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ELSEVIER

Agricultural Economics 19 (1998) 27–32

AGRICULTURAL ECONOMICS

Pasture taxes and agricultural intensification in southern Mali[1]

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Abstract

This study integrates biophysical simulation data with a farm household model of intertemporal optimization, to investigate changing crop–livestock management practices in the Sudano–Guinean zone of Mali. Over a 15-yr time horizon we find that free grazing on the commons remains more attractive to the representative household than adopting more labor- and capital-intensive confinement systems, but that a relatively low level of pasture tax (around US$3 per livestock unit per year) would be sufficient to induce intensification. Because confinement raises output, the net cost of the tax to the household is only about US$1 per unit per year. Imposing pasture taxes to induce intensification could raise community welfare, if the value of commons resources liberated by reduced grazing pressure exceeds that level. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Technical change; Sustainability; Crop–livestock interactions

1. Introduction

The management of common-property pastures is a critical economic and ecological issue in Africa, where extensive grazing practices combined with increasing herd sizes have raised widespread alarm about overgrazing. The fear of a possible "tragedy of the commons" (Hardin, 1968) has led countries to introduce a wide range of interventions, such as privatization, establishing state-protected forests, restricting the number of animals or strengthening local systems of governance over the common property resource (Bromley and Cernea, 1989).

One key policy option is the imposition of pasture taxes or grazing fees. In theory such Pigouvian taxes could offset herders' incentives to overuse open-access resources (e.g., Dasgupta and Heal, 1978, pp. 55–78), but the difficulty of choosing the appropriate level of the tax makes it an awkward instrument for governments. In particular, the tax may well impose costs to herders far in excess of its benefits to them or to others, thus creating a worse problem than it solves.

In this paper, we investigate the long-run welfare costs of pasture taxes in the context of livestock–crop interactions, where the intensification of livestock management is linked to more intensive crop production. Our analysis is designed to replicate conditions in Southern Mali, a region of densely populated African savannah facing acute environmental pressures on both common pastures and household cropping

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[1]Contributed paper presented at the 23rd International Conference of Agricultural Economists, August 10–16, 1997, Sacramento, CA.

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PII S0169-5150(98)00028-0

systems. Here as in many mixed-farming environments, using open-access pastures leaves most animal wastes in the grazing areas, whereas intensifying livestock management would permit more manure to be used on crops.

We address the potential impact of pasture taxes in this system by modeling a representative household that chooses from a wide variety of agropastoral activities to maximize discounted utility over a 15-yr time horizon. We abstract from risk and focus on the intertemporal evolution of productivity and farmers' choice of technique, particularly the impact of constructing *parc amelioré* corrals which permit the feeding of crop residues to livestock and the production of high-quality organic fertilizer. Adopting this confinement technique has high capital and labor costs, but the resulting manure helps stabilize crop yields over time, and the withdrawal of animals from the commons helps restore ground cover in overgrazed areas. We use the model to calculate the minimum pasture tax needed to induce farmers to adopt parc amelioré methods, along with the welfare cost to them of doing so and giving up their use of the commons.

As long as the social gains from reduced grazing pressure exceed the private cost of withdrawing the animals, imposing the tax would raise social welfare. In our model it turns out that the representative household's cost is relatively low, about US$1 per tropical livestock unit (TLU) per year, so there could well be net social gains from imposing pasture taxes. We find the minimum tax needed to induce withdrawal to be relatively low as well, about US$3 per TLU per year. This is less than one-seventh of the pasture taxes recently imposed in Mali on an experimental basis. We conclude that the long-run benefits to cropping systems of more intensive livestock management can be a key factor in evaluating the welfare impact of grazing policy, and can be used to help set appropriate tax levels. In the case of Southern Mali, cropping benefits are relatively large, so that relatively low pasture taxes may help limit overgrazing and also reduce soil degradation.

2. Context

Southern Mali, in the Sudano–Guinean rainfall zone of the Sahel region, offers one of Africa's most dramatic agricultural success stories, with rapid growth of cotton production for export as well as sorghum and other food crops for local consumption. Although productivity has grown, reduced fallow times and increased reliance on inorganic fertilizer has led to a contentious debate over the long-run sustainability of the cropping system (Berckmoes et al., 1990; Van der Pol, 1992; Pieri, 1992; Dureau et al., 1994; Coulibaly et al., 1993).

Animal traction is a key input in crop production, and livestock (including small ruminants) are farmers' primary instrument for savings and investment. Natural increase in local human and livestock populations has been compounded by the immigration of transhumant herders escaping the Sahelian droughts of the early 1970's and 1980's. As a result, settlement densities have reached around 41 persons and 28–30 tropical livestock units (TLUs, defined as 250 kg liveweight) per square kilometer. Under these conditions, severe stress is being put on the traditional system of open-access grazing of bush areas and crop residues, with livestock waste remaining in the grazing areas. Widespread concern about environmental damage in overgrazed pasture areas and declining fertility in cropped areas has led to the imposition of pasture taxes in some areas, and some adoption of more intensive crop–livestock production systems.

A key innovation being introduced in Southern Mali is the construction of parc amelioré corrals, in which animals are confined on a bedding and fed crop residues and industrial feedstocks (for details, see Bosma et al., 1994). The corrals are covered, thereby preserving the nutrient value of the livestock wastes while promoting the decomposition of crop residues and other field offtake. Applying the resulting organic fertilizer leads to higher and more stable crop yields by improved moisture retention and nutrient availability. The principal constraints on adoption are far higher levels of labor (mostly in the off-season) and of capital (mostly for the corral itself).

Numerous authors have addressed the role of crop–livestock integration around the world (notably Boserup, 1965; Pingali et al., 1987) and in Africa (see especially McIntire et al., 1992). The innovation of our study is to provide an empirical model of the long-run dynamics of these interactions, extending the household modeling tradition of Singh et al. (1986) to include intertemporal optimization over the biophysical relationships between crops, livestock, and soil resources, thus providing an empirical measure of the costs and benefits of taking animals off the commons and at the same time avoiding the long-run costs of soil degradation (McConnell, 1983).

3. A household model of long-run crop–livestock interactions

In the simulation experiments the household maximizes its utility in consumption plus terminal wealth by selecting annual crop and livestock production activities plus investment decisions from a wide set of technology and resource management options. The household derives utility through the consumption of a set of nonfood goods in period $t \in T$ such that the maximal discounted utility derived in the model may be written:

$$\underset{c_t}{\text{Maximize}}\ U(\cdot) = \sum_{t=0}^{T} \beta_t u(c_t) + \beta_T W_{T'} \qquad \beta \in \{0,1\} \tag{1}$$

as the producer aims to choose consumption bundles (c_t) in each time period that maximize welfare [$U(\cdot)$], which is each year's utility of consumption [$u(c_t)$] summed over time and discounted by β_t plus terminal wealth (W_T) at the end of the time horizon. To make the problem computationally tractable, in the simulations presented here each year's utility function, $u(c_t)$, is linear. The time horizon, T, is 15 yr.

Consumption levels are constrained by an expenditure constraint, which is each year's net profits from crop sales, π_t, minus farm and nonfarm expenses, E_t, and taxes, τ:

$$c_t(\pi, r, p*, \tau) = \pi_t - E_t - \tau = P'_{nt} Y_{nt} - W'_{it}\left(X^{i'}_{nt} S\right) - w'_{lt} X_{lt} - B(r) - A - P_{nt} *' Y_{nt} - \tau \tag{2}$$

where P_n and $P_n{*}$ are producer and consumer prices for $n \in N$ commodities Y_n, w_i and w_l are the prices for variable crop and livestock inputs X^i and X_l, (S is a $1 \times n$ summation vector), net savings B, dependent upon the real rate of interest r, and investments (notably in livestock operations, including the construction and capital cost of corrals as well as cattle, small ruminants and animal traction equipment) is denoted as A. Variable livestock costs include health and supplemental feeding plus grazing and head taxes. All variable inputs except land and labor may be purchased, and credit is available for biochemical inputs at a real interest rate of around 10%.

To capture the economic costs of soil degradation (and the potential gains from restoring fertility), the model incorporates the biophysical relationship between crop yield and initial soil status plus subsequent cultivation history. We capture the marginal productivity of land through soil-response functions, estimated separately for three distinct soil types based on topographic sequence. The response functions correlate crop yield with a vector of soil attributes Q, including chemical elements such as available nitrogen, phosphorous, potassium and micronutrients, biological aspects such as organic carbon and humus, physical attributes such as the sand, silt, and clay content and the overall pedon depth, acidity, and cation exchange capacity. For a given initial Q, yield may vary over time depending on stochastic weather and pest risks, ε, variable inputs, $X_l^{\,i}$ use of labor, $X_l^{\,L}$ and household assets, A, as well as the history of production on the land parcels as represented by an autoregressive function θ:

$$Y_{nt} = g\left(Q, X^i_{nt}, X^L_{nt}, A, \varepsilon | \theta Y^z_{t-1} + \theta Y^z_{t-2} + \ldots + \theta Y^z_{t-j}\right) \quad \forall y \in \{Y\} x t \in \{T\} \tag{3}$$

To capture soil degradation, we estimate a biophysical function for land productivity under each crop and production technique ($Y_n^{\,z}$) over time, in the context of stochastic rainfall:

$$Y^z_{nt} = e^{\gamma \cdot t + \lambda \cdot \text{rainfall}} \tag{4}$$

Each year's yield is based on the number of years that technique has been used ($\lambda \times t$), and that season's weather (rainfall), using the logarithmic approximation to the logistic curve to capture the nonlinear nature of this relationship. The function's parameters (γ,λ) are estimated using the output of a biophysical simulation model, through an OLS regression of the logarithm of crop yield under each technique, against total rainfall in that year and the number of previous years that technique had been in continuous use.

The yield functions are estimated for a total of 207 possible techniques, each part of a multiyear rotation centered about cotton production. The crop growth model used is a version of the environmental policy integrated climate model (see EPIC, 1996), calibrated to local conditions using the results of long term trials, soil surveys, climate data, and interviews with researchers and farmers. Details of the data, procedures and results are documented in Dalton (1996).

In estimating our reduced-form yield function (Eq. (4) above) we use the year's total annual rainfall, but in the EPIC model the entire sequence of daily stresses is preserved and has a major influence on yields and nutrient uptake. EPIC also captures the influence of crop characteristics and cultivation techniques on nutrient leaching and surface runoff, and the feedback of these factors on crop performance over time. The use of a biophysical model to estimate yield functions for each technique not only provides an empirical foundation for estimating soil degradation effects, it also provides a foundation for ex-ante estimates of the payoff from soil-altering innovations such as livestock corrals. Linking agronomic changes to a full household model identifies their economic value over time, and the optimal timing of technical change.

Three broad livestock-production techniques are available in the model. The most extensive technique is to graze on the commons and on crop residues after harvest. In this approach, almost all the nutrient value of the manure is lost. A somewhat more labor-intensive technique is to stake livestock in the evening, and periodically collect the resulting manure (known as terre de parc) for use on crops. The most intensive method is to confine animals in a parc amelioré, which produces a larger volume of higher-quality manure but requires a greater investment of labor and capital. Construction of the parc is modeled as an integer choice, as is the subsequent annual decision to maintain it. All materials to construct the parc can be financed under a parastatal credit program over 5 yr at 10% real interest rate.

The household optimization problem thus consists of the objective function (Eq. (1)) subject to an array of constraints on land, labor (human as well as animal), implements and capital. The biophysical determinants of crop yields (Eq. (4)) are integrated directly into the objective function. Intertemporal transition equations are used to account for population growth, the transfer and accumulation of wealth, the physical deterioration, financial depreciation and productivity of animal traction implements, and temporal lags in organic fertilizer production. Initial conditions are calibrated to the 1995 cropping season, and solving the model identifies the utility-maximizing set of production activities over the subsequent 15-yr period, including the optimal timing of implement purchase and technology adoption.

4. Policy options and results

The presence of open-access grazing resources implies that individual households' choices may not maximize aggregate welfare, and that government intervention could be Pareto-improving. There are three possible types of intervention: government could (a) strengthen common-property governance schemes, or define use—rights over grazing areas and create local markets in those rights; (b) impose taxes on users of common land to reflect its social cost; or (c) offer subsidies to users of substitute techniques to reflect their social benefits.

In Mali, as in much of Africa, the preservation of collectively-owned grazing lands that cover a wide variety of terrain is seen as extremely valuable. Herders cover long distances in search of moisture and forage, exploiting a highly diverse ecosystem. Grazing periods are brief and herd location is difficult to predict. In this context, the transaction costs involved in any common-property governance schemes or market solution would be very high relative to the value of the resource, making such arrangements difficult to establish and enforce. In this analysis we consider only the administratively easier possibility of using public access charges to make herders pay the social cost of pasturage. Indeed the Malian government has been experimenting with such pasture taxes on an ad hoc basis, charging 1000 FCFA (approximately US$2) per TLU per month in some areas. Subsidy-based interventions are also possible, and in Mali some foreign-aid programs have been involved in helping farmers construct parc amelioré corrals to help preserve the commons and improve soil fertility.

We evaluate the impact of grazing policy on crop production by solving our model for the minimum levels of grazing taxes or corral subsidies needed to induce a change in technique. Our first result is that *no* level of construction-cost subsidy is sufficient to

Table 1
Grazing tax and organic fertilizer use associated with adoption of corrals

	Without new cultivar		With new cultivar	
	Low prices	High prices	Low prices	High prices
Min. grazing tax (FCFA/TLU)	1350	1352	1345	1450
Organic fertilizer use (mt/farm)	29.06	21.96	25.54	21.96

A tropical livestock unit (TLU) is 250 kg liveweight. In the absence of the parc amelioré, organic fertilizer use is approximately 10 mt/farm.
Source: Model results, based on data and procedures detailed in Dalton (1996).

induce a switch to corrals over the model's time horizon, as its recurrent costs exceed its benefits relative to continued use of the commons. We therefore turn to a grazing fee, and solve the model for the minimum level of tax needed to induce corral construction in the first year of simulation. Table 1 presents the resulting tax levels, and the resulting quantities of organic fertilizer added to crop production, under four sets of conditions. These scenarios consider the possibility that relative cereal prices will be at historically high or low values, and also the possibility that farmers will have available to them a recently-released sorghum cultivar.

The minimum tax required to induce the shift into the parc amelioré system is slightly less than 1500 FCFA (about US$3) per TLU per year, an order of magnitude lower than the levels being introduced by the Malian government. Although adoption of the corral increases gross farm income, it has high investment costs and would not be undertaken as long as open-access grazing is freely available.

Once the tax is imposed, farmers' use of the corral shifts cropping patterns slightly, away from millet and groundnuts and towards the more nutrient-responsive cotton, maize and sorghum rotation, and more than doubles organic fertilizer use. With the corral, 17.4 of 19.0 hectares receive organic fertilizer, at an average rate of slightly more than 3.75 t per hectare every 3 yr. The yield effect of this organic fertilizer application is quite small in the early years, but over 15 yr the resulting improvement in soil quality increases cotton and sorghum output by up to 100 kg/yr. This increase is not enough to compensate farmers for the costs of the corral, however, so the switch reduces welfare.

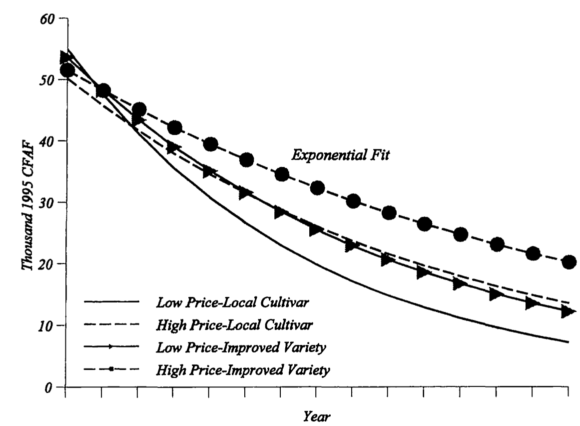

Fig. 1. Annual household welfare loss from adopting corrals.

Table 2
Impact of the grazing tax on household welfare

	Without new cultivar		With new cultivar	
	Low price	High price	Low price	High price
Loss in utility (thousand FCFA)	231.40	255.50	262.60	295.10
Percentage change	3.00	2.70	3.10	2.60
Loss per TLU (thousand FCFA)	6.65	7.35	7.55	8.49

All values are cumulative over the model's 15-yr time horizon.
Source: Model results, based on data and procedures detailed in Dalton (1996).

The cost to households of switching from open-grazing to the corrals is a measure of the value to the farmer of using the community's grazing areas. From Table 2, we note that, on average over the period, grazing on communal areas contributes about 3% of farm income. But the cost of foregoing this income source declines over time, as the benefits of recycling field nutrients gradually raise crop yields. Fig. 1 shows the pattern of declining cost for the four scenarios.

5. Conclusions

This paper demonstrates the strong links between grazing practices and crop productivity. We show that, under current conditions in the study areas of Southern Mali, it is optimal for farmers to continue open-access grazing as long as it is feasible to do so, since the labor and capital costs of adopting confinement methods exceed the nutrient-recycling benefits they provide in crop production. Switching to confinement through the parc amelioré system is projected to impose a welfare cost on adopters of about US$1 per TLU per year.

To determine the net social benefits of adoption, it is necessary to value the benefits of reducing grazing pressure. Should forced adoption of confinement systems be desirable, we find that the construction subsidies currently being offered in Mali are not likely to be effective in spurring adoption, because the recurrent costs of maintaining corrals exceed their benefits. To induce adoption, a small grazing tax is needed, on the order of US$3 per TLU per year. This is far smaller than the current grazing taxes currently being imposed on an experimental basis in Mali, and almost certainly feasible to implement in the West African context.

Acknowledgements

The authors are grateful to the Institut d'Economie Rurale (IER) in Mali for its collaboration on this project, the Africa Bureau of USAID for financial support, and Jock Anderson, Gerald Shively and Peter Hazell for comments on an earlier draft.

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