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Farm productivity in Rwanda: effects of farm size, erosion, and soil conservation investments

Fidele Byiringiro [a], Thomas Reardon [b,*]

[a] United Nations Economic Commission for Africa, Addis Ababa, Ethiopia
[b] Department of Agricultural Economics, Michigan State University, East Lansing, MI 48824, USA

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Abstract

This paper examines the effects of farm size, soil erosion, and soil conservation investments on land and labor productivity and allocative efficiency in Rwanda. There were several key results. First, there is a strong inverse relationship between farm size and land productivity, and the opposite for labor productivity. For smaller farms, there is evidence of allocative inefficiency in use of land and labor, probably due to factor market access constraints. Second, farms with greater investment in soil conservation have much better land productivity than average. Those with very eroded soils do much worse than average. Smaller farms are not more eroded than larger farms, but have twice the soil conservation investments. Third, land productivity benefits substantially from perennial cash crops, and the gains to shifting to cash crops are highest for those with low erosion and high use of fertilizer and organic matter. Program and policy effort to encourage and enable farmers to make soil conservation investments, to use fertilizer and organic matter, and to participate in cash cropping of perennials will have big payoffs in productivity. Land markets that allow smaller farmers to buy land could also increase aggregate productivity.

1. Introduction

Research on African farm productivity from the 1960s to the present has focused on differences between smallholders and largeholders in dual agricultural systems and on differences between technology groups or land tenure status in smallholder systems [1]. Over the past three decades, however, soils have degraded and erosion has become a major environmental problem in many African countries. Access to land has become increasingly constrained in smallholder agricultural areas that were formerly land-abundant.

Study has been rare, however, of how growing land constraints and degradation have affected farm productivity in smallholder areas. These effects are issues of urgent importance in the East African highland tropics. In Rwanda, for example, population density has risen rapidly over the last three decades and is now among the highest in Africa, and poverty is widespread. With increasing land constraints (associated with a secular tendency to smaller farms), farmers are increasingly pushing onto the fragile 'extensive margins', the hillsides (von Braun

* Corresponding author. e-mail: reardon@pilot.msu.edu.

[1] Eicher and Baker (1982) review the studies in the 1960s and 1970s. Selected studies of farm productivity after that are reviewed below.

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et al., 1991; Clay, 1993). Half of the farmland is moderately to severely degraded. Improving farm productivity and combatting land degradation are key food security strategy goals of the Rwandan Ministry of Agriculture (Commission Nationale d'Agriculture, 1992).

This paper explores the determinants of farm productivity in Rwanda, using a nation-wide, 1240 household survey over one year (1990–1991) by the Rwandan Ministry of Agriculture, Division of Agricultural Statistics (MINAGRI/DSA). We address two questions. First, how does farm size affect land and labor productivity and allocative efficiency on smallholder farms? This is one way to approach the more general question of how increasing land constraints and population density are affecting crop productivity. Second, how does land degradation, specifically erosion, affect farm productivity, and conversely, how do anti-erosion (soil conservation) investments affect crop productivity?

Our hypotheses are as follows.

First, neither theory nor empirical evidence allows us to offer an unambiguous hypothesis for the relation between crop productivity and farm size, nor the relation between farm size and allocative efficiency.

On the one hand, smaller farmers may crop available land more intensively, using more labor, and fallowing less, whereas large farmers may underuse land, fallowing more, planting less densely, and using less labor per hectare. Smallholders could face a virtual wage or opportunity cost of labor that is lower than the market wage, and apply labor until its marginal value product becomes a fraction of the market wage (Ellis, 1993).

There is empirical evidence to support the hypothesis of an inverse relationship between farm size and land productivity. In India, for example, Bardhan (1973) and Deolalikar (1981) show that smaller farms have higher land productivity but lower labor productivity. They point to the greater labor intensity of smallholder farms as the reason. Empirical tests of the hypothesis in Africa have tended to focus on dualistic agricultures with land distribution Gini coefficients in excess of 0.50 (for example, van Zyl et al., 1995 for maize in South Africa, Carter and Wiebe, 1990 for wheat in Kenya); they find an inverse relationship. Tests have been rarer in smallholder agriculture with Gini coefficients for land distribution in the 0.30–0.40 range. An example is Barrett (1994), who shows an inverse relationship for rice farmers in Madagascar.

On the other hand, larger farmers could in theory compensate for less family labor per hectare with hired labor, non-labor variable inputs, and capital, to meet or surpass land productivity on small farms. Adesina et al. (1994) show this for large rice farms in Cote d'Ivoire, and Rao and Chotigeat (1981) for large farms in India. In both cases, larger farms had better access to capital and nonlabor variable inputs than do small farms. Moreover, smaller farms might also have lower land productivity because their more intensive farming fatigues and degrades the soil. Yet Ellis (1993) notes that a zone with better soils might attract more farmers, giving rise to smaller farms with better yields than in other zones.

Moreover, comparisons have been rare of allocative efficiency of small and large farms (testing whether there is equality between the marginal value product of a factor and the price of that factor in the market). Exceptions include Carter and Wiebe (1990) for Kenya, Adesina et al. (1994) for Cote d'Ivoire, and Savadogo et al. (1994) for Burkina Faso. The Burkina study examined animal traction user and non-user groups. The Kenya and Cote d'Ivoire studies compared labor and capital marginal value products (MVPs) between smallholders and largeholders, and compared the MVPs to factor prices. They found that among smallholders the MVP of capital is well above the capital price for smallholders, and near equality for largeholders; from this finding they inferred constraints on access to capital among smallholders. They also found that among smallholders the MVP of labor is well under the farm-labor market wage.

Second, we expect that land degradation reduces land productivity, and soil conservation investments raise it. The direction of the hypothesized effect is common sense, but the empirical importance of the effect has rarely (particularly in Africa) been examined in developing countries outside of field-station experiments. A rare example is Bhalla and Roy (1988), who incorporated farm-land quality (proxied by soil type, color, and depth) in their analysis of the relationship between Indian farm size and productivity. Moreover, we expect interaction effects between land quality, farm size, and farm productivity. Suppose small and large farms have equal land quality, and there is an inverse relation between farm size and land productivity. Then, if small farms were to suffer greater land degradation, that would offset the inverse relationship between farm size and land productivity. If they were to suffer less degradation, it would magnify the inverse relationship.

We proceed as follows. Section 2 presents methods and data, Section 3, patterns in the data, Section 4, regression results, and Section 5, conclusions.

2. Methods and data

We use a production function relating output to inputs and other 'conditioners' reflecting farm and plot characteristics such as soil erosion. From the estimates of the function, we compute MVPs of land and labor. We compare these MVPs with factor market prices to test for allocative efficiency and infer constraints in access to inputs. We then regress the MVPs against conditioning factors such as farm size and degree of soil erosion.

2.1. Production function form

We use an unrestricted translog production function because it is general and flexible and allows analysis of interactions among variables (Antle and Capalbo, 1988) [2]. The Cobb-Douglas is a special case of the translog, when the interaction terms have zero coefficients. But unlike the Cobb-Douglas, the translog function does not always generate elasticities of substitution of one, and the isoquants and marginal products derived from the translog depend on the coefficients on the interaction terms (Debertin, 1986) [3]. The general form is:

$$\ln y = \beta_0 + \Sigma_i \beta_i \ln X_i + \Sigma_j \beta_j Z_j + \Sigma_i \Sigma_i \beta_{ii} \ln X_i \ln X_i + \Sigma_i \Sigma_j \beta_{ij} \ln X_i Z_j + \beta_k D_k \quad (1)$$

where βs are coefficients, x, inputs, z, conditioning factors, and D, dummy variables.

2.2. Data

The data used are from a survey with weekly observations over 1990–1991, aggregated to a one-year cross section. The sample is a nationwide stratified-random sample of 1240 farm households, operating 6464 plots. The baseline survey covered inputs and outputs to cropping, and other plot and farm characteristics, but did not: (1) enumerate allocation of own-and hired-labor to specific crops; (2) enumerate allocation of purchased inputs (fertilizer, pesticides, lime) to specific fields or crops; (3) directly observe levels of soil erosion. (We calculated erosion from plot characteristics and other data; see below.) The baseline data are supplemented by data from the one-shot, plot-level, 1991 Agroforestry Survey which enumerated soil conservation measures taken by the same sample of households interviewed in the baseline survey.

2.3. Regression specification

The specification retained is as follows [4].

$$\begin{aligned}\ln(\text{OUTPUT}) = {} & \beta_0 + \beta_1 \text{lnLABOR} + \beta_2 \text{lnLAND} \\ & + \beta_3 \text{FERTSHARE} + \beta_4 \text{EROSION} \\ & + \beta_5 \text{SHAREHVC} + \beta_6 \text{FRAGMENT} \\ & + \beta_7 \text{AGEFARM} + \beta_8 \text{DISTANCE} \\ & + \beta_9 \text{RENTED} + \beta_{10} \text{NORTHWEST} \\ & + \beta_{11} \text{SOUTHWEST} + \beta_{12} \text{NORTHCENTER} \\ & + \beta_{13} \text{EAST} + \beta_{14} \text{lnLABOR}^* \text{lnLAND} \\ & + \beta_{15} \text{lnLABOR}^* \text{FERTSHARE}\end{aligned}$$

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[2] Our use of the unrestricted form avoids problems of inflexibility of the translog under restrictions, discussed in Driscoll et al. (1992).

[3] The marginal product of x_1 in the translog model is given as follows in a two-input model with output y: MPP of $x_1 = y[\beta_1/x_1 + \tau/2 \ln x_2 (1/x_1)]$. Debertin (1986), p. 208.

[4] The retained regressors were tested for exogeneity using the procedure in Rivers and Vuong (1988), and they were all found exogenous. To reduce the computational burden, we discarded variables not significant statistically (at 10%) or important economically. The variables dropped included the quadratic terms for labor and land, and interaction terms that included FRAGMENT, AGEFARM, DISTANCE, RENTED, and dummies for SOUTHWEST, NORTHCENTER, and EAST. We tested and rejected (at 5%) the hypothesis that the coefficients on these rejected variables are different from zero.

$$+ \beta_{16} \ln\text{LABOR} * \text{EROSION}$$
$$+ \beta_{17} \ln\text{LABOR} * \text{SHAREHVC}$$
$$+ \beta_{18} \ln\text{LABOR} * \text{NORTHWEST}$$
$$+ \beta_{19} \ln\text{LAND} * \text{FERTSHARE} +$$
$$\beta_{20} \ln\text{LAND} * \text{EROSION}$$
$$+ \beta_{21} \ln\text{LAND} * SHAREHVC$$
$$+ \beta_{22} \ln\text{LAND} * \text{NORTHWEST} + u \qquad (2)$$

OUTPUT is the value of crops produced (the sum over crops, the output of each of which is weighted by the market price at harvest 1990). The aggregate is used because, although our data show allocation of land to specific crops, we lack data on labor and fertilizer allocation per crop. Moreover, most Rwandan farms have a large share of land in mixed cropping.

Bardhan (1973) notes, however, that such aggregation overlooks the effect of crop mix and that differences in aggregate productivity between small and large farms are attributed to size or returns to scale while in reality they are the result of the crop composition of output. That is, farmers who grow crops with higher market prices appear to be more 'productive' than others who may produce the same physical yields, but of crops with lower market value. We address this problem by controlling for crop mix, with the proxy being the share of 'high value crops' (SHAREHVC), bananas and coffee, in the gross value of output. These are 'cash perennial crops' that tend also to protect the soil better than (semi-subsistence) annual crops, such as grains, tubers, roots, and pulses.

LABOR is expressed in adult-equivalent-days per hectare, and is the sum of family labor and hired labor. It is treated as exogenous because it is mainly family labor from family size and composition data [5].

LAND is hectares of cultivated land. It treated as exogenous because 90% of farmed land is owned, not rented, landholdings are set by traditional land rights, and there is no formal land market for purchase and sale.

[5] Available labor for the household in person-days per hectare (total family labor + labor hired − labor sold) is standardized into adult equivalents (AE): 1 for adults (aged between 16 and 60) and 0.25 for children (between 6 and 15) and seniors (above 60).

All farmers use hoe and machete and none uses animal traction. There is very little use of chemical fertilizer, lime, and pesticides (see Section 3). Soil fertility is maintained mainly by fallow and use of manure. We lack data on quantities of fertilizer and manure used. For simplicity, we assume that plots are equally fertilized, and use a proxy variable, FERTSHARE, the share of cultivated area on which manure, compost, chemical fertilizer, lime, or pesticide is used.

FRAGMENT, the number of plots, reflects farm fragmentation. DISTANCE is the average time the farmer must travel from the residence to the plots (averaged over plots, weighted by plot area). We expect that the more plots the farm has, and the more distant they are from the residence, the less productive is the farm operation.

Two variables reflect soil quality, AGEFARM and EROSION. AGEFARM is the average number of years since cultivation began on currently farmed plots (averaged over plots, weighted by plot area). We expect older plots to be less productive.

EROSION is the average annual soil loss in tons ha^{-1} per farm (averaged over plots, weighted by plot area). It is calculated using the Universal Soil Loss Equation, the USLE (Morgan, 1986; Hudson, 1993). Using the survey data and secondary data [6], one index per plot is calculated as the product of the following indices: (1) rainfall and runoff; (2) soil erodibility; (3) length of the plot (compared with a standard field of 22.6 m); (4) slope of the plot relative to a standard (9%); (5) *C*-value (the ratio of soil loss on a plot under a standard treatment of cultivated bare fallow compared to the soil loss expected from the crop mix and cropping practice used on the current plot); (6) soil conservation practices expressed as the ratio of the soil loss of the plot (given soil conservation measures used thereon) to that of a plot with no conservation practice.

Land RENTED is the share of cultivated area rented per household. Our hypothesis is ambiguous as to its effect. On the one hand, we expect that farmers invest less effort in improving rented plots. On the other hand, farmers usually seek to rent the best land available.

[6] See Byiringiro (1995) for details concerning data used.

Table 1
Farm characteristics

Farm size strata [b]	Smallest	Middle	Largest	Overall	CV
OUTPUT per farm (RWF [a])	21600	34300	52600	36.300	0.88
OUTPUT ha^{-1} (RWF ha^{-1})	74400	42100	26100	47400	1.07
LABOR (days ha^{-1})	1251.0	557.0	271.0	689.0	0.95
LAND (ha)	0.34	0.83	2.38	1.19	0.83
FRAGMENT (plots ha^{-1})	13.0	7.0	3.0	8.0	0.81
AGEFARM (years)	17.9	18.4	20.8	19.1	0.72
EROSION (t ha^{-1})	4.3	4.7	4.6	4.5	1.11
SOILCONS (m ha^{-1})	672.8	414.1	344.6	477.2	1.50
FERTSHARE	68.1	66.2	68.1	67.5	0.44
Chem. fert. expend. (kg ha^{-1})	0.08	0.07	0.08	0.08	14.30
DISTANCE (min)	8.25	9.08	11.65	9.70	1.11
RENTED (%)	9.9	10.0	5.60	8.50	1.93
SHAREHVC (%)	0.34	0.32	0.36	0.34	0.65
Stratum's share land	0.10	0.22	0.68	1.00	
Gini Coefficient land				0.38	

Variables are defined in the text.
[a] 140 RWF = 1 US$ in 1990.
[b] Strata are defined in the text.Number of cases (households) per tercile: 373, 374, 376 for first, second and third tercile.All strata means are significantly different at the 5% level except the following: (1) middle and top terciles for SOILCONS; (2) all terciles for FERTSHARE, chemical fertilizer expenditure, EROSION, AGEFARM, and RENTED; (3) bottom and middle terciles for SHAREHVC.

Dummy variables are used to capture effects of agroclimatic zone. The zone dummy variables are NORTHWEST, SOUTHWEST, NORTHCENTER, and EAST. The constant of the function contains the effect of the SOUTHCENTER zone. The zones follow the delineation given by Clay and Dejaegher (1987). They differ by rainfall, altitude, soil quality, crop mix, and vegetal cover. The Northwest zone covers the volcanic highlands and the upper parts of Lake Kivu's shore and the Zaire-Nile divide. It has high rainfall, relatively small farms, and soils with low organic matter. The Southwest, Northcenter, and Southcenter are similar, with low yields, smaller farms, and poor, degraded soils. The East is a low altitude plain, with less rainfall and bigger farms, more fertile soils, and was recently colonized. In general, the western zones are rainier and higher altitude, with soils that have been farmed much longer than those to the east.

3. Patterns

Table 1 shows patterns in outputs, inputs, and plot and farm characteristics compared across terciles of farms grouped according to relative farm size: 'smallest', averaging 0.34 ha; 'middle', 0.83 ha; 'largest', 2.38 ha [7]. Despite its name, the 'largest' tercile farms are still much smaller than farms in other agroecological regions of Africa outside the tropical highlands. But the average largest-tercile farm is seven times larger than the average smallest-tercile farm. The largest tercile holds 68% of the land, compared with only 10% by the smallest. The Gini coefficient of landholding is 0.38.

Compared with the largest farms, the smallest farms: (1) have three times higher land-yields in value terms; (2) use four times more labor per hectare; (3) have four times the number of plots per hectare (hence the farms are more fragmented); (4) have farmed the holding for fewer years; (5) have plots clustered closer to the domicile; (6) have nearly twice the share of land rented; (7) have only slightly less eroded soils; (8) have twice as much soil conservation investment per hectare; (9) use the same (tiny) amount of chemical fertilizer; and (10) have about

[7] The smallest tercile has farms less than 0.58 ha; the middle, between 0.58 and 1.45; the largest, greater than 1.45 ha.

the same share of land under 'high valued crops' (coffee and bananas).

That the smallest farms are at present no more eroded than the largest farms may be due to the farms' being newer and receiving more soil conservation investment. They are not, on average over the country, husbanded more carefully in terms of receiving more soil amendments or having more of their area planted to the land-protecting perennials, bananas and coffee. Nor do they have the option of fallowing as much as larger farmers do. As these smallest farms age, one can expect in the long term for them to suffer greater soil degradation — unless this is obviated by more use of soil amendments and more land under perennials.

4. Regression results

4.1. The determinants of production

Table 2 shows production regression results. We discuss only significant coefficients. Effects are in general as expected. Positive effects on the aggregate value of crop output are produced by LAND, LABOR, and SHAREHVC, being in the NORTHCENTER and the EAST, and by the interaction of LABOR and the NORTHWEST, and by LAND and the NORTHWEST. Negative effects are produced by the interaction of LAND and EROSION, by AGEFARM, by being in the NORTHWEST, and by the interaction of LABOR and FERTSHARE (the last being unexpected).

4.2. Average and marginal value products and their determinants

Table 3 shows average value products (AVPs) and marginal value products (MVPs) of land and labor. They are calculated taking into account the sole effects of the factor plus the effects of its interactions with other variables.

The AVP and the MVP of land (labor) decrease (increase) as the farm-size tercile increases. Bhalla (1988) notes, however, that an observed inverse relationship between farm size and the MVP or AVP of land can depend on how one stratifies the sample. To test the robustness of our findings, and to see how the MVPs are affected by other variables, we specified the following function quadratic in land [8]:

$$\begin{aligned}\text{MVP}(\text{land}; \text{labor}) &= \beta_0 + \beta_1\text{LAND} + \beta_2\text{LAND}^2 + \beta_3\text{EROSION}\\ &\quad + \beta_4\text{SOILCONS} + \beta_5\text{FERTSHARE}\\ &\quad + \beta_6\text{SHAREHVC} + \beta_7\text{NORTHWEST} + u \end{aligned} \tag{3}$$

Table 4 shows regression results for (3). They show a strong inverse relationship between farm size (LAND) and the MVP of land, and a positive relationship between farm size and the MVP of labor. The relations are U-shaped. EROSION has a strong negative effect on the land MVP, but the effect on labor's is not significant. The effect of SOILCONS on the land MVP is strong and significant, but the effect on the labor MVP is not. In contrast to its insignificant or counter-intuitive effects on output, here FERTSHARE improves land productivity, as expected. NORTHWEST zone farmers also have greater land productivity after controlling for farm size, probably due to the rich soils and high rainfall. A greater SHAREHVC also strongly increases both land and labor productivity in value terms.

Table 3 also compares the MVPs of land and labor with factor prices — the market wage and the land rental rate (as a proxy for the market price of land). Observe that the farmers in the smallest-farms tercile apply labor until the labor MVP is only a third of the market wage compared to two-thirds for the largest farms. This implies a 'bottling-up' of labor on the smallest farms, with a lower opportunity cost of labor than that reflected in the farm labor market. This may be due to constraints to access to that labor market as well as to nonagricultural employment opportunities.

On the smallest-tercile farms, the land MVP is much higher than the land rental rate, indicating constraints on access to land. By contrast, for the largest farms, the land MVP and the rental rate come near equality.

[8] We tested for correlation between SOILCONS and EROSION and rejected multicollinearity.

Table 2
Translog production function estimates

Variable	Coeff.	Variable	Coeff.
(1) LABOR	0.54 *** (0.13)	(13) EAST	0.41 *** (0.06)
(2) LAND	0.38 ** (0.19)	(14) LABOR * LAND	0.01 (0.03)
(3) FERTSHARE	0.60 (0.64)	(15) LABOR * FERTSHARE	−0.01 (0.01)
(4) EROSION	0.01 (0.07)	(16) LABOR * EROSION	0.07 (0.11)
(5) SHAREHVC	2.98 *** (0.91)	(17) LABOR * SHAREHVC	−0.34 ** (0.15)
(6) FRAGMENT	−0.001 (0.002)	(18) LABOR * NORTHWEST	0.22 ** (0.09)
(7) AGEFARM	−0.003 (0.001)	(19) LAND * FERTSHARE	−0.02 ** (0.007)
(8) DISTANCE	0.002 (0.002)	(20) LAND * EROSION	−0.10 *** (0.07)
(9) RENTED	0.001 (0.001)	(21) LAND * SHAREHVC	0.13 (0.10)
(10) NORTHWEST	−0.56 ** (0.57)	(22) LAND * NORTHWEST	0.19 *** (0.07)
(11) SOUTHWEST	−0.05 (0.06)	CONSTANT	6.55 *** (0.76)
(12)NORTHCENTER	0.18 *** (0.05)	Adj. R^2, F Statistic	0.54 60.10 ***

The dependent variable is the logarithm of gross value of output in 1990 agricultural production in RWF.
[a] Standard errors are in parentheses.
[b] *** Significant at 1%; ** significant at 5%; * significant at 10%.
[c] Definitions of variables in text.

We then controlled for all other variables and varied each of several key conditioning variables to see its effects on the MVPs of labor and land. Table 5a shows percentage changes in MVPs as one moves from low to high (defined in the table) farm size (LAND), EROSION, FERTSHARE, SHAREHVC, and SOILCONS. Table 5 b–e show, each in turn, the effects of a given change (e.g. in 5b from low to high EROSION) on the MVPs of various strata of farms defined by the categories (again, low or high) of FERTSHARE, SHAREHVC, and LAND. The key findings from these tables are as follows; we focus on the effects on the land MVPs, as land is the scarcest factor. The effects on the labor MVPs are included in the tables for reference.

First, when EROSION increases from low to high, Table 5a shows the land MVP decreases 30%. Table 5b shows that on farms with a high SHAREHVC (of cash perennials, coffee and bananas) and high FERTSHARE, the effect of moving from low to high EROSION is only 24%. With a low SHAREHVC (hence a high share of annual crops, which have high C-values, which make land more erodible) and low FERTSHARE, increasing EROSION from low to high has a large impact, 51%.

Table 3
Marginal and average factor products

Farm strata (terciles)	Labor (RWF/Adult-equivalent-day)		Land (1000s RWF ha^{-1})	
	MVP	AVP	MVP	AVP
Smallest	37.1	64.2	28.6	74.4
Middle	39.7	76.8	16.1	42.1
Largest	58.8	95.7	9.8	26.1
Overall	45.3	81.6	18.1	47.4
Factor price	100.0		7.5	

Farm size terciles are defined in the text.
Factor prices (wage of labor and rental price of land) were derived from the baseline labor transactions data. The wage rate is for one day of labor. They are median values.

Table 4
Regression of marginal value products of land and labor on farm size and farm characteristics

Variables	MVP of Land	MVP of Labor
Constant	14436.25 *** (2185.52)	17.64 (14.43)
LAND	−8825.79 *** (984.81)	17.31 *** (6.50)
LAND^2	778.81 *** (134.25)	−1.76 ** (0.89)
EROSION	−982.87 *** (123.50)	−1.20 (0.82)
FERTSHARE	37.06 ** (19.57)	0.02 (0.13)
SOILCONS	5.36 *** (0.82)	0.001 (0.005)
SHAREHVC	24206.04 *** (2906.89)	32.62 * (19.19)
NORTHWEST	21719.13 *** (1736.34)	37.33 *** (11.46)
Adj. R^2 F Statistic	0.31, 74.24 ***	0.02, 2.78 ***

Standard errors are in parentheses. *** Significant at 1%; ** significant at 5%; * significant at 10%.

Table 5
Percentage changes in marginal value product of land and labor with changes in conditioning factors from 'low' to 'high' (with the average levels defined after Table 5a)

(5a) Variation of one conditioning factor while holding other variables constant:		
Moving from:	MVP of labor	MVP of land
Smallest-tercile to largest	35%	−36%
Low EROSION to High	−15%	−30%
Low FERTSHARE to High	2%	15%
Low SHAREHVC to High	27%	57%
Low SOILCONS to High	2%	21%
(5b) Effect of a change from Low to High EROSION for various farm categories		
Moving from Low EROSION to High	MVP of Labor	MVP of Land
Low SHAREHVC, Low FERTSHARE	−21%	−51%
Low SHAREHVC, High FERTSHARE	−22%	−45%
High SHAREHVC, Low FERTSHARE	−14%	−29%
High SHAREHVC, High FERTSHARE	−16%	−24%
(5c) Effect of a change from Low to High FERTSHARE for various farm categories		
From Low to High FERTSHARE	MVP of labor	MVP of land
Low EROSION, Low SHAREHVC	7%	27%
Low EROSION, High SHAREHVC	4%	11%
High EROSION, Low SHAREHVC	6%	44%
High EROSION, High SHAREHVC	2%	18%
(5d) Effect of a change from Low to High share of high value crops (bananas/coffee) for various farm categories		
From Low to High SHAREHVC	MVP of labor	MVP of land
Low EROSION, Low FERTSHARE	39%	58%
Low EROSION, High FERTSHARE	49%	92%
High EROSION, Low FERTSHARE	29%	39%
High EROSION, High FERTSHARE	42%	67%
(5e) Effect of a change from Low to High soil conservation investment for various farm categories		
From Low to High SOILCONS	MVP of labor	MVP of land
Low EROSION, Low FERTSHARE, Low SHAREHVC	+1.5%	+25%
High EROSION, Low FERTSHARE, Low SHAREHVC	+1.9%	+42%
Low EROSION, High FERTSHARE, Low SHAREHVC	+1.5%	+22%
High EROSION, High FERTSHARE, Low SHAREHVC	+1.8%	+35%
Low EROSION, Low FERTSHARE, High SHAREHVC	+1.2%	+16%
High EROSION, Low FERTSHARE, High SHAREHVC	+1.4%	+21%
Low EROSION, High FERTSHARE, High SHAREHVC	+1.2%	+15%
High EROSION, High FERTSHARE, High SHAREHVC	+1.4%	+19%

Averages for categories (formed by stratifying sample into terciles and taking the average of the lowest and highest terciles. Farm-size: smallest, 0.34 ha; largest, 2.38 ha; average, 1.2 ha. EROSION: low, 1 t ha^{-1}; high, 8 t ha^{-1}; average, 4.6 t ha^{-1}. FERTSHARE: low, 40%; high, 90%; average, 67.3%. SHAREHVC: low, 15%; high, 54%; average, 34%. SOILCONS: low, 345 m ha^{-1}; high, 673 m ha^{-1}; average 477 m ha^{-1}.

Second, when SOILCONS (soil conservation investment per hectare) increases from low to high, Table 5a shows that the land MVP increases by 21%. Table 5e compares over farms using a triple stratification (low and high EROSION, SHAREHVC, and FERTSHARE), holding all else constant. The farms that benefit most from soil conservation investment are those with high EROSION, low SHAREHVC (again implying a high share of annual crops, which protect the soil less than the cash perennials), and low *or* high FERTSHARE. The effect of moving from low to high SOILCONS is 42% and 35%, respectively for low and high FERTSHARE. Those that benefit least are those with low EROSION, high SHAREHVC, and low *or* high FERTSHARE. The effect of moving from low to high SOILCONS is to increase land MVP only 15% for high FERTSHARE and 18% for low. Hence, from the viewpoint of the reduction of erosion and improvement of land fertility, producing cash perennials and investments in soil conservation are to a certain extent substitutes.

Third, when FERTSHARE increases from low to high, hence more cultivated land receives chemical fertilizer and/or organic matter, Table 5a shows that the land MVP rises by 15%. Table 5c shows that on farms with high EROSION and low SHAREHVC, the gain in land MVP in moving from low to high FERTSHARE can be as high as 44%. Hence, the need for soil amendments is greatest where land is already eroded and annual crops are intensively cropped and thus there is need for replacement of soil nutrients.

Fourth, when SHAREHVC increases from low to high, hence perennial cash cropping increases in importance, Table 5d shows that the impact is quite high on land MVP (92%) (the cash perennials coffee and bananas pay so much more than food annuals such as beans and tubers and grain). The effect is highest where farm conditions are good — when EROSION is low and FERTSHARE is high, and lowest (39%) when farm conditions are poor (high EROSION, low FERTSHARE). Hence, producers of cash perennials have incentive to improve farm conditions, although producing bananas and coffee is itself a fertility-enhancing and soil-protecting measure.

5. Conclusions

This paper addressed the issue of how growing population pressure and land constraints — which translate into tiny farms and land erosion — affect land and labor productivity. We explored: (1) whether the smaller farms have greater average and marginal land productivity than the larger farms, and whether the smaller farms are less allocatively efficient; and (2) whether and how much soil erosion reduces, and soil conservation investments increase, land productivity. Both queries were answered with a strong affirmative. Moreover, the inverse relationship is *not* mitigated by the smaller farms' being more eroded, despite their farming more intensively (with less fallow). In fact, smaller farms are *not* more eroded than larger farms. Moreover, the inverse relationship is *not* mitigated by larger farms' using more nonlabor inputs or by their putting more of their land under cash perennials. In fact, larger farms do *not* do more of either compared to smaller farms.

Moreover, we find the marginal value product of land on smaller farms to be well above the rental price of land, implying factor use inefficiency and constraints to land access. By contrast, the marginal value product of labor on smaller farms was well below the market wage. This implies a 'bottling up' of labor on smaller farms, and constraints to access to labor market opportunities, and perhaps barriers to entry into small business. Hence, attention to the reform of land markets is needed even in situations where land size distribution is only moderately unequal and absolute farm sizes are small. Attention to ways to increase small farmers' access to the labor market will help employ 'surplus' household labor while providing more income to the poor.

The smallest-tercile farms do at least one thing quite differently to offset their being able to fallow much less. They invest twice as much per hectare in soil conservation compared with the largest-tercile farms. The biggest gainers from such investments are farms with a high share of annual food crops, high erosion, and low fertilization rates. Those that gain the least are those with a high share of perennial cash crops and low erosion. While it pays perennial cash crop producers to enhance farm conditions, to a certain extent producing coffee and bananas is a substitute for costly conservation investments (because bananas and coffee retain soil and provide cover). Cash cropping also strongly increases smallholder incomes.

But only one-third of farmland (in all strata) is under cash perennials. For the rest of the land (under semi-subsistence grains, legumes, and roots and tubers), the gross payoff is high to soil conservation and fertilizer/manure application. Hence, programs and policies that reduce the cost and increase the use of these investments and inputs will have great returns to land productivity in a country where each hectare will count in the struggle for food security.

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