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Economics of erosion-control and seed-fertilizer technologies for hillside farming in Honduras

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Abstract

With population growth still at very high rates and large-scale commercial farmers and cattle ranchers owning much of the more fertile valley land, small-scale farmers are concentrated on increasingly marginal, steeply sloping hillsides in Central America. The continuing soil erosion and land degradation in these low-input staple crop production hillside farming systems lead many to be pessimistic about increasing the agricultural incomes of these farmers. However, this study shows that the appropriate combination of improved technologies and agricultural policy or alternative production diversification strategies can improve the incomes of small-scale hillside farmers in southern Honduras by over 50%. The technology components considered are stone walls and ditches combined with living tree barriers to prevent erosion of the hillsides, and a package of improved sorghum seed, seed treatment, and modest doses of nitrogenous fertilizer. A whole-farm mathematical programming framework is used to determine the potential farm-level income effects of the soil-conservation and seed-fertilizer technologies. The main conclusion is that erosion-control devices and yield-increasing crop varieties and fertilizer are an effective technology introduction strategy for the erosion-prone hillside landholdings found in many areas of Central America. If policy actions or diversification strategies for disposal of surplus grain are found which are effective in reducing the risk of low income from cereal price reductions in high-production years, adoption of the improved technologies is shown to be profitable for small-scale farmers. Another benefit not explicitly considered would be to slow the very rapid growth of urban poverty in these countries. Sensitivity analysis results indicated that neither risk aversion nor the increased availability of crop land or initial cash have any substantial effects on the predicted adoption level of the improved technologies, or on their income impacts for these farmers.

Throughout Central America, small-scale farmers producing subsistence crops and especially maize and sorghum have occupied the steeply sloping hillsides more appropriate for forest uses. Cattle ranching and industrial crops such as bananas, fruits and vegetables, and sugar cane have taken over the flat land of the valleys. The growing population has reduced the amount of land available for agriculture. Because hillside landholdings must be shared by more people every year, they have become increasingly frag-

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mented (Cook, 1988). Hillside farming in Central America is especially intensive along the Pacific coast, which covers the southern regions of Guatemala, El Salvador, and Honduras, and northwest Nicaragua. Farming in these regions is dominated by maize and bean monocrops and maize/sorghum and maize/beans relay cropping systems (where maize is planted first as soon as the rains start and sorghum and/or beans are planted a few weeks later), with minimal levels of purchased inputs, intensive use of family labor, and slash-and-burn cultivation practices. The cleared land is shallow and low in natural nutrients, resulting in rapidly declining yields after only a few crop seasons (Hawkins, 1984). Fallow periods are being steadily reduced due to the increasing difficulty of finding new land to clear (Thompson, 1992). This has resulted in decreasing levels of staple food production for many hillside farmers. As agriculture becomes less and less viable for family subsistence, migration rates to the cities have increased, with the resulting problems of rapid urbanization.

While the origins of hillside cultivation can be traced to the land tenure systems, it is very difficult to achieve any improvement in their situation given the land tenure legislation and the present distribution of political power. An alternative is to develop and disseminate new technologies which attenuate the negative effect of hillside farming on the natural environment, and which could allow farmers to use hillside land more intensively, maintain yields over time, and reduce the need to periodically abandon their fields in search of new land. This approach has the advantage of achieving the combined goals of improving farm incomes and the sustainability of these hillside farming systems. The governments of the Central American countries have chosen this technology development alternative as their approach to developing sustainable agricultural production systems (see Kaimowitz, 1992). In Honduras, a large project was initiated in 1982 aimed at developing technologies to solve one of the main problems of hillside farming in the southern region, erosion of the topsoil. In addition, improved varieties of the main crops grown by these farmers, especially sorghum, were developed to substitute for the low yielding traditional varieties. If these technologies prove to be profitable and environmentally sustainable, then they could generate substantial benefits from increased food production and the implementation of more intensive and sustainable hillside farming systems.

In this study, we estimate the effects of two types of improved technologies, erosion-control devices and new sorghum varieties combined with fertilizer, on the welfare of small-scale hillside farmers in southern Honduras, with special focus on the effects on both food production and income. An analysis of the sensitivity of the key results to risk aversion, policy changes, and factor availabilities, is also presented. While these issues are relevant in all regions where hillside agriculture is practiced, the economic evaluation is focused on Honduras. The methodology used in this analysis emphasizes the sequential nature of the farmers' decisions under risk and, with appropriate technical coefficients, can be applied in different regions to estimate the potential of resource-conservation and/or seed-fertilizer technologies in hillside agriculture. A brief description of the hillside farmers of southern Honduras, based on the results of an extensive survey in the region, is presented in the next section; then a discussion of the two types of technologies to be analyzed is provided. Subsequent sections deal with the procedures and data employed, discussion of results, and the conclusions and implications of the results.

1. Small-scale hillside farmers in southern Honduras

Hillside agriculture in Central America, and especially in southern Honduras, is labor-intensive and risky due to wide fluctuations in yields and prices. Rainfall in the region, lasting from late April through early December, is highly variable with a bi-modal seasonal distribution, allowing two crop seasons per year. Landholdings are located on steep hillsides, and farmers have little access to markets for inputs and outputs or to credit for agricultural production. Maize is the main staple food in Honduras, especially in rural areas. Sorghum is used as an animal feed and is also an important substitute for maize as human food in rural areas, especially in the south. Since it is more tolerant to drought than maize, sorghum enables farmers in regions with erratic rainfall to diversify their crops, thus increasing the likelihood of at least some minimum quantity of grain production even in low rainfall years. By producing both maize and sorghum, small-scale farmers ensure an adequate *tortilla* supply.

Farm interviews in southern Honduras in 1988/89 and follow-up visits in 1990 are the main data sources for this analysis. One hundred nineteen farmers were interviewed and 67 were classified as small-scale farmers, having access to less than 5 ha. Based on this classification and the total number of farms, there would be about 17000 small-scale farms (56%) in the south (López-Pereira, 1990). Survey results indicate that total annual income for an average small-scale farm family of seven in southern Honduras is $792 (1990 U.S. dollars), including sales and the value of home consumption of cereals (39%), off-farm labor (37%), and sales of farm animals (15%). These farmers often have to sell their cereals at harvest time when prices are lowest to pay off production loans, and buy grain later at higher prices; 29% of their cash expenses are for cereal purchases. Although minimum cereal prices were officially maintained in Honduras at the time this study was done, small-scale farmers were rarely able to take advantage of them (López-Pereira and Sanders, 1992). For example, between 1978 and 1984, government purchases averaged only 2.8% of total cereal grain production (MNR, 1986), and most of these were purchases from large-scale farmers and intermediaries (truckers) in central locations. Small-scale farmers do not have the means to take their harvest to these central locations and sell it directly at official prices; having to sell at much lower prices to the intermediaries, thus they do not directly benefit from official guaranteed prices.

Most of the small farms are located on the hillsides. One half had slopes of more than 50%, 5% had slopes between 15% and 50%, and 45% had slopes of less than 15% (see López-Pereira, 1990; Thompson, 1992). Thus, the main problem for these farmers is to prevent the farm from washing down into the valley during the heavy rainstorms typical of the region. This can be done with the construction of erosion-control and moisture-retention structures on the hillsides. Farmers in the sample were found to use improved crop varieties only when they have improved their soils with erosion-control devices. Of the farmers sampled, 43% had adopted a combination of erosion-control technologies and at least one new sorghum variety in 1989.

2. Technologies to be analyzed

Subsistence slash-and-burn crop production strategies of small-scale farmers in southern Honduras have provoked a constant search for new land to grow food crops. This situation prompted the Honduran government to establish programs to reverse this land deterioration and soil depletion process in this and other regions of the country. The Ministry of Natural Resources (MNR) and the U.S. Agency for International Development (USAID) have worked jointly over the last decade on projects to protect and control the use of watersheds in the south. The programs are aimed principally at reducing hillside soil degradation due to erosion and minimal use of fertilizers, and low food crop yields resulting from the use of traditional varieties and poor soil and crop management practices. A new phase of this collaboration started in 1990 with the Land Use and Productivity Enhancement Project (LUPE).

The soil conservation technologies (SCTs) used in these programs are stone walls combined with permanent leguminous trees, requiring mainly local materials, substantial amounts of labor, and small cash investments. Therefore, adoption of the SCTs by small-scale farmers depends mainly on the availability of materials for their construction and the farmers' opportunity cost of family labor. Since the erosion-control devices are built during the off-season, they compete with alternative off-farm employment opportunities for family labor, but not with the high seasonal labor demands of the crop season. To provide incentives for construction of the devices, government programs include a food-for-work (FFW) arrangement, under which farmers are paid in food for the time they spend building the structures on their farms. Once they are built, however, the devices require substantial labor for maintenance, about 30 man-days per hectare per crop season, which is not paid for with the FFW program.

Many benefits are obtained from building the SCTs on these farms. Some of these benefits accrue almost immediately after the devices are built, mainly in the form of increased and more stable crop yields. The SCTs are estimated here to provide a 20% yield gain during the first year, with a less than proportional increase in yield variability (Table 1). Even though these are modest yield gains for a very large labor input (see López-Pereira, 1990; Vonk, 1988), farmers can then make the transition to a permanent and more intensive farming system, with improved seed and fertilizers. Long-term benefits of the SCTs also accrue as the soil characteristics gradually improve (providing higher and more stable yields), and trees mature (providing firewood, forage, and organic fertilizer) after the first year of adoption (Thompson, 1992). When the expected benefits and costs to the farmer over the project life are taken into account, the SCTs provide an estimated internal rate of return (IRR) of 39% (López-Pereira, 1990). [1]

The combination of more intensive farming and the recuperation of less productive hillside land allowed by the SCTs, makes possible more food production per unit of land. In southern Honduras, 2400 ha had been put into these devices by 1990 (López-Pereira, 1990). The adopting farmers (52% of the sample) put an average of 0.4 ha into stone walls. Ditches (31%) and permanent leguminous tree barriers (25%) are also utilized on an average of 0.3 ha. However, the farmers perceive soil erosion to be less of a constraint than water availability and distribution (Thompson, 1992).

The other technology package to be analyzed is a combination of improved sorghum seed, seed treatment, and modest doses of fertilizer. Approximately 56% of the sorghum in Honduras is produced in the south, where farmers grow local varieties called *maicillos* on hillsides, usually as a relay crop after maize and sometimes as a monocrop. Improved sorghum varieties have been developed recently by MNR and the International Sorghum and Millet Collaborative Research Support Program (INTSORMIL). The most important of these varieties are the hybrid *Catracho* and the variety *Sureño*. These are high-yielding sorghums with good tortilla quality, and show good response to chemical fertilizers, especially under improved soil and moisture conditions. Both are short-season varieties and mature in approximately 100 days; hence, unlike the local *maicillos* they can fit into either the first or second season of the region's bi-modal rainfall regime. [2] Approximately 15% of the sorghum area was planted to these new cultivars in 1990. The combined technologies of the SCTs, new cultivars, and fertilization gave a social internal rate of return to the public research and extension investment of 20–40% (López-Pereira et al., 1992).

With the SCTs present, the new sorghums provide higher yields, with less than proportional

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[1] This farm-level IRR estimate for the SCTs includes all the benefits and costs per hectare of stone walls and tree barriers over a 10-year horizon (other than the labor costs for their construction since this labor is paid for with the FFW program. See discussion above for a description of the FFW program). Hence these are financial (as opposed to social) cost-benefit calculations. Income effects of the SCTs under the whole-farm model analyzed below include only labor cost for maintenance of the SCTs and the initial effects on crop yields and yield variability in the first year after they are built. Social gains from a more permanent agriculture resulting from adoption of the SCTs include the reduction of the hillside erosion and deforestation, and reduced migration to other agricultural or urban areas. A more thorough social accounting of the costs and benefits of itinerant versus permanent agricultural systems was beyond the scope of the analysis reported here.

[2] *Catracho* has been de-emphasized recently by the National Sorghum Program due to the difficulty in producing hybrid seed and the farmers' custom of producing their own seed. As an open pollinated variety, on-farm seed production of *Sureño* is easier.

Table 1
Average yields (kg/ha) and standard deviation (SD) of yields for traditional and new crops in southern Honduras, with and without SCTs in two crop seasons

Crops	First season		Second season	
	Yield	SD	Yield	SD
Without soil conservation technologies				
Monocrops				
Maize	585	176	615	166
Beans	163	46	171	43
Maicillo (traditional sorghum)	780	203	–	–
Relay crops				
Maize/*Maicillo* [a]				
Maize	423	110	–	–
Maicillo	–	–	553	155
New sorghum varieties:				
Sureño	1,025	420	1,076	398
Catracho	1,230	529	1,292	504
With soil conservation technologies				
Monocrops				
Maize	702	194	738	183
Beans	196	51	206	47
Maicillo	936	223	–	–
Relay crops				
Maize/*Maicillo*				
Maize	508	121	–	–
Maicillo	–	–	664	171
New sorghum varieties:				
Sureño	1,179	452	1,238	428
Catracho	1,415	569	1,486	542

[a] The maize/*maicillo* relay crop is planted in the FS. The maize is harvested at the end of the FS and the *maicillo* at the end of the SS. Sources: SIECA, 1984; Gómez et al. (1989); and socioeconomic survey of farmers in southern Honduras, 1989 and 1990.

Table 2
Labor and cash requirements for crops in the first and second-seasons, southern Honduras

	Labor requirements (man-days per ha)			Cash requirements ($/ha)
	Planting	Weeding	Total	
First-season crops				
Maize	8	25	70	16.50
Beans	11	24	54	25.00
Sureño	8	20	68	27.30
Maicillo	5	17	54	15.73
Catracho	10	26	77	29.40
Maize/*Maicillo*	8	23	69	18.59
Second-season crops				
Maize	8	25	70	16.50
Beans	11	24	54	25.00
Sureño	8	20	68	27.30
Catracho	10	26	77	29.40
Maicillo (from 1st season) [a]				
Monocrop	–	–	15	–
With maize relay crop	–	–	15	–

[a] *Maicillo* is planted in the first season either as a monocrop or as a relay crop after maize. It is harvested at the end of the second season. Source: Socioeconomic survey of farmers in southern Honduras, 1989 and 1990. See López-Pereira (1990) for details.

increases in yield variability (Table 1). Introduction of these new varieties, however, often implies a mono-culture system, a major shift from the traditional maize/*maicillo* relay cropping, practiced by most small-scale farmers. Another important aspect of adopting the new varieties is the cash investment required for seed and fertilizer purchases (Table 2; see also López-Pereira and Sanders, 1992). Cash-poor farmers would probably need to borrow to adopt them, increasing their financial risk. These risk aspects need to be included in the economic analysis of the new sorghum varieties. The introduction of improved seed and fertilizer technologies on hillside farms is only viable if the fields are improved first with erosion-control and moisture-retention devices; otherwise, the chemical inputs would primarily fertilize the valley rather than the field.

3. Procedures

Lambert and McCarl (1985) argue that the most appropriate procedure for farm-level risk analysis is to use direct expected-utility maximization (DEMP). The power utility function used in this study is widely considered appropriate for risk-averse decision makers, and has been used in farm models with stochastic variables and dynamic decisions (e.g., Turvey and Baker, 1990; Krause et al., 1990). This functional form has the appealing characteristic of constant relative risk aversion; implying that, as wealth increases, the decision maker will proportionately increase his/her investment in risky enterprises (in the absence of constraints). Discrete Stochastic Programming (DSP) is a modeling tool to analyze decision making under uncertainty through time (Rae, 1971a,b; Kaiser, 1986; Turvey and Baker, 1990). One important feature of DSP is that it allows for the modeling of stochastic resources and technical coefficients, whereas many other risk programming models allow for stochastic variables only in the objective function. Stochastic resources and technical coefficients are important in sequential and adaptive decision making. Survey results indicated that farmers in the region apparently adjust their cropping decisions depending upon the weather and other within-season phenomena, as has been observed in other regions (e.g., Hawkins, 1984; Shapiro et al., 1993). Hence, a sequential and adaptive modeling technique would be appropriate because it appears to be more consistent with observed farmer behavior.

Traditional crop yields in southern Honduras are highly variable due to weather conditions. One farmer adjustment mechanism in response to risk is to modify cropping decisions for the second season depending on yields and prices realized in the first season. Yields of the new sorghum varieties and other agricultural technologies are also highly variable, as are cereal grain prices. Small-scale farmers were found to be averse to risk, hence a utility function that reflects risk aversion is needed to represent their objectives. DSP allows for all these factors to be included in a whole-farm modeling framework and was used in this study. DSP models have a relatively short history of applications for evaluation of new agricultural technologies in developing countries. Recent studies have been done for Portugal (Serrao, 1988) and Niger (Adesina and Sanders, 1991; Krause et al., 1990; Shapiro et al., 1993).

DSP models require the specification of discrete and sequential states of nature, definition of activities and constraints in the model, and specification of the decision-maker's utility function or objective function (Kaiser, 1986). Depending on the number of stages and states of nature per stage, and the number of decision variables at each stage, DSP models can grow in size and complexity very quickly. This tendency of DSP models to grow exponentially as the number of stages and states of nature increase is known as 'the curse of dimensionality', and is considered their main drawback. Even with the availability of powerful computer hardware and software, large DSP models can become intractable and very costly to run. Thus the number of stages (decision points) and states of nature must be kept under control.

A DSP model for a small-scale farmer can be conceptualized as a set of decisions that the farmer has to make at the beginning of each crop season (stage) based on subjective expectations of future stochastic events and on resource constraints. The farmer decides on the types of crops and area planted to each, subject to constraints on borrowing, labor utilization, and input use in the current stage. Simultaneously, plans are made for future decision points. These decisions are similar to contingency plans since they depend on the future state of nature that occurs. Therefore a framework for analysis of the technologies in these environments should be one that includes sequential decision making under risk. The DSP methodology used in this study takes into account both the sequential nature of the decisions and risk, as well as, farmers' aversion to risk. Discrete states of nature were obtained using the method of Gaussian Quadrature (GQ). This methodology determines discrete points in random variable space (states of nature) and associated probabilities so that the lower order moments of the discrete approximation match the lower order moments of the true distribution, which is addressed further in the next section.

4. Farm-level DSP model

The DSP model developed for the farm-level evaluation of the erosion-control and seed-fertilizer technologies in southern Honduras was focused on decisions regarding crop mix, borrowing, land rental, off-farm labor supply, labor hiring, grain inventory management (consumption, sales, and purchases) and animal inventory management (sales and purchases) decisions. An important aspect of the structure of a DSP model is the organization of the 'stages'. Stages are described in terms of the time sequencing of decisions and random variable realizations. Constraints and activities in stages after the first are conditional on the outcomes of random variables and the activity level choices in previous stages.

The random events which are explicit in the model are the realizations of crop yields and prices at harvest times. Since there are two growing seasons per year in this part of Honduras, First Season (FS) and Second Season (SS), two sets of random variables are used representing yields and prices at the end of each season, respectively (i.e., the DSP model consisted of three stages, with decisions made for cropping and other activities in the first and second seasons and crop sales after harvesting). At the beginning of the FS, late April or early May, the decision variables are the crop mix (maize, beans, *maicillo, Sureño*, and *Catracho* monocrops and maize/*maicillo* relay crop), amount of land rented, amount of labor to be hired for planting and weeding, off-farm labor sold, grain and animal purchases and sales, and cash retained for future use. These decisions are subject to a number of constraints, which for the small-scale farm model were derived from survey results and are detailed below.

At the end of the FS, yields for maize monocrop, the maize part of the maize/*maicillo* relay crop, bean monocrop, and new sorghum varieties (*Sureño* and *Catracho*) in monocrop are realized, for a total of five yield random variables. The means and standard deviations of these yield variables are presented in Table 1, and their correlation matrix is displayed in Table 3. At the

Table 3
Correlation coefficients of yields for crops harvested at the end of the first season

Crop	Maize monocrop	Maize in relay [a]	Beans	*Sureño*	*Catracho*
Maize monocrop	1.00				
Maize in relay [a]	0.80	1.00			
Beans	0.65	0.40	1.00		
Sureño	0.59	0.49	0.45	1.00	
Catracho	0.62	0.43	0.49	0.80	1.00

[a] Maize in relay is the maize portion of the maize/*maicillo* relay crop. The *maicillo* part of the system is harvested at the end of the second season.

beginning of the SS (mid to late August) the farmer makes a number of decisions which are conditional on the yield and price outcomes which were realized at the end of the FS. These decisions include the mix of crops planted during the SS (maize, beans, *Sureño* and *Catracho* monocrops), amount of land to rent, amount of labor to hire during planting and weeding, amount of off-farm labor to be sold, grain and animal purchases and sales, and the level of borrowing. These decisions are made subject to a set of constraints which is similar to the set of FS constraints (also detailed below). At the end of the SS, yields are realized for the SS crops (maize, beans, *Sureño*, and *Catracho* monocrops) and FS *maicillo* crops which mature in the SS. The parameters of this distribution (which is assumed to be joint normal and independent of FS yields) are given in Tables 1 and 4.

To allow incorporation within the discrete stochastic programming framework, a discrete approximation to the joint distributions of the random yields and prices must be made. Because only average yields and the variances and covariances between yields within a season were available, it is assumed that yields are jointly normally distributed, and the method of Gaussian Quadrature (GQ) for joint normal random variables was used (see Preckel and DeVuyst, 1992). The virtue of this approach is that the discrete approximations to the distributions exactly match the means, variances and covariances, and third order moments (i.e., skewness and coskewness) of the original distributions. For the version of the model based only on traditional technologies, this approach resulted in eight states of nature for yields from the first season crops and 16 independent states of nature for yields from the second season crops, resulting in a total of 128 ($= 8 \times 16$) terminal states in the model. For the version of the model with new sorghum varieties available, this approach resulted in 32 states of nature for yields from the first season crops and 64 independent states of nature for yields from the second season crops, resulting in a total of 2048 ($= 32 \times 64$) terminal states.

Ideally crop prices would have been treated as additional random variables in the analysis. Unfortunately, inclusion of that additional set of random variables would have greatly expanded the number of terminal states of nature in the model, causing it to grow beyond current computer storage capacity. As a compromise, regression analysis was performed to determine whether prices were related to regional yields. This analysis determined that there was a significant negatively sloped relationship between regional yields and prices as was expected for this principal sorghum producing region of Honduras (see Table 5). These regression relationships were used in the model to determine prices by state of nature based on yields by state of nature.

As in the FS, and based on the results of the farm survey, limits were imposed on some activities and transactions during the SS in order to model more realistically the farmers' situation (see López-Pereira, 1990, for more details on the farm model). The objective of the farm planning model is the maximization of the expected utility of the distribution of ending wealth. A direct

Table 4
Correlation coefficients of yields for crops harvested at the end of the second season

Crop	Maize monocrop	Beans	*Maicillo* monocrop [a]	*Maicillo* in relay [a]	*Sureño*	*Catracho*
Maize monocrop	1.00					
Beans	0.68	1.00				
Maicillo monocrop [a]	0.59	0.45	1.00			
Maicillo in relay [a]	0.65	0.45	0.80	1.00		
Sureño	0.62	0.55	0.74	0.73	1.00	
Catracho	0.65	0.55	0.76	0.70	0.84	1.00

[a] *Maicillo* in relay is the *maicillo* portion of the maize/*maicillo* relay crop planted in the FS. The *maicillo* part of the system, as well as the *maicillo* monocrop planted in the FS, is harvested at the end of the SS.

Table 5
Least squares estimates of price-yield relationships used in the models with and without the new sorghum technologies [a]

Description	Intercept	Coefficient [b]
Models with no new sorghums [c]		
First Season		
Maize	0.4550	−0.0005214
Beans	1.0325	−0.0032670
Sorghum	0.3050	−0.0003505
Second Season		
Maize	0.3600	−0.0003824
Beans	0.9890	−0.0030054
Sorghum	0.2385	−0.0002774
Models with the new sorghums		
First Season		
Maize	0.4005	−0.0003640
Beans	0.9050	−0.0020658
Sorghum	0.2150	−0.0001017
Second Season		
Maize	0.3440	−0.0003038
Beans	0.9280	−0.0022000
Sorghum	0.1905	−0.0000892

[a] The equations were estimated by least squares using regional crop yield distributions and cereal prices. The fitted equations were: Price = $a + b$ (Yield), where price is in \$/kg and yield in kg/ha, a is the intercept and b the slope coefficient.

[b] All slope coefficient estimates were statistically significant at the 1% level.

[c] These yield-price relationships where used for the base farm model with no new technologies and also for the model with the SCTs only.

Sources: Socioeconomic survey of farmers in southern Honduras, 1989 and 1990; price survey of grain wholesalers in southern Honduras, 1990; and Tables 1–3.

expected-utility maximization of wealth objective (Lambert and McCarl, 1985) with a power utility function is used to determine optimal crop plans (see Appendix 1). Thus, if E[·] is the mathematical expectation operator, W is the random variable denoting ending wealth, and ρ is the coefficient of relative risk aversion, the objective function to be maximized is:

$$E[(1/(1-\rho)) * W^{(1-\rho)}]$$

A general matrix form of the model is presented in Appendix 1. The data used in the analysis were obtained from the farm survey mentioned above, supplemented with secondary regional data on yields and prices, and personal communication with extension agents and supervisors in the region (López-Pereira, 1990; see also Tables 1–4).

5. Farm resource base

Based on the results of the surveys, an average small-scale farmer situation is presented as the base case in the models. Initial household resource endowments and constraints are therefore based on these survey results. In the first season, land use for crops is constrained by the amount of crop land owned (the survey average of 1.7 ha) plus the amount rented. The total quantity of labor used for crops, sold off the farm, used for maintenance of the SCTs, and animal husbandry is constrained by total family plus hired labor. Family labor available during planting and weeding periods in the FS was 14 and 32 man-days, respectively, and total family labor available was 200 man-days.

Inventory constraints for grains ensure that all grain available either from initial stocks or through purchases is either used for animal feed or for human consumption, sold, or retained for future use. Initial stocks are modest with stocks of maize, beans and sorghum at 250, 45, and 250 kg, respectively. Inventory constraints for animals ensure that the initial stock of animals plus purchases less sales (net animal inventory) as adjusted for on-farm animal production during the season was equal to the number of animals retained. Initial stocks of chickens, pigs and cattle were 12, 2 and 2 head, respectively. In addition, the sources and uses of cash were constrained to be equal. The sources of cash during the FS (prior to the realization of any random events) are animal sales, grain sales, borrowing (at an interest rate of 4.5% per month), initial cash holdings (\$25), remittances from relatives (\$1.50 per month), and wages received from off-farm labor. The uses of cash during this period were for variable costs of crop production (including both hired labor and materials such as seed and fertilizer), purchases of animals and grain, grazing for cattle (other species were fed from grain stocks) at a price of \$2.50 per month, purchases

Table 6
Estimated income and risk of income effects of new sorghum and related technologies for hillside farmers in southern Honduras at four risk aversion levels [a]

Description	Relative risk aversion			
	0.0	0.5	1.5	5.0
Certainty equivalent of income ($)				
Traditional farm, no new technologies [b]	276.21	274.45	270.74	261.53
Farm with the SCTs only	314.60	311.73	306.08	296.84
Farm with SCTs and new sorghums	343.00	340.77	336.97	324.04
Change in CE from base case [b] (%)				
Farm with the SCTs only	13.90	13.58	13.05	13.50
Farm with SCTs and new sorghums	24.18	24.16	24.46	23.90

[a] All model runs included a minimum grain consumption constraint.
[b] Results from the model without new technologies are considered the base case.
Source: Modeling results.

of food other than grain at a cost of $22.50 per month, and saving for future use.

Available land for rent in the FS was limited to 1 ha at a rate of $7.50 per ha per season. Labor could be hired at two prices. Up to one man-day during planting and five man-days during weeding were available at a rate of $1.38 per man-day, and an additional two man-days during planting and ten man-days during weeding at $1.50 per man-day. Thus the supply of hired labor was somewhat price responsive. Up to 20 days of off-farm employment were available at a wage of $1.13 per man-day, and an additional 15 man-days at a wage of $1.00 per man-day. Borrowing was limited to no more than $113. Animal purchases were limited to no more than 10 chickens and 2 pigs (and no cattle), and animal sales were limited to no more than half of the initial stocks. Household consumption needs of maize, sorghum and beans for the FS was 226, 93 and 59 kg, respectively.

In the second season, the set of constraints is similar to that in the first season. Cropping area is again limited by land available plus land rented.[3] Labor use for planting and weeding is also limited by available family labor (14 man-days during planting, 32 man-days during weeding and 319 man-days total) and hired labor, and the total quantity of labor used for crops, sold off the farm, used for maintenance of soil conservation devices (30 man-days per ha per season), and animal husbandry is constrained by total family plus hired labor. As in the FS, material balances for maize, beans and sorghum enforce that the uses are equal to the sources in the SS. Animal inventory constraints by species require that the number of animals available at the end of the SS equal the number of animals retained from the FS, less sales, plus purchases, adjusted for on-farm net production (births). A cash balance constraint also equates sources and uses of cash within the SS. Constraints defining ending wealth are similar to the cash balance constraints. That is, they set ending wealth equal to the sources of cash less uses of cash. However, both the sources and uses of cash are somewhat simplified because the purpose is simply to value the farmer's assets at the end of the planning horizon rather than to determine their disposition.

6. Model scenarios

The model is solved for various levels of risk aversion and three technology scenarios: 1) the base traditional farm; 2) the base farm with the SCTs; and 3) the base farm with the SCTs and new sorghum seed-fertilizer technologies com-

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[3] Note that SS crop area includes crops planted at the beginning of the SS *and* any *maicillo* in monocrop or in maize/*maicillo* relay crop planted in the FS, since all the *maicillo* is planted at the beginning of the FS but harvested at the end of the SS.

bined. The SCTs are considered a fixed resource on the farm, and the model solutions determine how much area would be cropped and what crop mix is selected when the SCTs are in place. Therefore, model results indicate the changes in crop mixes and adoption of the new sorghum technologies when the SCTs are available. The levels of risk aversion used range from zero to five, to cover the range typically used in the literature (Binswanger, 1980), and represent risk neutrality (zero), mild risk aversion (0.5 and 1.5), and extreme risk aversion (5). It should be noted that all the models also included a minimum subsistence consumption constraint in all states of nature. Therefore, even with zero risk aversion the model had some risk avoidance characteris-

Table 7

Estimated crop area and grain production effects of new sorghum and related technologies for hillside farmers in southern Honduras at four risk aversion levels [a]

Description	Relative risk aversion			
	0.0	0.5	1.5	5.0
Crop area [b] (ha)				
Traditional farm, no new technologies				
FS: Maize	0.75	0.75	0.72	0.73
Beans	0.10	0.10	0.10	0.10
Maize/*maicillo*	1.31	1.31	1.31	1.27
Total FS crop area	**2.16**	**2.16**	**2.13**	**2.10**
SS: Maize	1.39	1.39	1.39	0.54
Beans	0.00	0.00	0.00	0.89
Total SS crop area	**1.39**	**1.39**	**1.39**	**1.43**
Farm with SCTs only				
FS: Beans	0.45	0.45	0.41	0.22
Maize/*maicillo*	1.16	1.16	1.18	1.33
Total FS crop area	**1.61**	**1.61**	**1.59**	**1.55**
SS: Maize	1.54	1.54	0.30	0.34
Beans	0.00	0.00	1.22	1.03
Total SS crop area	**1.54**	**1.54**	**1.52**	**1.37**
Farm with SCTs and new sorghums				
FS: Beans	0.37	0.26	0.26	0.17
Maize/*maicillo*	0.12	1.12	0.92	0.98
Catracho	0.08	0.17	0.36	0.38
Total FS crop area	**1.58**	**1.55**	**1.54**	**1.52**
SS: *Sureño*	0.00	0.00	0.87	1.49
Catracho	1.58	1.58	0.91	0.23
Total SS crop area	**1.58**	**1.58**	**1.78**	**1.72**
Total grain production (kg)				
Traditional farm, no new technologies [c]	2,590	2,590	2,571	2,168
Farm with the SCTs only	2,583	2,583	2,426	2,069
Farm with SCTs and new sorghums	3,852	3,951	4,064	3,897
Production change from base case [c] (%)				
Farm with the SCTs only	−0.27	−0.27	−5.64	−4.57
Farm with SCTs and new sorghums	48.73	52.55	58.07	79.75

[a] All model runs included a minimum grain consumption constraint.

[b] Crops with zero area at all risk levels are not listed (e.g., FS Sureño).

[c] Results from the model without new technologies are considered the base case.

Source: Modeling results.

tics in this minimum consumption constraint, and thus could not be considered a true risk neutral model.

Results of the base model without the SCTs and new sorghum technologies represent the current situation that hillside farmers face. Results of this model are therefore used to validate it against the average farmer situation found in the surveys. This validation process indicated that the model closely replicated the situation of small-scale hillside farmers in the region (see López-Pereira, 1990, for more details on model validation).

The programs to estimate the discrete approximations of the joint distributions of yields using GQ were developed using SAS software (SAS, 1985), and the different versions of the DSP model were developed and solved using GAMS/MINOS software (Brooke et al., 1988; Murtagh and Saunders, 1983). Model output included the optimal level of the crop combinations available, labor distribution, land use and land rental, borrowing, total grain production, terminal wealth for each combination of FS and SS states of nature, and the expected value of the utility of ending wealth. In addition, sensitivity analysis was performed in the model with the SCTs and new sorghum technologies to estimate the effect of changing initial values of key parameters, such as cash and crop land availability and cereal prices, on adoption of the new technologies.

7. Results and discussion

Although the SCTs are extremely labor-intensive and their effect on the certainty equivalent (CE)[4] of income is only a 13.5% increase for a risk-averse farmer (Table 6), they stabilize the agricultural system, making possible the transition from an itinerant agriculture into a more intensive one, and allowing for higher input use (such as improved seed and chemical fertilizer) with only small increases in production risk. Increases in income from adoption of the SCTs are not very sensitive to risk aversion, and range from 13.1% to 13.9%. Although the introduction of the SCTs means lower total grain production and smaller crop area than in the base case for all risk levels (Table 7), the value of this production is higher. This is because a greater bean area and smaller maize area are planted when the SCTs are in place, resulting in higher income (see Tables 6 and 7). Also, since beans are less labor-intensive than maize, they become more attractive to offset some of the extra labor required for maintenance of the SCTs.

When the SCTs are adopted, model results indicate that using improved varieties and purchased inputs such as fertilizers is optimal. Introduction of the new sorghums and fertilizer when the SCTs are in place results in a 24% increase in income under all risk aversion levels, compared to 13.5% with only the SCTs (Table 6). Whereas this effect on income is approximately constant across risk aversion levels, the range of available farm activities is widened by the new sorghums, and risk aversion does have a small effect on the optimal crop mix and grain production level (Table 7). The area under new sorghums is increased, and area under beans and maize/*maicillo* is reduced in the FS as risk aversion increases. Total new sorghum area remains stable at 100% of total crop area in the SS across risk aversion levels. The effect of introducing the new sorghums and the SCTs on grain production under risk neutrality is a 49% increase relative to the base case without new technologies, and an 80% increase for extreme risk aversion (Table 7).

Besides conserving the soil, the SCTs increase water retention, and thus reduce the risk of fertilization not being profitable, allowing for an increase in area with the input-intensive sorghum technologies. Interestingly, *Sureño* is not used in the FS under any risk aversion levels, nor in the SS at low risk levels. However, at higher risk aversion levels SS *Sureño* area increases, to the

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[4] In the remainder of the paper, the 'CE of income' is shortened and referred to as 'income'. In the model, income is uncertain, and a random variable with outcomes that vary by state of nature. The certainty equivalent of income is the amount of certain income that the decision maker would exchange for the probability distribution of income.

point where, under extreme risk aversion, it comprises 87% of total crop area. Thus, *Sureño* is a good risk-spreading alternative for the more risk-averse farmers. In summary, model results indicate that, once a sustainable production system is attained with the SCTs, farmers would introduce *Sureño* and/or *Catracho* with fertilizer on about 25% of the crop area in the FS and on all of the crop area in the SS, achieving a 50% increase in grain production and a 24% gain in income regardless of their risk preferences.

One principal problem with the introduction of the new technologies is the reduction of cereal grain prices resulting from high production in good rainfall years, especially in the period immediately after harvest. If the substantial risk of cereal grain price collapse could be reduced by, for example, making the prevailing policy of guaranteed minimum cereal grain prices effective for small-scale farmers, increases in income from the combination of SCTs, new sorghums, and fertilizer are substantially higher (Table 8). When price supports are assumed to be effective, the income for a strongly risk-averse farmer increases from $262 without new technologies to $371 with the SCTs (a 42% increase), to $401 with SCTs and new sorghums (a 53% increase). As well, total grain production would almost double in the latter case. The greater potential effect on farmer income and cereal production, and greater potential adoption of the new technologies resulting from eliminating the cereal price collapse in good rainfall years, indicates the importance of further policy initiatives in this area. As discussed above, hillside farmers in the region are net purchasers of cereal grains, usually selling at the time of lowest market prices and having to purchase grain back at high prices, as they are usually unable to access official guaranteed prices. Our results indicate that the combination of technologies (erosion-control + seed-fertilizer), supplemented with effective policy actions to reduce the risk of low income from price collapses, would substantially increase farmers' incomes, and would make pos-

Table 8
Potential effect of new sorghum and related technologies for hillside farmers in southern Honduras, with prevention of the price collapse[a] and two levels of risk aversion

Description	Traditional farm with		
	No new technologies	SCTs only	SCTs and new sorghums
No risk aversion ($\rho = 0$)			
Certainty Equivalent ($)	276	374	415
Percentage change from base case	–	36	50
Area under new sorghums (% of total crop area)	–	–	81
Total grain production (kg)	2,590	2,735	4,439
Percentage change from base case	–	6	71
Extreme risk aversion ($\rho = 5$)			
Certainty Equivalent ($)	262	371	401
Percentage change	–	42	53
Area under new sorghums (% of total crop area)	–	–	73
Total grain production (kg)	2,168	2,735	4,290
Percentage change	–	26	98

[a] The lowest values in the distribution of maize and sorghum prices in the model were increased from $ 0.04 and $ 0.02/kg to $ 0.10 and $ 0.07/kg, respectively, so everywhere there was a lower value in the price distributions they were replaced with these minimums. These were the prevailing minimum prices offered by the official marketing agency in 1990.
Source: Modeling results.

sible permanent and profitable agricultural systems, in contrast with the itinerant subsistence hillside farming. [5]

Another factor hypothesized to limit the effect of the new technologies on the farmers' incomes and grain production, is the limited crop land available and little initial cash that they have to start the FS. Sensitivity analysis was performed on these two variables to estimate their effect on income, technology adoption, and grain production for a risk-averse farmer (relative risk aversion of 1.5) with the SCTs in place. The amount of crop land available was increased from 1.7 to 3.4 ha, and initial cash was increased from $25 to $50. The result of increasing initial cash is only a modest gain in income, from a 24% gain before the cash increase to 29% with the additional cash (Table 9). A doubling of available crop land increases income by 30% over the base case; whereas a combined doubling of land and initial cash results in a 35% gain in income. These are small income effects relative to those obtained without the increases in land and capital endowments for the risk-averse farmer. Increases in land and cash have only slight effects on total expected grain production.

Thus, the main result of increasing cash and crop land are reductions in the amounts of borrowing and land rented, respectively, and no substantial effects on income or total grain production. Note, however, that total area under new sorghums in the FS is reduced substantially when available crop land and cash are increased. Crop area under the new sorghums (as percent of total crop area) in the FS decreases from 23% before the land and cash increases, to only 3% when crop land and cash are doubled (Table 9). This is due to the greater flexibility that the farmer has with additional land, making the FS maize/*maicillo* relay crop more attractive, as this crop alternative increases from 0.92 ha to 1.36 ha when crop land is doubled. Also, total cropped area increases only slightly (by 0.25 ha in the SS) despite the doubling of available crop land, indicating that other factors, such as labor, become limiting. For example, the shadow price for labor increases from $1.68 to $1.89 per man-day when available land is doubled. This result, in which increased availability of crop land tends to reduce the incentive to use yield increasing technologies due mainly to other resources becoming constraining, is consistent with those obtained in other studies (e.g., Ramaswamy and Sanders, 1992).

8. Conclusions and implications

One of the most pressing needs of hillside farmers in southern Honduras is to improve soil, water, and crop management practices to prevent the soil from washing down into the valley, and to produce food crops in more sustainable farming systems. Building the erosion control structures has made it possible for these farmers to make the transition to intensive, sustainable agriculture from a difficult environment of itinerant agriculture. The erosion-control devices have been shown here to be moderately profitable for small-scale hillside farmers. Once the environment is stabilized, the profitability of the farm can be substantially increased with other new technologies, including improved crop varieties and fertilizer, as shown here for new sorghum varieties and moderate doses of chemical fertilizers.

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[5] When this study was conducted, the Honduran government had in place a system of guaranteed cereal prices, but agricultural policy changes since then make this an unlikely mechanism for cereal grain price stabilization, especially for small-scale farmers. Nevertheless, the results would be the same with other alternatives for reducing the price risk. One such strategy could be to make credit available for crop production under flexible terms to allow the farmers to hold their grain surplus for a few months and sell it at higher prices, and to build simple storage facilities with that purpose. Another alternative would be to diversify the farm operations further by, for example, increasing the production of small animals such as pigs and chickens using the surplus maize and sorghum as feed. Again, the net effect of any strategy allowing for a moderation of the price uncertainty would be similar to that presented in Table 8. A comprehensive welfare analysis of various price stabilization alternatives is beyond the scope of the analysis in this paper.

Table 9
Effect of changes in land and cash endowments on income and adoption of new sorghum technologies for a risk-averse farmer with the SCTs [a]

Description		Crop land (ha)			
		1.7	1.7	3.4	3.4
	Initial cash ($)	25	50	25	50
CE of income ($)		336.97	348.77	352.34	364.08
% change from base case [b]		24.46	28.82	30.14	34.48
Total crop land (ha)					
First season		1.54	1.54	1.53	1.53
Second Season		1.78	1.76	2.04	2.02
Area with new sorghums (% of total crop area)					
First season		23.2	22.1	4.2	2.8
Second season		100.0	100.0	100.0	100.0
Total		64.3	63.6	59.0	58.1
Grain production (kg)					
First season		1025	1011	802	783
Second season		3039	3043	3437	3443
Total		4064	4054	4239	4226
% change from base case [b]		58.1	57.7	64.9	64.4
Borrowing ($)					
First season		80.86	55.71	84.19	58.95
Second season		62.14	33.51	77.61	49.05
Rented land (ha)					
First season		0.00	0.00	0.00	0.00
Second season		1.00	1.00	0.00	0.00

[a] Results only for relative risk aversion of 1.5.

[b] The base case results are considered here those of the farm model with no new technologies, and a risk aversion factor of 1.5 (see Tables 6 and 7).

Source: Modeling results.

Results also indicate that the expected price reductions likely to occur from increased grain production in good rainfall years, is a major factor limiting the potential income effect from the combined adoption of the new technologies. The limitations imposed by the price collapse on the potential income effects, are more important than those imposed by the amount of crop land or cash that these farmers have to start the FS. Further initiatives to help the farmers cope with the price instability need to be investigated to accelerate the diffusion of the erosion-control and seed-fertilizer technologies.

This technology combination and institutional collaboration could serve as a model for small-scale farmer development programs in the rainfall erratic, hillside regions of Central America. [6] Finally, the analysis and results presented here relate only to the introduction of erosion-control and sorghum seed and fertilizer technologies, ig-

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[6] The attractiveness of the soil conservation devices is dependent on the value of the opportunity cost of labor for their construction. Subsidy programs used by the government to encourage their construction made this a very attractive investment in the 1980s. However, further research is needed to obtain estimates of the opportunity cost of labor during the off-season for the hillside farmers, in order to determine the economic costs and benefits of the SCTs to the society in the absence of subsidy programs. (See López-Pereira, 1990.)

noring the possible effects of new maize, bean, or other crop varieties that may also become economically attractive once the SCTs are in place. There could be more attractive returns to higher-valued crops in an improved farm with the SCTs, and the economics of these new alternatives should also be analyzed.

Appendix 1

Discrete stochastic programming model formulation

The subject of this model is a small-scale hillside farming household in southern Honduras. The time horizon for the model is a single year. Due to the rainfall pattern in this tropical climate, there are two growing seasons in a year. Thus, the year is divided into three parts or stages: first season planting (stage 0), first season harvest/second season planting (stage 1), and second season harvest (stage 2). During the first season planting (stage 0), the current resources available to the farm are known with certainty. After the first season harvest and before the second season planting (stage 1), the yields and prices for crops planted during the first season are realized.

Decisions regarding planting of second season crops are made conditional on the levels of yields and prices which were realized for the first season crops. At the end of the second season harvest (stage 2), the yields and prices for crops planted during the second season are realized. Thus, the level of income at the end of stage 2 (and also end of planning horizon) is conditional on the realization of yields and prices from both the first and second season harvests. There are 32 states of nature, or potential realizations, for first season crop yields and prices, and 64 states of nature (independent of first season yields) for second season crop yields and prices (see the section on the farm level DSP model for a discussion of the treatment of the grain price variables in the model). The farmer's objective is of the expected utility variety (Lambert and McCarl, 1985), and the particular utility function is the isoelastic power utility function. The mathematical formulation of the model follows:

$$\text{Maximize } \mathrm{E}\left[\mathrm{U}(W_{ij})\right] = \Sigma_i \Sigma_j \left[(1/(1-\rho)) * P_{ij} * W_{ij}^{(1-\rho)}\right] \tag{1}$$

subject to:

$$(A_0)(X_0) \leq B_0 \tag{2}$$

$$(A_{1i})(X_{1i}) \leq B_{1i} \tag{3}$$

$$(A_{2ij})(X_2)_{ij} \leq B_{2ij} \tag{4}$$

$$-(T_1)(X_{1i}) + (T_2)(X_{2ij}) \leq 0 \tag{5}$$

$$-(C_0)(X_0) - (C_{1i})(X_{1i}) - (C_{2ij})(X_{2ij}) + (W_{ij}) = 0 \tag{6}$$

$$(W_{ij}), (X_{2ij}), (X_{1i}) \geq 0 \tag{7}$$

where

A_0 $= (n_0 \times m_0)$ matrix of resource requirements in stage 0 (zero) prior to the realization of any random events.

X_0 $= (m_0 \times 1)$ vector of decision variables in stage 0.

B_0 $= (n_0 \times 1)$ vector of resource endowments in stage 0.

A_{1i} $= (n_1 \times m_1)$ matrix of stochastic resource requirements under state of nature i in stage 1 ($i = 1, 2, \ldots, 32$).

X_{1i} $= (m_1 \times 1)$ vector of decision activities in stage 1 under state of nature i.

B_{1i} $= (n_1 \times 1)$ vector of resource endowments for state of nature i in stage 1.

A_{2ij} $= (n_2 \times m_2)$ matrix of resource requirements for activities in stage 2, when state of nature i in stage 1 is followed by state of nature j in stage 2 ($j = 1, 2, \ldots, 64$).

X_{2ij} $= (m_2 \times 1)$ vector of decision activities in stage 2, when state of nature i in stage 1 is followed by state of nature j in stage 2.

B_{2ij} $= (n_2 \times 1)$ vector of resource endowments in stage 2, when state of nature i in stage 1 is followed by state of nature j in stage 2.

T_1, T_2 = matrices for preserving proper sequencing of activities and resource transfers between decision stages and states of nature.

C_0 = $(1 \times m_0)$ vector of net returns for activities performed in stage 0.

C_{1i} = $(1 \times m_1)$ vector of net returns for activities initiated in stage 1 under state of nature i.

C_{2ij} = $(1 \times m_2)$ vector of net returns for activities initiated in stage 2 under state of nature i in stage 1 and state of nature j in stage 2.

W_{ij} = wealth outcome from the combination of activities under state of nature i in stage 1 and state of nature j in stage 2 occurring.

P_{ij} = joint probability associated with state of nature i in stage 1 and state of nature j in stage 2, and where $\Sigma_i \Sigma_j P_{ij} = 1$.

ρ = relative risk aversion coefficient; when the coefficient is zero, the objective function collapses into the risk-neutral case.

Eq. (1) is the objective function to be maximized, the expected value of the utility of ending wealth. A power functional form for utility is used in this analysis.

Eq. (2) represents constraints for input-output relationships and resource endowments corresponding to activities performed in stage 0.

Eq. (3) represents constraints for input-output relationships and resource endowments corresponding to activities performed stage 1. It requires all activities to be feasible under each state of nature i in stage 1.

Eq. (4) represents constraints for input-output relationships and resource endowments corresponding to activities performed in stage 2. It requires all activities to be feasible under each combination of stage 1 state of nature i and stage 2 state of nature j.

Eq. (5) represents a series of transfer activities and resources from stage 1 to stage 2 and from stage 2 to the end of the planning period under the corresponding states of nature.

Eq. (6) represents a final transfer of the value of all resources from all activities under the different joint probability combinations to a summary wealth variable, which is used in the objective function.

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References

Adesina, A. and Sanders, J.H., 1991. Peasant farmer behavior and cereal technologies: stochastic programming analysis in Niger. Agric. Econ., 5: 21–38.

Binswanger, H.P., 1980. Attitudes toward risk: experimental measurement in rural India. Am. J. Agric. Econ., 62: 396–407.

Brooke, A., Kendrick, D. and Meeraus, A., 1988. GAMS: A User's Guide. Scientific Press, Redwood City, CA.

Cook, M.G., 1988. Soil conservation on steep lands in the tropics. In: W.C. Moldenhauer and N.W. Hudson (Editors) Conservation Farming on Steep Lands. Soil and Water Conservation Society, Ankeny, IA.

Gómez, F., Meckenstock, D., Oviedo, E. and López-Pereira, M.A., 1989. Transferencia de Tecnología de Sorgos: Lotes Demostrativos. SRN Reporte Técnico, 1.

Hawkins, R., 1984. Intercropping maize with sorghum in Central America: a cropping system case study. Agric. Syst., 15: 79–99.

Kaimowitz, D., 1992. La experiencia de Centro América y la República Dominicana con proyectos de inversión que buscan sostenibilidad en las laderas. Presented at the Seminar Agricultura Sostenible en America Latina, 9–10 September, BID-IICA, Washington DC.

Kaiser, H.M., 1986. An overview and empirical application of discrete stochastic sequential programming. Mimeo, Cornell University, Ithaca, NY.

Krause, M.A., Deuson, R.R., Baker, T.G., Preckel, P.V., Lowenberg DeBoer, J., Reddy, C. and Maliki K., 1990. Risk sharing versus low cost credit systems for international development. Am. J. Agric. Econ., 72: 911–922.

Lambert, D.K. and McCarl, B.A., 1985. Risk modeling using direct solutions of nonlinear approximations of the utility function. Am. J. Agric. Econ., 67: 846–852.

López-Pereira, M.A., 1990. Economics of sorghum and soil-erosion control technologies for small hillside farmers in southern Honduras. Ph.D. dissertation, Purdue University, West Lafayette, IN.

López-Pereira, M.A. and Sanders, J.H., 1992. Market factors, government policies and adoption of new technology by small Honduran farmers: a stochastic programming application. Q. J. Int. Agric. 31: 55–73.

López-Pereira, M.A., González-Rey, D. and Sanders, J.H., 1992. The impacts of new sorghum varieties and other associated technologies in Honduras. In: T. Schilling and D. Stoner (Editors) Proc. Int. Conf. Sorghum and Millet Collaborative Research Support Program, 8–12 July 1991, Corpus Christi, TX. INTSORMIL Publ. 92-1, Lincoln, NE.

MNR, 1986. Programa Nacional de Granos Básicos a Mediano Plazo: 1986–90. Ministry of Natural Resources, Tegucigalpa, Honduras.

Murtagh, B.A. and Saunders, M.A., 1983. MINOS 5.0 User's Guide. Technical Report SOL 83-20, Stanford University, Palo Alto, CA.

Preckel, P.V. and DeVuyst, E., 1992. Efficient handling of probability information for decision analysis under risk. Am. J. Agric. Econ., 74: 655–662.

Rae, A.N., 1971a. Stochastic programming, utility, and sequential decision making in farm management. Am. J. Agric. Econ., 53: 448–460.

Rae, A.N., 1971b. Empirical application and evaluation of discrete stochastic programming in farm management. Am. J. Agric. Econ., 53: 425–438.

Ramaswamy, S. and Sanders, J.H., 1992, Population pressure, land degradation and sustainable agricultural technologies in the Sahel. Agric. Syst., 40: 361–378.

SAS, 1985. SAS User's Guide: Statistics, Version 5 edition. SAS Institute Inc., Cary, NC.

SIECA, 1984. Elasticidades precio-ingreso de los principales productos alimenticios en Honduras. Secretaría Permanente del Tratado General de Integración Económica Centroamericana, Tegucigalpa, Honduras.

Serrao, A., 1988. Farm-level response to agricultural development strategies in the evora dryland region of Portugal. Ph.D. dissertation, Purdue University, West Lafayette, IN.

Shapiro, B.I., Sanders, J.H., Reddy, K.C. and Baker, T.G., 1993. Evaluating and adapting new technologies in a high-risk agricultural system – Niger. Agric. Syst., 42: 153–171.

Thompson, M., 1992. The effect of stone retention walls on soil productivity and crop performance on selected hillside farmers in southern Honduras. Tropsoils CRSP Report, Texas A&M University, College Station, TX.

Turvey, C. and Baker, T., 1990. A farm-level financial analysis of farmers' use of futures and options under alternative farm programs. Am. J. Agric. Econ., 72: 946–57.

Vonk, J., 1988. Soil and water conservation in Perú. In: W.C. Moldenhauer and N.W. Hudson (Editors) Conservation Farming on Steep Lands. Soil and Water Conservation Society, Ankeny, IA.