Risk Analysis of Optimal Resource Allocation by Fish Farmers in Rwanda

Work Plan Seven, Africa Study 7

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Introduction

The main objective of many small-scale fish farming projects in developing nations is to supply protein-rich food to rural people at reasonable prices and to provide them with limited but steady income and employment (Belsare 1986). Rwanda is a country characterized by subsistence agriculture and occurence of nutritional deficiencies. For example, across the country 37% of the total population consumes fewer calories than the minimum requirement, and 64% of the population is deficient in protein intake (World Bank, 1989). However, in some regions, caloric deficiencies are found in 82% of the population, and protein deficiencies are found in 85% of the population.

Surveys conducted in Rwanda showed that many small-scale fish farmers consider fish to be a cash crop. Findings by Engle et al. (1993) indicate that fish farming provides cash to a family in addition to supplementing the diet of Rwandan farmers. Molnar et al. (1991) and Engle et al. (1993) showed that fish production represents the main cash crop for over 50% of group members and private pond holders. Previous studies used partial farm analyses and economic engineering techniques to assess costs and return of fish production (Moehl, 1993; Engle et al., 1993).

Budget analysis is an important step in economics research, but it is a static analysis that does not take into account the following:

- factors such as fluctuations in prices, yields, and costs;
- farming system interactions in terms of labor, marketing, and resource constraints;
- social, economic, or welfare effects of the technology; and
- market factors.

A farmer's decision to adopt a new technology will depend upon these variables.

In many developing nations, the lack of comprehensive and appropriate data preclude whole-farm analysis that explicitly accounts for the types of factors involved. This study uses survey data from subsistence fish farmers in Rwanda to formulate a whole-farm model. This model will be used to analyze decision-making and resource allocation to meet the dual objectives of maximizing profit, while still satisfying the household's demand for food. The specific objective of this study was to determine farm plans that maximize returns to a representative Rwandan farm family's resources, subject to constraints of the farm family's proteinic and caloric requirements.

Materials and Methods

Model

A mathematical programming model was developed to determine optimal resource allocation on subsistence farms in Rwanda. The general form of the model was: maximize P = C _ X, subject to AX _ B, and x _ 0; where P is the objective function, C _ is a (1 x n) vector of coefficients associated with each activity, X is a (1 x n) vector of activities, A is an (m x n) matrix of technical coefficients, and B is an (m x 1) vector of constraints.

The primary objective of the model was to maximize net returns above variable cost while satisfying basic household nutritional needs. Production, sales, home consumption, and purchasing activities were included in the model. Thirteen different crops raised in the marais (valley bottomland in Rwanda where fish are raised) were modeled, including fish, sweet potatoes, Irish potatoes, cassava, taro, sorghum, maize, sweet peas, beans, soybeans, peanuts, rice, and cabbage. Data on crop yields, costs, and labor were obtained from Hishamunda (1993).

The principal factors that limited generation of cash income were land holdings, labor, and capital. Household nutritional requirements were modeled as requirements for the family to consume a minimum level of kilocalories of energy and grams of protein. Single balance rows were used for both energy and protein. Most crops are consumed fresh in Rwanda. Since there is little storage (other than for dried beans), storage activities were not included.

Separate models were developed for individually- and cooperatively-managed farms. Other scenarios included in the model were: 1) all enterprises with both protein and energy constraints; 2) all enterprises with protein constraints alone; 3) all enterprises with energy constraints alone; and 4) all enterprises without energy and protein constraints. The General Algebraic Modelling System (Brooke et al., 1992) was used to obtain solutions to the linear programming model. The quantities of fresh produce that could be sold from the farm at any given harvest were incorporated into the model as an additional marketing constraint because wholesale storage facilities are not available for fresh produce in Rwanda.

The risk programming model was based on Target MOTAD methodology (Hazell, 1971; Tauer, 1983; Watts et al., 1984). Risk variables included in the model were yield risk, price risk, and marketing risk. Decreasing levels of willingness to incur risk (or increasing levels of risk aversion) were incorporated into the model to provide insight into which management strategies are "best" for individuals who prefer lower levels of risk despite the fact that lower levels of risk generally result in lower levels of profit. See Tauer (1983) for details on modelling risk in economic analysis and methodologies to account for individual preferences regarding willingness to assume higher or lower levels of risk in farm management decision-making.

The model was validated following steps outlined in Hazell and Norton (1986). The validation process included comparisons of model results with existing data from the Rwandan Ministry of Agriculture and Forestry (Ministère de l'Agriculture, de l'Elevage et des Forêts, 1989) and the International Service for National Agriculture Research (ISNAR, 1992). Qualitative reviews by expatriates with long-term experience in extension activities with fish farmers in Rwanda were also incorporated into the validation process. As a result of the validation process, improvements were made to the model prior to developing the analyses presented in this paper.

Data

Data used in the analysis were taken from a cost of production survey of Rwandan fish farmers conducted in 1991 (Hishamunda et al., in press). A total of 267 completed questionnaires covering 10 of 11 prefectures in the country provided data to describe in detail sociodemographic, land, and labor allocation, along with relative cost characteristics of fish farmers' production systems.

All enterprises produced by cooperatives, with the exception of Irish potatoes, showed positive income above variable costs and positive net returns to land, labor, and management; however, fish farming yielded the highest income above variable costs (Table 1). Revenues generated from fish production included sale of both marketable-sized fish and fingerlings. If the sale of fingerlings was removed from revenue, fish production was the fourth most

Table 1. Estimated cost and returns for marais agricultural enterprises, Rwanda, 1995. Coop.: Cooperative respondent; Ind.: Individual respondent; $1 U.S. = 145 Rwandan Francs (RWF). Data regarding income above variable cost is from Hishamunda (1993).

Crop	Gross Receipts		Variable Cost		Income above Variable Cost[1]	
	Coop. (RWF)	Ind. (RWF)	Coop. (RWF)	Ind. (RWF)	Coop. (RWF)	Ind. (RWF)
Fish[2]	3,076	3,408	279	337	2,797	3,071
Sweet Potato	1,294	1,471	520	388	774	1,083
Irish Potato	1,275	2,103	1,607	1,789	-332	313
Cassava	1,080	1,160	365	955	715	205
Taro	855	960	288	403	567	557
Sorghum	810	540	325	154	485	386
Maize	1,175	925	407	424	768	501
Sweet Pea	-	400	-	302	-	98
Beans	1,360	920	393	414	967	506
Soybean	1,193	864	674	412	518	452
Peanuts	-	1,968	-	148	-	1,820
Rice	-	1,325	-	366	-	959
Cabbage	2,380	3,120	429	551	1,951	2,569

[1] Values for income above variable cost were taken from Hishamunda (1993).
[2] An additional 2.8 kg/ha and 3 kg/ha of fingerlings were produced in cooperatively- and individually-managed farms, respectively.

profitable enterprise following cabbage, peanuts, and sweet potatoes.

Labor values from survey data were used. Survey data included hours of labor per week for males, females, and children of different ages who participated in farm activities such as feeding, harvesting, and weeding. Mean values were used in the initial formulation, and minimum and maximum values were used to set bounds on sensitivity analyses. Household size averaged two adult members and one child for individually-managed farms, and cooperatives averaged 13 families with a range from 2 to 54 families participating in a fish cooperative.

Soybeans produced the most protein/hectare for both individually- and cooperatively-managed farms followed by beans (Table 2). Sweet potatoes produced the greatest amount of energy on individually-managed farms, and maize produced the highest amount of energy on cooperatively-managed farms.

Farm prices of some products varied considerably throughout the year, but the price of fish did not vary. To assess the effect of price seasonality, a data set that provided mean prices for various crops by month from 1986 to 1992 was obtained from the Service des Enquêtes et des Statistiques Agricoles (Clay, 1993). Marketing options that included different prices in different months were incorporated to account for seasonal price effects. Price data by "prefecture" for the period were used to examine differences among regions.

Results and Discussion

Individually-Managed Ponds

Basic Solution to Meet Household Nutritional Requirements

Table 3 presents the linear programming results. When all enterprise options identified on Rwandan fish farms were included in the model, along with the protein and energy levels recommended for an adequate diet, there was no feasible solution to address household nutritional requirements. The average land holding of 0.04 ha for individual farmers was too low to meet the minimum nutritional needs of a family, much less generate

Table 2. Crop yield and nutritional production for marais agricultural enterprises, Rwanda, 1995. Coop.: Cooperative respondent; Ind.: Independent respondent; $1 U.S. = 145 Rwandan francs.

Crop	Yield		Energy		Protein	
	Coop. (kg/ha)	Ind. (kg/ha)	Coop. (kg/ha)	Ind. (kg/ha)	Coop. (kg/ha)	Ind. (kg/ha)
Fish[1]	1,300	1,370	1,235	1,302	232	247
Sweet Potato	12,940	14,710	13,975	15,887	246	280
Irish Potato	8,500	14,020	4,879	8,048	102	168
Cassava	5,400	5,800	5,524	5,933	27	29
Taro	5,700	6,400	4,497	5,050	80	90
Sorghum	2,700	1,800	8,200	5,467	192	128
Maize	4,700	3,700	15,158	11,932	400	314
Sweet Pea	-	500	-	1,560	-	102
Beans	3,400	2,300	10,305	6,972	666	451
Soybean	2,650	1,920	9,726	7,046	824	597
Peanuts	-	1,640	-	4,559	-	192
Rice	-	5,300	-	10,971	-	212
Cabbage	11,900	15,600	2,737	3,588	178	234

[1] An additional 2.8 kg/ha and 3 kg/ha of fingerlings were produced in cooperatively- and individually-managed farms, respectively.

income. The land allocation issue will need to be addressed on a political level to allow for development of economically viable production alternatives that meet household nutritional needs.

This result was not unexpected. In some regions, caloric and proteinic deficiencies in the daily diet may occur in as much as 82% and 85% of the population, respectively (World Bank, 1989). The results of this analysis support estimates of the extent of malnutrition in Rwanda which is linked to a combination of the small land holdings and the low crop yields on subsistence holdings.

The survey data indicated that average total land holdings were 0.04 ha with a range from 0.01 to 0.16 ha. At a land allocation of 0.11 ha, without an energy constraint, the protein requirement could be met by producing 0.10 ha of soybeans. An additional 0.01 ha would be used to produce cabbage for sale to generate income. Without a protein constraint, all 0.11 ha would be used for sweet potato production, even though 0.11 ha would not produce the energy required for a family. With both protein and energy constraints included, 0.04 ha were allocated to sweet potato production and 0.07 ha to soybean production; however, nutritional requirements were not met under this production regime. Without any nutritional constraints, the 0.11 ha were allocated to cabbage production for a net farm income of Rwandan francs 28,259 (RWF) (1 U.S. $ = RWF 145). All 0.11 ha scenarios that included nutritional requirements, generated negative net farm income.

Approximately 0.20 ha of land were required in order to completely meet all nutritional requirements. Net farm income was RWF 5,198. Increased land holdings from 0.20 to 0.50 ha increased net farm income from RWF 5,198 to RWF 76,622. As land area was increased to 0.50 ha, both cabbage and peanuts were raised as cash crops.

Risk Analysis

At low levels of willingness to incur risk, the optimal product mix involved the selection of crops with low variability in yield, and those cash crop options with low coefficients of market risk. These crops were soybeans and sweet potatoes to meet household nutritional requirements and fish as the main cash crop. Even without fingerling sales, fish were selected over cabbage as the optimal cash crop. Fish have a lower variation in market price and fewer constraints compared with cabbage. At higher levels of willingness to incur risk, cabbage was selected as the optimal cash crop if fingerlings could not be sold.

Table 3. Basic results of linear programming analysis of optimal resource allocation on individually-owned subsistence farms, where all nutritional requirements are met by 0.20 and 0.50 ha of land, Rwanda, 1995.

Scenarios	Crop	Land (ha)	Crop Use	Net Income (RWF)
WITHOUT FINGERLINGS				
0.11 ha	unfeasible			
0.20 ha	sweet potato	0.08	consumption	5,198
	soybeans	0.07	consumption	
	cabbage	0.04	sale	
0.50 ha	sweet potato	0.08	consumption	72,622
	soybeans	0.07	consumption	
	cabbage	0.13	sale	
	peanuts	0.22	sale	
WITH FINGERLINGS				
0.11 ha				
All Nutritional Requirements	sweet potato	0.04	consumption	-4,444
	soybeans	0.07	consumption	
Protein Requirements	fish - large	0.006	sale	-1,855
	fingerlings	0.001	sale	
	soybeans	0.102	consumption	
Energy Requirements	sweet potatoes	0.11	consumption	-4,268
No Requirements	fish - large	0.09	sale	33,780
	fingerlings	0.02	sale	
0.20 ha	fish - large	0.037	sale	7,427
	fingerlings	0.007	sale	
	sweet potato	0.08	consumption	
	soybeans	0.07	consumption	
0.50 ha	fish - large	0.009	sale	73,648
	fingerlings	0.002	sale	
	sweet potatoes	0.082	consumption	
	peanuts	0.123	sale	
	cabbage	0.210	sale	

Cooperatively-Managed Ponds

Basic Solution to Meet Nutritional Requirements

Table 4 presents results of the models of cooperatively-managed ponds both with and without fingerling sales. Results followed trends similar to those of individually-managed ponds.

The average land holding of cooperatively-managed ponds was 0.51 ha with an average number of 13 cooperative members. This area was too small to produce enough nutrition for an average-sized cooperative whose membership consisted of families of average size. To fully meet nutritional requirements, land holdings of 2.00 ha would be required. Land holdings of cooperatives ranged from 0.01 ha to 6.03 ha, and the number of members ranged from 2 to 54.

Under a scenario which excluded fingerling production, limited available land area to 0.51 ha, and required meeting of all nutritional needs, the model selected the production of 0.21 ha maize and 0.30 ha soybean for home consumption. Considering only the need to meet protein requirements, all 0.51 ha were placed into soybean production for home consumption. When only energy requirements were considered, the model selected 0.51 ha of maize production. None of the model results for scenarios requiring the meeting of nutritional needs were profitable. Without factoring in any

Table 4. Results of linear programming analysis of cooperatively-managed subsistence farms in Rwanda, 1994 (1 U.S. $ = RWF 145).

Option	Crops	Land (ha)	Crop Use	Income (RWF)
WITHOUT FINGERLINGS				
0.51 ha				
All Nutritional Requirements	maize	0.21	consumption	-28,641
	soybeans	0.30	consumption	
Protein Requirements	unfeasible			
Energy Requirements	unfeasible			
No Nutritional Requirements	cabbage	0.51	sale	99,501
2.00 ha				
All Nutritional Requirements	maize	1.28	consumption	-10,349
	cabbage	0.30	sale	
2.50 ha				
All Nutritional Requirements	maize	1.38	consumption	8,670
	soybeans	0.30	consumption	
	cabbage	0.43	sale	
WITH FINGERLINGS				
0.51 ha	soybeans	0.21	consumption	-28,641
All Nutritional Requirements	unfeasible			
Protein Requirements	unfeasible			
Energy Requirements	unfeasible			
No Nutritional Requirements	fish - large	0.41	sale	142,600
	fingerlings	0.10	sale	
2.00 ha	fish - large	0.26	sale	12,321
All Nutritional Requirements	fingerlings	0.06	sale	
	soybeans	0.30	consumption	
	maize	1.38	consumption	

nutritional constraints, the model selected cabbage as the profit-maximizing crop and without fingerlings. Cabbage marketed without fingerlings generated a net income of RWF 99,501.

When land holdings were increased to 2.00 ha, additional land areas were allocated to cabbage production to generate income as family nutritional requirements had been met. Net farm income was still negative at 2.00 ha, but became positive at holdings of 2.50 ha and above. The maximum land holdings of cooperatively-managed ponds was 6.01 ha. It is clear that there are some cooperatives with adequate land to meet the nutritional requirements of member families and still generate cash income.

Risk Analysis

At low levels of willingness to incur risk, the optimal product mix continued to be soybeans and maize to meet household nutritional requirements, and fish production served as the primary cash crop. For individually-managed farms, as levels of willingness to incur risk increased, cabbage was selected as the profit-maximizing cash crop if there was no market for fingerlings.

Discussion

The original model specified that household nutritional requirements need to be satisfied with the mix of farm products produced. Given this specification, when risk factors were introduced into the model, there was little change in the optimal product mix. When the nutritional specifications were dropped from the model, risk factors then dictated more stable, albeit lower yielding, subsistence crops already under production by most Rwandan farmers. Thus, the need to provide for household food security dictates the use of the commonly-raised subsistence crops as the risk management strategy of choice for Rwandan farmers. Explicit estimation of risk parameters in the model generated results that were equivalent to model results which specified the achievement of household nutritional requirements. Both approaches demonstrated the rationality of subsistence farmers' selection of crops with stable, although lower, yields to maximize food security.

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