Dillon and Hardaker 1977; Hazell 1971; Cocks 1968; Rae 1971a, 1971b; Wicks and Guise 1978; Flinn, Jayasuriya and Knight 1980; Carlsson, Hovmark and Lindgren 1969; Anderson 1974; and Ghodake 1981.

The list of methods provided below has been constructed in the belief that it includes most of the methods likely to be useful for assessment of dryland technology.[5] The methods are listed in approximate order of increasing complexity.

Method	Abbreviation
Whole-farm budgeting	WFB
Simplified programming	SP
Linear programming	LP
Linear risk programming	LRP
Quadratic risk programming	QRP
Linear stochastic programming	LSP
Nonlinear stochastic programming	NSP
Goal programming	GP
Monte Carlo programming	MCP
Systems simulation	SS

Before evaluating these methods, it is useful to consider the criteria that are relevant to the choice of a particular method for use in technology assessment in dryland agriculture. A number of criteria that are judged to be relevant are listed in Table 1.

The first criterion considered is the need to be able to handle many constraints, variables and interrelationships between variables, the need for which arises from the complexity of dryland agriculture. Second, it is desirable that a method should permit risk to be incorporated into the analysis in a realistic way. Risk pervades almost all aspects of dryland agriculture, so that, ideally, the representations of risk should not be confined to one part of the model only, such as the objective function but should possibly be considered in the constraints also. Third, the capacity of alternative methods to permit the real goals and objectives of farmers is considered. It is generally accepted that farmers have other goals than income maximization. They are concerned about risk and security, about meeting farm family needs for food, and other essentials, about having available enough time for leisure, and so on.

Next, a criterion of degree of objectivity is introduced. If the technology assessments performed are to be accepted by scientists, extension worker and policy makers, they should depend no more than is absolutely necessary on subjective judgements by the analyst using the method. Of course, complete objectivity is not attainable, but methods

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5. Note that the models listed here are confined to the static or single-period case. At least in principle, most of the models listed can be extended to the dynamic case, although usually this involves a substantial increase in complexity. Because the focus of this paper is on cropping technology, and because perennial crops are not widespread in dryland areas, the discussion which follows is confined to static, one-period models.

Table 1. A subjective rating of some whole-farm modeling techniques[a]

Characteristics	WFB	SP	LP	LRP	QRP	LSP	NSP	GP	MCP	SS
Capacity to handle many constraints, variables and interrelationships	1	1	4	4	3	3	2	3	2	(2)[b]
Capacity to incorporate risk in a realistic way	1	1	1	2	3	4	4	(1)	(2)	(4)
Capacity to incorporate the real goals and objective of farmers	3	1	1	2	3	2	3	3	4	4
Objectivity of approach (low dependence on subjective judgements of analyst)	1	2	3	3	3	3	3	3	3	2
Optimising algorithm used	N	N	Y	Y	Y	Y	(Y)	Y	N	N
Computer needed	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Ease of calculation/access to computer programs	4	4	3	3	2	3	2	2	2	1

[a]Ratings are on a scale of from 1 (low) to 4 (high). Y means 'Yes', N means 'No'.

[b]Particularly uncertain ratings are in parentheses.

do vary in the extent to which they depend on judgements by the analyst. A related issue is whether the method embodies an optimising algorithm. The need for a computer is considered next, followed by a criterion relating to the difficulty of the computing task. Obviously this is lowest for methods that require no computer but, even for the computer-based methods, there are differences in accessibility of needed computer codes, size and speed of computer required, and so on.

Brief descriptions of these methods are provided here. The whole-farm budgeting method involves the specification of one or more farm plans derived mainly on the basis of skill, experience and judgement of the analyst. The plans so obtained are then evaluated in terms of the income they produce and in terms of consistency with the key resource constraints. The capacity of the technique, while related to the ability of the analyst, is nevertheless very limited in relation to the complexity of the task of technology assessment for dryland agriculture. Simplified programming offers a number of procedures which exploit the advantages of linear programming without use of a computer. Semi-formal rules for activity selection are designed to reach a near-optimal solution to a whole-farm planning problem. While SP is somewhat more objective than WFB, it seems ill-suited to the circumstances of dryland agriculture.

Linear programming can handle many variables and constraints. An optimizing algorithm is used to obtain the solutions. However, the limitations of LP are well known. One important limitation is the use of single-valued coefficients, implying no consideration of risk. Linear risk programming is the name given to the several variants of LP that have been developed to account for risk in objective function coefficients. Probably the best of these methods in the present context is Minimization of Total Absolute Derivation (MOTAD) programming (Hazell 1971). LRP methods combine the advantages of LP with some considerations of risk, albeit at the cost of some increase in matrix use. There is closer conformity with farmers' real objectives in the sense that expected income and its variability can both be considered. This method accounts for risk only in objective function coefficients whereas, in practice, appreciable risk often attaches to other planning coefficients. Quadratic risk programming closely follows LRP except that it allows risk to be considered in non-linear terms, which is more realistic but more demanding of computer facilities.

The linear stochastic programming technique allows one to incorporate risk considerations in the constraints. Of the various LSP models, two that appear attractive in the context of dryland agriculture are discrete stochastic programming (Cocks 1968; Rae 1971a, b) and stochastic MOTAD programming (Wicks and Guise 1978). As with the move from LRP to QRP, the shift from LSP to nonlinear stochastic programming (NSP) gains advantages in model realism in terms of representation of

risk and farmers' real objectives. Too little experience has been gained in the use of stochastic programming in general and NSP in particular to make a confident appraisal of the latter technique for technology assessment in dryland agriculture.

Goal programming involves the identification of a number of goals and is used to obtain solutions satisfying these goals at different priority levels. The priority levels assigned are pre-emptive in the sense that all goals at a higher level of priority must be satisfied before lower-level goals are considered. However, there are no grounds to suppose that dryland farmers actually order their goals in a pre-emptive fashion. Monte Carlo programming is a computer-based whole-farm modeling method wherein a large number of farm plans are generated using a random selection procedure. The method is reasonably effective only for models with relatively few variables and constraints. Hence, for the reasons previously discussed, the applicability of the method to dryland technology assessment seems doubtful.

Systems simulation is the numerical exploration of a symbolic model, used to mimic the behavior of the modeled system. The SS approach provides for almost unlimited flexibility in the way the circumstances of the real system are modeled. There are, however two important associated disadvantages. First, optimization is not possible. Second, the task of model specification is likely to be very time consuming, at least for any reasonably realistic model of a whole-farm system. SS may also be prohibitively expensive.

On the basis of the above discussion and the ratings given in Table 1 it is argued that mathematical programming (MP) approaches, especially those which allow some account to be taken of risk, provide the most suitable framework for whole-farm modeling as part of dryland technology assessment. The one important proviso to this conclusion is, of course, that access to suitable computer facilities is essential.[6] Given that this condition is satisfied (which it certainly will not be in all research environments), the four techniques judged to be most suitable are LRP, QRP, LSP and NSP. The choice between these four will depend largely on the nature of the particular problem under study and the availability of quadratic and general nonlinear computer programs. Problems in which

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6. In the absence of appropriate computer facilities, it is necessary to rely on the budgeting approaches of WFB or SP. Of the two, WFB appears to be the more satisfactory. Because of the amount of 'hand' calculation involved, SP is restricted to small, simplistic, models and has the disadvantage of playing down the judgement of the analyst in favor of arbitrary activity selection rules that nevertheless fail to guarantee an optimal and objective solution. WFP involves a more honest recognition of the place of intuition in non-computerized planning. Anderson and Hardaker (1979) have argued that the value of intuitive judgement in technology assessment should not be underrated.

risk in the constraints is important must be handled using stochastic programming (LSP or NSP). While QRP is a reasonably standard technique that has been quite widely used for farm modeling, NSP remains something of a novelty so that, at least initially, the technique would rank lower than the other three for routine applications. The choice between linear and quadratic risk programming might depend mainly on the availability of suitable QRP computer code.

USE OF MATHEMATICAL PROGRAMMING FOR WHOLE-FARM MODELING

The whole-farm approach implies a need to define representative farm situations for which the analysis is to be carried out. There is wide diversity in the circumstances of individual farmers within any population. This diversity relates to differences in farmers' factor endowments as well as to differences in their goals and objectives. This diversity means that no one set of circumstances can be representative of more than a very small proportion of the target population. It follows that several farm models are likely to be needed to span at all adequately the range of farm circumstances encountered in the target population.

Table 2 provides an outline of a typical MP farm planning matrix that could be used for dryland technology assessment. The model outline relates to the LRP approach. Other approaches would differ chiefly in the way that risk is represented. It is useful to review briefly the main features of this outline matrix dealing first with the rows and then with the columns.

A key assumption embodied in the whole-farm approach, especially in the use of MP methods for technology assessment is that, on the whole, farmers are rational and will follow a farm plan that is consistent with their goals and objectives. It is assumed that, provided these goals and objectives are properly accounted for in a planning model, the results of such models can be used to predict which technologies farmers will adopt and how they will choose to adjust their existing patterns of resource use in the light of newly available technologies.

The choice of an appropriate objective function is a key issue in whole-farm modeling. The objective function chosen will commonly be the maximization of some measure of net income or, given the recognition of risk, of expected net income. In risk programming, the objective function may be changed to the minimization of some measure of risk such as mean absolute deviation or variance. Expected net income is then treated as a constraint and is usually varied parametrically over its feasible range. Such parametric variation allows the 'efficient possibility set' of substitutions between expected income and risk to be mapped. The same general approach can be used to explore substitution possibilities between other pair of goals such as net income and leisure (Powell and Hardaker 1969).

Table 2. Outline of a whole-farm model using linear risk programming

	Activities				Risk-variables	Relationship	Right-hand side
	Crop	Livestock	Marketing	Consumption			
Objective function	C_1	C_2	C_3	C_4	λ	0	0
Land and cropping constraints	$+A_{11}$	$+A_{12}$	0	0	0	L,G	B_1
Labor constraints	$+A_{21}$	$+A_{22}$	$\pm I$	0	0	L	B_2
Machinery constraints	A_{31}	A_{32}	$-I$	0	0	L	B_3
Capital and credit constraints	$\pm A_{41}$	$\pm A_{42}$	$\pm I$	$+I$	0	L,G	B_4
Family needs constraints	$-A_{51}$	$-A_{52}$	$\pm A_{53}$	$+I$	0	G	B_5
Product tie rows	$\pm A_{61}$	$\pm A_{62}$	$\pm A_{63}$	0	0	E,L	B_6
Institutional and social constraints	A_{71}	A_{72}	A_{73}	0	0	E,L,G	B_7
Risk constraints	A_{81}	A_{82}	0	0	I	E,L	B_8

C - Vector of objective function coefficients
λ - Parametric value of risk consideration in objective function
$\pm A$ - Input-output coefficient in particular sub-matrix
I - Identity sub-matrix
0 - Null matrix
B - Vector of restriction coefficients
L - Less than or equal to; G-Greater than or equal to; E-Equal to.

Nonlinear programming provides a potential to incorporate the farmer's utility function directly into the MP framework. For this purpose the utility function may be defined in terms of one or more than one dimension. Of course, this requires that the utility function be measured (see Anderson, Dillon and Hardaker 1977, ch. 4).

Land constraints specify the area of the farm being modeled, disaggregated on the basis of season, land quality, access to irrigation, and so on. Constraints may also be included on area of particular crops or groups of crops, reflecting, for example, disease, pest or weed control considerations. Labor constraints may be disaggregated on a seasonal basis and according to the different categories of labor, e.g. male, female, and animal labor. Machinery constraints specify capacities of any field machinery or fixed equipment owned or hired by the farmer.

Capital and credit constraints may be specified in varying degrees of detail according to how important these aspects are thought to be. Family needs for cash can usually be represented in the capital constraints. However, given the semisubsistence orientation of many dryland farmers in developing countries, it may be necessary also to prescribe minimum levels of consumption of various food crops. Again, there is scope for variation in the degree of detail with which these minimum needs constraints are specified. As with capital, stochastic representation may be desirable.

The next section of the matrix shown in Table 2 accounts for production and use within the model of various agricultural products and byproducts. Institutional and social constraints may relate to many things but are likely to refer chiefly to farm or village level restrictions on the purchase or sale of particular factors or products. Such constraints are needed to reflect the small size and relative isolation of markets for some agricultural inputs and outputs.

The risk constraints in an LRP model are typically tie rows that allow the risk inherent in individual activities to be aggregated for transfer to the objective function.

The outline matrix in Table 2 includes first the crop and livestock activities that can be employed on the farm being modeled. Each such activity is represented in the matrix by a separate column, expressed on a per unit basis (per ha, per head, etc.). Positive matrix coefficients conventionally indicate resource demand and negative coefficients product supply.

Marketing activities may include buying and hiring in activities as well as selling and hiring out activities. Trading opportunities may be represented not only for main products but also for byproducts and for input factors. Any borrowing and saving activities would be included in this part of the matrix. Consumption activities may be needed to transfer cash and food crops from the appropriate tie rows into constraints specifying family minimum needs. Net income may be transferred to the objective function. Finally, among the activities, LRP requires the specification of risk variables used to measure, via the risk constraints, the riskiness of the selected farm plan.

In the right-hand side or B column the resource endowments or constraint specifications are recorded. Corresponding to each constraint, the nature of the relationship implied ($\leq$ = or $\geq$) must also be indicated.

Incorporating New Technologies

A key feature of the whole-farm approach to the assessment of technologies is that 'new' technologies (i.e., technologies representing somewhat different ways of doing things 'down on the farm' [Anderson and Hardaker 1979]) must be matched against existing technologies. This means that these new technologies will normally be represented in an MP model by the addition of extra crop or livestock activities. Some new technologies may also lead to changes in the right-hand side vector. For instances, some technologies may increase the effective availability of irrigation or may permit cropping limits to be relaxed through better control of some pest, disease, or weed.

Data Gathering and Processing

The representation of the model in the outline form of Table 2 tends to divert attention from the substantial data gathering task implicit in the MP approach to whole-farm modeling. A large farm planning matrix may involve some hundreds, even thousands, of coefficients and, for each of these, data must be carefully gathered and analyzed. Information will need to be collected from farms and farmers, from research stations, from scientists, engineers and other specialists, and from many other sources.

Relatedly, the data processing task for a large MP study is a substantial one, even with access to good computing facilities. Quite apart from the task of finding an optimal solution, entering the data into the computer and verifying it is a time-consuming but important task. Modern MP packages often embody efficient data handling systems to facilitate this part of the work.

BENEFITS OF WHOLE-FARM MODELING FOR TECHNOLOGY ASSESSMENT

Most obviously, the whole-farm approach has the potential to provide a more realistic assessment of the suitability and acceptability of technologies to dryland farmers. Predicted upon the assumption of rational behavior, MP modeling can permit identification of those technologies that are consistent with specified goals and objectives of farmers and those that are not.

A second benefit of the whole-farm approach is that it can provide useful feedback to agricultural scientists on the economics of prospecive prototype technologies that they may be contemplating or working on. Indeed, it is possible to envisage an interactive approach between the scientist and the economist, beginning at the stage when scenarios of possible new technologies are being discussed and carrying on throughout the various phases of research to the point where the technology has been tested in the field and is ready for dissemination to farmers.

The whole-farm approach will not only segregate technologies into those that are acceptable from those that are unacceptable to a particular group of farmers but will also permit identification of key constraints inhibiting more effective exploitation by farmers of their resources. That is, it will be possible to identify which constraints faced by which groups of farmers are preventing adoption of improved technologies. Some of these constraints may be amenable to policy intervention, e.g., credit availability. Thus, whole-farm analysis may be useful in analyzing the effects at the farm level of certain policy changes, both in general and on the acceptability and scope for adoption of specific technologies.

Finally, the approach can provide forecasts of the implications of new technologies in terms of their likely consequences on such important economic parameters as agricultural output, employment, and levels and distribution of agricultural incomes. These forecasts may be useful in two ways. First, some technologies may pass the test of acceptability to farmers but may be predicted to produce consequences that are inconsistent with social objectives. For example, mechanization may increase unemployment, worsen income distribution, creating more poverty and malnutrition, even though it earns more profits for the large farmers. Policy intervention may be possible to mitigate undesirable consequences, perhaps by changing the economic environment in which farmers make adoption decisions. Thus, in the mechanization example, credit policy might be changed to restrict the availability of subsidized credit for purchase of farm machinery, or a special sales tax might be imposed on the machinery.

A second use of forecasts of implications of new technology relates to research planning. Given a range of imagined new technologies which could be the alternative outcomes of different research strategies, it is possible to use a whole-farm approach to predict the consequences of these technologies, if brought into being, in terms of the chosen social objectives of the research organization or the government. Such forecasts should be useful in helping to guide the allocation of scarce research resources amongst alternative programs and the assignment of research priorities within programs.

CONCLUSIONS

The desirability of a whole-farm modeling approach to the assessment of technology was explained earlier in the paper. It has been argued that mathematical programming provides the best means of undertaking such analyses. The approach is expensive in terms of time and money required for data collection and costs of computing. It also needs considerable input by trained personnel who need to have acquired experience in the methods used. However, the benefits reaped from the whole-farm approach to technology assessment appear to be substantial. It is, a priori, believed that the benefit-cost ratio is greater than one. Current research employing this approach to technology assessment in the Economics Program at ICRISAT is designed to test this proposition.

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