PN-ABL-545
77792

Risk Sharing versus Low-Cost Credit Systems for International Development

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Low-cost credit programs in developing countries have failed to achieve agricultural technology adoption goals. This research attributes the failure to the inability of poor farmers to bear the combined business and financial risks posed by adopting new technologies and develops proposals for the design of credit programs that reduce these risks. Agronomic and socioeconomic data are combined through simulation and mathematical programming to analyze problems of decision making under risk for developing countries. The results will assist in the design of new rural financial institutions conducive to the adoption of new production technologies by subsistence farmers.

Key words: credit, mathematical programming, Niger, risk sharing, simulation, technology adoption.

A goal of many international development efforts is to improve a developing country's agricultural production system. If successful, greater food security, improved nutritional standards, and increased incomes are achieved. One approach to increasing agricultural production is to disseminate new technologies (e.g., improved seed varieties, fertilizers, intercropping, and moisture retention tillage). A major impediment to this approach is a slow rate of adoption. Slow rates of adoption may be attributed to a high level of risk, poor infrastructure for the distribution of modern inputs, and insufficient capital. Risk and capital as constraints to technology adoption are addressed in this study.

A common approach to satisfy the capital needs of new technologies is to provide small farmers with low interest credit. Nearly all developing countries have a subsidized agricultural credit program (World Bank). However, these programs have typically not led to a significant increase in the adoption of technologies. Such programs have not adequately addressed the risk-bearing aspect of technology adoption; and, in fact, conventional credit programs compound the riskiness of technology adoption by adding financial risk. Several authors (Binswanger and Sillers, Bromley and Chavas) suggest that insufficient opportunities to spread risks to other parties limits farmers' use of credit and adoption of new technologies.

The purpose of this research is to determine the effects of several factors on the adoption of technologies recently developed by the National Agronomic Research Institute of Niger (INRAN). The factors studied are the interest rate on credit, the amount of farmer equity, credit repayment insurance based on weather, and risk sharing by suppliers of labor and fertilizer. Policy recommendations for the design and implementation of rural financial institutions are also developed.

This paper presents a unique approach to analyzing the problems of financing and risk bearing for new technologies in developing countries. The research demonstrates how simulation and mathematical programming can be com-

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This research was partially supported by the U.S. Agency for International Development, Science and Technology Bureau, Technology of Soil Moisture Management Project under USDA PASA No. BST-4021-P-AG-108D-00, and by the National Agronomic Research Institute of Niger (INRAN) and the Niger Applied Agricultural Research Project (USAID Contract No. 683-0256).

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1

bined to organize agronomic and socioeconomic data for analyzing problems of decision making under risk. Additionally, the results will assist in the design and implementation of new rural financial institutions in Niger that will be conducive to technology adoption.

Agricultural Technologies in South-Central Niger

Agriculture in south-central Niger is characterized by low and variable rainfall, poor soils, and a dependence on millet and sorghum for subsistence. Agriculture without irrigation is possible only during the rainy season which starts in May–July and usually ends in late September (Konate). Soils consisting of at least 90% sand predominate, and on these soils millet is the principal crop (Ouattara and Persaud). In 1984, 71% of 442 fields surveyed in two villages were planted to millet, sorghum, cowpea, and peanut intercropped (Swinton and Samba). Intercropping spreads labor requirements over longer periods, increases land-use efficiency, reduces the extent of insect damage to cowpea, and reduces the risk of a complete crop failure. Cowpea is the dominant intercrop in south-central Niger because of its drought tolerance and the relatively strong market in neighboring Nigeria.

Millet is generally planted immediately after the first rain of the year that exceeds 10 millimeters. Cowpea is usually interplanted in the millet two to six weeks thereafter. Under traditional practices, planting densities are very low. The first weeding of the season usually occurs at about the same time as cowpea planting. A second weeding follows approximately one month after the first.

The timeliness of planting and the first weeding of millet are extremely important in Niger because the rainy season usually lasts just 60–100 days, while the dominant millet varieties need an average of 90–100 days to mature (ICRISAT 1987). Delays in planting often cause the grain-fill period for millet to occur after the rains stop, thus substantially reducing yields (Pearson, Seetharama et al.). Late planting further reduces millet yields because the first rains quickly reduce nitrate levels in the root zone of millet seedlings through leaching and denitrification (Greenland). Cowpea fruit set and the duration of the reproductive period are reduced by the high temperatures and drought stresses that occur after the rains stop, also reducing yields (Wien and Summerfield). Furthermore, intercropped cowpea yields suffer from competition for sunlight if planted more than 15 days after millet (Wien and Summerfield, Reddy, ICRISAT 1986). These factors combine to make yields extremely variable and weather dependent.

Researchers at INRAN have investigated technologies to increase millet and cowpea intercrop yields. The most economically promising technology (T4) combines selected crop varieties, increased planting density, and nitrogen (N) and phosphorous (P) fertilizer applications (Ly et al., Issa et al., and Krause et al.). Selected varieties with traditional planting practices (T2) and selected varieties with increased planting density (T3) have also been compared to traditional varieties and planting practices (T1). The combination of increased planting density and N and P fertilizer applications appears to increase crop yields by increasing water use efficiency and overcoming soil-fertility constraints. The selected plant varieties have a slightly shorter-than-average time to maturity.

Neither fertilizer, increased density, nor selected varieties have been widely adopted by farmers in south-central Niger despite many years of extension service and agricultural project activities. In the villages of Maiguero and Rigial Oubandawaki only 12% of the farmers surveyed (on 4% of the cropland) used chemical fertilizer in 1984. This dropped to 2% of those surveyed (0.2% of the cropland) in 1985 (Krause et al.). Possible explanations for the nonadoption include: (*a*) the technologies may not be profitable; (*b*) they may be more risky than traditional technology, and farmers are risk-averse; (*c*) selected seed and fertilizer may not be available on a timely basis; (*d*) labor constraints may make it difficult to increase planting density and apply fertilizer without delaying the completion of these operations; (*e*) farmers may have insufficient cash and insufficient and/or expensive credit to pay for selected seed and fertilizer; and (*f*) extension may not be effective. Informal discussions with farmers in south-central Niger indicate that availability of both labor and cash are major constraints, with long-term profitability and riskiness also important.

Previous Analyses

Budget analysis of the four millet-cowpea intercrop technologies indicates that the technology combining selected crop varieties, increased planting density, and N and P fertilizer applications (T4) provided significantly higher

returns to labor and management per hectare in 1985 and 1986 than any of the other three technologies tested. These budgets were based on data collected in on-farm trials in Maiguero and Rigial Oubandawaki villages in south-central Niger. Analysis of the on-farm trials of 1987 indicates a lower return to labor and management per hectare for the T4 technology than for other treatments. However, the 1987 on-farm trials were carried out during the second-worst drought ever recorded in the region.

Labor requirements are much higher for treatments T3 and T4 than for treatments T1 and T2. As a result, net returns per day worked and returns to management (measured by gross revenues minus cash costs and a charge for labor) were often lower for treatments T3 and T4 than for treatments T1 and T2 (table 1).

A linear programming analysis based on 1986 on-farm trial data indicated that yield penalties for delays in completing planting and first weeding operations reduce the optimal land area for the T4 technology (Krause et al). The analysis also indicated that hiring laborers to increase the optimal land area for the T4 technology is profitable. However, the profitability of hired labor was sensitive to the rate of interest charged for variable cash expenses including labor.

The Farm Planning Model

New agricultural technologies for developing countries are typically designed either to improve average yields or to increase resistance to insects, diseases, or adverse weather conditions. Hence, a deterministic framework does not address all of the aspects of adoption. Rather, a stochastic analysis is needed.

Financial liquidity and defaulting on loans are especially important when expanded credit use accompanies technology adoption. Previous research indicates that small farmers primarily view credit as a form of insurance in times of distress where production risks are severe (Kamajou and

Table 1. Budget Analysis of Millet-Cowpea Intercrop Treatments, Based on Prices at Harvest, by Village and by Year, INRAN On-Farm Trials

	Treatment (FCFA/ha)			
Item	T1	T2	T3	T4
Maiguero, 1985:				
Return to labor and management[a]	30,904	33,796	35,892	58,536
Return per day of work[b]	1,398	1,516	1,132	1,106
Return to management[c]	17,644	20,416	16,872	22,196
Maiguero, 1986:				
Return to labor and management[a]	12,986	15,007	17,039	28,044
Return per day of work[b]	461	552	458	560
Return to management[c]	(3,922)	(1,313)	(5,305)	(1,992)
Rigial Oubandawaki, 1986:				
Return to labor and management[a]	14,212	15,688	18,482	27,296
Return per day of work[b]	492	521	462	522
Return to management[c]	(3,110)	(2,384)	(5,506)	(4,096)
Maiguero, 1987:[d]				
Return to labor and management[a]	8,199	8,711	9,850	10,977
Return per day of work[b]	443	461	401	364
Return to management[c]	(2,472)	(2,044)	(3,744)	(5,091)
Rigial Oubandawaki, 1987:[d]				
Return to labor and management[a]	7,694	13,586	8,750	12,031
Return per day of work[b]	362	603	314	370
Return to management[c]	(4,393)	1,277	(6,892)	(5,105)

[a] Gross revenue minus cash input costs.
[b] Measured in francs CFA per man-day equivalent.
[c] Gross revenue minus total variable input costs, including an opportunity cost of labor computed at 600 FCFA per man-day equivalent.
[d] N fertilizer was not applied to T4 in 1987.

Baker, Binswanger and Rosenzweig). In order to avoid the loss of future access to credit, they are reluctant to default on a loan, especially in the semi-arid tropics where collateral is limited (Binswanger and McIntire, Binswanger and Sillers) and the transaction cost of establishing access to credit is high (Adams and Nehman, Feder and O'Mara).

Discrete stochastic programming, or DSP (Cocks and Rae 1971a,b), was used to obtain a simultaneous focus on technology adoption and credit. The DSP model in this study incorporates choices of crop mix (of both traditional varieties and new varieties), production practices (including the use of fertilizers, higher planting densities, and intercropping), and the level of credit from traditional and government sources. Yields and prices are treated as correlated random variables, and the time horizon is two years.

A biological simulation model of intercropped millet and cowpea production is used to estimate the yields for the twenty-one years for which both price and rainfall data are available. The estimated yields and actual prices for the twenty-one years represent different states of nature in the discrete stochastic model. Two years of production, consumption, and cash flow are included in the model in order to consider the dynamic effects of crop yield and revenue outcomes in one year on decision making in the following year. The farm planning model maximizes expected utility, which is a function of the wealth generated by each state of nature, the probability of each state of nature and a risk aversion coefficient.

The Annual Submodel

Production is modeled via activity analysis.[1] Activities are included for raising crops under five systems of cultivation: traditional methods for intercropping cowpea and millet (T1); intercropped cowpea and millet with selected seed varieties (T2); intercropped cowpea and millet with selected seed and higher planting densities (T3); intercropped cowpea and millet with selected seed, higher planting densities, and fertilizer applications (T4); and monocrop millet. To reflect the importance of timing for planting and first weeding on crop yields, twenty-eight alternative cropping schedules for each intercrop system and fourteen alternative schedules for monocrop millet are considered.[2]

Activities are also included for hiring labor, millet consumption, sales of millet and cowpea, purchase of millet (for consumption), and borrowing. Borrowing is available from two sources. family members (loans of millet which must be repaid in kind with an interest rate of 10% per cropping season) and government borrowing (addressed at length below).[3]

Constraints are included on total land area, labor by period, and minimum consumption. Millet, cowpea, and monetary capital inventory balance constraints are also included. The annual submodel is divided into a rainy season followed by a dry season. Inventory balance and consumption constraints are replicated for each season. Rainy-season inventory balances are linked to dry-season inventory balances by transfer activities. The rainy season is further disaggregated into twelve alternately wet and dry periods because rains are intermittent and some activities, such as planting and urea fertilizer application, are generally successful only during the brief periods immediately following each rain. Labor constraints are specified for each of these twelve periods.

The availability of land and labor does not change in the two-year planning horizon. The farm has 4.14 hectares of homogenous, arable land available for cultivation, which is the average observed in a 1984 survey of twenty-five farms in Maiguero village (Swinton). Labor availability is based on the same survey, which showed an average of 1.3 adult men, 1.5 adult women, and 0.4 adolescents (10–13 years) per farm. These family laborers are available forty hours per week (Krause et al.). Family labor may be supplemented by hiring laborers at 600 francs CFA per day (8 hours). Hours required for planting, first weeding, second weeding and fertilizer applications for each intercrop system are based on on-farm trial data (Issa et al.) and hours required by operation for monocrop millet are based on farm survey data (Swinton and Samba) from the Madarounfa *arrondissement* in south-central Niger.[4]

The minimum consumption constraints are

[1] A complete model formulation is available from the authors upon request.

[2] The development of the yield penalties and labor schedules is discussed in Krause.

[3] Activities were also included to represent borrowing from moneylenders. Due to the high rate of interest on moneylender credit (50% per cropping season), government credit was far more attractive. Moneylender credit was not used in any optimal solution.

[4] An *arrondissement* is a territorial unit in the Nigerien administration.

based on an annual requirement for an adult male of 280 kilograms of millet. This requirement is multiplied by consumer-equivalent coefficients, which vary by age and gender (Matlon, Collion), and the average number of consumers per farm household in Maiguero village within each age and gender group (Swinton).

The initial endowments of millet, cowpea, and monetary capital are 365 kilograms, 12.5 kilograms, and 7,000 francs CFA, respectively. These endowments correspond to a poor (but not unreasonably so) farmer. The millet and cowpea endowments are sufficient to plant all 4.14 hectares with intercropped millet and cowpea and satisfy the rainy-season consumption constraint.

The inventory balance constraints account for the seasonal inflows and outflows of millet, cowpea, and monetary capital. Production activities draw upon cash inventories in the rainy season to purchase inputs, then augment millet and cowpea inventories after the harvest in the dry season. In the case of traditional production technologies, no inputs are purchased, but millet and cowpea inventories are drawn upon in the rainy season for seed. Labor hiring adds labor to the available family labor specified by periods within the cropping season but draws upon rainy season cash inventories. Borrowing activities augment either cash or millet inventories in the rainy season, then subtract the principal plus interest from the corresponding dry season inventories. Sales activities draw upon dry season millet and cowpea inventories and augment cash inventories. Consumption activities draw upon millet inventories and cash inventories in order to satisfy minimum consumption requirements. These activities constitute all sources and uses of cash. While net income may be negative in a given year, the level of monetary capital must always be positive.

Price and Yield Distributions

Risk is incorporated into the model via discrete probability distributions for prices and yields of cowpea and millet. Using this distribution, crop inventories and cash flow at the end of the dry season are accounted for by state of nature. The farmgate price distribution is based on historical market prices which were deflated and adjusted for transportation (table 2).

Cowpea and millet yields for the various technologies were not available for all of these years. To surmount this problem, "historical" yields were constructed synthetically based on weather data using a modified version of the GROWIT

Table 2. Historical Prices and Simulated Yields for Millet and Cowpea, Niger, 1961–85

Year	Millet[a] Price (FCFA/kg)	Cowpea[a] Price (FCFA/kg)	Millet Yield (kg/ha)				Cowpea Yield (kg/ha)			
			T1	T2	T3	T4	T1	T2	T3	T4
1961	65	96	248.2	273.4	227.0	621.1	59.7	59.0	160.1	304.9
1962	56	96	299.1	331.8	277.5	713.4	57.8	57.8	178.4	318.1
1963	49	82	445.8	518.8	432.8	1131.1	50.8	50.8	164.8	279.4
1964	46	59	252.2	285.4	225.0	633.2	57.2	57.2	156.7	306.6
1965	95	63	347.7	380.4	315.6	792.3	61.6	61.6	165.4	338.5
1966	67	96	257.3	321.5	266.7	786.0	39.2	39.2	77.1	150.4
1967	43	63	131.4	194.4	167.6	455.6	38.4	38.4	83.1	162.5
1968	54	43	290.3	307.4	254.4	474.0	22.9	23.0	66.0	98.3
1969	64	66	286.3	334.4	270.1	750.4	60.6	60.6	126.1	233.9
1970	67	65	247.4	273.5	214.6	626.8	69.5	69.5	128.4	249.7
1971	70	102	379.5	427.9	343.0	829.6	43.9	43.9	63.4	109.0
1972	110	134	175.4	185.8	146.7	208.5	10.8	10.8	21.0	31.2
1973	104	156	233.8	255.8	206.9	471.9	35.0	35.0	87.8	161.5
1974	81	191	144.5	232.4	193.0	467.5	23.5	23.4	66.9	129.0
1979	112	291	361.6	393.9	326.8	753.7	58.7	58.7	156.0	308.5
1980	103	254	255.2	264.4	216.2	582.6	50.5	50.5	130.0	233.6
1981	177	193	357.8	414.5	344.0	[illegible]	51.1	51.1	147.9	299.9
1982	150	183	250.5	282.4	239.9	616.8	22.5	22.5	85.6	123.9
1983	105	192	324.8	397.7	338.0	765.0	48.9	48.9	124.4	245.6
1984	157	252	314.7	355.4	285.8	627.6	20.5	20.5	66.6	113.9
1985	65	166	209.4	279.7	233.2	405.6	17.6	17.8	66.6	98.1

[a] Price data were taken from Ministry of Agriculture, Government of Niger, deflated and adjusted for transportation differentials.

5

biological plant growth simulation model.[5] The model is in the form of a spreadsheet with each row representing one day of growth. The yields for the intercropping systems were simulated by linking the two individual crop models; thus, the competition between the crops for water, sunlight, and fertility was captured.

The simulation model was calibrated and validated with INRAN on-farm trial data from Maiguero and Rigial Oubandawaki. Calibration used data from Maiguero for 1986 and 1987, focusing on accurately simulating the average yield across the on-farm trials in each year.[6] A separate set of data, from Maiguero in 1985 and Rigial Oubandawaki in 1987, was used to validate the model. Together the 1985, 1986, 1987 data encompass the most representative weather patterns in Niger in the 1980s. The 1985 season had slightly less than average rainfall but was much shorter than the average rainy season. The 1986 season had an average rainfall and rainy season length. The 1987 season was short, with low rainfall. Validation runs showed that the simulated yields were all within the range of observed yields for each treatment. As another validation technique, observed yields were regressed on simulated yields. The t-tests on the coefficients for that regression did not indicate that the simulation results were biased estimates of the observed yields. That is, statistical tests failed to reject the hypothesis that the slope of the regression line was one and that the intercept was zero.

The yield data were generated by recalculating the spreadsheet model for each season's rainfall for the twenty-one years covering 1961–74 and 1979–85, using daily weather observations (table 2).[7] The 1975–78 period was omitted because Maradi rainfall data are not available for that period. The simulated yields represent twenty-one equally likely states of nature. In each state of nature, the yields simulated for each year are paired with the crop prices for that year to form an empirical joint distribution of prices and yields. Prices and yields were assumed independent across years.

The distributions show that the improved millet variety (treatment 2) can produce moderate millet yield increases with only a small increase in millet yield variance, compared to the traditional technology. The increased crop density in treatment 3 results in much higher average cowpea yields but depressed average millet yields. The cowpea yield variability for treatment 3 is more than twice that of the traditional methods. The addition of fertilizer in treatment 4 substantially increases the mean yield and variance of both millet and cowpea.

Interyear Structure

The model is a discrete sequential stochastic program focused on a two-year planning horizon. The dynamics of financial liquidity are captured by the use of accounting constraints and monetary capital inventory variables which require sources and uses of funds to be equal for each period and state of nature. Inventories are accounted for in each of the twenty-one states of nature during year one for cowpea, millet, and monetary capital. These inventories are then passed forward as starting inventories for the twenty-one replications of the annual planning model, representing the planning problem of the second year conditional on the outcomes of the first year. Similarly, for each of the second-year submodels, year-end levels of equity capital are determined. This scheme yields a distribution of 441 realizations (21 × 21) of equity capital at the end of the two-year planning horizon. Because the outcomes of the two years are assumed stochastically independent, the twenty-one possible outcomes for each year are equally likely, and the probability of each of the 441 realizations of equity capital is equal to 1/441.

Objective Function

Following Lambert and McCarl's direct expected-utility mathematical programming procedure, the objective function for the planning problem is maximization of the expected utility of terminal wealth. Net income from sources

[5] The original model was developed by Smith and Loewer, and the modified version is documented in Lowenberg-DeBoer and Chemey.

[6] The simulated yields represent the average output that could be expected by a farmer of average management ability using a given technology on several widely separated fields in the community. This approach assumes that the traditional approach to reducing intra-annual variation is successful. The traditional approach consists of planting many widely scattered fields in the hope that at least some field will benefit from the rain. The spatial variability of rainfall in Niger is high. To the degree that the traditional strategy is not successful, the simulated yields underestimate the variability.

[7] An alternative approach would have been to use total annual rainfall for a longer data period, as in Carter and Matlon. However, to reflect the strong relationship between the intraseasonal distribution of rainfall and crop yields, we chose to use daily weather data for the shorter time period in constructing the yield distribution. This choice also reflects conventional wisdom that rainfall patterns prior to 1960 do not represent current conditions.

-6'

other than farming is assumed to be zero.[8] The endowment of initial monetary capital is assumed to include all cash and near-cash assets. A power utility function was chosen in preference to the negative exponential because it displays the desirable property of constant relative risk aversion. Thus, the objective function to be maximized is

$$E[U(W)] = \sum_{i=1}^{441} \frac{W_i^{1-r}}{1-r} P_i,$$

where W is the ending capital (wealth) random variable, U is the utility function, W_i is ending wealth in the ith state of nature, P_i is the probability of the ith state of nature, and r is the coefficient of relative risk aversion.

Analysis of Risk and Credit Effects

In this section, three risk-sharing alternatives are compared to a base case: a risk-bearing credit system, a scheme of risk sharing by hired laborers, and a risk-sharing option by fertilizer suppliers. In the base model, the farmer is assumed to have a relative risk aversion coefficient equal to one. This level off relative risk aversion is characterized by Binswanger as intermediate. In this base model, the government is assumed to offer production loans at an interest rate of 10% per cropping season (approximately 20% per annum). These loans must be repaid in full at the end of each cropping season. To focus attention on the immediate effects of policies, only results from the first period will be reported.

Base Case Results and Sensitivity Analysis

Results for the base model show that planted area is distributed between cropping systems T2, T4, and monocrop millet, with the vast majority in monocrop millet (table 3). The area in T4 is about 21% of the total. The area in monocrop millet is substantial, amounting to 64% of the available area. The large proportion of monocrop millet is consistent with actual monocrop millet plantings in the study period, in the same villages (Swinton, table 9, p. 20). Government borrowing is 4,760 francs CFA (approximately U.S. $16), amounting to a 70% increase in available capital.

The standard approach to encouraging technology adoption with subsidized credit involves a concessionary interest rate. The area in the improved technology, T4, is only moderately sensitive to the level of the interest rate. Halving the interest rate results in an increase in the percentage of land in T4 to 27%, while doubling the interest rate decreases the use of T4 to 15% of total land (table 3). At the same time, the level of government borrowing shifts far more widely—more than tripling with the lower rate and falling to less than half of the base for the higher rate. Thus, the proportional change in government borrowing was far greater than the proportional change in T4 plantings.

Aversion to risk makes an important contribution to these results. To demonstrate this fact, two additional cases are considered—risk neutral and strongly risk averse (relative risk aversion of 5.0). Binswanger characterizes a relative risk aversion coefficient of 5.0 as being severe. Both of these cases employ the 10% subsidized interest rate for government borrowing and should be compared to the base case. In the case of risk neutrality, there is a massive shift to the new technology, with over 96% of the land area devoted to T4 and the balance in monocrop millet. Government borrowing in the risk-neutral case is only moderately higher at 5,180 francs CFA (versus 4,760 in the base case.) In the strongly risk-averse case, area in T4 falls to about 6% of the total land, and no funds are borrowed from the government. Hence, risk aversion plays a significant role in technology selection.

The sensitivity of the area planted with T4 to the level of risk aversion results from the increased business and financial risk for T4 relative to the traditional technology. Financial risk plays a significant role here because monocrop millet does not require borrowing (the only capital input is seed) and T4 requires a relatively large amount of borrowing for capital to purchase fertilizer and improved seed.

To see the importance of risk-bearing capital to the decision to adopt the new technology, the sensitivity of the cropping pattern to the level of initial equity capital is examined. In the first case, the consequences of reducing the initial capital by half to 3,500 francs CFA are studied. In this case, the area in T4 is reduced to only 11% of total land, with only a modest reduction in the level of government borrowing. In the second

[8] Although Hill and Matlon indicate that some farmers in this region have substantial nonfarm income, they also indicate significant income inequalities and that the relatively resource-poor farmer assumed in this analysis has negligible nonfarm income.

Table 3. Results of the Discrete Stochastic Programming Credit Model for Five Technologies, Under Different Assumptions

Scenario	Initial Capital (goat)	Interest rate (%)	Risk Aversion Coefficient	Millet-Cowpea Intercrop[a] T2 (ha)	Millet-Cowpea Intercrop[a] T4 (ha)	Millet Monocrop (ha)	Total Area (ha)	Government Borrowing (FCFA)
Base	1.0	10.0	1	0.613	0.881	2.646	4.140	4,760
Interest rate:								
low	1.0	5.0	1	0.498	1.103	2.539	4.140	14,550
high	1.0	20.0	1	1.318	0.608	2.214	4.140	2,290
Risk level:								
neutral	1.0	10.0	0	0.000	3.980	0.160	4.140	5,180
strongly averse	1.0	10.0	5	1.149	0.264	2.727	4.140	0
Initial capital:								
1/2 goat	0.5	10.0	1	1.026	0.473	2.641	4.140	4,050
20 goats	20.0	10.0	1	0.000	4.140	0.000	4.140	0
Debt repayment:								
100%	1.0	10.0	1	0.486	1.191	2.463	4.140	16,240
90%	1.0	10.0	1	0.000	1.803	2.337	4.140	50,000
Labor risk sharing								
CE equals wage[b]	1.0	10.0	1	0.000	1.427	2.713	4.140	8,830
Double risk premium[c]	1.0	10.0	1	0.691	0.848	2.601	4.140	4.770
Fertilizer risk sharing								
CE equals fertilizer[d] cost	1.0	10.0	1	0.000	1.485	2.655	4.140	11,050
Double risk premium[e]	1.0	10.0	1	0.000	1.423	2.717	4.140	8,790

[a] Technologies T1 and T3 did not enter the solutions.
[b] In this case, the laborer receives half the normal wage at the time of the work and an additional payment at year end which is proportional to the revenue of the traditional system, T1. The level of the proportional payment is chosen so that the certainty equivalent value of the total payment, assuming a worker with a logarithmic utility function, is equal to the normal wage.
[c] This case is similar to the "CE equals wage" case, except the payment is increased so that the worker's expected payment exceeds the normal wage by twice as much. Thus, workers receive their normal wage plus "double the risk premium" of the previous case.
[d] This case is similar to the "CE equals wage" case for labor risk sharing. Fertilizer suppliers receive half the normal payment at planting time and an additional payment at year end which is proportional to the revenue from the new technology, T4. The level of the revenue-proportional payment is chosen so that, for a fertilizer supplier with a logarithmic utility function, the certainty equivalent value of the payment distribution is equal to the normal payment.
[e] As with the "double risk premium" case for labor risk sharing, the revenue-proportional payment is increased until the expected payment exceeds the normal payment by twice as much as in the previous case.

case, the level of initial capital is increased by a factor of twenty from the base endowment to represent the capital available to a relatively wealthy farmer. This results in complete adoption of T4 over the entire farm, with no borrowed capital. Thus, it appears that the level of risk-bearing capital is of great importance to technology adoption decisions.

The complementary relationship between equity capital and capital-using technology adoption is consistent with theoretical expectations. Increases in equity capital, *ceteris paribus*, substitute for borrowing and reduce financial risk. Therefore, additional amounts of the more risky technology can be adopted.

Because a policy that directly increases the risk-bearing capital available to the farmer is impractical, policies which result in risk-sharing arrangements between farmers and other members of society should be considered. Instituting these risk-sharing policies (in conjunction with a low-interest credit program) may increase the rate of technology adoption. Two ways of achieving risk sharing in Nigerien subsistence agriculture are by redesigning the credit system to include risk-bearing features or by instituting risk sharing with input suppliers.

A Risk-Bearing Credit System

In the United States, risk is shifted from farmers to others in the society through crop yield insurance programs, disaster payments, and price stabilization programs. These programs are publicly provided at high cost. The goal of this section is to examine the potential effectiveness of alternative (conceivably private) programs that will encourage technology adoption.

The principal difficulty with subsidized-interest agricultural credit programs to encourage technology adoption is that the targeted farmers

9

have limited means to insure against crop failure and loan repayment problems (Binswanger and Rosenzweig). This is especially true when risks are highly covariant (Binswanger and McIntire), meaning that most of a farmer's neighbors and nearby family are likely to suffer similar crop failures at the same time. The informal credit market in the semi-arid tropics mostly draws upon local equity capital (Binswanger and McIntire, Hill, Rosenzweig), and so is also limited by covariant risk. Agricultural credit programs could be much more effective if redesigned to share the farmer's risk by making the level of repayment depend upon the weather. Hence, after a drought the farmer would not be expected to repay the loan and interest in full. In contrast, if rainfall is plentiful, the farmer would repay the loan, the interest, and a premium to offset losses to the credit system during the drought years.

For illustration, a risk-bearing credit system was implemented in the context of the farm planning model. The states of nature were separated into wet and dry years based on annual rainfall. Years with 350 millimeters of rain or more were treated as wet years, while others were treated as dry. For the twenty-one years in the sample, this specification resulted in five dry and sixteen wet states of nature. The loan repayments were calculated so that the average interest rate was 10%, corresponding to the base solution on average. In the first case, the level of repayment in dry states of nature was set equal to the principal—no interest paid. To get an average interest rate of 10%, the level of repayment for wet states of nature was calculated to be 1.13125 francs CFA per franc CFA borrowed. Thus, in the sixteen wet states of nature a premium of 3.125% was paid to offset the interest lost in the five dry states of nature. Area planted in T4 with this arrangement increased from 21% to 29% of land area, and government borrowing under the risk-sharing credit program was 3.4 times the level of borrowing in the base case. These results are similar to the base model, with a lower (5%) interest rate. Hence, by offering the risk-bearing credit, a similar level of technology adoption is achieved with a higher (10%) expected interest rate.

The formal flexibility in the loan repayment plan is somewhat similar in concept to the flexible payment plan suggested by Lee and the variable amortization plan proposed by Baker. However, the plans proposed by Lee and Baker were for long-term debt, and a key feature of their proposals is for the farmer himself to diversify his cash flow over time by building reserves in good years which are drawn on for payments in poor years. The main risk taken by a lender participating in the plan is the variability in cash flow from year to year. Rahman and Barry develop an amortization plan for intermediate and long-term debt which incorporates an insurance component to cover risk present in the early years of a term loan before a building of reserves has occurred. The study here includes only seasonal debt, and carryover of debt from year to year is not modeled. Thus, the flexible repayment plans considered here are quite simple and rely entirely on the lender accepting the risk. The lender could then diversify the risk across borrowers and across time.

A second flexible repayment plan was modeled—an arrangement which required only 90% of the principal to be repaid during the five dry states of nature. In this case a repayment of 1.1625 francs CFA during the sixteen wet states of nature is required to achieve an average interest rate of 10%. The area planted in T4 increased by more than a factor of two (44% of total land area), while borrowing increased to the upper bound, more than ten times the base case borrowing. Borrowing actually exceeded the amount of capital needed to run the farm.

When borrowing exceeds the amount of capital used to run the farm, the extra capital is simply carried to the end of the cropping season. If the season has been dry, only .90 francs CFA for every franc CFA borrowed is repaid, providing a "profit" of 0.10 francs for each franc borrowed. Because crop revenues are low in dry years, the marginal utility of this profit is high relative to marginal utility in wet years. Additionally, in some of the worst states of nature, the 0.10 francs CFA profit may be needed to help repay loans acquired to increase the area planted to T4 or for consumption requirements. If the season is wet, the borrower repays 1.1625 francs CFA for a loss of .1625 francs CFA. This loss generally occurs in years of higher income. In essence, when less than full principal repayment is required, the negative correlation between loan payment and crop revenue is so attractive that borrowing more funds than needed to run the farm is optimal in spite of the 10% average interest rate. However, a credit program with incentives to borrow more than is needed to run the business would appear unacceptable.

Risk Sharing By Labor Suppliers

One candidate group in society that could share the risk of crop production would be hired

9

workers. The idea is to make the payments to labor partially dependent on the productivity of the cropping year. Risk sharing by labor would probably work only with family and friends because other laborers are often migrant or are in immediate need of cash to buy food. However, variable payments for labor by family and friends would be consistent with many social traditions in south-central Niger. Exchanges of labor without cash payment and many other complex debt relationships are common in the study region (Hill) and have a risk-sharing effect that would be similar to offering laborers a payment which varies according to production.

For illustrative purposes, the risk-sharing payment arrangement was designed to provide half of the normal wage when the work is done and to provide an additional payoff after harvest which is proportional to gross revenue per hectare using that year's yields and prices. Clearly, if laborers are risk averse, they would not be willing to accept such a payment scheme unless the expected payment at harvest time is greater than half of the normal wage. Hence, the payment scheme is chosen so that the second payment is proportional to revenues for the traditional technology, T1, in each state of nature and so that the certainty equivalent of the distribution of harvest time payments is equal to half of the normal wage.[9] When this risk-sharing scheme is implemented in conjunction with subsidized credit, a substantial increase in T4 results. Area planted using the T4 system increases to 34% of land area, and borrowing from the government increases by over 86% when compared to the base case.

Because laborers may need a further inducement to accept this arrangement, an additional case was examined in which the difference between the expected end-of-season payment and one-half of the original wage was doubled. While this gives additional incentive to hired labor, the increase in costs discourages the adoption of the technology, T4. In this case, the area devoted to T4 is slightly less than in the base case and government borrowing is approximately equal to the base.

Risk Sharing by Fertilizer Suppliers

Another group which might bear some of the risk is fertilizer suppliers, particularly because one of the principal fertilizer suppliers in Niger is the government. Primarily selling through cooperatives and rural development projects, the government accounts for about 20% of fertilizer sales to farmers (Josserand). The government also has considerable leverage to influence private fertilizer traders as a wholesale purchaser and the enforcer of customs regulations. The government of Niger could institute a variable payment schedule for its fertilizer sales, with higher payments in the farmers' high-revenue years and lower in low-revenue years, and encourage private traders to offer similar payment schedules through competition or regulation.

Risk-averse private fertilizer suppliers would be more willing to accept a variable payment schedule if the expected payment contains a risk premium. Typically, retail margins are on the order of 50%. We assume that fertilizer suppliers, including the government, would want to recoup at least their variable costs with certainty. Hence, in the payment scheme employed to investigate risk sharing by fertilizer suppliers, farmers pay half the normal fertilizer costs at planting time and an additional amount after harvest which is proportional to the level of revenues generated by the technology which uses fertilizer, T4. Assuming that the level of risk aversion for fertilizer suppliers and farmers is the same, the variable (second) payments are set so that their certainty equivalent equals 50% of the usual fertilizer costs.

The resulting area planted in T4 is 36% of total land (table 3). Government borrowing is increased by 132% when compared to the base case. As with labor risk sharing, fertilizer suppliers may need more incentive to accept the risk-sharing proposition. Hence, a case is considered wherein the difference between the expected fertilizer cost and one-half of the original payment is doubled. This arrangement is also successful in encouraging the adoption of T4. The area in T4 is 34% of total land, and the level of government borrowing is increased by about 85% over the base level. Even with significantly higher expected payments to fertilizer suppliers, area planted in T4 remains relatively high.

Concluding Comments

The analysis presented here indicates that offering low-interest credit is a relatively ineffective may to encourage the adoption of agricultural technologies in Niger. Substantial changes in the interest rate produce modest changes in the rate of adoption. The problem is that subsistence

[9] The risk aversion of laborers is assumed identical to that of farmers for this illustration. Given evidence to the contrary, the payment schedule could be modified accordingly.

10

farmers frequently do not own sufficient risk-bearing capital to allow them to take the risks of financial leverage to adopt a new technology. Three approaches to redesigning or enhancing the government credit system are considered: a risk-bearing credit program with repayment schedules dependent upon rainfall; risk sharing by laborers, with part of the wages paid at harvest time proportional to the revenues of traditional technology; and risk sharing by fertilizer suppliers, with part of their payments proportional to the revenues from the fertilizer-using technology.

A risk-bearing credit program in which the level of debt repayment was dependent upon weather was found to increase technology adoption. When at least the principal was repaid regardless of weather, risk-bearing credit achieved the same level of technology adoption as a lower interest rate with the traditional nonrisk-bearing credit system. When the minimum repayment was less than the full principal, risk-bearing credit created improper incentives. The increases in the use of the new technology were significant, but the proportional increase in borrowing was far greater than the proportional increase in land dedicated to the new technology.

Risk sharing by laborers produced substantial or modest increases in technology adoption depending upon the premium offered to laborers to induce participation in the program. The most effective system modeled was risk sharing by fertilizer suppliers. That system produced significant increases in the area planted in the new technology, with reasonable increases in the level of government borrowing. This result is perhaps not surprising because, of all the systems considered, the fertilizer supplier risk-sharing system was most closely tied to the risk of the new technology.

The adoption of the new technology was very sensitive to the amount of equity capital available. Greater amounts of equity capital make it more feasible for the farmers to take the risk of the technology adoption. In this study, risk-sharing mechanisms were examined as alternatives to having sufficient equity capital. However, policies or institutions that increase the accumulation of capital, such as providing savings deposit facilities in rural areas (Adams), would increase technology adoption through capital accumulation.

This research has developed and demonstrated an approach to the redesign of credit institutions and risk-sharing arrangements in the context of a developing country interested in encouraging the adoption of new agricultural production technologies. The approach is consistent with microeconomic theory and thus correctly reflects the incentives to producers. While a number of factors outside of the model could invalidate the results (e.g., unwillingness of input suppliers to participate in risk sharing or clandestine sales of fertilizer purchased under the risk-sharing arrangements), the basic result is clear. The adoption of new agricultural production technologies by subsistence farmers can be encouraged effectively by offering credit in conjunction with risk-sharing arrangements with input suppliers.

[Received March 1989; final revision received February 1990.]

References

Adams, D. W. "The Conundrum of Successful Credit Projects in Floundering Rural Financial Markets." *Econ. Develop. and Cultur. Change* 36(1988):355–67.

Adams, Dale W., and G. I. Nehman. "Borrowing Costs and the Demand for Rural Credit." *J. Develop. Stud.* 15(1979):165–76.

Baker. C. B. "A Variable Amortization Plan to Manage Farm Mortgage Risk." *Agr. Finan. Rev.* 36(1976):1–6.

Binswanger, H. P. "Attitudes toward Risk: Experimental Measurement in Rural India." *Amer. J. Agr. Econ.* 62(1980):395–407.

Binswanger, Hans P., and John McIntire. "Behavioral and Material Determinants of Production Relations in Land-Abundant Tropical Agriculture." *Econ. Develop. and Cultur. Change* 36(1987):73–99.

Binswanger, Hans P., and Mark R. Rosenzweig. "Behavioral and Material Determinants of Production Relations in Agriculture." *J. Develop. Stud.* 22(1986):503–39.

Binswanger, Hans P., and Donald A. Sillers. "Risk Aversion and Credit Constraints in Farmers' Decision-Making: A Reinterpretation." *J. Develop. Stud.* 20(1983):5–21.

Bromley, David W., and Jean-Paul Chavas. "On Risk, Transactions, and Economic Development in the Semiarid Tropics." *Econ. Develop. and Cultur. Change* 38(1989):719–36.

Carter, Michael R., and Peter Matlon. "An Empirical Characterization of Risk and Potential Household Differentiation in the Semi-Arid Tropics of West Africa." Dep. Agr. Econ. Work. Pap., University of Wisconsin, 1989.

Cocks, K. D. "Discrete Stochastic Programming." *Manage. Sci.* 15(1968): 72–79.

Collion, Marie-Helene J. "Colonial Rule and Changing Peasant Economy in Damagherim, Niger Republic." Ph.D. thesis, Cornell University, 1982.

Feder, Gershon, and Gerald T. O'Mara. "Farm Size and the Diffusion of Green Revolution Technology." *Econ. Develop. and Cultur. Change* 30(1981):59–76.

11

Greenland, D. J. "Nitrate Fluctuations in Tropical Soils." *J. Agr. Sci.* 50(1958):82–92.

Hill, Polly. *Rural Hausa: A Village and a Setting.* Cambridge: Cambridge University Press, 1972.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). *ICRISAT Sahelian Center Annual Report 1985.* Niamey, Niger: ICRISAT Sahelian Center, 1986.

——. *ICRISAT West African Programs Annual Report 1986.* Niamey, Niger, ICRISAT Sahelian Center, 1987.

Issa, M., K. Maliki, A. Berrada, R. Deuson, G. Ibro, M. Krause, G. Numa, K. C. Reddy, and B. Shapiro. "Evaluation des essais en milieu reel sur les cultures associees mil-niebe: resultats de la campagne de 1986." Niamey, Niger: INRAN/DECOR Document No. 17F. B.P. 429, 1987.

Josserand, Henri P. "Retrospective Study of Fertilizer Supply and Demand in Niger." Report to the Ministry of Agriculture of Niger, Center for Research on Economic Development (CRED). University of Michigan, 1986.

Kamajou, Francois, and C. B. Baker. "Reforming Cameroon's Government Credit Program: Effects on Liquidity Management by Small Farm Borrowers." *Amer. J. Agr. Econ.* 62(1980):709–18.

Konate, M. "Climate of the Sorghum and Millet Cultivation Zones of the Semi-arid Tropical Regions of West Africa." *Agrometeorology of Sorghum and Millet in the Semi-arid Tropics: Proceedings of the International Symposium,* pp. 101–14. Patancheru, India: ICRISAT Center, 1984.

Krause, M. A. "Documentation of the Madarounfa, Niger Linear Programming Models." Mimeographed. West Lafayette IN: Dep. Agr. Econ., Purdue University, 1988.

Krause, M. A., K. Maliki, K. C. Reddy, R. R. Deuson, and M. Issa. "Labor Management Effects on the Relative Profitability of alternative Millet-cowpea Intercrop Systems in Niger." *How Systems Work: Proceedings of the 1987 Farming Systems Research Symposium.* Morrilton, AR: Winrock International Institute for Agricultural Development, 1987.

Lambert, D. K., and B. A. McCarl. "Risk Modeling Using Direct Solution of Nonlinear Approximations of the Utility Function." *Amer. J. Agr. Econ.* 67(1985):846–52.

Lee, W. F. "Some Alternatives to Conventional Farm Mortgage Loan Repayment Plans." *Can. Farm Econ.* 14(1979):12–20.

Lowenberg-DeBoer, J., and J. H. Cherney. "Biophysical Simulation for Evaluating New Crops: The Case of Switchgrass for Biomass Energy Feedstock." *Agr. Systems* 29(1988):233–46.

Ly, S. A., R. Deuson, K. Maliki, G. Numa, K. C. Reddy, and S. M. Swinton. Evaluation des Essais en Milieu Reel sur les Cultures Associees Milniebe: Resultats de la Campagne de 1985." Niamey, Niger: INRAN/DECOR Document No. 14F, B.P. 429, 1986.

Matlon, Peter J. *Income Distribution Among Farmers in Northern Nigeria: Empirical Results and Policy Implications.* Dep. Agr. Econ. African Rural Econ. Pap. No. 18, Michigan State University, 1979.

Ouattara, M., and N. Persaud. "Contraintes Liees au Sol et a l'eau et Adaptations a ces Contraintes par les Paysans Locaux lors de la Production Cerealiere en Culture Pluviale." *Niger Sorghum and Millet Workshop,* ed. J. D. Axtell and J. W. Clark, pp. 95–104. International Programs in Agriculture, Purdue University, 1985.

Pearson, Craig. "Pennisetum Millet." *The Physiology of Tropical Field Crops,* ed. P. R. Goldsworthy and N. M. Fisher, pp. 281–304. New York: John Wiley & Sons, 1984.

Rae, A. N. "An Empirical Application and Evaluation of Discrete Stochastic Programming in Farm Management." *Amer. J. Agr. Econ.* 53(1971a):625–38.

——. "Stochastic Programming, Utility, and Sequential Decision Problems in Farm Management." *Amer. J. Agr. Econ.* 14(1971b):39–52.

Rahman, Md. Lutfor, and Peter J. Barry. "Financial Control and Variable Amortization Under Uncertainty: An Application to Texas Rice Farms." *S. J. Agr. Econ.* 13(1981):99–103.

Reddy, Chandra K. "Rapport de l'Agronomie Generale: Campagne 1985." Mimeographed. Niamey, Niger: Institut de Recherches Agronomiques du Niger (INRAN). B.P. 429, 1987.

Rosenzweig, Mark R. "Risk, Implicit Contracts and the Family in Rural Areas of Low-Income Countries." *Econ. J.* 98(1988):1148–70.

Seetharama, N., V. Mahalakshmi, F. R. Bidinger, and Sardar Singh. "Response of Sorghum and Pearl Millet to Drought Stress in Semi-arid India." *Agrometeorology of Sorghum and Millet in the Semi-arid Tropics: Proceedings of the International Symposium,* Patancheru, India: ICRISAT Center, 1984.

Smith, Edward M., and Otto J. Loewer, Jr. "Mathematical Logic to Simulate the Growth of Two Perennial Grasses." *Transactions of the ASAE.* 26(1983):878–83.

Swinton, Scott M. "Les ressources agricoles des exploitations dans trois villages representatifs de l'arrondissement de madarounfa en 1984." Niger Document No. 7, B.P. 429, Niamey, Niger: Institut National de Recherches Agronomiques du 1985.

Swinton, S. M., and L. A. Samba. *Cropping Systems Budgets for South Central Niger in 1984 and 1985.* Dep. Agr. Econ. Staff Pap. No. 88-6, Purdue University, 1988.

Wien, H. C., and R. J. Summerfield. "Cowpea (Vigna unguiculata (L.) Walp.). *The Physiology of Tropical Field Crops,* ed. P. R. Goldsworthy and N. M. Fisher, pp. 353–83. New York: John Wiley & Sons, 1984.

World Bank. *World Development Report, 1986.* Washington DC, 1986.

-12-