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Crop Yield Variability and Risk Aversion as Barriers to the Adoption of Fire-free Land Preparation in the Eastern Brazilian Amazon?

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Abstract

In the Brazilian Amazon and at many other forest margins in the humid tropics, small-scale farmers depend primarily on low-input agriculture. The mechanization of land preparation is often proposed as a profitable and climate-friendly alternative to the traditional fallow-based slash-and-burn practice. Yet, adoption rates remain rather low.

Although the high economic performance of mechanical land preparation in experiments is primarily due to fertilization, many proponents tacitly assume that chemical fertilizers are being adopted together with the mechanization method. The question that motivates this paper is therefore: Why don't farmers use fertilizers to increase the productivity of the traditional production system in the first place?

Based on farm-household data from 270 smallholders in the Eastern Brazilian Amazon we find that factors, such as income, liquidity constraints, labor endowment and social connectedness have little or no explanatory power with respect to fertilizer use. Instead, fertilizers seem to be used only for crops that are clearly unprofitable without fertilization. In a further step we simulate a set of production functions that identify expected yield and yield variance of important annual and perennial crops as a function of fertilizer use. The production functions are integrated into a quadratic farm-household optimization model that accounts for production and price risks. The model suggests that risk aversion can induce farmers to increase or decrease fertilizer use intensity depending on how crop yield variance responds to fertilizer application.

A final section elaborates on the implications of the results for the adoption of mechanized land preparation technologies and the design of agricultural research and agro-environmental policies in the humid tropics.

1. Introduction

This paper explores the role of crop yield variability as one among several potential barriers to the adoption of fire-free land preparation technologies by small-scale farmers in the Bragantina region in the northeastern Brazilian Amazon. We focus on two technologies that substitute the traditional manual slashing-and-burning of forest fallows. Namely, mechanical chopping and mulching of standing vegetation, a technology that was proposed in order to maintain the fallow-based nature of annual cropping, and continuous agriculture using tractor pulled plows and harrows. Both technological alternatives require the use of chemical fertilizers to complement or substitute fallow nutrients and produce yields high enough to cover cash outlays for machine services. The expected benefits of fire-free mechanical land preparation are reduced green house gas emissions, nutrient losses, and material damages from accidental fires as well as higher monetary returns per hectare through the use of fertilizers (Denich et al. 2004).

Controlled experiments have shown that average yields of annual food crops are not significantly affected by the choice of land preparation technology if equal amounts of fertilizers are applied. Hence, using low cost slash-and-burn, farmers could potentially achieve equally high yields using adequate amounts of chemical fertilizers (Kato et al. 1999).

The question that motivates this paper is therefore: Given favorable terms of trade for fertilizers and crop products, why do farmers not use fertilizers to achieve higher yields in the first place?

To answer this question we use a farm and plot level data set collected in the 2001/2 agricultural year from 270 farms in three districts and secondary data from controlled yield experiments. We first test for the influence of factors that we deem relevant in determining the decision of smallholders to use fertilizers in section 2.

In section 3 we describe the methodology used to generate a set of yield and yield variance response to fertilizer functions using stochastic simulation. These functions are fed into a quadratic programming model that maximizes the certainty equivalent of whole farm income based on the well known “Expected Value Variance” approach. Sections 4 and 5 present the results of stochastic simulation experiments and selected model runs.

The final discussion in section 6 briefly reviews the main conclusions of earlier work on crop yield variability and sets these into the context of the eastern Amazon region.

2. Factors that influence fertilizer use

From an economic point of view, fertilizer use is typically determined by factors, such as relative prices, relative scarcity of production factors, and risk preferences. Relative prices are quite obviously in favor of using fertilizer for almost all common crops in the region (investing 1 R$ per cropping period in NPK increases the 18-year net present value of cassava and bean intercropping under slash-and-burn by at least 7 R$) and due to the permanent nature of cassava flower production, temporary liquidity constraints are at least not as binding as in the case of more seasonal agricultural activities (Börner 2006).

A Probit regression model was specified to assess how farm level and location specific factors affect the probability of fertilizer use in the study area (Table 1). The price of fertilizer has not been included as only marginal differences exist between districts. Price differentials might arise from transport cost, but were not considered because farmers regularly visit urban centers to sell produce. Transport costs would then accrue on the way back home in the form of a fee per bag, which depends on the distance to the market. To avoid collinearity problems only the distance to market has been used as an independent variable.

In Table 1, marginal effects can be interpreted as follows: A unitary increase in an independent variable increases the probability of using fertilizer by (marginal effect * 100)%. The estimation was done using data from 400 plots in the three survey districts that were planted with annual crops. Cassava was the most common main crop in all districts.

The estimates suggest that net per capita income and other farm-household characteristics are rather unimportant when it comes to fertilizer use. Instead, fertilizer use seems to depend on the type of crop that is to be planted.

Planting watermelons, cucumbers, or beans increases the probability of using fertilizer by 40 - 77%. Apart from perennial cash crops, that are also fertilized, these crops are among the most nutrient demanding annual cash and consumption crops and would practically not produce without fertilizers (Kato et al. 1999). Cassava and corn, on the other hand, produce low but sufficient yields without external nutrient supply and, thus, represent a minimum risk alternative to activities that require up-front cash outlays. In addition, modern methods used in cassava production are not equally well known in all municipalities, as they require a more sophisticated management or even mechanical land preparation. The Probit estimates partly confirm this by showing that the probability of fertilizer use drops off in the districts east of Castanhal although beans are frequently fertilized even in Bragança.

Table 1:Probit estimates of the determinants of fertilizer use

	Probit Model Fertilizer Use (yes/no)			
	coefficients	**z-value**	**marginal effect**	**z-value**
Farm-HH characteristics				
Net per capita income (R$/year)	0.00	(1.62)	0.000	(1.57)
Adult equivalents	-0.003	(-1.02)	-0.001	(-1.01)
Age of HH head (years)	-0.01	(-1.32)	-0.002	(-1.31)
Dummy participation in cooperation	0.402	(1.58)	0.080	(1.75)
Dummy machinery access to plot	0.645	(1.13)	0.107	(1.61)
Dependants in the HH (number)	-0.051	(-0.85)	-0.011	(-0.85)
Distance to community center (minutes)	-0.009	(-1.56)	-0.002	(-1.57)
Soil quality*	-1.22	(-1.70)	-0.266	(-1.74)
Main crops				
Dummy beans	2.525	(9.97)**	0.777	(14.18)**
Dummy cassava	-0.1	(-0.21)	-0.023	(-0.2)
Dummy maize	-0.001	(-0.01)	0.000	(-0.01)
Dummy sweet cassava	-0.121	(-0.32)	-0.025	(-0.34)
Dummy cucumbers	1.645	(3.08)**	0.566	(3.11)**
Dummy watermelon	1.241	(3.29)**	0.408	(2.77)**
Location				
Dummy Igarape Acu	-0.624	(2.48)*	-0.119	(-2.77)*
Dummy Bragança	-0.808	(2.82)**	-0.159	(-3.1)*
Constant	-0.15	(-0.15)		
Observations	400			
Absolute value of z statistics in parentheses				
* Significant at 5%; ** significant at 1%				
Pseudo R2	0.5185			
Log likelihood	-108.30864			

The Probit analysis shows that the measured farm and household characteristics have little or no influence in determining fertilizer use. Our hypothesis is therefore that factors related to the risk involved in applying fertilizers and the individual attitude of farmers towards these risks help to explain the low observed levels of fertilizer use.

3. Modeling crop yield variability

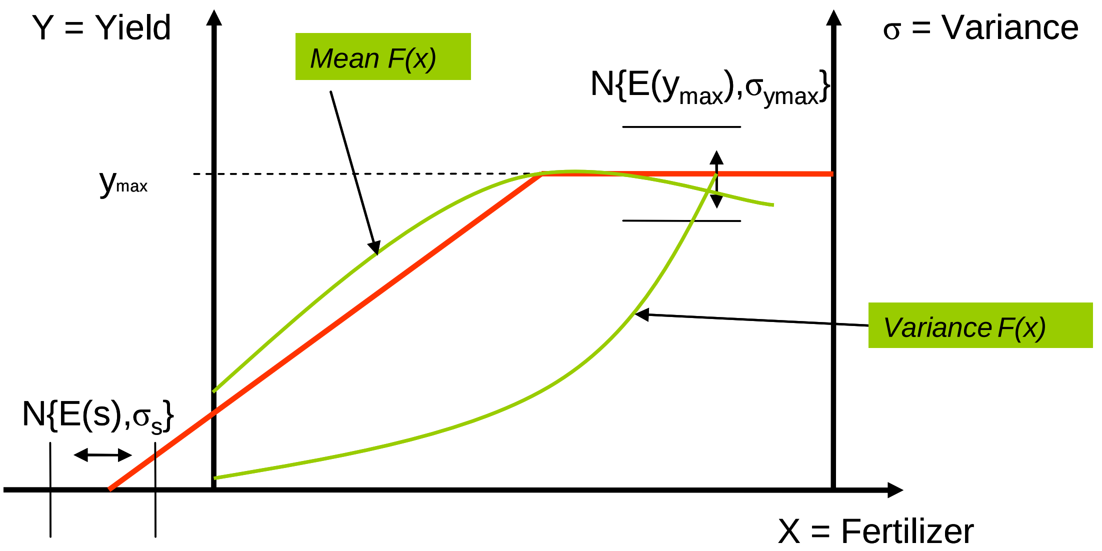
Agricultural production functions typically express average yield as a function of inputs. For our purpose it would be useful to be able to express yield variance as a function of fertilizer application. Following Berg (2003), we briefly outline a stochastic modeling approach that accomplishes this.

According to Liebig's principle of the minimum factor, the maximum attainable output level is limited by the minimum input factor, i.e. phosphorus in the case of soils in the Bragantina (see Kato 1999). This allows representing the underlying technology as a linear limited production function of the form:

$$y = a^{-1}(x+s) \text{ for } y \leq y_{max} \text{ and } y = y_{max} \text{ otherwise} \quad (1)$$

with $y_{max} = N\{\bar{y}_{max}, \sigma_{ymax}\}$ and $s = \{\bar{s}, \sigma_s\}$

where y is the yield, x is the level of input and a represents the quantity of x required per unit of y. y_{max} (maximum yield) and s (plant available phosphorus in the soil) are assumed to be uncorrelated random variables and the sources of uncertainty for the decision-maker.



Source: Modified from Berg (1998)

Figure 2: Linear limited production functions and Monte Carlo simulations

Depending on the distribution function of y_{max} and s, a Monte Carlo simulation generates a sample of potential progressions of the linear limited function in Figure 2, which allows estimating a production function with decreasing marginal productivity (see Mean f(x) in Figure 2). An additional useful output is the variance function (Variance F(x) in Figure 2) that describes the variance of yield depending on x. Note that depending on σ_{ymax}/σ_s the variance function can be increasing (large σ_{ymax} small σ_s) or decreasing (large σ_s small σ_{ymax}) with increasing x. This has important implications when comparing tropical soils with low nutrient reserves (i.e. low potential variability) and soils in temperate zones with higher nutrient reserves (high potential variability). Hence, in temperate zones, applying fertilizer can be interpreted as a means to reducing yield variance, whereas the opposite can be the case on nutrient poor tropical soils.
Given *Mean F(x)* and *Variance F(x)*, the objective function of a stochastic programming model with price and production risk, deterministic costs and excluding the covariance of prices and yields can be set up maximizing (Berg 2003):

$$CE = E(y) - \frac{\lambda}{2} V(y) \qquad (2)$$

where CE is the certainty equivalent composed of E(y), the expected farm income, V(y), the variance of farm income, and λ, the risk aversion parameter.

Omitting correlations between prices and yields, which are not significant in the Bragantina region, expected farm income and variance are defined as:

$$E(y) = \sum_{i=1}^{n} (E(p_i) E[f_i(x_i)] - c_{0i} - c_{1i} x_i) v_i - FC \qquad (3)$$

and

$$V(y)=\sum_{i=1}^{n}(E(p_i)^2 V[f_i(x_i)]+V(p_i)E\left[f_i(x_i)\right]^2)v_i^2 \\ +2\sum_{i=1}^{n}\sum_{j=i+1}^{n} v_i v_j \operatorname{cov}(GM_i,GM_j) \tag{4}$$

where p are prices for activities i, f(x) is the production function of activity i depending on input level x (here chemical fertilizer), v is the activity level, c_0 and c_1 are fixed and variable costs of i, FC are fixed farm costs and GM are the activity gross margins.

Omitting v and the covariance terms for simplification the first order condition for the optimal x of an individual activity becomes:

$$E(p)\frac{d}{dx}E[f(x)]-c_1 \\ -\frac{\lambda}{2}\left\{E(p)^2\frac{d}{dx}V[f(x)]+2V(p)E[f(x)]\frac{d}{dx}E[f(x)]\right\}=0 \tag{5}$$

Solving for the marginal expected yield results in:

$$\frac{d}{dx}E[f(x)]=\frac{c_1}{E(p)-\lambda V(p)E[f(x)]}+\frac{\frac{\lambda}{2}E(p)^2\frac{d}{dx}V[f(x)]}{E(p)-\lambda V(p)E[f(x)]} \tag{6}$$

Examining (6) provides some insight as to how the optimal input level x depends on the variance of yields and prices. For example, evidence from the Bragantina suggests increasing yield variance in response to fertilizer use. Hence, the derivative of V[f(x)] is positive until its maximum, which *ceteris paribus* leads to an increase of the second term on the right hand side of equation 6. The result is a higher marginal expected yield, i.e. a lower optimal input level. The same effect has an increase in price variability as it would reduce the denominators of both terms on the right hand side. As Berg (2003) shows, the impact of an increase in price variability may be neutralized if yield variability decreases in response to fertilizer use, which can be the case in temperate zones.

4. Simulated Yield and Yield Variance Response

Table 2 shows expected yield and variance function coefficients and characteristics for the main crop activities in the model. Sources of input parameters for the respective Monte Carlo simulations are documented in Börner (2006).

Table 2: Monte Carlo simulation results for expected yield and yield variance response

	Unit	Cassava Slash&Burn + mulching	Cassava mechanized	Beans Slash&Burn	Beans mechanized	Black pepper traditional (6 years)	Black pepper intensive (6 years)
				expected value functions			
Coefficients	a	1.32E+04	5.90E+03	2.78E+02	2.34E+02	6.09E+02	8.05E+02
	b	7.34E+02	1.09E+03	1.20E+02	9.99E+01	3.03E+01	6.52E+01
$a+bx-cx^2+dx^2$	c	-1.41E+01	-1.77E+01	-4.48E+00	-2.64E+00	-1.07E-01	-2.51E-01
	d	8.45E-02	9.29E-02	5.27E-02	2.31E-02	4.78E-05	2.59E-04
Coefficient of determination	R	0.98	1.00	0.99	1.00	1.00	1.00
				variance functions			
Coefficients	a	7.78E+07	1.32E+08	6.50E+04	7.48E+05	1.22E+06	3.18E+06
$\frac{a}{1+b\exp(cx)}+d$	b	2.11E+01	5.46E+01	1.55E+03	1.98E+01	6.11E+01	2.26E+02

	Unit	Cassava Slash&Burn + mulching	Cassava mechanized	Beans Slash&Burn	Beans mechanized	Black pepper traditional (6 years)	Black pepper intensive (6 years)
	c	-1.77E-01	-1.40E-01	-6.02E-01	-1.80E-01	-3.98E-02	-4.73E-02
	d	1.35E+07	3.46E+07	8.20E+03	-5.47E+03	8.28E+04	1.87E+05
Coefficient of determination	R	1.00	1.00	1.00	1.00	1.00	1.00
				maximum expected yield			
Fertilizer	kg P/ha	31	42	22	35		
Fertilizer	kg N/ha					158	180
Expected value of yield	kg/ha	24877	27356	1303	1484	2901	5916
Standard deviation of yield		9231	12191	270	854	1085	1798
				minimum variance			
Fertilizer	kg P/ha	0	0	0	0		
Fertilizer	kg N/ha					0	0
Expected value of yield	kg/ha	13172	5895	278	234	609	805
Standard deviation of yield		4125	6081	91	175	320	448

Monte Carlo simulations involved 1000 iterations and expected value and variance functions were estimated from the results. Several functional forms were tested and the best fit was obtained using the convex section of a cubic function for the yield response and a weibull specification for the variance response to fertilization

For cassava, maximum yields and standard deviations correspond to the average yield of the 4th quartile of yields observed for slash-and-burn and mechanization in the 2001/2 cropping season. Based on farmer interviews it was assumed that every sixth harvest is reduced by 75% due to diseases *(Phytophtora spp., Pythium scleroteichum).*

5. The Impact of Risk Aversion on Fertilizer Use

In the stochastic programming model, yield and yield variance response functions were linearized for each production activity using four model activities. Then the model was run with varying risk aversion parameters to assess the impact of risk aversion on fertilizer use and crop mix. We assume an average type of small-scale farm with ca. 15 hectares of land and 5 family members that represents roughly 50% of our farm-household sample (Börner 2006).

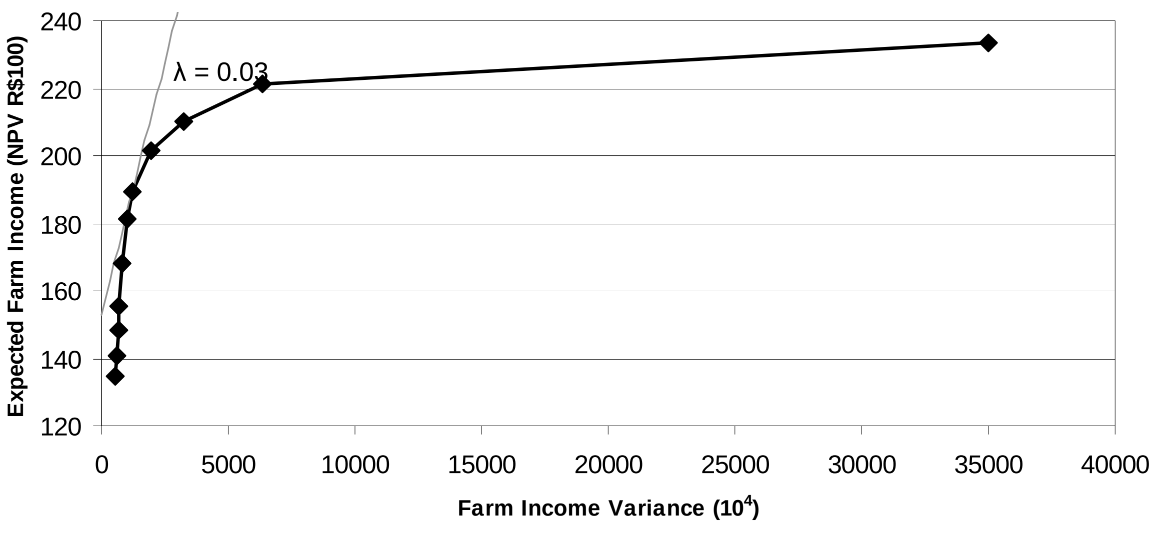


Figure 3: Expected Value Variance tradeoff curve for the stochastic programming model

Figure 3 demonstrates by how much the expected present value of discounted farm income decreases in order to reduce income variance by a given amount (black line). The grey line in Figure 3 has the slope of the risk aversion coefficient at the point of tangency with the expected value variance tradeoff curve and crosses the vertical axis at the certainty equivalent that corresponds to the respective degree of risk aversion.
Figure 4 demonstrates how increasing levels of risk aversion affect crop mix and fertilizer use for the crops under study. The simulation assumes that the chop-and-mulch technology can be offered at 50% of its estimated service costs (see Börner 2006). This assumption was necessary for chop-and-mulch to enter the optimal solution.

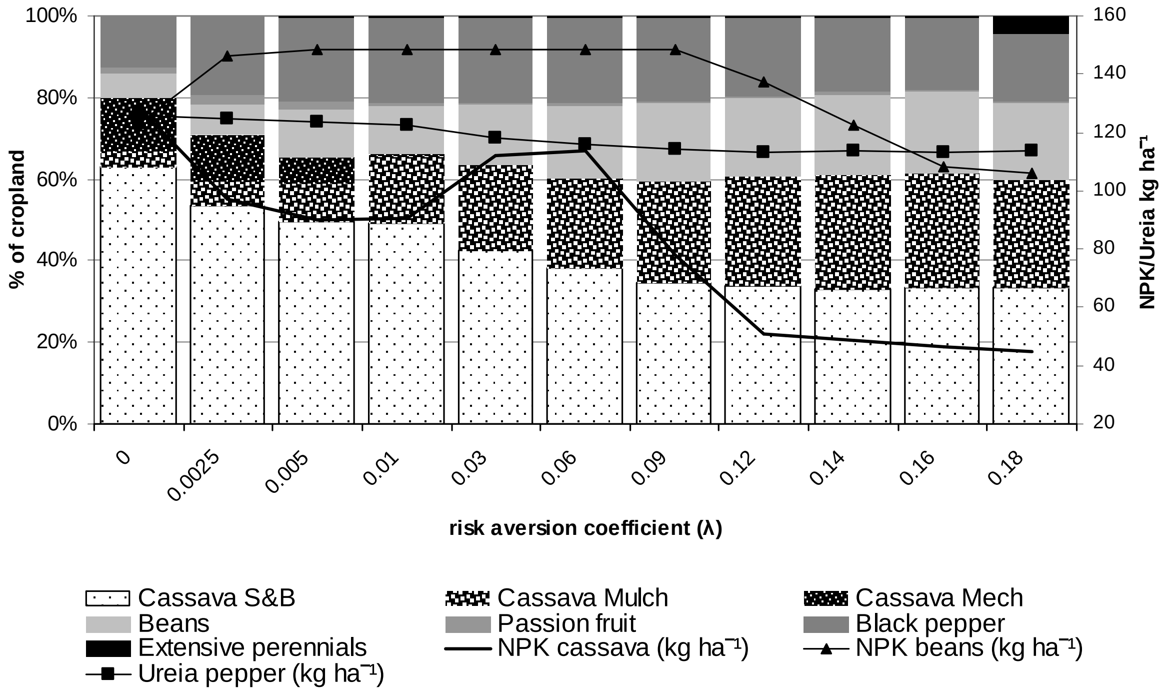


Figure 4: Crop mix and fertilizer use for different levels of risk aversion

The figure somewhat confirms the results obtained in section 2 by showing that fertilizer use is affected in different ways by increasing risk aversion depending on the type of crop. While fertilization of black pepper is hardly influenced by risk aversion, fertilization of beans increases at low and then decreases at high levels of risk aversion. Fertilization of cassava fluctuates depending on the optimal mix of land preparation technologies, but ultimately reduces to levels below 50 kg of NPK per hectare.

6. Discussion and Implications

In 1989, Anderson and Hazell compiled empirical studies on the variability of grain yields and found that the more intensive use of purchased inputs can indeed lead to increased yield variances. Their final remarks, however, remain inconclusive with regard to fertilizer use as the results of the studies they consider are somewhat contradicting, i.e. reduced yield variability through fertilization in Germany and increased variability in the Philippines.
As mentioned in section 3, our approach suggests that this is due to the differences in soil nutrient content and climate variability in tropical and temperate climate zones.
Although we do not intent to propose that crop yield variability is the single most important determinant of fertilizer use in the Bragantina region, we show that it can be a critical factor in the case of cassava production. Like many other root crops, cassava is more sensitive to the (often

climate dependent) incidence of *Phytophtora spp., Pythium scleroteichum* especially if harvested material is used for re-planting.
In the northeast of Pará, other than in many other parts of the world, cassava is a high value crop as it is on-farm processed to cassava flour that can yield a high market value. Prices for cassava flour can be highly variable at the local scale, which further increases risk for small-scale farmers that have no links to markets beyond the local marketplace.
Therefore we expect the average type of smallholder in the Bragantina region to be extremely reluctant in adopting mechanical land preparation technologies for cassava production as long as these require the use of fertilizers to be profitable alternatives to slash-and-burn. Since cassava production accounts for more than 60% in the land use mix on most of the farms in the Bragantina region, the potential for the existing mechanical alternatives to slash-and-burn remains rather low under current conditions.
Under the assumption that the introduction of mechanical land preparation is a desirable objective (see Börner 2006 for a more detailed discussion of this issue), a series of instruments exist that could potentially reduce the risks involved in small-scale cassava production.
Among these are price guaranties or crop-yield insurances that could be linked to specific land preparation technologies. The Brazilian PROAGRO program can serve as an example in this regard. Although PROAGRO was in high deficit during its early years, today it has become an important and popular complement of rural credit schemes.
Moreover, new cassava varieties that are less susceptible to the common diseases do exist, but are poorly disseminated. This also holds for innovative pest management practices that have proven successful in experiments, but have not yet found their way into the rural extension agenda.

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