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DEMOGRAPHIC PRESSURE AND THE SUSTAINABILITY OF LAND USE IN RWANDA

by

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Abstract: Increasing land scarcity forces Rwandan farmers to expand the area under food crops at the expense of pasture, fallow, and forest. Since the non-cropping uses of land provide more vegetative cover against erosion than most food crops, land scarcity appears to be associated with unsustainable land uses. However, demographic pressure also pushes farmers to grow crops in dense associations, which increases vegetative cover on cultivated fields. The estimated relationship between farm size and protective crop cover depends crucially on how the measure of vegetative cover is adjusted to account for high cropping densities. Without any adjustment, the association between land scarcity and erosive land use is strong; with the adjustment used here, it disappears, except for high-altitude areas, where bananas, the only major food crop that protects land well against erosion, do not grow well.

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1. Introduction

Does demographic pressure make agriculture less sustainable in developing countries? Literature presents two conflicting hypotheses (National Research Council 1993). The pessimistic, 'Ricardian,' hypothesis is that when population grows, farmers tend to mine their soils and expand cultivation to marginal, easily erodible land. The higher the rate of population growth and the more fragile the environment, the greater is the rate of erosion.

The optimistic hypothesis is that because land-scarce farmers depend on land productivity for food security, they attempt to prevent degradation. Above all, they use their relatively-abundant labor to adopt more sustainable labor-intensive land use practices and to invest in soil conservation. In Rwanda, the pessimistic hypothesis has much credibility. The most densely-populated country on the African continent, Rwanda has an average farm size below one hectare (DSA 1992). Farming has already expanded to cover the easily erodible hillsides. Almost one-third of cultivable fields are now located on slopes of 20 degrees or more. In a 1991 survey by the Ministry of Agriculture, 40 percent of field blocks were reported by their cultivators as degraded.

Yet economic theory could support either hypothesis. On the one hand, it suggests that land-scarce poor farmers may have a high rate of time preference and may sacrifice long-term sustainability for immediate food security. On the other hand, theory suggests that as population growth changes the relative endowments of land and labor, it also may change relative prices so that using labor to maintain the productivity of land becomes more attractive. In the end, the question is empirical and depends significantly on the characteristics of the land uses (crops) farmers can choose in a specific environment.

To understand fully what determines how sustainable are the land uses farmers choose, ideally one would first model the determinants of land use, and then model their impacts on the farming environment. The space here is too brief for both, so we focus on the second, and ask directly whether increasing land scarcity, reflected in miniaturization of farms, is associated with Rwandan farmers' having unsustainable land uses. This addresses an important unresolved debate in a context that should tell much about the future sustainability of agriculture in Africa.

We examine this longitudinal question with cross-sectional data by comparing how well the land uses chosen by more and less land-scarce farmers protect the land against erosion. Land use is here defined to include the allocation of land to different uses (crops, pasture, fallow, and woodlot) and cultural practices such as intercropping and crop-planting density. This definition excludes treatment of soil conservation investments, which are studied with the same data base by Clay and Reardon (1994).

Section two explains the data and the methods used. Section three presents the results and section four concludes.

2. Data and Methods

This study uses data for 821 sample households that derive from the detailed rural household survey conducted in 1991 by the Division of Agricultural Statistics (DSA), Ministry of Agriculture and Livestock of Rwanda.

Our approach has four steps. First, we categorize farm households into landholding quartiles according to their land scarcity using the criterion of cultivable land per adult equivalent.[1] All pastures, fallows, and woodlots are considered cultivable. Second, we compare over quartiles the average index of the protective crop cover on farm fields, without controlling for other factors. Third, we repeat the comparison with stratifications for agroclimatic zone and for altitude.

Fourth, to control better for agroclimatic factors we use regression analysis with observations aggregated over fields to farm-household observations. The control variables include rainfall and altitude.

[1] Conversion into adult equivalents is based on Miniplan (1988).

In addition, a multiplicative dummy variable is introduced to allow the coefficient for farm size to differ for high altitudes where bananas do not grow well (MINAGRI 1978). The hypothesis is that since bananas are highly caloric and also protect the land well against erosion, the areas where few bananas are grown would show a stronger link between erosive land uses and demographic pressure.

The dependent variable in the analysis is an index of the protective vegetative cover provided by crops or other land use such as pasture, known as the C-value (erosion index measuring crop protective cover). Soil scientists use C-values together with data on slope, rainfall, and soil type to predict erosion (Wischmeier and Smith 1978). The C-value itself is not a measure of erosion but, other things being equal, a lower C-value indicates less erosion. Depending on the varieties and cultural practices, the protective cover provided by a given crop varies widely and its C-value needs to be estimated empirically for different environments. The crop-specific C-values used in this paper are estimated in Lewis (1986) and Lewis, Clay, and Dejaegher (1988) based on Rwandan field data.

Although C-values are specific to cultural practices such as weeding and mulching, the C-value estimates used here are the same for all farm-size quartiles. However, it is known that all major crops show 50-100 percent higher yields on the fields of the most land-scarce quartile compared to those of the least land-scarce quartile (Uwamariya, Kangasniemi, and Reardon 1993). This suggests that small farmers (in terms of cultivable land per adult equivalent) use much more labor per unit of land than large farmers. The impact of this on the protective crop cover is unclear, since while some ways of using additional labor (weeding) are likely to expose land to erosion, others (mulching) clearly increase soil protection and crop cover.

Since more than one-half of cultivated fields in Rwanda are intercropped, a key question is how to estimate C-values for crop associations. Because few empirically-based estimates were available for crop associations, we used C-values estimated for purely cropped fields to compute C-values for the associations. Our unadjusted C-value is an average of crop-specific C-values weighted by the estimated land shares of each crop in a given association. However, DSA's data show that planting densities on intercropped fields are higher than on purely-cropped fields, which suggests that there is more vegetation, and thus more crop cover against erosion. Also DSA's field experiments indicate that the average C-value of the crops grown in the association overstates the C-value (exposure to erosion) of the association (Lewis 1986). In the literature, reduced erosion is mentioned as one of the reasons farmers continue to rely on intercropping (Fussel and Serafini 1985).

To adjust C-values for high densities we divide the unadjusted C-value by the sum of the densities of the crops grown in the association (for technical details, see Kangasniemi 1993). On average, the adjustment reduces C-values (increases soil protection, ceteris paribus) of the intercropped fields from .20 to .13.

Rwanda's main export crop, coffee, is usually mulched and has a very low C-value (.02). Also forest (C=.06), fallow (C=.10), and pasture (C=.10) cover the land well. Of the main food crops, only bananas have a low C-value (.04), whereas beans (.19), tubers (sweet potato: .23, potato: .22, and cassava: .26), and cereals in particular (maize: .35 and sorghum: .40) provide much less protective cover against erosion.

Table 1 shows the differences in land use by farm-size quartiles. The smallest farms, compared to the other quartiles, dedicate more of their cultivable land to bananas, tubers, cereals, and coffee. They cultivate a larger share of their land at the expense of pasture, fallow, and forest.

3. Results

Results of the C-value calculations for the cultivated, cultivable, and intercropped fields of each farm size quartile at the national level are shown in Table 2. All differences between the quartiles that show up in the table are significant at the .1% level.

When land use on *all fields* is examined, the unadjusted C-values show that land-scarce households allocate their land to uses that provide less protective cover against erosion than the uses chosen by those with more land. However, the density-adjusted C-values show no clear relationship, suggesting that small farmers (in terms of cultivable land per adult equivalent) make up much of the difference by growing crops in higher densities.

This key result is compatible with the finding that there are no significant differences between farm size quartiles in the share of fields reported as degraded (Clay 1993).

When only *cultivated fields* are compared, neither measure suggests that demographic pressure pushes farmers to grow more erosive crops. Due to the higher densities on their intercropped fields, land-scarce farmers may actually generate less exposure to erosion on their cultivated fields. Thus, the reason they do worse or at least not better than larger farmers when all fields are compared is that they need to cultivate a larger share of their land at the expense of pasture, fallow, and forest.

The examination of the subset of *intercropped fields* shows that land-scarce farmers have substantially higher cropping densities on their intercropped fields. This covers their intercropped fields better against erosion than do their less land-scarce neighbors.

The result that the degree of protective crop cover is almost the same on small and on large farms holds well in three of the five agroclimatic zones (Table 3). In the North West, agricultural land uses are more erosive than elsewhere, particularly on small farms. The reason presumably is that much of the North West is of too high altitude for bananas, which are the only major food crop that covers the land well against erosion. Differences in banana production may also explain the results for the North Central zone. To explore this further, comparisons were also made separately for altitudes below and above 1900 meters. At the high altitudes, which cover roughly one-fourth of Rwanda's cultivable land, land scarcity was strongly associated with erosive land use practices.

Table 4 shows that using regression analysis to control for rainfall and altitude with does not change the basic results presented above. The first equation confirms the finding that when the estimates of crop cover are adjusted downward for densely-intercropped fields, farm size is not significantly associated with erosive land use, except for the high-altitude areas. The most important determinant of crop cover is altitude, largely because few bananas are grown at high altitudes.

The second equation (Table 4, right column) illustrates that without the adjustment for density, the result is entirely different. If small farmers are not 'given credit' for their higher cropping densities in the calculation of the C-values, land scarcity appears to make land use much more erosive. In contrast, the association of crop cover with altitude becomes insignificant if the higher densities at low altitudes are not accounted for.

4. Conclusions

Although increasing land-scarcity forces Rwandan farmers to cultivate a larger share of their land at the expense of forest, pasture, and fallow, it also encourages them to grow more perennials and to grow crops in dense associations. While the expansion of cultivation contributes to erosion, especially when it occurs on easily erodible steep slopes, perennials and dense associations are a form of intensification that makes land use more sustainable. The estimated net impact of these changes depends crucially on how one adjusts the estimates of vegetative crop cover for high cropping densities. With the adjustment used here, small farmers do not appear to have substantially more erosive land uses than large farmers, except in the high-altitude areas.

Our adjustment for high cropping densities reduces the estimated C-values on the intercropped fields of the smallest farm-size quartile almost by one-half, which may be too generous. On the other hand, no adjustment was made for purely-cropped fields, which probably also have higher cropping densities on small farms than on large farms. Without field experiments, it is impossible to say whether our adjustment is too optimistic.

With or without adjustment for high cropping densities, land uses appear erosive at high altitudes, where few bananas are grown. Crop cover on these areas is poor and is becoming less protective with increasing land scarcity. Moreover, fields in high-altitude areas are much steeper than elsewhere, which makes them even more vulnerable to erosion. At high altitudes, finding ways to channel the additional labor provided by population growth to soil conservation through investments such as anti-erosion ditches and terraces and land use practices such as mulching and agroforestry is a major challenge. Since much of the environmentally sustainable labor-based intensification at lower altitudes involves banana production, agricultural research on banana varieties that grow well on high altitudes might have a high payoff in terms of environmental sustainability and long-term food security.

In sum, our cross-sectional comparisons give only limited support for the hypothesis that demographic pressure makes land use less sustainable. Although this gives some optimism regarding the environmental impacts of population growth in the nearby future, it does not change the fact that during the recent past population growth has already forced Rwandan farmers to cultivate marginal lands. On the steep slopes, the current levels of crop cover are insufficient to control erosion. The current rate of land degradation is alarming, and measures to reduce it are badly needed. To design policies that promote soil conservation investments and land use practices that protect the soil against erosion, especially on easily erodible areas, decision makers need information on the determinants of investments and land use. Research that provides such information deserves priority in Rwanda and other countries facing similar problems.

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Table 1: Land Allocation by Farm Size Quartile

	Farm Size Quartile (Ares/AE)				C-value
	0- 9 ares	9-15 ares	15-26 ares	26- ares	
Cereals	12%	12%	10%	9%	.35-.40
Tubers	26%	24%	22%	13%	.22-.26
Beans	16%	15%	12%	10%	.19
Fallow/Past.	9%	13%	19%	30%	.10
Forest	5%	5%	8%	13%	.06
Banana	18%	19%	18%	15%	.04
Coffee	6%	5%	5%	4%	.02
Other	7%	7%	7%	6%	.02-.35

Means Shares for Seasons A and B, Weighted by Farm Size
Source: DSA/MINAGRI Survey Data, Agricultural Year 1991

Table 2: Crop Cover Indices by Farm Size Quartile

	Cultivable Fields		Cultivated Fields		Intercropped Fields		
	Density-adjusted C-value	Un-adjusted C-value	Density-adjusted C-value	Un-adjusted C-value	Density-adjusted C-value	Un-adjusted C-value	Total Density
Farm Size per Adult Equiv.							
0- 9 ares	.13	.17	.14	.19	.11	.19	1.889
9-15 ares	.13	.17	.14	.18	.13	.20	1.758
15-26 ares	.13	.16	.14	.18	.13	.20	1.698
26- ares	.12	.14	.14	.17	.14	.20	1.585

Means Weighted by Field Size. All visible differences significant at 1% level.
Source: DSA/MINAGRI Survey Data, Agricultural Year 1991

Table 3: Erosivity (C-value, or Crop Cover) Indices by Farm Size, Zone, and Altitude

	Agroclimatic Zone					Altitude (m)	
	North West	South West	North Central	South Central	East	-1900	1900-
Farm Size per Adult Equiv.							
0- 9 ares	.17	.11	.12	.11	.11	.12	.17
9-15 ares	.18	.12	.13	.11	.11	.12	.16
15-26 ares	.17	.12	.12	.11	.11	.12	.14
26- ares	.15	.10	.11	.11	.10	.12	.12

Mean Adjusted C-values of cultivable fields weighted by field size
All visible difference between quartiles significant at 1% level.
Source: DSA /MINAGRI Survey Data, Agricultural Year 1991

Table 4: Regression Results for Crop Cover Index (Cultivable Fields)

Independent Variable	Dependent Variable	
	Adjusted C-value	Unadjusted C-value
Intercept	.00641	.09889
(t)	(.70)	(2.28)
Rainfall (cm)	-.00025	-.00085
(t)	(-5.88)*	(-4.25)*
Altitude (100m)	.00871	.00592
(t)	(14.52)*	(2.08)
Land (ares/ad.eq.)	-.00003	.00340
(t)	(.54)	(12.88)*
Land*dummy for alt.> 1900 meters	-.00048	.00008
(t)	(-4.09)*	(-.15)
Adj. R Square	.24	.21

* significant at the 1% level
Source: DSA/MINAGRI Survey Data, 1991