Soil Quality and Soil Fertility Investments on Rented Versus Owned Plots: Evidence from a Matched Tenant/Landlord Sample in Malawi

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There is reason to believe that the growth of farmland rental markets in Sub-Saharan Africa (SSA) mayb be associated with a structural transformation process for the region. For example, in the US and EU nearly 50% of the farmland is rented (Kirwan and Roberts 2016). Functioning land rental markets provide the flexibility to allow tenants to expand area cultivated bring more capital into the sector while at the same time potentially providing landlords with compensation for their land assets while they engage in other pursuits outside of agriculture.

Though most land cultivated by smallholders in SSA is managed in customary system where operators lack formal titles, recent evidence from the region suggests growth in land rental markets has been pronounced (Holden, Otsuka, and Place 2009; Chamberlin and Ricker-Gilbert 2016). Though starting at a much lower level than in the developed world, Chamberlin and Ricker-Gilbert (2016) find that the percentage of households renting in land rose from 7.5% in 2002/03 to 15.4% in 2008/09 in Malawi and from 0.9% in 2001/02 to 3% in 2012/13 in Zambia. This suggests that lack of formal tenure security is not inhibiting growth in rental market participation.

At the same time, much of the region is facing a soil fertility crisis: it is estimated that on average 22 kilograms of nitrogen, 2.5 kg of phosphorus and 15 kg of potassium per hectare of cultivated land have been lost per year in SSA over the past 20 years (Sanchez et al. 2002). The fact that the pronounced loss of soil fertility has been occurring at the same time land rental participation is growing is extremely salient because there is a general perception that rented sub-plots receive lower soil fertility enhancing investments than owner-cultivated sub-plots.[1] For example, Gavian and Fafchamps (1996) and Muraoka et al. (2018) both find that rented in sub-plots are less likely to receive animal manure than are owner-cultivated sub-plots. This is a logical finding, given that rental contracts tend to

[1] In this article, a 'plot' is a field that may contain one or more sub-plots. In our context, the rental decision actually occurs at the sub-plot level, as within a plot, one or more sub-plots may be rented while other sub-plots may be owner-cultivated.

be short-term in nature while the soil fertility benefits of applying animal manure take multiple years to be realized.

With these considerations in mind, the objective of the present article is to estimate the soil fertility differences on owner-operated vs. rented sub-plots using a matched tenant/landlord sample of smallholder households in Malawi collected during 2016. In addition, our data collection includes soil samples that provide quantitative estimates of nitrogen (N), phosphorus (P), potassium (K), pH, organic matter, silt, clay, sand and texture on tenants' largest owner-operated and rented-in sub-plots, along with the largest sub-plot that is owener-operated by their landlords. This allows us to expand our estimates of soil quality beyond the self-reported indicators that are included in most studies. To our knowledge, this is the first article to combine soil samples with a matched tenant/landlord dataset in any context.

One of the challenges associated with accurately estimating soil fertility and/or other impacts of land rental markets is that most studies in the region (and all of the studies mentioned above) severely underreport the activities of landlords. In fact, a recent article by Deininger, Savastano, and Xia (2017) use nationally representative LSMS-ISA data from six countries in SSA collect within the past five years to show that total area rented out makes up less than 50% of total area rented in all six countries (Ethiopia, Malawi, Niger, Nigeria, Tanzania, and Uganda). Furthermore, rented out land makes up less than 6% of rented in land in three of the six countries (Malawi, Nigeria, and Uganda). In Malawi, Lunduka *et al*. (2009) found only eight percent of landlords against 20% of tenants. The failure of most datasets to fully capture the landlord side of the rental market at best leaves out important details as to the landlords' intentions, and at worst biases any results and conclusions that are drawn from such incomplete datasets.

Data used in this study come from four districts in Malawi that were purposively sampled based on the potential for active land rental market participation (as inferred from the 2009/10 nationally representative IHS3 data). These districts are: Lilongwe, Salima and Nkhotakota in the Central region and Zomba in the Southern region. Nkhotakota and Salima were selected to represent rural areas, while Lilongwe and Zomba were selected to represent peri-urban areas. The total target sample size was 600, representing 150 farm households per sampled district. Sample households included those renting in land (tenants) or renting out land (landlords), and those that neither rent in nor out (autarkic). Each sampled landlord was matched to his or her tenant as pairs for the household interviews. Thus if a tenant household was sampled, its corresponding landlord was automatically sampled for the interview and vice versa.

Given our unique data, we are able to use tenant-landlord pair fixed-effects in our identification strategy to control for unobservable differences between tenants and landlords who participate on opposite sides of a rental arrangement. The fact that we have soil samples for multiple sub-plots within the household allows us to use a within-household sub-plot-level fixed effect, something that is not available in most other studies. We also have a rich set of household-level demographic and sub-plot-level information that should control for the vast majority of remaining unobserved time-constant and time-varying unobservable factors that might bias our coefficient estimates. That being said, as with any observational study, our results cannot be treated as fully causal. Nonetheless, we believe that the analysis employed in our article uncovers important relationships that are useful for smallholder agricultural policy in SSA.

Our results suggest that when it comes to observable measures of soil quality and investment such as erosion control, and/or tree planting, landlords are less likely to rent out their good quality sub-plots to tenants. This is what we would expect given the short-term nature of rental agreements in Malawi. It is also consistent with other studies from the region (Gavian and Fafchamps 1996, and Muraoka et al. 2018). However, unique to our analysis, when we consider quantitative measures of soil fertility, such as phosphorous which is a relatively time-constant measure of soil fertility and is not easily observable to tenants or landlords, it seems that landlords are actually renting out better quality sub-plots to tenants than what they or the tenants owner-cultivate themselves. It raises the question: are tenants better able to observe quantitative measures of soil quality than are landlords? It also begs the question of how soil quality can be maintained and enhanced as rental market participation inevitably increases in SSA.

Data

Data used in this study come from four districts in Malawi that were purposively sampled based on the potential for active land rental market participation (as inferred from the 2009/10 nationally representative IHS3 data). These districts are: Lilongwe, Salima and Nkhotakota in the Central region and Zomba in the Southern region. Nkhotakota and Salima were selected to represent rural areas, while Lilongwe and Zomba were selected to represent peri-urban areas. The total target sample size was 600, representing 150 farm households per sampled district. Interviews took place during the 2015/16 season. We then randomly sampled individual farming households from the village list of all households. Sample households included those renting in land (tenants) or renting out land (landlords), and those that neither rent in nor out (autarkic). Each sampled landlord was matched to his or her tenant as pairs for the household interviews. Thus if a tenant household was sampled, its corresponding landlord was automatically sampled for the interview and vice versa. This process was repeated until a sample size of 10 matched pairs was reached (i.e. 20 households). Furthermore, 10 autarkic households were randomly selected from the list as control households. Thus a total of 30 households were sampled per village for the household interviews.

After cleaning the data the households used in the analysis farm 1,502 unique sub-plots, of these 404 are rented-in (cultivated by tenants), while 1,191 are owner-cultivated. Of these 1,191 owner cultivated sub-plots, 25 percent are cultivated by tenants, 33 percent are cultivated by landlords and 42 percent are cultivated by autarkic households.

Soil data

We took soil samples and GPS estimates of the area of sub-plots according to the following criteria: the largest owner-operated sub-plot cultivating maize and/or other annual crops for all households (tenant, landlords, and autarkic). In addition, we took soil samples and GPS estimates of the area of the largest rented-in sub-plot for each tenant and matched it to the landlord who had rented it out during that season. In total, we are able match 533 sub-plots to their soil samples and GPS area estimates. Of these, 161 sub-plots belong to autarkic households, 124 are the owner-operated sub-plots of the landlords, and 248 are cultivated by tenants. Of the 248 tenant controlled sub-plots, 172 are rented-in and 74 are owner-operated.

Our survey team included soil technicians from the Lilongwe University of Agriculture and Natural Resources (LUANAR) soil lab. The technicians took two soil samples from each selected sub-plot. Technicians took one sample from the top soil while a second sample was collected three feet below the surface using an auger to give a measure quality in the sub-soil. Having a measure of quality in the top-soil and in the sub-soil, gives us a more robust estimate of the soil health on the sub-plot.

After collection and labeling, the soil lab at LUANAR analyzed the soil samples for the following measures in both the top-soil and sub-soil: nitrogen, phosphorus, ph, organic matter, silt, clay, sand and texture. These quantitative measures allow us to measure soil quality broadly. In addition, we ask all households about their perceptions of the soil quality on their owned and rented-in, and rented-out sub-plots. This allows us to compare quantitative measurements of soil quality with farmers' assessments of soil quality. Furthermore, since we ask tenants and landlords about the soil quality on the rented sub-plot that connects them along with soil quality on their owner-operated sub-plots, it allows us to understand about how their perceptions about soil quality affect the rental decision.

Methods

The empirical models estimated in this article test how sub-plots that are rented-in vs owner-operated differ in i) quantitative measures of soil fertility, ii) their operators' assessment of soil fertility, and iii) past soil fertility investments that have been made on the sub-plot. We also test how these soil fertility investments differ between tenant and landlords' owner-operated sub-plots. To address these questions, we estimate soil fertility measure or investment on sub-plot i for household j in rental pair p as follows:

1) $S_{ijp} = \alpha_1 R_{ij} + \alpha_2 T_j + \alpha_3 A_j + \alpha_4 L_j + \alpha_5 H_j + \varepsilon_{ij}$

Where *S* represents soil fertility measure or investment decision on the sub-plot. As mentioned in the data section, the quantitative measures of soil fertility are nitrogen, phosphorus, ph, organic matter, silt, clay, sand and texture. In addition, the sub-plot operator's assessment of soil fertility is measured as i) whether the soil color is black or brown, as opposed to grey, red or other color indicating poor soil quality, ii) if the sub-plot is flat rather than sloped, iii) if the soil is of mixed sandy and clay loamy soil, as opposed to being mostly sandy or mostly clay which are of poorer quality, iv) if the sub-plot operator rates the soil as being good, fair or poor quality. The soil fertility investment decisions from the previous years on the sub-plot are i) if a fruit tree is planted on it, ii) if any type of agro-forestry is practiced on the sub-plot, iii) if crop residues were left on the sub-plot in the previous year, iv) if the sub-plot has any erosion control structures, such as terraces or contour ridges.

On the right hand side of equation 1, the variable *R* is a binary indicator of whether or not the sub-plot is rented-in or owner-cultivated (by either a tenant or landlord), and α_1 represents the corresponding parameter to estimate. Previous literature indicates that rented in sub-plots are less likely to receive organic manure than owner-operated sub-plots as the benefits of applying organic manure to soil fertility take several years to materialize and rental contracts are short-term (Gavian and Fafcahmps 1996, Yamano et al. 2011, Ricker-Gilbert et al. 2017, Muraoka et al. 2018). Therefore, if our measures of soil fertility are related to organic manure application, we might expect the coefficient estimate on $\hat{\alpha}_1$ to have a negative sign.

Equation 1 also includes the variable T, which is a binary indicator equal to one if household j who operates sub-plot i is a tenant, and equal to zero if the household is a landlord. The corresponding parameter to estimate is α_2, and a statistically significant coefficient estimate on $\hat{\alpha}_2$ suggests that a tenant's owner-operated sub-plot has a higher level of soil fertility or greater soil fertility investment than does his or her landlord pair on that person's owner-operated sub-plot *ceteris paribus*.

The key hypotheses in this study are considered in the variables R, and T and tested by the coefficient estimates on $\hat{\alpha}_1$ and $\hat{\alpha}_2$ of equation 1. However, we include a number of controls in the model including the value of total household assets denoted by A, with corresponding parameter α_3. It is important to consider household assets and the disparity in them between tenants and landlords as recent empirical evidence from Malawi and elsewhere in Southern Africa finds that tenants on average are significantly wealthier than landlords (Chamberlin and Ricker-Gilbert 2016; Ricker-Gilbert et al. 2017). This wealth discrepancy could influence the rental decision and also affect soil fertility on rented vs. owner-operated sub-plots. In addition, we control for household pre-rental landholding, denoted by L in equation 1 with α_4 as corresponding parameter. Pre-rental landholding is defined as all land that is cultivated by the household (excluding rented-in land) in addition to land that will be rented out, and land that is fallowed, used as a woodlot or in pasture.[2] This is an important factor to consider in our model because larger landholdings are often found to be empirically correlated with lower yields (Carletto et al. 2013). As such, there may be some relationship between household landholding, the rental decision, and soil fertility measures and investments that should be controlled for in the regression. Finally we control for household demographics that could affect the rental decision and soil fertility and investment such as number of family members, education of the household head, if the household head is a migrant, if the head is a relative of the chief, if the head is a female and the age of the head. The corresponding parameter vector is denoted by α_5 in equation 1. The sub-plot specific error term is denoted by ε. The next section discusses how we deal with potential correlation between the error term and observed covariates in our model.

Identification strategy

Our primary concern for identifying the coefficients of interest in equation 1 is that there may be correlation between the error term and the observed covariates particularly in R and T, due to omitted variable bias. This is an obvious problem and people do not randomly enter into rental contracts with each other, so we are concerned that some factors that are unobservable to us may jointly determine i) the decision to be a tenant or landlord, ii) their subsequent decision of which sub-plots to rent-in, or rent-out, and which to cultivate themselves and the soil fertility and investment measures in our study. We deal with this in two ways. First, by adding the rich set of controls as mentioned above including numerous demographic

[2] Land may also be borrowed-in where one household lets another household cultivate their land with no money exchanged. For the purpose of this analysis, we consider borrowed land to be rented land at a zero price.

characteristics we are able to bring those factors out of the error term, thus removing them as omitted variables in the model.

Second, we estimate equation 1 using rental-pair specific fixed effect FE. This method follows Bellemare (2012) and Deininger et al., (2013), and it allows us to take advantage of the within pair variation of our tenants and landlords. This specification drops autarkic households but allows us to estimate the soil fertility and investment measure on sub-plot i for household j in rental pair p, it is presented as follows:

2) $S_{ijp} = \alpha_1 R_{ijp} + \alpha_2 T_{jp} + \alpha_3 A_{jp} + \alpha_4 L_{jp} + \alpha_5 H_{jp} + a_p + v_{ijp}$

where the covariates and parameters to estimate are the same in equation 3 as in equation 1 except for the fact that the error term now has two components. The unobserved pair-specific FE is represented by a, which captures unobserved differences within-in tenant-landlord pairs that could influence the rental decision and S in our model. Such unobservable factors include social and power dynamics and social connections within the rental partner pair. Our use of the pair-specific FE allows us to control for potential correlation between these factors and the covariates in our models. The individual specific error term is represented by v. It is assumed to be i.i.d. normal, conditional on the observed covariates and a. Ultimately, we recognize that even with the pair-specific FE estimator and our controls that we cannot assume full causality of our results. Nevertheless, we feel that our data, model, and results are unique and demonstrate some important associations that are very important for smallholder agricultural policy in SSA.

The models on soil fertility and investments in equations 1 and 2 are estimated linearly using a linear probability model (LPM). Equation 1 is estimated as pooled LPM while equation 2 is estimated using LPM with rental pair FE. LPM has the advantage over a non-linear estimator such as probit of providing easy to interpret coefficients, and it allows us to use tenant-landlord pair FE, which would be biased in probit estimation, due to the incidental parameters problem (Wooldridge, 2010). We cluster the standard errors of our estimates at the tenant-landlord pair level to deal with concerns about heteroscedasticity and serial correlation.

Results

Table 1 presents the descriptive results comparing means and standard deviations of key right hand side variables used in the analysis for tenants, landlords, and autarkic households. It is clear from the table that the population of tenants is different from the population of landlords. This can be seen in the fact that tenants have higher levels of education on average (7.65 years) compared to landlords (4.94). In addition, tenants are more likely to be migrants than landlords, 48% vs. 31% on average. This is consistent with other studies and makes sense that tenants would come from outside in search of land to farm (Wineman and Liverpool-Tasie 2016). Tenant household heads are also younger than landlords on average and significantly less likely to be female headed, 8%, compared to 26%. Furthermore, tenants have a significantly higher average value of non-land assets at USD 760 compared to USD 120 for landlords. In fact the only assets that landlords seem to have more of than tenants is pre-rental landholding, with the average landlord holding 1.90 hectares, and the average landlord holding 0.92 hectares. These statistics are consistent with other studies from southern Africa and suggest that tenants have more resources than landlords, apart from land (Chamberlin and Ricker-Gilbert 2016; Ricker-Gilbert et al. 2017). These descriptive statistics provide *prima facia* evidence of tenants bringing education and assets into agriculture and using those resources to acquire land from less well-off landlord households.

[Table 1 here]

Table 2 compares the quantitative soil quality measure across owner-operated and rented-in sub-plots for tenants in the sample. These measures are compared for both top-soil and sub-soil on the sub-plots. The main difference between owner-cultivated and rented-in sub-plots is in the level of phosphorus that is in both the top-soil and sub-soil. On average rented-in sub-plots have a phosphorous level that is 5.34 units higher than the tenant's owner-operated sub-plot in the top soil, and this difference is 4.61 units in the sub-soil. This finding is particularly salient given that phosphorus is a nutrient that stays in the soil for multiple years and changes little in the short-run. This would suggest that tenants are trying to rent-in sub-plots of better quality with higher levels of soil fertility than on their owner-cultivated sub-plots. Several other measures of soil quality such as nitrogen and organic matter in the top-soil and silt and clay in the top and sub-soil are significantly different at the 10% significance level between owner-cultivated and rented-in sub-plots. These findings support the argument that tenants maybe trying to rent-in sub-plots of better quality than what they owner cultivate.

[Table 2 here]

Table 3 is analogous to the previous table, except that it compares soil quality measures across owner-operated and rented-out sub-plots for landlords in the sample. The results are generally consistent with those in table 2. They suggest that phosphorous levels are higher on the sub-plots that landlords rent out than then are on sub-plots that they owner-cultivate. On average rented-out sub-plots have a phosphorous level that is 7.25 units higher than the landlord's owner-operated sub-plot in the top soil, and this difference is 5.42 in the sub-soil. This finding is consistent with the idea that landlords rent out their better quality land to tenants, at least in terms of phosphorous levels.

[Table 3 here]

Table 4 provides descriptive statistics for the soil fertility investments and operators' self-assessment of soil quality on tenants owner-operated and rented-in sub-plots. The evidence from this table stands somewhat in contrast to that of table 2. For example, rented-in sub-plots are significantly less likely to have good quality soil color that is either black or brown according to the operator. They are also 10 percentage points more likely to rate the soil on rented-in sub-plots as being poor compared to their owned plots on average. Rented in sub-plots are also significantly less likely to have fruit trees planted on them, and they are 29 percentage points less likely to have crop residues left on them from the previous year. Fruit tree planting and leaving crop residue are investments that pay off by enhancing soil fertility in the longer-term. Given the short-term nature of rental contracts in Malawi, it seems unlikely that these investments would be cost-effective for a tenant to make on a rented-in plot.[3]

[Table 4 here]

Table 5 is analogous to table 4 except that it provides descriptive statistics for the soil-fertility investments and operators' self-assessment of soil quality on landlords' owner-operated and rented-out sub-plots. The findings from table 5 are consistent with table 4 as landlords are on average 14 percentage points more likely to have erosion control structures on sub-plots that they cultivate than they are on sub-plots that they rent-out. In addition, landlords are 27 percentage points more likely to have left crop residues on sub-plots that they

[3] Ricker-Gilbert et al. (2017) find that the median landlord plans to rent out his or her sub-plot for zero additional years beyond the current one.

cultivated this year than on sub-plots that they rented out. These are rational choices given the benefits of erosion control and short-term nature of rental contracts in Malawi.

[Table 5 here]

Table 6 presents the results for the model where the dependent variables are quantitative measures of soil fertility: nitrogen, phosphorus, ph, organic matter, silt, clay, sand and texture in the top-soil. Table 7 presents the same dependent variables in the sub-soil. These two tables are the result of estimating the model presented in equation 2 estimated via LPM with rental-pair FE. The top RHS variables in the table, if the sub-plot is rented-in, and if the sub-plot is controlled by the tenant, test the key questions in our article of whether quantitative soil fertility measures are affected by rental status and management by tenants vs. landlords. Results from table 6 show that on average only soil texture in the top-soil is higher on rented-in vs. owner-cultivated sub-plots. The effect is marginally statistically significant (p-value=0.07) and the coefficient suggests that on average texture is 0.30 units higher on rented-in compared to owner-cultivated sub-plots. Table 7 suggests that in the sub-soil, rented-in plots have marginally higher levels of silt on average, at 0.55 additional units than do owner-cultivated sub-plots (p-value=0.078). There is no statistical difference in soil quality measures for either top or sub-soil on owner-operated plots between tenants and landlords. The results from tables 6 and 7 are not strong but provide some marginal evidence that is consistent with tables 2 and 3 suggesting that rented-in sub-plots have higher soil fertility than do owner-operated sub-plots.

[Table 6 here]

[Table 7 here]

Table 8 presents the regression results for factors affecting soil fertility investments and operators' self-assessment of soil quality. As in tables 6 and 7 this table presents the estimated results from equation 2 and is estimated by LPM with rental-pair FE. As in the previous two tables the key variables are: if the sub-plot is rented-in, and if the sub-plot is controlled by the tenant. Results of these tables are consistent with the descriptive results in table 5, but somewhat in contrast to findings in earlier tables related to quantitative measures of soil fertility. For example, table 8 shows clear evidence that rented-in sub-plots have lower levels of observable measures of self-assessed soil fertility and soil fertility investments on average than do owner-operated sub-plots. Column 1 of table 8 shows that rented-in plots are 12 percentage points less likely to have good quality soil that is black or brown on average (p-value = 0.039). In column 2, rented-in plots are 16 percentage points less likely to have fruit trees planted on them (p-value=0.013), and 18 percentage points less likely to have had crop residues left on them in the last season (p-value=0.006) on average, compared to owner-cultivated sub-plots. In addition, rented-in sub-plots are also 11 percentage points more likely to be rated as being of poor soil quality by their operator than are owner-operated sub-plots on average. There is no statistical difference in soil fertility investments and operators' self-assessment of soil quality between tenants' and landlords' owner-cultivated sub-plots.

[Table 8 here]

Conclusions

The objective of the present article is to estimate the soil fertility differences on owner-operated vs. rented sub-plots using a matched tenant/landlord sample of smallholder households in Malawi. To our knowledge this is the first study that combines quantitative data on soil fertility including estimates of nitrogen, phosphorus, ph, organic matter, silt, clay, sand and texture with issues of land rental markets and land tenure. In addition, we have a matched sample of tenant and landlord pairs which allows us to use rental-pair level fixed effects to control for unobserved differences in their relationship that may affect rental and soil fertility decisions.

Results from our analysis suggest that when it comes to observable measures of soil quality and soil fertility investment such as adding erosion control structures and/or tree planting, landlords are less likely to rent out their good quality sub-plots that have these investments to tenants. This is certainly what we would expect given the short-term nature of rental agreements in Malawi, and is consistent with other studies from the region which find that rented-in sub-plots are significantly less likely to receive organic manure than are owner-cultivated sub-plots (Gavian and Fafchamps 1996; Muraoka et al. 2018). However, completely unique to our analysis, when we consider quantitative measures of soil fertility, such as phosphorous which is a relatively time-constant measure of soil fertility and is not easily observable to tenants or landlords, it seems that landlords are actually renting out better quality sub-plots to tenants than what they or the tenants owner-cultivate themselves. It raises the question: are tenants better able to observe quantitative measures of soil quality than are landlords?

Though we cannot answer this question directly in our analysis, or results are relevant for contemporary policy debates in SSA. Population is growing in the region against a fixed land base. As such, land rental markets are the most salient way for land based resources to be re-allocated among those who which to expand their cultivated area and potentially invest management and capital in the sector, and those who may wish to leave the sector and engage in other activities. However, given the fact that we find tenants have higher education than landlords and to be wealthier than landlords on average in terms of all assets besides land, it raises the question of the egalitarian nature of land rental markets, and if tenants are able to engage in extracting sub-plots of better quality from their less well-off landlord rental partners. This has implications for the long-run fertility and health of African soil, which are already in crisis.

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Table 1. Descriptive Comparisons between tenant, landlord, and autarkic households

	Tenant		landlord		Autarkic		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Head education	7.65	4.14	4.94	3.66	5.25	3.71	6.29	4.10
=1 if household head is migrant	0.48	0.50	0.31	0.46	0.27	0.44	0.37	0.48
Landholding in hectares	0.92	1.04	1.90	1.49	1.26	0.99	1.25	1.21
number of members in household	5.63	2.34	5.05	2.02	5.11	2.01	5.34	2.18
=1 if HH head is female	0.08	0.27	0.26	0.44	0.31	0.46	0.19	0.39
=1 if head is relative of chief	0.50	0.50	0.58	0.50	0.58	0.49	0.54	0.50
age of household head in years	40.50	11.42	47.88	15.82	48.75	14.72	44.71	14.11
value of total household assets	$760	$2,716	$120	$295	$246	$645	$456	$1,912

Note: number of sub-plot level observations is 533. Of these, 161 sub-plots belong to autarkic households, 124 are the owner-operated sub-plots of the landlords, and 248 are cultivated by tenants. Of the 248 tenant controlled sub-plots, 172 are rented-in and 74 are owner-operated.

Table 2. Comparison of soil-fertility measures between tenants owner-operated and rented-in sub-plots

	Owner- operated sub-sub-plot	Rented-in sub-sub-plot	difference		p-value
Top-soil					
nitrogen	0.06	0.08	-0.02	*	(0.09)
phosphorus	35.26	40.60	-5.34	***	(0.00)
PH	5.86	5.88	-0.02		(0.35)
organic matter	2.15	2.68	-0.53	*	(0.09)
silt	8.36	8.63	-0.27	*	(0.08)
clay	25.67	24.52	1.15	*	(0.06)
sand	66.36	67.19	-0.83		(0.16)
texture	4.76	4.82	-0.06		(0.26)
Sub-soil					
nitrogen	0.06	0.06	0.00		(0.21)
phosphorus	28.58	33.19	-4.61	***	(0.00)
PH	5.77	6.03	-0.26		(0.11)
organic matter	2.07	2.20	-0.13		(0.21)
silt	8.26	8.59	-0.33	*	(0.06)
clay	25.56	24.41	1.15	*	(0.08)
sand	66.56	67.35	-0.79		(0.20)
texture	4.70	4.77	-0.07		(0.26)

Note: number of sub-plot level observations is 248 tenant controlled sub-plots, 172 are rented-in and 74 are owner-operated by tenants; p-values in parentheses; ***, **, and * denote that the corresponding coefficients are statistically significant at the 1%, 5% and 10% level respectively.

Table 3. Comparison of soil-fertility measures between landlord's owner-operated and rented-out sub-plots

	Owner-operated sub-sub-plot	Rented-out sub-sub-plot	difference		p-value
Top-soil					
nitrogen	0.07	0.08	-0.01		(0.36)
phosphorus	33.48	40.73	-7.25	**	(0.02)
PH	5.83	5.89	-0.06		(0.25)
organic matter	2.43	2.71	-0.28		(0.36)
silt	8.70	8.61	0.09		(0.61)
clay	25.73	24.32	1.41		(0.90)
sand	66.00	67.42	-1.42		(0.13)
texture	4.86	4.83	0.03		(0.58)
Sub-soil					
nitrogen	0.06	0.06	0.00		(0.41)
phosphorus	27.79	33.21	-5.42	**	(0.03)
PH	5.68	6.03	-0.35		(0.20)
organic matter	2.16	2.21	-0.05		(0.40)
silt	8.30	8.55	-0.25		(0.21)
clay	24.79	24.40	0.39		(0.62)
sand	67.35	67.40	-0.05		(0.49)
texture	4.92	4.76	0.16		(0.83)

Note: number of sub-plot level observations is 296. Of these, 124 are the owner-operated sub-plots of the landlords, and 172 are rented-out sub-plots that tenants control; p-values in parentheses; ***, **, and * denote that the corresponding coefficients are statistically significant at the 1%, 5% and 10% level respectively.

Table 4. Comparison of soil-fertility Investments made on tenant's owner-operated and rented-in sub-plots

	Owner-operated sub-plot	Rented-in sub-plot	difference		p-value
soil is black or brown	0.76	0.54	0.22	***	(0.00)
sub-plot is flat	0.57	0.64	-0.07		(0.28)
mixed clay and sand	0.28	0.22	0.06		(0.29)
fruit trees planted	0.42	0.27	0.15	**	(0.02)
erosion control	0.28	0.22	0.06		(0.25)
agro-forestry	0.20	0.17	0.03		(0.60)
crop-residues last year	0.74	0.45	0.29	***	(0.00)
soil rated good	0.49	0.38	0.11		(0.11)
soil rated fair	0.39	0.40	-0.01		(0.95)
soil rated poor	0.12	0.22	-0.10	*	(0.06)

Note: number of sub-plot level observations is 248 tenant controlled sub-plots, 172 are rented-in and 74 are owner-operated by tenants; p-values in parentheses; ***, **, and * denote that the corresponding coefficients are statistically significant at the 1%, 5% and 10% level respectively.

Table 5. Comparison of soil-fertility Investments made on landlord's owner-operated and rented-out sub-plots

	Owner-operated sub-plot	Rented-out sub-plot	difference		p-value
soil is black or brown	0.48	0.56	-0.08		(0.23)
sub-plot is flat	0.61	0.64	-0.03		(0.60)
mixed clay and sand	0.24	0.2	0.04		(0.53)
fruit trees planted	0.37	0.32	0.05		(0.52)
erosion control	0.35	0.21	0.14	***	(0.01)
agro-forestry	0.18	0.18	0.00		(0.92)
crop-residues last year	0.75	0.48	0.27	***	(0.00)
soil rated good	0.39	0.41	-0.02		(0.83)
soil rated fair	0.39	0.39	0.00		(0.96)
soil rated poor	0.21	0.2	0.01		(0.84)

Note: number of sub-plot level observations is 296. Of these, 124 are the owner-operated sub-plots of the landlords, and 172 are rented-out sub-plots that tenants control; p-values in parentheses; ***, **, and * denote that the corresponding coefficients are statistically significant at the 1%, 5% and 10% level respectively.

Table 6: Factors affecting soil fertility measures (top-soil) across sub-plots

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	nitrogen	phosphorus	ph	organic	silt	clay	sand	texture
=1 if sub-plot is rented-in	-0.03	0.34	0.03	-1.04	0.22	-0.74	0.52	0.30*
	(0.331)	(0.934)	(0.691)	(0.329)	(0.535)	(0.567)	(0.719)	(0.073)
=1 if sub-plot is controlled by	0.01	0.41	-0.16	0.18	-0.24	0.17	0.02	-0.10
tenant	(0.792)	(0.929)	(0.228)	(0.791)	(0.590)	(0.922)	(0.990)	(0.672)
Head education	-0.00	0.50	0.00	-0.01	0.01	-0.37**	0.36*	-0.02
	(0.831)	(0.408)	(0.832)	(0.858)	(0.925)	(0.043)	(0.083)	(0.550)
=1 if household head is migrant	-0.00	1.28	-0.26**	-0.08	0.19	2.54**	-2.75*	-0.01
	(0.758)	(0.685)	(0.016)	(0.735)	(0.692)	(0.047)	(0.072)	(0.939)
Landholding in hectares	-0.01***	0.78	-0.07	-0.29***	-0.04	0.79	-0.81	-0.11
	(0.002)	(0.545)	(0.123)	(0.002)	(0.821)	(0.151)	(0.223)	(0.129)
number of members in hh	0.00	-1.11	0.00	0.07*	0.07	-0.33	0.28	0.03
	(0.101)	(0.193)	(0.933)	(0.096)	(0.541)	(0.283)	(0.443)	(0.511)
=1 if HH head is female	0.01	7.86*	-0.19	0.40	0.34	-1.24	0.98	-0.13
	(0.166)	(0.095)	(0.286)	(0.164)	(0.591)	(0.451)	(0.613)	(0.576)
=1 if head is relative of chief	0.01	-1.78	0.06	0.30	-0.10	-0.77	0.92	-0.18
	(0.339)	(0.697)	(0.698)	(0.365)	(0.878)	(0.728)	(0.716)	(0.514)
age of household head in years	-0.00	0.05	-0.00	-0.00	0.03	-0.03	0.00	-0.00
	(0.657)	(0.698)	(0.477)	(0.681)	(0.117)	(0.566)	(0.964)	(0.642)
Log value of total household assets	0.00	1.18	-0.00	0.03	0.02	0.09	-0.13	-0.06
	(0.740)	(0.484)	(0.970)	(0.728)	(0.898)	(0.866)	(0.830)	(0.470)
Constant	0.08***	31.39***	6.28***	2.70***	7.01***	28.67***	64.82***	5.36***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	372	372	372	372	372	372	372	372
R-squared	0.014	0.024	0.051	0.014	0.022	0.043	0.037	0.047
Number of tenant-landlord pairs	163	163	163	163	163	163	163	163

Note: Models estimated via LPM rental-pair FE with LPM; p-values in parentheses; ***, **, and * denote that the corresponding coefficients are statistically significant at the 1%, 5% and 10% level respectively.

Table 7: Factors affecting soil fertility measures (sub-soil) across sub-plots

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	nitrogen	phosphorus	ph	organic matter	silt	clay	sand
=1 if sub-plot is rented-in	-0.01	0.33	0.11	-0.17	0.55*	0.90	-1.46
	(0.627)	(0.898)	(0.441)	(0.640)	(0.078)	(0.503)	(0.323)
=1 if sub-plot is controlled by tenant	-0.00	-0.19	0.18	-0.03	0.12	-0.17	0.01
	(0.951)	(0.959)	(0.585)	(0.945)	(0.793)	(0.925)	(0.997)
Head education	0.00	0.84*	0.07	0.09	-0.06	-0.15	0.21
	(0.142)	(0.068)	(0.303)	(0.142)	(0.272)	(0.359)	(0.275)
=1 if household head is migrant	-0.02**	0.11	0.01	-0.58**	-0.13	-0.16	0.26
	(0.037)	(0.968)	(0.990)	(0.038)	(0.757)	(0.909)	(0.872)
Landholding in hectares	-0.01***	-0.09	-0.07	-0.23***	0.15	-0.15	-0.07
	(0.008)	(0.923)	(0.298)	(0.008)	(0.517)	(0.768)	(0.904)
number of members in hh	0.00	-0.14	-0.09	0.00	0.08	0.58	-0.64
	(0.983)	(0.844)	(0.363)	(0.962)	(0.435)	(0.134)	(0.154)
=1 if HH head is female	0.01	7.30*	-0.11	0.36	-1.26**	-2.03	3.37*
	(0.270)	(0.056)	(0.658)	(0.265)	(0.010)	(0.267)	(0.098)
=1 if head is relative of chief	0.01	-0.42	-0.82	0.28	-0.53	0.44	0.15
	(0.412)	(0.914)	(0.323)	(0.422)	(0.308)	(0.825)	(0.946)
age of household head in years	0.00	0.02	0.01	0.00	-0.01	-0.02	0.03
	(0.710)	(0.845)	(0.592)	(0.687)	(0.506)	(0.680)	(0.623)
Log value of total household assets	-0.00	0.78	-0.13	-0.13	-0.14	-0.74	0.87
	(0.422)	(0.556)	(0.358)	(0.429)	(0.366)	(0.165)	(0.150)
Constant	0.07***	20.91**	6.66***	2.48***	9.56***	26.99***	63.97***
	(0.004)	(0.013)	(0.000)	(0.004)	(0.000)	(0.000)	(0.000)
Observations	372	372	372	372	372	372	372
R-squared	0.047	0.047	0.034	0.046	0.061	0.026	0.035
Number of Number of tenant-landlord pairs	163	163	163	163	163	163	163

Note: Models estimated via LPM rental-pair FE with LPM; p-values in parentheses; ***, **, and * denote that the corresponding coefficients are statistically significant at the 1%, 5% and 10% level respectively.

Table 8: Factors affecting soil investments across sub-plots

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	black or brown soil	Sub-plot is flat	Mixed soil	Fruit trees planted	Erosion control	Agro-forestry	Crop residues left	Good soil	Fair soil	Poor soil
=1 if sub-plot is	-0.12**	0.00	-0.07	-0.16**	-0.03	-0.04	-0.18***	-0.09	-0.02	0.11**
rented-in	(0.039)	(0.992)	(0.209)	(0.013)	(0.612)	(0.337)	(0.006)	(0.155)	(0.717)	(0.042)
=1 if sub-plot is	0.17	0.11	0.08	-0.02	-0.13	-0.07	-0.05	0.04	0.06	-0.09
controlled by tenant	(0.135)	(0.261)	(0.294)	(0.811)	(0.184)	(0.191)	(0.569)	(0.705)	(0.566)	(0.309)
Head education	-0.01	0.00	-0.01	-0.00	0.00	0.02**	-0.00	-0.00	-0.01	0.01
	(0.483)	(0.742)	(0.474)	(0.844)	(0.941)	(0.034)	(0.956)	(0.947)	(0.578)	(0.428)
=1 if household	0.15*	0.09	0.09	-0.01	0.05	-0.04	-0.02	-0.16**	0.16*	-0.01
head is migrant	(0.076)	(0.312)	(0.161)	(0.912)	(0.555)	(0.441)	(0.760)	(0.046)	(0.088)	(0.939)
Landholding in	0.05	0.07	0.01	0.01	-0.02	-0.03	-0.03	-0.02	0.04	-0.02
hectares	(0.238)	(0.110)	(0.622)	(0.846)	(0.650)	(0.232)	(0.199)	(0.725)	(0.409)	(0.520)
number of	-0.03	0.00	-0.00	-0.03	-0.02	-0.00	0.01	0.00	-0.01	0.01
members in hh	(0.153)	(0.957)	(0.764)	(0.146)	(0.225)	(0.751)	(0.392)	(0.999)	(0.695)	(0.666)
=1 if HH head is	-0.10	0.07	-0.16*	-0.10	-0.04	0.01	0.04	0.06	0.03	-0.09
female	(0.378)	(0.496)	(0.064)	(0.341)	(0.673)	(0.901)	(0.670)	(0.567)	(0.767)	(0.401)
=1 if head is relative	-0.07	-0.18	-0.00	-0.06	-0.03	0.05	0.04	0.03	0.08	-0.11
of chief	(0.552)	(0.123)	(0.989)	(0.569)	(0.746)	(0.378)	(0.628)	(0.779)	(0.465)	(0.338)
age of household	-0.01*	0.00	-0.00	0.00	0.00	0.00	-0.00	0.00	-0.00	0.00
head in years	(0.067)	(0.967)	(1.000)	(0.800)	(0.520)	(0.984)	(0.776)	(0.491)	(0.498)	(0.918)
Log value of total	-0.00	-0.05	-0.01	-0.00	0.04	0.02	-0.00	0.04	-0.02	-0.02
household assets	(0.965)	(0.149)	(0.569)	(0.898)	(0.218)	(0.475)	(0.930)	(0.206)	(0.567)	(0.432)
Constant	0.93***	0.72***	0.30	0.62**	0.23	0.11	0.68***	0.19	0.50**	0.31
	(0.000)	(0.003)	(0.145)	(0.018)	(0.157)	(0.400)	(0.000)	(0.406)	(0.031)	(0.125)
Observations	372	372	372	372	372	372	372	372	372	372
R-squared	0.075	0.051	0.039	0.080	0.034	0.042	0.092	0.041	0.025	0.048
Number of tenant-landlord pairs	163	163	163	163	163	163	163	163	163	163

Note: Models estimated via LPM rental-pair FE with LPM; p-values in parentheses; ***, **, and * denote that the corresponding coefficients are statistically significant at the 1%, 5% and 10% level respectively.