Tailoring agricultural extension to farmer needs: A user-friendly farm-household model to improve decision making in participatory research

T. Bernet¹, O. Ortiz¹, R. D. Estrada², R. Quiroz¹ and S. M. Swinton³

Abstract

Farmers operate within specific natural and socio-economic settings. When those settings are very diverse, as in mountainous areas, agricultural extension services have often found it difficult to tailor interventions to the specific needs of client farmers. In such settings, extensionists need cost-efficient tools to evaluate ex-ante strategies and activities with the potential to raise farmers’ income. This need has become more critical as governments in developing countries continue to downsize expenditure on extension services and donors demand impact from their investments. This paper outlines a computer-based farm-household model designed to assist extensionists and researchers in advising farmers. The model allows the user to define specific production options and resource constraints under different scenarios. Based on these criteria, it identifies the production activities that generate the highest net income over an entire year. Model application in different regions has proven its flexibility to capture and analyze a variety of production systems. The model is best applied within a participatory setting, facilitating accurate specification of site-related attributes and effective dialogue between farmers and extension personnel.

INTRODUCTION

Agricultural extension performs an important function worldwide in enhancing the competitive-ness of agricultural production. Although the stepwise liberalization of agricultural trade mandated by WTO agreements has increased the potential role of agricultural extension, government cut-backs in many countries, particularly developing countries, have led to a general crisis in public agricultural extension (Bebbington et al. 1993). Many local NGOs have tried to fill the gap, implementing extension services through private grants. Scarce resources, however, challenge the effectiveness of their work. To meet this challenge, agricultural extensionists need to prioritize their interventions, fine-tune their methodological approaches, and select efficient decision-support tools to efficiently target the needs of farmers within specific environ-mental and socio-economic settings (Patanothai 1997). Within this context, quantitative farm optimization models have per-

¹ International Potato Center, P.O. Box 1558, Lima 12, Peru. E-mail: t.bernet@cgiar.org
² CONDESAN, c/o CIAT, Cali, Colombia
³ Dept. of Agricultural Economics, Michigan State University, E. Lansing, MI 48824-1039, USA
formed well in assessing production opportunities, strategies, and policies (Dent et al. 1995; Austin et al. 1998). Qualitative approaches have helped researchers and extensionists to improve farmer participation in the research process, provoking a more effective exchange of information (Nieuwkoop et al. 1994; Goldey et al. 1997). Because these participatory approaches draw farmers into the problem identification process, they have helped create a better framework for technology adoption (Okali et al. 1994).

Nonetheless, both qualitative and quantitative approaches suffer from deficiencies when it comes to effective decision-making in the extension process. Qualitative, participatory approaches tend to fail within settings that are either very complex or involve new aspects, such as new technologies and policies, when farmers cannot draw on past experience (Bebbington 1994; Martin & Sherington 1997). Participatory approaches are also unsuitable when farmers tend to prioritize prestigious technologies (e.g., tractors, electric fencing and milking machines) rather than those technologies that lead to higher agricultural income. Quantitative approaches, on the other hand, have disappointed many times because the applied mathematical models have not adequately reflected farmers' specific production contexts and objectives—especially in the case of poor farmers (Dorward et al. 1997; Martin and Sherington 1997). The inflexibility of most mathematical models (Jones et al. 1997), the complexity of their setup (Hochmann et al. 1994), and the lack of effective communication between researchers, extension workers, and stakeholders (Garforth and Usher 1997) explain why quantitative modeling is still not widely used for agricultural extension. To the extent that appropriate decision-making is becoming a critical aspect of participatory approaches—as indicated by new approaches such as Goal-Oriented Project Planning (GOPP) or Rapid Appraisal of Agricultural Knowledge Systems (RAAKS)—corresponding analytical decision support tools become essential in agricultural extension and policy-making. A subsequent application of our model in a mountain area of Northern Peru (Cajamarca) underscores its potential use in prioritizing strategies and policies and making agricultural extension more effective.

MODEL OUTLINE

Reflecting Farmers' Decision Making in Varying Conditions

Models are only as good as their ability to capture reality. Accordingly, a farm-household optimization model must reflect farmers' decision-making correctly. The model must be able to consider the specific production constraints of a farmer while correctly weighting his main objectives (Jones et al. 1997). Because these production constraints vary widely among farmers and regions, models must be flexible in order to be effective.

The model presented here comprises both fixed and variable features to allow this flexibility. The fixed feature embraces a limited number of production activities and constraint options related to crop and livestock production. The variable feature allows the user to specify the conditions for each fixed feature, using site-related data. In other words, given a limited amount of potential options to describe the different domains of a potentially mixed farming system, the user defines the production activities, resources, production factors, technologies, and prices, etc., which collectively portray the farmer's specific production and decision-making context (Figure 1). The consideration of a specific context has proven essential in assessing farmers' willingness to
adopt new technologies (De la Briere 1996; Obando and Montalvan 1994; Winters et al. 1998). Once the context has been defined, the model optimizes the site-specific input over four trimesters (3-month periods) to capture the variation in production factor needs and availability throughout the year. Production factors include variables such as irrigation water, labor, capital, and feed.

Based on this user-defined information, the model indicates how annual farm-household profit can be maximized. Thus, the resulting "optimal solution" refers to maximum expected profitability to be reached within a specified context, as determined by a set of (potential) production activities and production constraints. Optimal production patterns derived in this way provide insight on the household’s potential profitability. When these optimal production patterns are compared with the actual production patterns, need for action in terms of strategies and policy can be defined.

Considering All Production Aspects of Mixed Farming Systems

This model can be applied to farming systems that involve only crop or livestock production, or comprise both of these components—targeting many different production systems within developing countries. The principal production constraints defined by this model include access to land, water, labor, capital, and feed (Table 1). The capital and feed constraints receive special attention in the model since they are of particular importance to small farmers. Because a major concern of small farmers is to meet their family’s daily needs, they tend to favor activities that provide regular and reliable income, and hence guarantee a minimum income throughout the year (Winters et al. 1998). By defining a minimum income for each trimester, the model is able to reflect this propensity of farmers. The model solutions show that meat and milk production gain importance when a more equal income distribution is to be achieved, since livestock demand...
activities provide a steadier annual income than crop production (Mosley 1982; Orskov 1993). In such a setting, mixed crop/livestock systems often become optimal (Bhende & Venkataram 1994).

The model entails a detailed feed balance for cattle and sheep, involving different potential feed sources such as green and conserved fodder, crop residue, and feed concentrates. The model requires that the animals' nutrient requirements for crude protein and metabolized energy are covered and that a minimum fiber intake is guaranteed. At the same time, the model limits the fresh and dry matter intake according to user-defined coefficients in relation to the genotype of the animal and herd management. Variables include body weight, milk production and milk fat content, levels of food intake, mortality and replacement rates, date of first calving and average calving intervals. While mortality and replacement rates are applied to both cattle and sheep, coefficients for first parturition and the parturition interval are only modifiable for cattle. The basis of the feed balance is "one cow equivalent" or "one sheep equivalent", defined as herd units by metabolic size consisting of one adult female (cow or ewe) plus the relative share of the other animals in the herd. By contrasting feed requirements and maximum intake for one equivalent cow with the different feed options, the model indicates (i) the optimum number of animals, (ii) the number of hectares used for fodder production, (iii) the amount of feed concentrate purchased, and (iv) the amount of stored fodder (hay and silage) (Figure 2).

For crop production, the user may specify up to nine crop options, either agricultural or fodder crops. For each crop, on the basis of one hectare, the user specifies the production factors requirements per trimester such as water, male/female labor, animal traction, tractor hours, and capital. Moreover, he defines yield and price levels, the amount of fodder that is provided to animals by fodder crops, crop residues, and fallowed land together. When land derives fodder for animals, the water and nutrient content is specified (dry matter, protein, energy, and fiber content). No link exists in the model to relate soil and climate data with expected yields.

Since the user is obliged to define numerous coefficients, a user-friendly model setup is essential. Easy changing of input data also facilitates sensitivity analysis, for assessing the impact of different scenarios on profit and production. Since this model does not explicitly evaluate risk, sensitivity analysis is needed to analyze farmer behavior under uncertain conditions. In this case, the model is run with different yield levels and prices. Such risk assessment
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is particularly important in analyzing the behavior of poor farmers, since they favor production activities that entail little risk and guarantee income and thus food (Hanagarth 1989; Altieri 1991; Morlon 1992).

Helping the User Apply the Model

The model presented here is designed to help the user understand and apply it. However, "The risk of getting lost in the complexity of the system is ever-present" (Cacho et al., 1995). Data entry, data analysis, and data display is structured in such a way to help the user understand the functioning of the model. If the user does not understand the model, he risks obtaining misleading, distorted results.

The model operates in Microsoft® Excel (Version 97). Being dominant spreadsheet software, model users should not have problems accessing the software and becoming familiar with it, if they have not yet used it so far. Familiarity with the software has proved to be an important factor in transferring a model successfully from the designer to potential users, since this obviously increases the user's awareness of the model's functioning (Hochman et al., 1994). In this sense, Excel is appealing, since it allows the user to track the mathematical equations of the fixed features in the model. Once a user is familiar with the software, he or she can create customized tables and graphs to better summarize and present the most relevant results in each case.

At present, the model is contained in one Excel workbook file with 8 input sheets, 1 analysis matrix sheet, 4 result sheets, and 2 output sheets (Figure 3). On the input sheets, the user specifies all coefficients related to the activity and constraint options (the requirements and availability of production factors, prices, etc.). This information is then processed by the fixed model feature and flows into the matrix sheet, where the specific linear problem is solved. The final results are then displayed in detail in the result sheets. Currently, the model contains two output sheets that list and graphically display the most relevant results.

User-specified data is processed stepwise within and across different spreadsheets. The display of these preliminary results helps the user ensure that the model is running correctly. Once the data enters the matrix sheet, it becomes far too complex to efficiently check for errors. Moreover, often these preliminary results are of interest per se, since they provide important reference data from the literature. For example, the user might want to compare the

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**Figure 2.** Modeling of the nutrient and feed constraints in relation to cattle and sheep.
calculated feed requirements and maximum feed intake of cows, heifers, and calves, with published data. When different dairy cattle are analyzed (considering different production levels), the display of feed requirements according to maintenance, production, and gestation is very helpful.

Because accurate data entry is so important, the model is designed to guide the user through the process of data entry. On the model-input sheets, cells that require user-defined data are color-coded. Additional information appears next to these cells to clarify the data required (Figure 4). Those cells not used for data entry are write-protected (i.e., they cannot be edited) to prevent model distortions.

In spite of all these user-friendly features, users must devote a minimum amount of time to understanding the model's functioning. Otherwise, like many other linear programming models, this model will remain a "black box", whose results might be interpreted improperly. This could lead to its misuse in agricultural extension.
MODEL APPLICATION

The relevance of the model is illustrated by an application to three ecological zones within a Andean watershed. The purpose of using the model within this context was to understand small farmer production systems in order to identify appropriate strategies to raise incomes, especially focusing on milk production. This case stresses the ability of the model to reflect different production conditions and its usefulness in extension and policy-making. For more detailed results of this study, see Bernet & Tapia (1999).

Production Systems in the Study Area

The study area relates to the Encañada watershed, located in the province of Cajamarca, northern Peru. This watershed was chosen for this analysis since it comprises the three common ecological zones of the Peruvian Andes: Valley, Slope (lower hills), and Jalca (upper hills). Each of these zones reflects specific environmental conditions that vary with altitude, ranging from 2,800 to 3,700 m (PIDAE, 1995).

The economic situation of farmers in each of these zones is strongly determined by climate, topography, and access to irrigation, inducing a different set of feasible production activities and constraints for each zone (Table 2). Since most farms in the study area are small—about 70 percent comprising less than 3 hectares (Bernet & Tapia, 1999)—incomes are very low, and farmers have difficulties saving money for investments. Production for home consumption is important to secure the family's base nutrition. However, the sale of surplus agricultural production is equally important to generate cash for acquiring products that cannot be produced by the farmers themselves. These include food items (rice, sugar,
etc.), intermediate production inputs (fertilizer, pesticides, etc.), and other commodities (kerosene, batteries, etc.), as well as services (public transportation, school and medical services, etc.).

The relative importance of livestock and crop production varies among the three ecological zones. In the Valley, milk production dominates since access to irrigation allows for cultivation of permanent pastures, primarily ryegrass-clover mixtures. With no access to irrigation—which is generally the case in the Slope zone and sometimes in the Jalca—agricultural crops dominate the production system, cultivated mainly during the rainy season (December until May). The pronounced seasonality of production has strong implications for these relatively poor farmers. They face a strong variation in financial liquidity as they require considerable amounts of cash to purchase seed, fertilizer, and pesticide at the onset of the rainy season while income is delayed until harvest time. Hence, these farmers tend to be very dependent on (usually expensive) seasonal credits in order to handle the investments at the beginning of the planting season. Continuous climatic and price risks explain why farmers in the study area prefer to hold livestock if the natural conditions allow it—for animal traction as well as for meat and milk production—providing a steadier and more secure income than agricultural crops (Mosley 1982; Orskov 1993).

**Model Results**

The base runs—reflecting optimal production patterns according to average production conditions (yields, prices, labor costs, water availability, etc.)—show strong differences in expected profit for each zone (Table 3). This is explained by the varying feasibility to cultivate permanent pastures due to differences in access to irrigation, since milk production is more profitable than crop cultivation.

Obviously, Valley and Jalca farmers would be affected much more than Slope farmers would if constrained to have no animals. The lack of fodder conservation would harm the Valley farmer most, due to the lack of fodder in the dry season. The Slope and the Jalca farmers would be affected less, since crop residues provide an important share of the feed resources during this period. Indeed, the model shows that a lack of fodder storage (hay and silage) has an even stronger effect when combined with poor herd management (e.g., when calving occurs in all seasons and use of feed concentrate is limited to lactating cows). In such a setting, the model manifests a strong interaction between these components, as the total profit loss is higher than the sum of the individual effects.

This interaction is also apparent in the reverse scenario, when better fodder and herd management practices are combined. When cows are put on pasture earlier, profit increases considerably in the Valley, as the protein content of the ryegrass-clover mixture is higher in younger plants. In the Slope

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**Table 2.** Characteristics of the three common agro-ecological zones in northern Peru.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Valley</th>
<th>Slope</th>
<th>Jalca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude</td>
<td>2,500 – 3,200 m</td>
<td>3,200 – 3,500 m</td>
<td>&gt; 3,500 m</td>
</tr>
<tr>
<td>Frost occurrence</td>
<td>strong</td>
<td>Weak</td>
<td>Strong</td>
</tr>
<tr>
<td>Average temperatures</td>
<td>high</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Access to irrigation</td>
<td>almost 100 %</td>
<td>almost none</td>
<td>partial</td>
</tr>
<tr>
<td>General soil quality</td>
<td>good</td>
<td>Bad</td>
<td>good</td>
</tr>
<tr>
<td>Main crops</td>
<td>permanent pastures</td>
<td>potatoes, cereals</td>
<td>fodder crops, potatoes</td>
</tr>
<tr>
<td>Number of livestock</td>
<td>high</td>
<td>low</td>
<td>medium</td>
</tr>
<tr>
<td>Purpose of livestock</td>
<td>milk production</td>
<td>animal traction</td>
<td>milk and traction</td>
</tr>
<tr>
<td>Number of sheep</td>
<td>low</td>
<td>high</td>
<td>medium</td>
</tr>
</tbody>
</table>

Source: PIDAE, 1995
zone, better fodder management improves profits only slightly because of the minor importance of livestock. When the daily intake of feed concentrates is limited to 2 kg per cow or when a genetically improved dairy cattle is presumed, the model can no longer find a solution for Slope zone (i.e., the Slope farmer is not able to feed his dairy cows under these circumstances).

These results show two things: (1) access to irrigation for growing permanent pastures is essential to promote milk production, and (2) genetic improvement of dairy cattle only makes sense when good fodder management is put in practice. Correspondingly, if natural conditions are not favorable for milk production, interventions on the crop side are inevitable. A price or yield increase of 10 percent for all agricultural crops enhances profit by more than 60 percent in the Slope. In this case, the model indicates that the farmer should expand potato production as that becomes more profitable than other agricultural crops.

Need for Action

Because of the varying relative importance of milk versus crop production, the model results suggest different interventions for each ecological zone (Table 4). In the pasture-based production system of the Valley, interventions that lead to better fodder and herd management have priority. Special attention must also be given to fodder storage (hay and silage production). In the Jalca, good management of annual fodder crops (oats mixed with field beans) is key, since these crops occupy a high share of the land that has no access to irrigation. In the Slope zone, extension interventions are required that focus on crop marketing—assuming that interventions on the crop side would lead to lower prices at the local level and thus lower profits. Where access exists to irrigation water in this zone, the promotion of sprinkler irrigation could be of interest to boost the cultivation of permanent pastures on the slopes, leading to positive impacts for farmers (income) and the public (erosion protection). Further research is needed to study the feasibility of such investments, taking into consideration that local credit institutions provide only loans with high interest rates (around 2 percent per month).

Nonetheless, since most farms are very small—and land is the most limiting production factor on profit—non-agricultural extension interventions and policies that promote off-farm income are crucial. Regular off-farm employment cannot only generate higher total income but can also provide continuous

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**Table 3. Effect of different scenarios on expected profit for the three ecological zones.**

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Valley</th>
<th>Slope</th>
<th>Jalca</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base run</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 Expected profit per hectare under average conditions</td>
<td>500 $</td>
<td>125 $</td>
<td>250 $</td>
</tr>
<tr>
<td><strong>Scenarios</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A No animals</td>
<td>-30%</td>
<td>-9%</td>
<td>-35%</td>
</tr>
<tr>
<td>B No fodder storage (hay and silage)</td>
<td>-23%</td>
<td>-6%</td>
<td>-8%</td>
</tr>
<tr>
<td>C Calving in all seasons</td>
<td>-10%</td>
<td>-15%</td>
<td>-3%</td>
</tr>
<tr>
<td>D Max. 2kg of feed concentrate (cow/day)</td>
<td>01%</td>
<td>No sol.</td>
<td>0%</td>
</tr>
<tr>
<td>E No fodder storage, calving in all seasons</td>
<td>-32%</td>
<td>-23%</td>
<td>-14%</td>
</tr>
<tr>
<td>1 Increased protein in raygrass-clover (9 to 11%)</td>
<td>34%</td>
<td>0%</td>
<td>14%</td>
</tr>
<tr>
<td>2 Increase of the raygrass-clover yield by 10%</td>
<td>4%</td>
<td>0%</td>
<td>3%</td>
</tr>
<tr>
<td>3 Increase of oats for forage by 60%</td>
<td>13%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>4 Higher yielding genotype (4000 liters per campaign)</td>
<td>12%</td>
<td>No sol.</td>
<td>15%</td>
</tr>
<tr>
<td>5 Yield and price increase in agricultural crops (by 10%)</td>
<td>0%</td>
<td>62%</td>
<td>4%</td>
</tr>
<tr>
<td>1,2,3 Better fodder management</td>
<td>73%</td>
<td>10%</td>
<td>35%</td>
</tr>
<tr>
<td>1,2,3,4 Better fodder management with better genotype</td>
<td>90%</td>
<td>9%</td>
<td>55%</td>
</tr>
</tbody>
</table>
Thus, farmers are put in a better position to invest in milk production. Off-farm work opportunities, for men especially, would also enhance the shift from crop towards milk production, since the activities involved in milk production are less time consuming than those in crop production. Moreover, women often execute all activities.

CONCLUSIONS

So far, the farm-household optimization model presented here has proven flexible enough to reflect different production contexts. The model’s successful application in prioritizing extension and research activities in different ecological zones qualifies it as a potentially valuable decision-support tool for future efforts in agricultural extension and policy-making.

This farm-household model is intended for use in participatory agricultural research and extension. In such a setting, model results could be more easily communicated and discussed between researchers, extension workers, and farmers, allowing more appropriate decision-making. Farmer participation would also help to validate the model results. Moreover, farmers could efficiently be involved in data collection, since the use of site-specific data is a primary requirement for achieving the most beneficial results.

The model is especially valuable in circumstances where farmers cannot draw on past experience, such as new technologies and policies. In such a setting, the model could be useful in appraising the potential impact of such changes. Based on hypothetical data, it could assess under which conditions potential improvements are likely to be profitable. Depending on the specific results, simple trials in farmers’ fields might be established in order to obtain actual data.

The successful dissemination of this model in extension will require changes at several levels. Certainly, the model itself would benefit from further improvements, most notably making its setup even user-friendly. But also institutional changes are needed to enable wider use of such decision support tools in extension. Incentives are needed to encourage the application of such a model in a participatory setting in order to overcome the tendency of many NGOs to execute their projects without any real farmer participation or close collaboration with research institutions (Bebbington et al., 1993, Pretty, 1995). International donors could play an important role in “reversing the flow of funds” by letting farmers choose those NGOs and extension services which best meet their needs (Scheuermeier et al., 1998). Such a demand-driven approach could induce further improvements in quantitative modeling for agricultural extension and would provide a perfect opportunity to determine the real practical value of such models.

REFERENCES


<table>
<thead>
<tr>
<th>Strategies for extension</th>
<th>Valley</th>
<th>Slope</th>
<th>Jalca</th>
</tr>
</thead>
<tbody>
<tr>
<td>I To improve management of permanent pastures</td>
<td>++</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>II To improve management of annual fodder crops</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>III To improve herd management</td>
<td>++</td>
<td></td>
<td>++</td>
</tr>
<tr>
<td>IV To implement fodder conservation practices</td>
<td>++</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>V To promote off-farm work</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>VI To improve commercialization of crops (storage, marketing)</td>
<td></td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>VII To establish sprinkler irrigation on the Slope</td>
<td></td>
<td>++</td>
<td></td>
</tr>
</tbody>
</table>


