



Soil Quality in Uganda: Do Transfer Rights Really Matter?

Francisco M. P. Mugizi ¹

Received: 3 August 2021 / Accepted: 10 January 2022 / Published online: 24 January 2022
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2022

Abstract

This paper uses a unique decade-long panel data with lab-tested soil measures from farmers in Uganda to examine the relationship between transfer rights and soil quality. We find that transfer rights are associated with better soil. This possibly has to do with the ways farmers with transfer rights manage their land compared to farmers without transfer rights. We find strong positive correlation between transfer rights and use of chemical fertilizers. Although we find no strong correlation between transfer rights and agricultural intensification in terms of manure use, the strong positive relationship found between transfer rights and soil quality may suggest that farmers with transfer rights may be investing in soil improvement through other means such as use of compost, crop residues, and fallowing.

Keywords Property rights · Land tenure · Investment incentives · Soil quality · Agricultural intensification · Uganda

Introduction

Economists have long argued that property rights to land that are secure and easily transferable increase investment incentives (Feder and Feeny 1991, Besley 1995, Brasselle et al. 2002, Goldstein and Udry 2008, Abdulai et al. 2011, Deininger et al. 2011, Fenske 2011). In agricultural societies of Sub-Saharan Africa (SSA), tenure security and transferability of land can incentivize farmers to invest in land improvement. This may in turn increase the quality of land and boost agricultural productivity. Moreover, land tenure security and transferability of land induce intensification of farming (Otsuka and Place 2001). Notwithstanding, tenure insecurity¹ and lack of transfer rights remain problems in SSA (Namubiru-Mwaura and Place 2013). This may negatively affect investment in land improvement and agricultural intensification, thus contribute to

deterioration of the quality of soil. Soil quality matters in SSA since majority of its people live in rural areas and derive their livelihoods from agriculture, a land based sector.

In many parts of SSA, there are concerns of soil quality exhaustion (Sanchez 2002, Henao and Baanante 2006, Tully et al. 2015, Mugizi and Matsumoto 2020, 2021a). At the same time, the region's fertilizer usage rate to replenish the soil is very low (FAO 2015). Soil quality deterioration may seriously affect many people who derive their livelihoods from agriculture. Indeed, declining soil fertility is the primary biophysical reason for stagnant per capita food production in SSA (Sanchez et al. 1996, Sanchez 2002, Place et al. 2003, Morris et al. 2007). Conversely, an increase in soil fertility has been associated with increase in yields; Lal (2006) estimates that for every ton/ha increase in soil organic carbon, maize, wheat, and rice yields increase by 30–300, 20–70, and 10–50 kg/ha, respectively, across the developing world.

In this paper, we examine whether transfer rights (ability of farmers to transfer their land without seeking approval) is associated with soil quality. If farmers can transfer their land without seeking for approval, then their right to land is more secure. We provide more details of this variable in sub-section *Measures of land rights and agricultural intensification*. We also examine the relationship between transfer rights and agricultural intensification by focusing on increased fertilizer use. We use panel data collected from farmers in Uganda in 2003 and 2012. The data contains six lab-tested soil variables—carbon, nitrogen, phosphorus, potassium, calcium, and soil pH. Since none of them can in isolation provide an

✉ Francisco M. P. Mugizi
mugizif2@gmail.com

¹ Department of Geography and Economics, University of Dar es Salaam, Mkwawa University College of Education, P.O Box 2513, Iringa, Tanzania

¹ Although land tenure security is generally defined as “the certainty that a person's rights to land will be recognized by others and protected in cases of challenges” (FAO 2002), one of its dimensions is whether the plot manager believes that he or she has complete transfer rights (Bambio and Bouayad 2018; Hayes et al. 1997; Place and Hazell 1993). In this paper, we focus on this dimension of tenure security.

extensive picture of quality of the soil; we use all of them to construct the soil quality index—details are in sub-section *Measure of soil quality*. We use Uganda as an ideal case study for three reasons. It used to be one of the countries with most fertile soils in the tropics (Chenery 1960); to-date it is one of the countries with the highest nutrient depletion in Africa (Henaio and Baanante 2006), more so, in highly populated areas (Mugizi and Matsumoto 2021a), the areas that used to be potential for agriculture. Second, the country's current fertilizer use intensity is one of the lowest in SSA (FAO 2015). Third, land in Uganda is increasingly becoming scarce due to population growth, hence, concerns of tenure insecurity including land conflicts are high (Mugizi and Matsumoto 2021b).

Although the link between transfer rights and incentives to invest in land improvement has been studied, our distinctive contribution is the use of comprehensive actual soil information with six soil quality measures. Moreover, these measures are decade-long panel data, thus makes it possible to study soil quality dynamics. Besides, extant studies examine whether transfer rights induce investment in soil management and conservation; none explicitly examine whether transfer rights improve soil quality. We go beyond the existing literature and examine whether such investments translate into improved soil quality. Because soil quality is deteriorating in Uganda (Mugizi and Matsumoto 2021a), it is important to understand whether transfer rights influence soil quality. Our decade-long panel data allows us to use household fixed effects model to control for unobservable household or parcel specific time-invariant characteristics that could bias our estimates. We also include region-year specific effects to control for unobserved region-year specific characteristics that would affect soil quality hence helps to clean our estimates of time trends region bias. We find that transfer rights are positively correlated with soil quality. We also find a strong positive correlation between transfer rights and use of chemical fertilizers. We, however, find no strong correlation between transfer rights and manure use.

Theoretically land rights increase incentives to invest in soil improvement through three main channels (Besley 1995, Brasselle et al. 2002, Goldstein and Udry 2008, Abdulai et al. 2011, Fenske 2011). First, better land rights reduce farmers' uncertainties about ownership of land. This assurance increase farmers' incentive to invest in land especially long-term investment such as use of manure, crop rotation, fallowing, and mulching. Second, with better land rights or greater land transferability, farmers may relax their credit constraints by using land as collateral to access credit from lenders and use the borrowed funds to invest in land improvements. Third, better land rights reduce transaction costs and increase the incentive to invest on land. The right to transfer land to others, encourages investment on land, as it makes it easier to convert land into liquid assets through selling or renting. Thus, the benefits of the investment made can be realized at any time. By incentivizing farmers to undertake short-term investment

in soil management or improvement including use of chemical fertilizer, and long-term investment such as use of manure, mulching, crop residues, compost, crop rotation, fallowing, or other practices that maintain soil fertility, higher levels of transfer rights should improve the soil quality.²

Dozens of studies have examined the link between transfer rights or tenure security and investment in land improvement (Besley 1995, Gavian and Fafchamps 1996, Deininger and Jin 2006, Kabubo-Mariara 2007, Deininger and Ali 2008, Deininger et al. 2008, Goldstein and Udry 2008, Abdulai et al. 2011, Deininger et al. 2011, Fenske 2011, Bambio and Bouayad 2018). Some studies have examined the short-run investment like use of chemical fertilizers and others have looked at the long-run investment such as application of manure.³

With regard to transfer rights and long-term investment, Deininger et al. (2008) found that in Uganda perceived transfer rights had marginal significant impact on the propensity to undertake soil conservation measures. Abdulai et al. (2011) revealed that owner operated with transfer rights are more likely to invest in organic fertilizers in Ghana. Gavian and Fafchamps (1996) unveiled no relationship between manuring and whether local customs allow land sales, but farmers who cultivated both borrowed and owned fields diverted manure toward owned fields in Niger. Similarly, in Ghana farmers with local political power fallow their land over long duration than their counterparts (Goldstein and Udry 2008). In West Africa, Fenske (2011) found strong link between tenure and fallow, but weak link for manure. Jacoby et al. (2002) showed that organic fertilizer use is significantly higher on private plots in China.⁴ Regarding short-term investment, such as use of chemical fertilizers,⁵ Abdulai et al. (2011) found that owner

² Due to data limitations, we only look at the use of manure and chemical fertilizer.

³ Chemical fertilizers are short-term investments—they last in the soil for only one cropping season. Manure is a long-term investment—it lasts in the soil for more than one cropping season; thus, has long-lasting benefits for soil.

⁴ Others (Besley 1995; Place and Otsuka 2002; Deininger and Jin 2006; Deininger et al. 2008; Abdulai et al. 2011; Bambio and Bouayad 2018) examine land rights impact on tree planting. However, tree planting may not necessarily increase the soil quality; in fact, it may reduce it.

⁵ However, the effect of inorganic and organic fertilizers on soil quality can be complicated. Although chemical fertilizers are high in nutrient content and are used rapidly by crops and the use of chemical fertilizers increase the fertility of soil and crop productivity especially in short-term (Chen et al. 2010), long-term, excessive and inappropriate use of chemical fertilizers may pose risk to soil quality (Dong et al. 2012; Guo et al. 2010). Conversely, although organic fertilizers release nutrients in a more sustainable way, they are comparatively low in nutrient content, and the nutrient release rate is too slow to meet crop requirements in a short time. Nevertheless, long-term application of organic manure improve the quality of soil organic matters (SOM) (Chen et al. 2010). Due to these complexities, studies suggest an appropriate combination (Chen et al. 2010; Liu et al. 2017).

operated with transfer rights were more likely to use mineral fertilizers than those without transfer rights in Ghana. In contrast, Fenske (2011) found a weak link between tenure and chemical fertilizer uses in West Africa. Similarly, in China Jacoby et al. (2002) showed that chemical fertilizer use is not significantly higher on private plots.

Notwithstanding some few exceptions, the documented positive association between transfer rights and investment in land improvement suggests that transfer rights may affect soil quality. Surprisingly, however, none of the existing studies examines whether transfer rights affect the quality of soil. This remains an empirical question of policy relevance in SSA where soil fertility exhaustion is one of the major reasons for low agricultural productivity. We fill the existing void in the literature by examining whether transfer rights are associated with soil quality. We hypothesize that parcels perceived to have transfer rights have better soil than those perceived to have no transfer rights. We also examine how transfer rights affect agricultural intensification. As discussed earlier, one of the pathways through which transfer rights may increase the soil quality is by incentivizing owners to invest in land improvement. We, therefore, expect to find a positive correlation between transfer rights and agricultural intensification.

Against this backdrop, the remainder of this paper is organized as follows. Section *Property rights in Uganda* describes property rights in Uganda, highlighting the country's tenure systems in relation to land rights. Section *Data and descriptive statistics* describes the data. Section *Estimation strategies* lays out the estimation strategy. Section *Estimation results* presents and discusses the results. Section *Conclusion and policy implications* concludes and draws out implications for policy.

Property Rights in Uganda

Land rights in Ugandan context can be understood by looking at the four land tenure systems—mailo, leasehold, freehold, and customary that exist in the country. These have different levels of land rights and tenure security. Mailo land tenure system is dominant in central Uganda. It was introduced by the 1900 Buganda Agreement—an agreement between Great Britain and the Kingdom of Buganda that was signed during colonial era whereby about 19,600sq. miles of land were given to some individuals to own in perpetuity. The 19,600sq. miles were divided into mile blocks (mailo) and awarded to Buganda king, chiefs and other officials in Buganda kingdom (West 1965). Local peasants who were previously on the land did not get any share. Consequently, they became tenants on land and had to pay rent to the landlords (Mwesigye and Barungi 2021).

Under mailo system, landlords own certificates of title and have full rights while tenants have usufruct rights. This tenure is also characterized by overlapping rights. This is because landlords own titles but because tenants have been on the land for long time, they consider it theirs (Mwesigye and Barungi 2021). Consequently, this landlord-tenant relationship has been one of the sources of land conflicts (Deininger and Castagnini 2006). Thanks to the 1998 Land Act—it contains some steps to increase tenure security of tenants and grants some protection to tenants. As per the Act, tenants that have been on land for 12 years cannot be removed without compensation. Also, if the landlords want to sell land, priority should be given to current tenants. Moreover, with the consent of the registered owner, mailo tenants can apply for certificate of occupancy that includes rights to give, lease, mortgage or inherit land (Deininger et al. 2008).

Customary land tenure is a system where ownership and disposition of land is in accordance with customary rules. In Uganda, there are three different types of customary tenure. In some communities, land is held communally; in others, it belongs to a particular clan; in other communities, individuals hold land (Amone and Lakwo 2014).⁶ Therefore, in communities where land rights are purely communal, transfer rights are restricted. In communities where individual land rights are weak, individuals are required to seek approval of clan heads or extended family members before transferring land. In communities where the land rights are more privatized, individuals have rights to sell, give or bequeath land without seeking consent from the extended family or clan members (Mwesigye and Barungi 2021).

Freehold tenure system is mainly in western part of the Uganda. Under this system, land is held in perpetuity and the owner is given a certificate of title. This system allows ownership of land indefinitely giving full powers over its use and disposition. Individual farmers enjoy full rights, such as transfer rights, rights to bequeath and give, and the right to use land as collateral; however, only a small amount of land in Uganda falls under this system. Because owners have certificate of titles, tenure security is likely to be high.

⁶ In Uganda, communal land includes gardens, pastures, grazing areas, burial grounds, and hunting areas commonly known as common property regimes. Communal land is mainly found in Northern Uganda. It is mainly utilized by the pastoralist communities in Northern Uganda and parts of the cattle belt in the West. User rights are guaranteed in form of farming, seasonal grazing, pasture, and other community activities. No specific ownership rights of control are conferred on users. Control and ownership are through the family, clan or the community. Similarly, under individual/family or clan customary tenure, emphasis is also in use rather than ownership. Male elders are the custodians of customary land in most communities and determine distribution of the land. However, the family has more control in the land utilization rather than the community (Busingye 2002).

Lastly, leasehold refers to the use of land for particular period—owning land on contract. According to Ugandan laws, a person can receive a lease for a period not more than 99 and 49 years, for citizens and non-citizens, respectively. Like freehold, under leasehold system, land titles are granted to owners, hence tenure security is likely to be high. Individual farmers have full transfer rights such as rights to bequeath and give. However, because of the high costs of surveying and demarcation involved in obtaining a land title, this regime also account the smallest share of land in Uganda.

Data and Descriptive Statistics

Data

The main source of data is Research on Poverty, Environment and Agricultural Technologies (RePEAT) project. We complement the RePEAT data with rainfall, temperature, and wind data sourced from the National Aeronautics and Space Administration. The National Graduate Institute for Policy Studies, Japan conducted the RePEAT surveys in collaboration with Makerere University of Uganda. The sample for the RePEAT project largely builds upon and complements a completed research project on policies for improved land management in Uganda which was conducted by International Food Policy Research Institute (IFPRI) and Makerere University between 1999 and 2001 (Pender et al. 2004). The IFPRI research project involved a survey of 107 communities (Local Council 1s—LC1's—the lowest administrative unit—usually a single village) selected from two-thirds of the regions in Uganda, including more densely populated and more secure areas in the southwest, central, eastern and parts of northern Uganda and representing seven of the nine major farming systems of the country. Within the study region, communities were selected using a stratified random sample. The stratification based on development domains defined by the different agro-ecological and market access zones, and differences in population density. The RePEAT project was conducted in 29 out of 32 districts and in 94 out of 107 LC1s studied by IFPRI.

The RePEAT questionnaires have detailed information including farm input use and land issues. The RePEAT data consist of five survey rounds: 2003, 2005, 2009, 2012, and 2015. In this paper, we use 2003 and 2012 rounds—the only years with soil data. Except for the 2015, the remaining rounds covered three regions—East, Central, and West. The Northern region was not surveyed due to insecurity concerns. During the first round, ten households were randomly selected from each of 94 communities, making a total of 940 households (Yamano et al. 2004). The fourth survey

round conducted in 2012 successfully traced 779 households of the original households. This gives us an attrition of 17%. To examine whether this attrition is random, we estimate a Probit model of 2003–2012 attrition on a number of 2003 household characteristics. In column 1 of Table 8, we present the results of this attrition model. We return to this issue in Section *Estimation strategies*, under estimation of Eq. (3).

Along with the 2003 and 2012 surveys, soil samples were collected from largest maize plot and in very few cases from non-maize cereal plot if the household did not cultivate maize. No sample was collected if the household did not cultivate any of these crops—only 16% and 9% did not cultivate the mentioned crops in 2003 and 2012, respectively. In both rounds, the soil samples were: taken from the same plots,⁷ collected at the same time of agricultural season, which is March through July, and collected before application of fertilizer. To account for intra-field variability, the samples were collected at a deepness of 0–20 cm from five different positions within each plot and properly mixed (Yamano and Kijima 2010). Then, they were analyzed in the soil laboratory at the World Agroforestry Centre in Nairobi. In testing the samples near-infrared reflectance spectroscopy, a method appropriate for large sample sizes was used (Shepherd and Walsh 2002). Prior to testing, the soils were air-dried and ground to pass through a 2 mm sieve, after which they were stored in paper bags at a reasonable room temperature. Then, for a selection of soil samples (20% of the total soil samples), soil properties were measured and calibrated to soil reflectance. The resultant calibrations and soil reflectance were used to predict the soil properties for the entire soil samples. After calibrations, an evaluation of prediction performance on predictive and actual observations was done using the coefficient of R^2 and root mean square error. Both tests revealed that the method had high level of prediction accuracy. However, detailed information on the mentioned procedures is only available in wave 1 and not in wave 2. In wave 2, what we know is that soil samples were analyzed by calibrations, but not the detailed procedures. Therefore, it is possible that soil analysis methods slightly differed across rounds. However, even if this may be the case, as long as the style of analysis changed wave 1 to wave 2 in the same way for everyone, not correlated with land rights, it should not bias our results (Mugizi and Matsumoto 2021a).

Because the soil samples were only collected from maize or non-maize cereal crops together with the fact that some got spoiled before they were analyzed (Matsumoto and Yamano 2009), we have only 559 households with soil

⁷ However, in the 2003 data, for some households we have missing information on soil parcel identification. More on this is given in Section *Estimation strategies*.

samples in the 2003 data. In 2012, we have samples from 741 households.⁸ After the cleaning process, we remain with a balanced panel data of 409 households.⁹ However, there is some missing information on parcel identification for some households in 2003,¹⁰ making it difficult to know for those households the exact parcel from which soil samples were collected. Therefore, we restrict the analysis to a subsample of households with the same soil parcel in both rounds. This gives us a balanced panel data of 313 households out of the original of 940 households—in Section *Estimation strategies*, we explain how we deal with this attrition when estimating Eq. (2). We use this balanced soil sample data in the main analysis—regressions that include soil quality. For regressions that do not include soil variables, we use the full sample.

We supplement the RePEAT data with rainfall (mm), temperature (degrees C) and wind speed 10 m (m/s) data sourced from the National Aeronautics and Space Administration-Prediction of Worldwide Energy Resources (NASA-POWER). NASA reports daily averaged air temperature (degrees C) at 2 m above the earth surface, daily wind speed at 10 m (m/s) above the earth surface, and average precipitation (mm/day). By specifying the Geographical Positioning System (GPS) coordinates, we downloaded the data. The RePEAT surveys have community-level GPS coordinates. We use the GPS coordinates to merge the two sets of data. Because NASA records daily data, before merging, we generate annual variables for five consecutive years (the survey year and 4 years preceding the survey). Then, we calculate the 5-year average for each of the variables. Because soil is also affected by biophysical factors such as climate, temperature, rainfall, and wind (Jenny 1995, Nkonya et al. 2005) which influence soil nutrient balances and soil quality in various ways,¹¹ we control for these agroclimatology data in most of the regressions.

⁸ Responses from recall back question on soil parcel identification asked in 2012 survey suggest that soil samples were collected from 763 households in 2003 and 841 households in 2012. The fact that we observe few households with soil samples in the data is evidence that many samples got spoiled during the process.

⁹ Thus, the first attrition related to soil sample households is about 27% (409 out of 559). When we treat households with missing values of soil samples as attrite cases, the attrition is also not random (Table 8, column 3). As a robustness check, we also weight the estimations by attrition weights estimated from this type of attrition. The results (not reported to economize space) remain unaffected.

¹⁰ The 2012 survey asked a recall back question to identify the soil parcel for the 2003 survey. Moreover, the 2012 survey identifies the soil sample parcels. This allows us to match the parcels.

¹¹ For example, although rainfall is important for moisture availability, which is important for soil health; excessive rainfall may lead to substantial leaching and depletion of soil nutrients through soil erosion. Conversely, drought may negatively affect nitrogen-fixation.

Measure of Soil Quality

To measure soil quality, we use six soil variables contained in our data—carbon, nitrogen, phosphorus, potassium, calcium, and soil pH to create a soil index.¹² We use principal component analysis (PCA) technique. The PCA extracts a linear combination of all the variables, which best describes and transforms them into one index (Gray 2011). It also determines weights intrinsically and assigns them to each indicator by its relative importance. The first principal component, which captures the greatest variation among the set of variables is used as the index. Except soil pH (which is normally distributed), other variables had some outliers; therefore, they were transformed to logarithms before creating the index. Because we are using the same soil data used by Mugizi and Matsumoto 2021a, we follow exactly their approach to construct the soil quality index as follows (Eq. 1):

$$SQI_{it} = \sum_{n=1}^6 V_n \left[\frac{z_{itn} - z_n}{sd_n} \right], \quad (1)$$

where, SQI_{it} is the soil quality index of farmland of household i in year t , V_n is the weight of each of the soil variables in the PCA model, and z_{itn} is the soil variable of the farmland of household i in year t . z_n and sd_n are the sample mean and standard deviation of variable n , respectively. Soil pH has ranges that are problematic—soil pH below 6.6 is acidity and above 7.3 is alkalinity (both not suitable for some crops, although it is very common to find cultivated fields outside of this range). Thus, an index in which soil pH enters as a continuous variable could be problematic.¹³ As a robustness check, we construct two alternative indices by using: five soil variables except soil pH; and, all the six soil variables but soil pH enters as a dummy, i.e., 1 if neutral (soil pH \geq 6.6 & soil pH \leq 7.3), and 0 otherwise. In addition, phosphorus and calcium reveal a dramatic increase (Table 1). The observed odd changes over time may have come from a change in the analysis protocol.¹⁴ To further check the robustness of our index, we construct other three alternative indices—the first excludes phosphorous, the second excludes calcium and the third excludes phosphorous, calcium, and soil pH.

Although the soil index is likely to be nonlinear, it is difficult to know the optimal level. Moreover, optimal level is likely to be site and crop specific (Srivastava et al. 2006, Musinguzi et al. 2013). Loveland and Webb (2003) and Musinguzi et al. (2013) document that the desired level of soil carbon content is 2%, regardless of the crop type. Regarding some specific crops, the optimal level of soil

¹² In the analysis, we also examine how each individual soil variable correlates with land rights.

¹³ For the remaining five soil variables, generally more is better.

¹⁴ Soil indicators from different year samples were obtained by calibration; the calibration was done year by year separately.

carbon content for maize is 1.9–2.2% in, that of soil pH for maize is 6.0–7.0 and for beans it is 6.0–6.5 (Musunguzi et al. 2016). The optimal level of phosphorous amount for corn is 13 mg/kg (Mallarino and Blackmer 1992). Although it may be difficult to establish the optimal level, anecdote evidence suggests that given the rate of soil degradation and low fertilizer usage in SSA, soil fertility is far less than the optimal. In Fig. 1, we show how the soil quality index is positively related to carbon content—the proxy for soil fertility (Marenya and Barrett 2009, Yamano and Kijima 2010). This is suggestive evidence that our index is a good measure of soil quality.

As a second suggestive evidence that our index captures soil fertility, in Fig. 2 we plot the relationship between soil fertility index or carbon content and the share of land allocated to various crops. We see that land allocated for cultivation of banana is high when soil fertility index or carbon is high; land allocated for other crops (cassava, sorghum, and potatoes) is high when soil quality index or carbon is low. The latter are drought resistant crops and grow relatively well on poor soils. We, however, acknowledge that creating an index for soil fertility, more so, in panel data setting is difficult (Michelson et al. 2013), and any one index is surely imperfect. That is why for robustness check, we re-estimate the

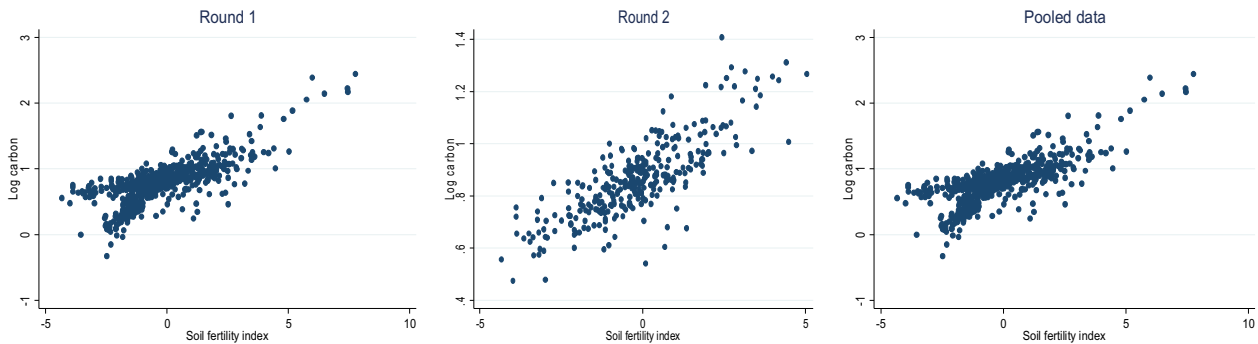


Fig. 1 Relationship between soil fertility index and carbon content in the soil

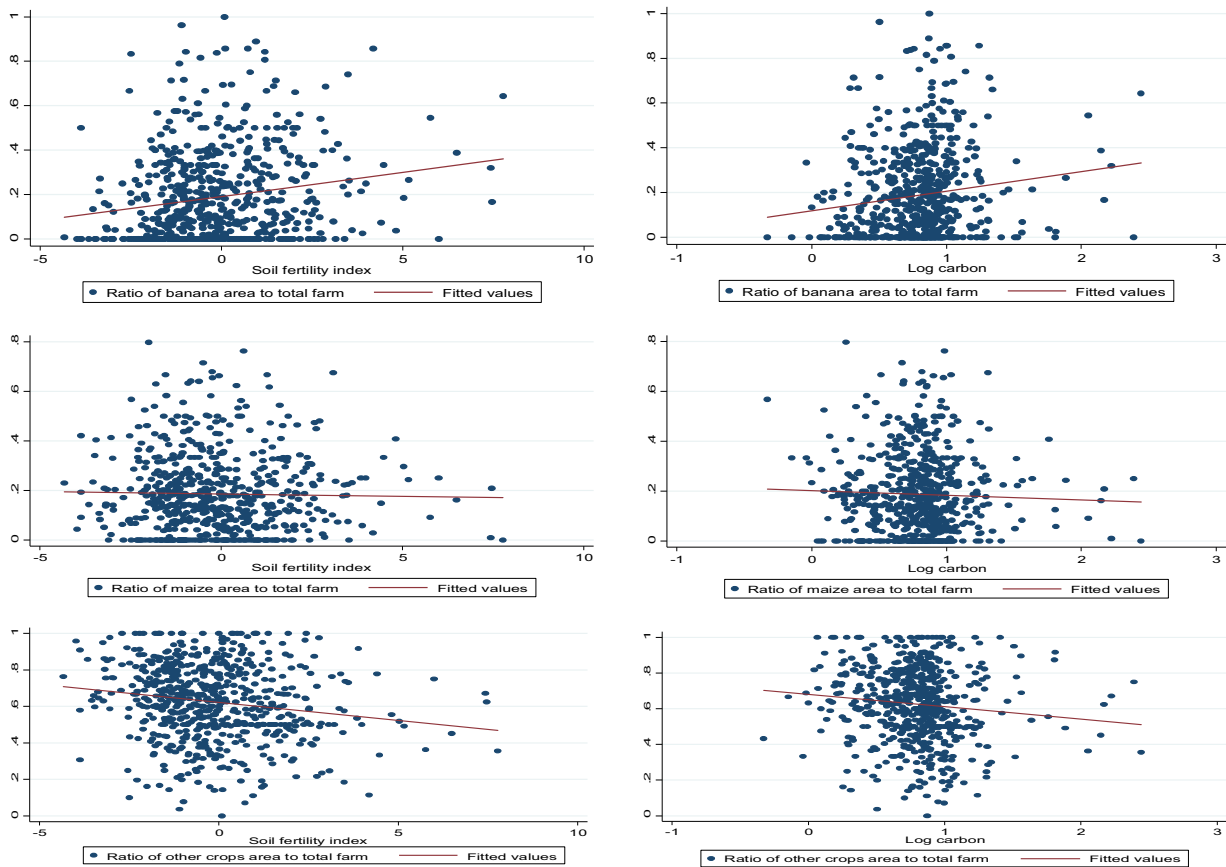


Fig. 2 Relationship between soil fertility index or carbon content and share of land allocated to various crops

regressions by using several soil indices and by separately using the six soil properties.

Measures of Land Rights and Agricultural Intensification

Another key variable worth discussing is measure of land rights. In this study, we focus on transfer rights. The household has full transfer rights over a parcel if it can sell the parcel without having to seek approval or consent from extended family members, clan or local authority; else, it has partial or no transfer rights (Bellemare 2013, Besley 1995). This variable is created from the following survey question: *Do you have a right to sell this parcel?*¹⁵ Although our transfer rights variable is perception of the household, and these rights may not necessarily correspond exactly to the rights that farmers care about in planning their investment, examining these self-reported transfer rights may shed some light. Notwithstanding, there are three concerns regarding our perceived transfer rights variable. First, beliefs on transfer rights take a long time to form and are unlikely to change much once formed. However, in a decade-long period, it is very likely that these beliefs may have changed. Indeed, it is this change of the perceptions that may have implications on household's investment decisions on land improvement. Second, is whether this perception on transfer rights is short-run or long-run. For example, if the perception is short-run and in the long-run households do not think they will still have the right; a household may appear in the dataset perceiving full transfer rights but not making investment that will be good for the long-run. Unfortunately, in our data, it is difficult to know whether the perception on transfer rights is short-run or long-run. Third, is whether the same person answered the question in both 2003 and 2012 surveys. If the same question is asked of a different individual, their perception may be different, leading to measurement error. Indeed, as Table 1 shows, for some few households the person who answered the question may not necessarily be the same in two rounds. We see that household characteristics such as headship, changed in two rounds (Table 1). However, even if the person who answered the question in 2003 and 2012 may have changed for some few households, this should not be a problem since it is this change of the perceptions that may have implications on household's investment decisions. Moreover, the person who answered the questions in both rounds is the household head (whether he/she changed or not), who is also a decision maker on investment in land management.

With regard to agricultural intensification, we focus on maize farming. Maize is one of the crops grown by many

¹⁵ Respondents to this question are household heads who are also the decision-makers on land uses, investments and agricultural production activities.

farmers in Uganda—76% and 85% of the surveyed households produced maize in 2003 and in 2012, respectively.¹⁶ Moreover, the soil samples were collected mainly from the maize parcels. We measure intensification by using two intensive farming practices-related variables: the amount of chemical fertilizer applied per hectare of the land cultivated, and the amount of manure applied per hectare of the land cultivated.

Descriptive Statistics

Table 1 reports the summary statistics. The proportion of households with perceived transfer rights decreased from 64% in 2003 to 57% in 2012.¹⁷ With regard to soil quality, during the decade period, the overall soil quality depleted although some soil nutrients improved—phosphorus, potassium and calcium increased. On the other hand, nitrogen and soil pH decreased from 0.22 to 0.17 and 6.62 to 6.19, respectively between 2003 and 2012. Carbon content almost remained stable. As stated earlier, we see an odd change for some soil variables. This may have come from a change in the analysis protocol. That is, although the method for the calibration should be the same, their reference samples (the samples with wet chemistry) used for the calibration are different and, hence, the regression coefficients estimated for the calibration. These differences affect the level and distribution of predicted contents. Therefore, the over-time comparison of the values of soil-contents may be problematic. That is why the trends of some soil variables in Table 1 are contrary to our expectations. Notwithstanding, overall the descriptive statistics suggest that both, land with perceived transfer rights and soil quality have decreased during the period this study covers.

Estimation Strategies

Transfer Rights and Soil Quality

To examine whether soil quality differs by transfer rights, in Eq. (2) we restrict the analysis to a subsample of households with the same soil parcel in both survey rounds. We use

¹⁶ One may be concerned that the change of crops may also affect soil quality results. However, since soil samples were taken from maize plots or non-maize cereal (millet, sorghum or wheat) plots if the household did not cultivate maize, we do not think that the change of crops in this case may affect soil quality because all these cereal crops have similar characteristics.

¹⁷ A further exploration of the data revealed that 21.1% of the 313 households (parcels) changed their perception on transfer rights from perceiving to have full transfer rights to perceiving having partial or no transfer rights, 13.4% changed from perceiving to have partial or no transfer rights to perceiving to have full transfer rights and 65.5% did not change.

Table 1 Summary statistics and *t*-test for equality of means of key variables

Variable	Year = 2003		Year = 2012		Mean Diff Sign
	Mean	Sd	Mean	Sd	
Soil quality index	0.041	1.87	-0.041	1.74	
Carbon (%)	2.29	1.34	2.40	0.38	
Nitrogen (%)	0.22	0.13	0.17	0.03	***
Extractable Phosphorus (cmol _c /kg)	11.85	7.72	33.07	27.97	***
Extractable Potassium (cmol _c /kg)	0.64	0.34	0.98	0.46	***
Extractable Calcium (cmol _c /kg)	7.08	5.74	9.74	5.92	***
Soil pH	6.62	0.55	6.19	0.53	***
1 if perceived transfer rights	0.64	0.48	0.57	0.50	***
Parcel size (ha)	1.63	3.98	1.60	2.49	
Year acquired	1983.14	13.64	1983.20	13.59	
Distance to homestead (minutes)	2.47	8.00	2.34	9.07	
1 if the parcel has a title	0.06	0.23	0.08	0.27	
Mode of acquisition					
1 if purchased	0.39	0.49	0.38	0.49	
1 if received as gift or inherited	0.57	0.50	0.56	0.50	
1 if rented-in	0.01	0.10	0.02	0.18	
1 if borrowed-in	0.02	0.13	0.01	0.11	
1 if walked-in	0.02	0.13	0.01	0.10	
Land ownership (ha)	1.78	1.73	1.18	1.90	***
Inorganic fertilizer use (Kgs/ha) ^a	0.31	2.73	2.26	9.01	***
Manure use (Kgs/ha)	12.44	95.88	0.81	8.29	**
% of households that used inorganic fertilizer	0.03	0.18	0.14	0.35	***
% of households that used manure	0.03	0.17	0.05	0.22	
1 if female headed household	0.11	0.31	0.16	0.36	*
Age of household head	45.83	14.24	53.74	13.22	***
Years of schooling of household head	5.80	3.67	6.02	3.74	
Household size	8.77	4.96	10.44	4.46	***
Community population density	459.15	663.89	466.78	523.77	
Rainfall mm (5-year average)	6.45	5.93	14.29	13.03	***
Temperature °C (5-year average)	73.34	17.27	70.31	16.14	***
Wind speed 10 m (m/s) (5-year average)	6.64	2.17	6.29	2.26	***
	Median		Median		
Carbon%	1.99		2.35		
Nitrogen (%)	0.19		0.16		
Extractable phosphorus (cmol _c /kg)	8.94		25.63		
Extractable potassium (cmol _c /kg)	0.58		0.91		
Extractable calcium (cmol _c /kg)	5.22		8.35		
Observations	313		313		

***, ** and * indicate the significance level of the mean difference test (t-test) at 1%, 5%, and 10% respectively

^aConverted to NPK equivalent

household fixed effects model with region-year specific effects. The former helps to control for unobserved time-invariant household or parcel¹⁸ characteristics that could be correlated with both soil quality and land rights. The latter affords control of unobserved region-year specific characteristics that would affect soil quality. The identifying assumption is that unobservables such as soil type, farm management ability, managerial skills, farmer’s risk preferences and entrepreneurial drive that might simultaneously affect the soil

quality as well as the perceived transfer rights are time-invariant, hence will be cancelled out by fixed effects. Moreover, the inclusion of region by time trends should mitigate the omitted variable bias that may arise from region-year specific unobservable characteristics that would affect the outcome variable and the explanatory variables of interest.

Although we use fixed effects and include many relevant controls, we cannot rule out the possibility that transfer rights may be endogenous to soil quality in such cases where farmers are more likely to acquire transfer rights of land with good soil quality. For example, it is possible that households with fertile lands have more incentives to demand and acquire private lands (this would increase their

¹⁸ Because we have one parcel per household, it could also be considered as parcel fixed effects and control any parcel level heterogeneity that are invariant overtime.

perception on transfer rights) to protect their fertile lands. To mitigate this concern, in alternative specification we use a time-invariant perceived transfer rights dummy. We exclude households who changed their perceptions from perceiving to have full transfer rights to perceiving having partial or no transfer rights or vice versa.¹⁹ To estimate this time-invariant variable, we interact it with year dummies (Wooldridge 2010 p.170). If its coefficient turns out to be positive, it will be suggestive evidence that full transfer rights are associated with better soil quality. It may also suggest that the soil quality of households with full transfer rights has increased over time (Wooldridge 2010 p.170). However, the omission of the households whose perceptions on transfer rights changed may not fully address the endogeneity issue because the resulting sample is obtained based on the endogenous variable. Therefore, the estimates cannot be assumed causal, but given the identification strategies explained above, it seems quite likely that the relationships estimated are at least partially causal.

Another concern is that the final sample—balanced soil sample may be biased and non-random. This is because out of the original of 940 households, our balanced soil sample has only 313 households. We follow Fitzgerald et al. (1998) and estimate a probit model of 2003–2012 attrition on a range of 2003 household characteristics. All, except two household characteristics (household head's age and land holdings) are not significant (Table 8, column 1). We find that households headed by older people and households with more lands were less likely to have remained. Another determinant of the soil sample attrition is the region dummies, which represent the soil sample spoilages and losses. Therefore, we do not think that the soil sample attrition is systematically correlated with household characteristics to create attrition biases. However, in Eq. (2) we control for any possible attrition bias with the inclusion of attrition weights²⁰ estimated based on the methods of inverse probability weights (Fitzgerald et al., 1998, Wooldridge, 2010). Moreover, because we use the household fixed effects models, if any attrition biases exist, they would be

¹⁹ We also examine those observations that changed their transfer rights more closely (Tables 12, 13). We isolate those households to exploit this variation to see how soil quality is related to farmers who changed their perception on transfer rights. Put differently, is the move from not perceiving to have full transfer rights to perceiving to have full transfer rights associated with an improvement in soil quality? We find that moving from not perceiving to have full transfer rights to perceiving to have full transfer rights is associated with an improvement in soil quality (Tables 5, 6). Conversely, moving from perceiving to have full transfer rights to not perceiving to have full transfer rights is not associated with improvement in soil quality (Tables 14, 15). This provides further supportive evidence of our argument.

²⁰ In Eq. (2), we use the more accurate attrition weights (313 out 940) because the first attrition level (779 out of 940) may be misleading here.

minimal.

$$SQI_{ijrt} = \pi_0 + \pi_1 Pr_{it} + \pi_2 H_{it} + \pi_3 V_{jt} + \gamma_{rt} + \alpha_i + \varepsilon_{ijrt} \quad (2)$$

where, i, j, r, t denotes household, community, region, and year of survey, respectively. SQI_{ijr} is the outcome variable—the soil quality index or each of the soil variables. Our parameter of interest is π_1 . Pr_{it} is a time-variant perceived transfer rights dummy equal to 1 if the household has complete transfer rights over a parcel and 0 otherwise. H_{it} is a vector of household specific controls. As explained earlier, the decision-maker on land uses, investments and agricultural production activities matters in association with that of transfer rights. In our case, the actual manager of land is the head of household. We, therefore, control for a number of household head's characteristics including whether household head is female, household head's years of schooling and household head's age. In H_{it} , we also control for household size, number of male adults, number of female adults, average years of schooling of male adults, average years of schooling of female adults, asset value, and livestock value. V_{jt} is a set of observable community characteristics including population density, rainfall, temperature and wind. γ_{rt} is expected to capture region-year specific unobservable characteristics which would affect soil quality as well as land rights. α_i is included to remove the effects of time-invariant household or parcel characteristics such as soil type, parental material, elevation and soil management ability that may bias our estimates. ε_{ijrt} is the error term that may be heteroskedastic and correlated within the community. We account for intra-community correlation by using robust standard errors clustered at the community level. We also include attrition weights to account for possible attrition that may result from non-randomness of households with soil samples.

Why Transfer Rights Improve Soil Quality?

Earlier, we argued that transfer rights might improve soil quality by incentivizing farmers to invest in land improvement. To understand why transfer rights improve soil quality, it is necessary to examine the effect of transfer rights on agricultural intensification as well. We do so by estimating Eq. (3).

$$AI_{pijrt} = \beta_0 + \beta_1 Pr_{pit} + \beta_2 FS_{pit} + \beta_3 H_{it} + \beta_4 V_{jt} + \gamma_{rt} + \varphi_i + \mu_{pijrt} \quad (3)$$

AI_{pijrt} takes two variants: quantity of manure applied (kg/ha) and amount of chemical fertilizer used (kg/ha). The variable of interest is Pr_{pit} . FS_{pit} denotes farm size in hectare, H_{it} is a set of household characteristics. V_{jt} is a vector of

Table 2 Transfer rights and soil quality

	Dependent variable: <i>Soil quality index</i>					
	(1)	(2)	(3)	(4)	(5)	(6)
1 if has transfer rights	0.402** (2.577)	0.425*** (2.869)	0.422*** (2.878)	0.405*** (2.957)	0.401*** (3.185)	0.406*** (3.243)
1 if female head household	0.043 (0.123)	0.110 (0.327)	0.068 (0.197)	0.103 (0.325)	0.136 (0.465)	0.165 (0.580)
Household head’s education	−0.063 (−1.431)	−0.069* (−1.693)	−0.071* (−1.687)	−0.068* (−1.851)	−0.072** (−2.347)	−0.074** (−2.462)
Household head’s age	0.003 (0.273)	0.001 (0.139)	0.003 (0.313)	0.004 (0.461)	0.006 (0.659)	0.005 (0.580)
Log population density	−0.439*** (−3.655)	−0.402*** (−3.347)	−0.411*** (−3.385)	−0.387*** (−3.601)	−0.247** (−2.638)	−0.228** (−2.413)
Rainfall mm (5 year average)	0.022 (0.492)	0.029 (0.670)	0.032 (0.728)	0.030 (0.691)	0.036 (0.867)	0.038 (0.952)
Temperature °C (5 year average)	−0.004 (−0.026)	0.043 (0.330)	0.041 (0.312)	0.048 (0.365)	0.116 (0.985)	0.135 (1.197)
Constant	−1.482 (−0.144)	−4.807 (−0.491)	−5.055 (−0.513)	−5.220 (−0.548)	−11.438 (−1.298)	−12.769 (−1.481)
Observations	626	626	626	626	626	626
R-squared	0.151	0.159	0.158	0.145	0.134	0.138
Number of households	313	313	313	313	313	313
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year* Region	Yes	Yes	Yes	Yes	Yes	Yes

Robust *t*-statistics are in parentheses. ***, ** and * represent significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at community-level. Estimates are weighted by attrition weights. In column 1, soil quality index is created by using six soil variables. In column 2, soil quality index is created by using five soil variables (excluding soil pH). In columns 3, soil quality index is created by using six soil variables but soil pH enters as a dummy variable i.e., 1 if neutral (soil pH ≥ 6.6 & soil pH ≤ 7.3), 0 otherwise. In column 4, soil quality index is created by using five soil variables (excluding phosphorous). In column 5, soil quality index is created by using five soil variables (excluding calcium). In column 6, soil quality index is created by using 3 soil variables (excluding phosphorous, calcium and soil pH). Other regressors included, but omitted from the table, are household size, number of male adults, number of female adults, average years of schooling of male adults, average years of schooling of female adults, per capita value of productive assets, per capita value of nonproductive assets, log value of livestock, land ownership (ha), wind 10 m (m/s) (5 year average), and log distance to the nearest district town

community-level variables,²¹ γ_{rt} , is the region-year fixed effects, and φ_i is the household fixed effects or parcel fixed effects. μ_{pijt} is the error term that may be correlated within a community. We, therefore, use robust standard errors clustered at the community. To control for possible attrition bias that may result from non-random of households (779 out of 940), in Eq. (3) we include attrition weights estimated from this attrition level.

²¹ Transferability of land rights is likely to evolve with commercialization. Similarly, fertilizer is likely to rise with commercialization. Failure to control for commercialization may lead to endogeneity problem arising from omitted variable. In V_{jt} , we also control for distance to the nearest district town (a proxy for commercialization).

Estimation Results

Transfer Rights and Soil Quality

Table 2 presents the results of the relationship between transfer rights and soil quality (Eq. (2)). The outcome variables are the six different measures of soil quality index. The explanatory variable of interest is a time-variant transfer rights dummy. The results show that parcels with complete transfer rights are statistically significant associated with better soil than those with partial or no transfer rights. The results suggest that households who perceive to have complete transfer rights over their lands are associated with around 0.4 points higher soil quality index compared to their counterparts who perceive to have partial or no

Table 3 Transfer rights and soil nutrients

	Log carbon (1)	Log nitrogen (2)	Log phosphorous (3)	Log potassium (4)	Log calcium (5)	Soil pH (6)	Soil pH (dummy) (7)
1 if has transfer rights	0.044 (1.256)	0.036 (0.941)	0.049 (0.671)	0.150*** (3.436)	0.095** (2.370)	−0.012 (−0.185)	−0.005 (−0.074)
1 if female headed household	0.013 (0.202)	−0.030 (−0.443)	−0.081 (−0.635)	0.135 (1.311)	0.031 (0.376)	−0.149 (−1.333)	−0.197* (−1.946)
Household head's education	−0.003 (−0.304)	0.000 (0.005)	−0.004 (−0.189)	−0.037*** (−3.062)	−0.012 (−0.830)	0.006 (0.369)	−0.012 (−0.728)
Household head's age	0.002 (1.173)	0.004* (1.703)	−0.003 (−0.726)	−0.001 (−0.275)	−0.002 (−0.659)	0.004 (0.908)	0.008* (1.848)
Log population density	0.008 (0.283)	−0.003 (−0.099)	−0.106* (−1.823)	−0.130*** (−2.954)	−0.172*** (−4.083)	−0.077 (−1.603)	−0.043 (−1.060)
Rainfall mm (5 year average)	0.005 (0.502)	0.005 (0.411)	−0.013 (−0.686)	0.013 (0.887)	0.004 (0.336)	−0.012 (−0.651)	0.014 (1.346)
Temperature °C (5 year average)	0.034 (1.020)	0.024 (0.647)	−0.084 (−1.466)	0.018 (0.385)	−0.028 (−0.677)	−0.086 (−1.315)	−0.003 (−0.077)
Constant	−2.795 (−1.119)	−5.431* (−1.884)	8.518** (2.109)	−1.142 (−0.340)	5.147 (1.656)	11.898** (2.609)	−1.568 (−0.514)
Observations	626	626	626	626	626	626	626
R-squared	0.265	0.310	0.693	0.455	0.382	0.356	0.178
Number of households	313	313	313	313	313	313	313
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year* Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust *t*-statistics are in parentheses. ***, ** and * represent significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at community-level. Estimates are weighted by attrition weights. Other regressors included, but omitted from the table, are the same variables omitted from Table 2

transfer rights over their lands. To check the robustness of the results, in Table 9 we re-estimate the regressions with year-district fixed effects instead of year-region fixed effects. The significance levels remain the same and the correlations are statistically significant and in the same direction. This provides further evidence that endogenous spatial variation is well soaked by our estimation strategy.

To shed light on how each of our soil variables is correlated with transfer rights, in Table 3 we report the regression results of the correlation between transfer rights and each of the six soil variables. In columns 1–5, we see that perceived complete transfer rights is positively correlated with carbon, nitrogen, phosphorous, potassium and calcium contents, respectively. However, except for potassium and calcium, other soil variables are statistically insignificant when considered individually. In column 4, those households who perceive their lands to have complete transfer rights their soils have 15 percentage points of potassium content higher than those with partial or no transfer rights. Similarly, households who perceive their lands to have complete transfer rights their soils have 10 percentage points of calcium content higher than those with partial or no transfer rights (column 5).

As a further check of the robustness of the main results, in Table 4, we use a time-invariant transfer rights dummy interacted with year dummy. As explained in Section *Data and descriptive statistics*, we exclude households who changed their perceptions from perceiving to have complete transfer rights to perceiving to have partial or no transfer rights or vice versa.²² The coefficient of the interaction term between the time-invariant complete transfer rights dummy and year dummy is positive and significant. This provides further suggestive evidence that households who perceive to have complete transfer rights of their lands are associated with better soil quality than those who perceive to have partial or no transfer rights. The positive and significant coefficient of the interaction term may also suggest that the soil quality of households with complete transfer rights of their parcels has increased over time. We also re-estimate the regressions with year-district fixed effects instead of year-region fixed effects (Table 10 in the appendix). The

²² The share of the households that changed perceptions on transfer rights is 34.5% (see Table 2 where we use all the 313 households and Table 4 where we use a subsample of households that did not experience changes in perceptions on transfer rights).

Table 4 Transfer rights and soil quality: Interacting transfer rights and year dummy

Dependent variable: <i>Soil quality index</i>						
	(1)	(2)	(3)	(4)	(5)	(6)
^a Transfer rights dummy*Year dummy (=2012)	0.726** (2.56)	0.658** (2.35)	0.701** (2.452)	0.718*** (2.749)	0.625** (2.506)	0.583** (2.325)
1 if female head household	0.161 (0.338)	0.140 (0.302)	0.088 (0.187)	0.255 (0.597)	0.185 (0.428)	0.171 (0.396)
Household head’s education	−0.074 (−1.318)	−0.084 (−1.650)	−0.088* (−1.701)	−0.075 (−1.550)	−0.085** (−2.087)	−0.089** (−2.218)
Household head’s age	0.011 (0.774)	0.006 (0.428)	0.008 (0.587)	0.015 (1.164)	0.013 (1.100)	0.010 (0.855)
Log population density	−0.458*** (−3.271)	−0.402*** (−2.912)	−0.411*** (−2.927)	−0.401*** (−3.213)	−0.231** (−2.081)	−0.204* (−1.823)
Rainfall mm (5 year average)	0.035 (0.633)	0.035 (0.672)	0.036 (0.686)	0.032 (0.635)	0.029 (0.635)	0.028 (0.650)
Temperature °C (5 year average)	0.073 (0.449)	0.117 (0.752)	0.108 (0.691)	0.097 (0.666)	0.156 (1.130)	0.174 (1.273)
Constant	−6.125 (−0.501)	−8.503 (−0.712)	−9.099 (−0.745)	−8.617 (−0.785)	−13.548 (−1.309)	−14.409 (−1.401)
Observations	410	410	410	410	410	410
R-squared	0.182	0.175	0.177	0.178	0.151	0.145
Number of households	205	205	205	205	205	205
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year* Region	Yes	Yes	Yes	Yes	Yes	Yes

Robust *t*-statistics are in parentheses. ***, ** and * represent significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at community-level. Estimates are weighted by attrition weights. In column 1, soil quality index is created by using six soil variables. In columns 2, soil quality index is created by using five soil variables (excluding soil pH). In column 3, soil quality index is created by using six soil variables but soil pH enters as a dummy variable i.e., 1 if neutral (soil pH ≥ 6.6 & soil pH ≤ 7.3), 0 otherwise. In column 4, soil quality index is created by using five soil variables (excluding phosphorous). In column 5, soil quality index is created by using five soil variables (excluding calcium). In column 6, soil quality index is created by using 3 soil variables (excluding phosphorous, calcium and soil pH). Other regressors included, but omitted from the table, are the same variables omitted from Table 2

^aTransfer rights dummy is time-invariant

results are consistent in general. The significance levels remain more or less the same and the correlations are statistically significant and in the same direction. We also show how each of the soil variables correlates with complete transfer rights (Table 11); our estimates bear the same signs and significance levels like those of Table 3.

To examine more closely those farmers who changed their perception on transfer rights, we isolate them. We do so in order to exploit the variation to see how soil quality relates to farmers who change their perceptions on transfer rights (Tables 12, 13). The results largely corroborate our main findings in Table 2 and Table 3, respectively—the size of the coefficients of interest and significance levels remain largely the same. Out of those

who changed their perceptions on transfer rights, we further examine whether the move from not perceiving to have complete transfer rights to perceiving to have complete transfer rights is associated with an improvement in soil quality. We find that moving from not perceiving to have complete transfer rights to perceiving to have complete transfer rights is indeed strongly associated with an improvement in soil quality (Table 5).

Similarly, in Table 6 we report the regression results of the correlation between transfer rights and each of the six soil variables of this subsample of households that moved from not perceiving to have complete transfer rights to perceiving to have complete transfer rights. The results strongly support our hypothesis. Except soil pH, other soil

Table 5 A subsample of households who moved from not perceiving to have complete transfer rights to perceiving to have complete transfer rights

Dependent variable: <i>Soil quality index</i>						
	(1)	(2)	(3)	(4)	(5)	(6)
1 if has transfer rights	2.064*** (3.441)	2.670*** (4.833)	2.369*** (4.247)	2.158*** (4.627)	2.334*** (5.075)	2.590*** (5.482)
1 if female head household	0.701 (1.662)	0.916** (2.072)	0.883** (2.053)	0.215 (0.588)	0.293 (0.678)	0.390 (0.862)
Household head's education	0.138 (0.960)	0.162 (1.126)	0.149 (1.113)	0.043 (0.353)	0.076 (0.549)	0.086 (0.617)
Household's head age	0.008 (0.412)	0.013 (0.704)	0.009 (0.527)	0.010 (0.589)	0.020 (1.145)	0.022 (1.253)
Log population density	-0.335 (-1.378)	-0.318 (-1.521)	-0.285 (-1.439)	-0.337* (-1.706)	-0.225 (-1.571)	-0.217 (-1.599)
Rainfall mm (5 year average)	0.036 (0.645)	0.027 (0.552)	0.042 (0.931)	0.090* (1.876)	0.078* (1.718)	0.072 (1.522)
Temperature °C (5 year average)	0.381 (1.691)	0.361 (1.687)	0.415** (2.160)	0.531*** (2.851)	0.451** (2.433)	0.433** (2.295)
Constant	-31.123** (-2.390)	-31.291** (-2.627)	-34.428*** (-3.087)	-41.795*** (-3.746)	-40.462*** (-3.613)	-39.847*** (-3.418)
Observations	84	84	84	84	84	84
R-squared	0.758	0.761	0.772	0.760	0.735	0.717
Number of households	42	42	42	42	42	42
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year* Region	Yes	Yes	Yes	Yes	Yes	Yes

Robust *t*-statistics are in parentheses. ***, ** and * represent significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at community-level. Estimates are weighted by attrition weights. In column 1, soil quality index is created by using all six soil variables. In column 2, soil quality index is created by using five soil variables (excluding soil pH). In columns 3, soil quality index is created by using six soil variables but soil pH enters as a dummy variable i.e., 1 if neutral (soil pH \geq 6.6 & soil pH \leq 7.3), 0 otherwise. In column 4, soil quality index is created by using five soil variables (excluding phosphorous). In column 5, soil quality index is created by using five soil variables (excluding calcium). In column 6, soil quality index is created by using 3 soil variables (excluding phosphorous, calcium and soil pH). Other regressors included, but omitted from the table, are the same variables omitted from Table 2

variables are statistically positively correlated with transfer rights. In column 1, we find that moving from not perceiving to have complete transfer rights to perceiving to have complete transfer rights increases the soil carbon content by 43 percentage points. Similarly, this move increases phosphorous, potassium, and calcium contents by: 118 percentage points, 128 percentage points, and 88 percentage points, respectively. In addition, the move increases nitrogen content by 11 percentage points; however, this is not statistically significant. Conversely, as expected moving from perceiving to have complete

transfer rights to not perceiving to have complete transfer rights is not associated with improvement in soil quality (Table 14 and Table 15). All these provide further supportive evidence that transfer rights indeed are associated with better soil quality.

Transfer Rights and Agricultural Intensification

In the previous analysis, we showed that households who perceive to have complete transfer rights of their lands are associated with better soil quality. To understand why transfer

Table 6 A subsample of households who moved from not perceiving to have complete transfer rights to perceiving to have complete transfer rights

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Log carbon	Log Nitrogen	Log phosphorous	Log potassium	Log calcium	soil pH	soil pH dummy
1 if has transfer rights	0.431** (2.225)	0.114 (0.597)	1.177*** (3.286)	1.284*** (6.387)	0.878*** (4.662)	-1.554*** (-4.411)	-1.345*** (-3.831)
1 if female head household	0.343** (2.701)	0.178 (1.299)	0.760*** (4.143)	0.088 (0.606)	0.031 (0.323)	-0.447* (-2.045)	-0.150 (-0.681)
Household head's education	0.046 (0.805)	0.033 (0.602)	0.149*** (2.776)	-0.020 (-0.352)	-0.005 (-0.112)	-0.034 (-0.549)	-0.057 (-0.655)
Household head's age	0.006 (0.693)	0.008 (1.007)	-0.001 (-0.096)	0.003 (0.376)	-0.002 (-0.352)	-0.007 (-0.780)	-0.018 (-1.342)
Log population density	-0.016 (-0.344)	0.007 (0.129)	-0.023 (-0.249)	-0.074 (-1.503)	-0.145** (-2.254)	-0.038 (-0.345)	0.150 (1.528)
Rainfall mm (5 year average)	0.009 (0.625)	-0.005 (-0.278)	-0.070** (-2.244)	0.052*** (4.137)	0.029* (1.937)	0.023 (0.558)	0.072*** (2.822)
Temperature °C (5 year average)	0.029 (0.423)	-0.031 (-0.411)	-0.155 (-1.224)	0.301*** (4.954)	0.175*** (4.806)	0.054 (0.478)	0.261* (1.966)
Constant	-3.348 (-0.847)	-3.191 (-0.715)	13.137 (1.543)	-20.581*** (-5.306)	-7.637** (-2.480)	4.652 (0.530)	-15.378* (-1.965)
Observations	84	84	84	84	84	84	84
R-squared	0.727	0.627	0.918	0.890	0.820	0.714	0.564
Number of households	42	42	42	42	42	42	42
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year* Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust *t*-statistics are in parentheses. ***, ** and * represent significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at community-level. Estimates are weighted by attrition weights. Other regressors included, but omitted from the table, are the same variables omitted from Table 2

rights improve the soil quality, we estimate Eq. (3) and present the results in Table 7²³. We find a positive correlation between complete transfer rights and application of manure (column 1). This relationship, however, is not statistically significant. This suggests no significant difference in manure use between farmers who perceive to have complete transfer rights and those who do not. One possible explanation for this result is that in our sample few people used manure—only 3% and 5%, in 2003 and 2012, respectively. Thus, regardless of the nature of transfer rights, the use of manure is very minimal in Uganda.

Interestingly, however, we find that parcels perceived to have complete transfer rights are associated with more use of chemical fertilizers than their counterparts (column 2). Although the use of chemical fertilizer is statistically positively associated with transfer rights, the effect of chemical

fertilizers on soil quality can be complex. Studies have shown that the use of chemical fertilizers increase the fertility of soil especially in short-term because chemical fertilizers have more nutrient contents and are consumed quickly by crops (see, Chen et al. 2010). Conversely, other studies (Dong et al. 2012, Guo et al. 2010) caution that excessive, long-term and inappropriate use of mineral fertilizers may negatively affect the quality of soil. Because of these complexities, agricultural experts should educate farmers to use chemical fertilizers sustainably. Notwithstanding, chemical fertilizer usage in Uganda is still very low.

Although the correlation between transfer rights and agricultural intensification is statistically significant on chemical fertilizers but not on manure use, the strong positive correlation between transfer rights and soil quality found suggests that the latter is affecting the former through other soil conservation means. These may include use of compost, crop residues, mulching or other practices that improve or maintain soil fertility. In fact, Yamano et al. (2004) show that application of crop residues is the mostly widely practiced in Uganda. However, in this paper, we are

²³ Here we use the full sample i.e., regardless of whether the soil sample was collected from the parcel or not. We also run the regressions with partial samples (soil samples) to see how the results match up. The results not reported to economize space are largely similar.

Table 7 Transfer rights and agricultural intensification

	(1)	(2)
	Manure (t/ha)	lnChemical (10 kg/ha)
1 if has transfer rights	0.003 (0.750)	0.280*** (2.746)
Cultivated land size (ha)	0.001 (1.178)	0.033 (0.442)
1 if female headed household	0.007* (1.807)	−0.200 (−1.150)
Household head's age	−0.000 (−0.916)	0.007* (1.763)
Household head's education	0.000 (0.308)	−0.008 (−0.343)
Ln population density	0.001 (0.619)	0.141** (2.111)
Constant	−0.061** (−2.261)	−5.576*** (−6.284)
Observations	1945	1945
R-squared	0.026	0.074
Number of parcels	872	872
Household FE	Yes	Yes
Year*Region dummies	Yes	Yes

Robust *t*-statistics are in parentheses. ***, **, and * indicates the significance level at 1%, 5%, and 10%, respectively. Robust standard errors are clustered at community-level. Estimates are weighted by attrition weights. Other regressors included, but omitted from the table, are family size, number of male adults, number of female adults, average years of schooling of male adults, average years of schooling of female adults, log value of assets, log value of livestock, land ownership (ha), and log distance to the nearest district town

unable to analyze these pathways due to data limitations. Nonetheless, existing studies on Uganda shed some light. Deininger and Ali (2008) found that full ownership rights provide significantly higher incentives to invest in soil conservation and manure application than occupancy rights. Similarly, greater transfer rights are correlated with significantly higher levels of long-term investment in Uganda (Deininger et al. 2008).

Conclusion and Policy Implications

Theoretically, transfer rights incentivize individuals to invest in land improvement. Empirical studies have documented a positive relationship between soil conservation-related measures and transfer rights. This suggests that transfer rights can play a vital role in land management and improvement. This is especially important in most SSA countries where soil quality

deterioration is a public concern. Yet, gaps on whether transfer rights may help to improve the quality of the soil remain. This is partly due to lack of objective panel soil measures in many usual surveys. We use a decade-long panel data with lab-tested soil measures from farmers in Uganda to examine the relationship between perceived transfer rights and soil quality.

We find that households who perceive to have complete transfer rights of their parcels have better soil than those with partial or no transfer rights. This suggests that households who perceive to have complete transfer rights have more incentives to invest in soil conservation than those who do not. The findings support the theoretical argument that secure land rights or transfer rights incentivize farmers to invest in soil management and improvement. Through which pathways does the positive relationship between transferability of land rights and soil quality we find operate? There are potential three main pathways. First, better land rights reduce farmers' uncertainties and increase their assurance about ownership of land—this in turn increases farmers' incentive to invest in land improvement. Second, with greater transferability of land rights, farmers may use land as collateral to borrow from lenders and use the borrowed funds to invest in land improvement. Third, the right to transfer land to others makes it easier to convert land into liquid assets through selling or renting, hence encourages investment on land. Although in this paper we are unable to empirically test each of these pathways explicitly (due to data limitations), the strong positive relationship between transferability of land rights and soil quality revealed suggests that at least some of these pathways may be behind the obtained results. Certainly, it has to do with the way farmers perceiving to have complete transfer rights are managing their land compared to farmers perceiving not to have. Moreover, although we do not find strong positive correlation between transfer rights and use of manure, the fact that strong positive correlation between transfer rights and soil quality is found suggests that farmers perceiving to have complete transfer rights may be investing in soil improvement and conservation through other means such as use of compost, crop residue and fallowing. However, due to data limitations we could not test these plausible pathways.

Although our findings may not be generalized to every part of SAA, they have important policy implications. The first policy implication is that the findings underscore the need to promote transfer rights. The second is to promote agricultural intensification. One way to achieve the latter is through policies that stimulate investment in land improvement. Such policies may include encouraging farmers to use external inputs such as chemical fertilizers and locally available inputs such as manure, compost, and crop residues. However, because the effect of chemical fertilizer on soil quality is complex and still an empirical issue, agricultural experts should assist farmers to use it sustainably.

Acknowledgements I would like to thank Prof. Tomoya Matsumoto, Prof. Yoko Kijima, Prof. Yamauchi Chikako, participants of the GRIPS Policy Analysis Workshops and four anonymous reviewers for their useful comments. This paper was presented at the Western Economic Association International’s (WEAI) Annual Conference, San Francisco, California, USA, 28th June–2nd July 2019. The author is appreciative of the financial support provided by the University of Dar es Salaam-Swedish International Development Agency Programme to attend the conference. Comments given by the conference participants were very useful.

Compliance with Ethical Standards

Conflict of Interest The author declares no competing interests.

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Appendix

- Table 8
- Table 9
- Table 10
- Table 11
- Table 12
- Table 13
- Table 14
- Table 15

Table 8 Determinants of attrition in the household survey and soil samples

<i>Dependent variable</i>	(1) Att1	(2) Att2	(3) Att3	(4) Att4
<i>Household characteristics at baseline survey</i>				
Household head’s age	−0.012*** (0.004)	−0.001 (0.003)	−0.008 (0.005)	−0.007** (−2.246)
Household head’s education	0.002 (0.023)	0.006 (0.017)	−0.001 (0.025)	0.004 (0.202)
1 if female headed household	0.216 (0.147)	0.087 (0.121)	0.083 (0.189)	0.115 (0.796)
Number of female adults	0.049 (0.039)	−0.068* (0.038)	0.002 (0.043)	−0.020 (−0.401)
Number of male adults	0.039 (0.037)	0.034 (0.036)	0.043 (0.045)	0.040 (0.948)
Average years of schooling of female adults	−0.013 (0.016)	−0.024 (0.018)	0.015 (0.023)	−0.006 (−0.379)
Average years of schooling of male adults	−0.009 (0.023)	−0.018 (0.019)	−0.013 (0.025)	−0.017 (−0.898)
Log of value of assets	−0.048 (0.054)	0.041 (0.057)	−0.008 (0.064)	0.029 (0.548)
Log of land holdings (ha)	−0.034 (0.023)	−0.099*** (0.029)	−0.079*** (0.037)	−0.128*** (−4.470)
<i>Region dummies^a</i>				
East	0.274** (0.126)	0.502** (0.202)	0.214 (0.167)	−0.419*** (−2.828)
West	0.060 (0.115)	0.411** (0.207)	0.414** (0.192)	−0.062 (−0.338)
Constant	0.122 (0.595)	−0.762 (0.630)	−0.334 (0.730)	0.632 (1.031)
Number of households	940	940	559	940

Robust standard errors are in parentheses. ***, **, and * indicates the significance level at 1%, 5%, and 10%, respectively. Att1: 1 if not interviewed in second survey. Att2: 1 if no soil sample in the first survey. Att3: 1 if soil sample available in the first survey but household not available in the second survey or available but soil sample not available. Att4: 1 if soil sample were not matched between the two rounds

^aReference category is Central

Table 9 Transfer rights and soil quality

Dependent variable: <i>Soil quality index</i>						
	(1)	(2)	(3)	(4)	(5)	(6)
1 if has transfer rights	0.470** (2.604)	0.477*** (2.706)	0.470*** (2.655)	0.472*** (2.918)	0.466*** (3.193)	0.461*** (3.185)
1 if female headed household	-0.120 (-0.362)	-0.082 (-0.256)	-0.099 (-0.299)	0.008 (0.025)	0.112 (0.387)	0.126 (0.444)
Household head's education	-0.091** (-2.237)	-0.096** (-2.517)	-0.097** (-2.444)	-0.086** (-2.426)	-0.088*** (-2.857)	-0.089*** (-2.918)
Household head's age	-0.008 (-0.777)	-0.006 (-0.615)	-0.005 (-0.506)	-0.005 (-0.551)	-0.001 (-0.129)	-0.000 (-0.054)
Log population density	-0.350** (-2.485)	-0.352** (-2.578)	-0.355** (-2.610)	-0.336** (-2.428)	-0.299** (-2.312)	-0.295** (-2.291)
Rainfall mm (5 year average)	0.024 (0.546)	0.032 (0.724)	0.036 (0.837)	0.027 (0.600)	0.031 (0.666)	0.035 (0.743)
Temperature °C (5 year average)	0.033 (0.254)	0.062 (0.493)	0.066 (0.510)	0.068 (0.530)	0.119 (0.981)	0.130 (1.119)
Constant	-2.497 (-0.282)	-6.819 (-0.764)	-6.750 (-0.758)	-6.553 (-0.711)	-13.586 (-1.417)	-15.348 (-1.606)
Observations	626	626	626	626	626	626
R-squared	0.349	0.341	0.343	0.307	0.260	0.259
Number of households	313	313	313	313	313	313
Household fixed effects	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>
Year* District	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>

Robust *t*-statistics are in parentheses. ***, **, and * indicates the significance level at 1%, 5%, and 10%, respectively. Robust standard errors are clustered at community-level. Estimates are weighted by attrition weights. In column 1 soil quality index is created by using all six soil variables. In column 2 soil quality index is created by using five soil variables (excluding soil pH). In column 3 soil quality index is created by using six soil variables but soil pH enters as a dummy variable i.e., 1 if neutral (soil pH ≥ 6.6 & soil pH ≤ 7.3), 0 otherwise. In column 4 soil quality index is created by using five soil variables (excluding phosphorous). In column 5 soil quality index is created by using five soil variables (excluding calcium). In column 6 soil quality index is created by using 3 soil variables (excluding phosphorous, calcium and soil pH). Other regressors included, but omitted from the table, are household size, number of male adults, number of female adults, average years of schooling of male adults, average years of schooling of female adults, per capita value of productive assets, per capita value of nonproductive assets, log value of livestock, land ownership (ha), wind 10 m (m/s) (5 year average), and log distance to the nearest district town

Table 10 Transfer rights and soil quality

Dependent variable: <i>Soil quality index</i>						
	(1)	(2)	(3)	(4)	(5)	(6)
^a Transfer rights*Year dummy(=2012)	0.599** (2.25)	0.526** (1.97)	0.562** (2.065)	0.570** (2.302)	0.497** (2.079)	0.454* (1.877)
1 if female headed household	-0.181 (-0.335)	-0.219 (-0.415)	-0.242 (-0.450)	-0.079 (-0.155)	0.012 (0.024)	-0.008 (-0.017)
Household head's education	-0.086 (-1.550)	-0.102* (-1.964)	-0.103* (-1.964)	-0.085 (-1.640)	-0.101** (-2.286)	-0.107** (-2.444)
Household head's age	-0.004 (-0.196)	-0.006 (-0.319)	-0.004 (-0.224)	-0.000 (-0.004)	0.002 (0.104)	0.001 (0.036)
Log population density	-0.335* (-1.809)	-0.306* (-1.854)	-0.317* (-1.886)	-0.306* (-1.726)	-0.222 (-1.519)	-0.205 (-1.485)
Rainfall mm (5 year average)	0.023 (0.421)	0.019 (0.377)	0.023 (0.444)	0.019 (0.364)	0.007 (0.142)	0.005 (0.110)

Table 10 (continued)

Dependent variable: *Soil quality index*

	(1)	(2)	(3)	(4)	(5)	(6)
Temperature °C (5 year average)	0.098 (0.602)	0.113 (0.731)	0.112 (0.703)	0.117 (0.715)	0.140 (0.894)	0.145 (0.960)
Constant	-5.157 (-0.457)	-7.630 (-0.715)	-8.941 (-0.820)	-8.919 (-0.783)	-13.559 (-1.273)	-14.586 (-1.420)
Observations	410	410	410	410	410	410
R-squared	0.384	0.371	0.377	0.339	0.286	0.281
Number of households	205	205	205	205	205	205
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year* District	Yes	Yes	Yes	Yes	Yes	Yes

Robust t-statistics are in parentheses. ** and * indicates the significance level at 5% and 10%, respectively. Robust standard errors are clustered at community-level. Estimates are weighted by attrition weights. In column, 1–6 soil quality indices are as defined in Table 9. Other regressors included, but omitted from the table, are the same variables omitted from Table 9

^aTransfer rights dummy is time-invariant

Table 11 Transfer rights and soil nutrients

	Log carbon (1)	Log nitrogen (2)	Log phosphorous (3)	Log potassium (4)	Log calcium (5)	Soil pH (6)	Soil pH (dummy) (7)
^a Transfer rights dummy*Year dummy (=2012)	0.052 (1.116)	0.031 (0.595)	0.099 (1.038)	0.287*** (3.145)	0.164* (1.915)	0.197** (2.084)	0.215** (2.320)
1 if female headed household	-0.093 (-1.216)	-0.170* (-1.967)	-0.103 (-0.514)	0.295* (1.719)	0.137 (1.161)	0.031 (0.204)	-0.247* (-1.956)
Household head’s education	-0.007 (-0.586)	-0.006 (-0.484)	-0.008 (-0.365)	-0.028 (-1.575)	-0.010 (-0.518)	0.013 (0.520)	-0.020 (-0.999)
Household head’s age	0.002 (0.690)	0.003 (1.011)	-0.006 (-0.851)	0.003 (0.577)	-0.000 (-0.012)	0.012* (1.901)	0.011** (2.106)
Log population density	0.010 (0.316)	-0.004 (-0.124)	-0.113* (-1.719)	-0.128** (-2.612)	-0.187*** (-3.716)	-0.111** (-2.046)	-0.042 (-0.924)
Rainfall mm (5 year average)	0.008 (0.730)	0.007 (0.597)	0.000 (0.018)	0.018 (1.037)	0.007 (0.382)	-0.001 (-0.047)	0.007 (0.585)
Temperature °C (5 year average)	0.053 (1.404)	0.046 (1.114)	-0.040 (-0.570)	0.035 (0.643)	-0.018 (-0.345)	-0.079 (-1.198)	-0.034 (-0.719)
Constant	-3.691 (-1.274)	-6.441** (-2.037)	5.698 (1.107)	-2.315 (-0.604)	4.355 (1.079)	9.888** (2.177)	-0.311 (-0.091)
Observations	410	410	410	410	410	410	410
R-squared	0.283	0.375	0.676	0.445	0.374	0.412	0.246
Number of households	205	205	205	205	205	205	205
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year* Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust t-statistics are in parentheses. ***, **, and * indicates the significance level at 1%, 5%, and 10%, respectively. Robust standard errors are clustered at community-level. Estimates are weighted by attrition weights. Other regressors included, but omitted from the table, are the same variables omitted from Table 9

^aTransfer rights dummy is time-invariant

Table 12 Transfer rights and soil quality: A subsample of households who changed their perceptions on transfer rights

	Dependent variable: <i>Soil quality index</i>					
	(1)	(2)	(3)	(4)	(5)	(6)
1 if has transfer rights	0.418** (2.629)	0.437*** (2.832)	0.435*** (2.854)	0.405*** (2.989)	0.398*** (3.242)	0.401*** (3.255)
1 if female headed household	0.079 (0.178)	0.236 (0.575)	0.213 (0.511)	0.109 (0.290)	0.219 (0.704)	0.289 (0.971)
Household head's education	-0.033 (-0.488)	-0.046 (-0.736)	-0.046 (-0.710)	-0.040 (-0.748)	-0.053 (-1.214)	-0.058 (-1.373)
Household head's age	-0.003 (-0.204)	-0.002 (-0.185)	-0.002 (-0.139)	-0.003 (-0.238)	-0.001 (-0.109)	-0.001 (-0.073)
Log population density	-0.249 (-1.340)	-0.239 (-1.303)	-0.242 (-1.328)	-0.216 (-1.203)	-0.134 (-0.794)	-0.130 (-0.763)
Rainfall mm (5 year average)	-0.024 (-0.445)	-0.006 (-0.118)	0.001 (0.014)	0.002 (0.048)	0.027 (0.604)	0.036 (0.800)
Temperature °C (5 year average)	-0.254 (-1.640)	-0.190 (-1.354)	-0.183 (-1.330)	-0.158 (-1.054)	-0.053 (-0.392)	-0.023 (-0.178)
Constant	11.953 (0.993)	6.103 (0.557)	5.540 (0.521)	5.260 (0.459)	-4.657 (-0.445)	-7.261 (-0.707)
Observations	216	216	216	216	216	216
R-squared	0.366	0.380	0.380	0.355	0.346	0.350
Number of households	108	108	108	108	108	108
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year* Region	Yes	Yes	Yes	Yes	Yes	Yes

Robust *t*-statistics are in parentheses. ***, **, and * indicates the significance level at 1%, 5%, and 10%, respectively. Robust standard errors are clustered at community-level. Estimates are weighted by attrition weights. In column, 1–6 soil quality indices are as defined in Table 9. Other regressors included, but omitted from the table, are the same variables omitted from Table 9

Table 13 Transfer rights and soil quality: a subsample of households who changed their perceptions on transfer rights

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Log carbon	Log Nitrogen	Lon phosphorous	Lon potassium	Log calcium	Soil pH	Soil pH dummy
1 if has transfer rights	0.040 (1.176)	0.028 (0.742)	0.074 (0.957)	0.158*** (4.029)	0.100** (2.465)	-0.003 (-0.044)	-0.001 (-0.010)
1 if female headed household	0.135 (1.410)	0.112 (1.138)	-0.052 (-0.255)	0.044 (0.423)	-0.018 (-0.161)	-0.323** (-2.100)	-0.101 (-0.703)
Household head's education	-0.008 (-0.561)	-0.001 (-0.089)	0.002 (0.057)	-0.037** (-2.239)	-0.003 (-0.165)	0.025 (1.247)	-0.001 (-0.054)
Household head's age	0.002 (0.847)	0.004 (1.475)	0.000 (0.078)	-0.004 (-1.160)	-0.001 (-0.294)	-0.001 (-0.094)	0.002 (0.335)
Log population density	0.031 (0.860)	0.024 (0.596)	-0.058 (-0.841)	-0.082 (-1.241)	-0.117** (-2.078)	-0.019 (-0.302)	-0.012 (-0.200)
Rainfall mm (5 year average)	0.003 (0.253)	0.005 (0.382)	-0.041* (-1.685)	-0.003 (-0.183)	-0.008 (-0.469)	-0.034 (-1.188)	0.032** (2.273)
Temperature °C (5 year average)	-0.004 (-0.127)	-0.021 (-0.499)	-0.166*** (-2.703)	-0.027 (-0.552)	-0.076* (-1.843)	-0.136* (-1.780)	0.037 (0.702)
Constant	-1.981 (-0.752)	-4.242 (-1.280)	12.831*** (2.811)	1.303 (0.335)	8.199** (2.373)	17.784*** (3.028)	-3.061 (-0.732)
Observations	216	216	216	216	216	216	216
R-squared	0.420	0.402	0.773	0.616	0.548	0.440	0.180
Number of households	108	108	108	108	108	108	108
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year* Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust *t*-statistics are in parentheses. ***, **, and * indicates the significance level at 1%, 5%, and 10%, respectively. Robust standard errors are clustered at community-level. Estimates are weighted by attrition weights. Other regressors included, but omitted from the table, are the same variables omitted from Table 9

Table 14 A subsample of households who moved from perceiving to have complete transfer rights to not perceiving to have complete transfer rights

Dependent variable: <i>Soil quality index</i>						
	(1)	(2)	(3)	(4)	(5)	(6)
1 if has transfer rights	1.525 (1.211)	1.821 (1.381)	1.828 (1.425)	1.819 (1.381)	1.870 (1.334)	1.984 (1.391)
1 if female headed household	0.339 (0.672)	0.605 (1.224)	0.553 (1.116)	0.530 (1.100)	0.669 (1.428)	0.784* (1.686)
Household head's education	-0.036 (-0.582)	-0.057 (-0.949)	-0.054 (-0.872)	-0.042 (-0.774)	-0.054 (-1.045)	-0.063 (-1.202)
Household head's age	0.009 (0.549)	0.007 (0.431)	0.009 (0.581)	0.003 (0.163)	-0.001 (-0.040)	-0.002 (-0.107)
Log population density	-0.271 (-0.981)	-0.226 (-0.818)	-0.263 (-0.960)	-0.169 (-0.593)	-0.067 (-0.232)	-0.046 (-0.162)
Rainfall mm (5 year average)	0.029 (0.389)	0.055 (0.745)	0.055 (0.758)	0.037 (0.493)	0.060 (0.871)	0.072 (1.051)
Temperature °C (5 year average)	-0.188 (-0.988)	-0.110 (-0.580)	-0.122 (-0.651)	-0.128 (-0.661)	-0.033 (-0.174)	0.004 (0.023)
Constant	2.198 (0.138)	-4.389 (-0.276)	-3.262 (-0.209)	-1.118 (-0.069)	-8.740 (-0.549)	-11.764 (-0.742)
Observations	132	132	132	132	132	132
R-squared	0.420	0.443	0.458	0.408	0.399	0.413
Number of households	66	66	66	66	66	66
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year* Region	Yes	Yes	Yes	Yes	Yes	Yes

Robust *t*-statistics are in parentheses. ***, **, and * indicates the significance level at 1%, 5%, and 10%, respectively. Robust standard errors are clustered at community-level. Estimates are weighted by attrition weights. In column 1–6 soil quality indices are as defined in Table 9. Other regressors included, but omitted from the table, are the same variables omitted from Table 9

Table 15 A subsample of households who moved from perceiving to have complete transfer rights to not perceiving to have complete transfer rights

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Log carbon	Log Nitrogen	Log phosphorous	Log potassium	Log calcium	soil pH	soil pH dummy
1 if has transfer rights	0.054 (0.180)	0.470 (1.439)	-1.281*** (-2.999)	0.101 (0.292)	0.107 (0.419)	-0.028 (-0.063)	0.091 (0.213)
1 if female headed household	0.154 (1.093)	0.112 (0.724)	-0.235 (-1.046)	0.184 (1.137)	0.086 (0.609)	-0.533*** (-2.797)	-0.227 (-1.143)
Household head's education	-0.011 (-0.657)	0.004 (0.243)	-0.003 (-0.093)	-0.042** (-2.220)	-0.008 (-0.391)	0.043** (2.045)	0.015 (0.520)
Household head's age	0.004 (1.191)	0.005 (1.412)	0.010 (1.625)	-0.008 (-1.407)	0.002 (0.305)	0.005 (0.532)	0.011 (1.262)
Log population density	0.063 (0.916)	0.039 (0.508)	-0.163* (-1.877)	-0.057 (-0.612)	-0.112 (-1.661)	-0.096 (-1.319)	-0.174* (-1.817)
Rainfall mm (5 year average)	0.008 (0.550)	0.017 (0.978)	-0.011 (-0.354)	-0.013 (-0.500)	-0.001 (-0.055)	-0.046* (-1.841)	0.005 (0.211)
Temperature °C (5 year average)	0.017 (0.396)	0.008 (0.153)	-0.122 (-1.641)	-0.077 (-1.195)	-0.067 (-1.298)	-0.163** (-2.282)	-0.051 (-0.675)
Constant	-4.624 (-1.377)	-7.550* (-1.843)	9.096 (1.680)	5.718 (1.007)	5.939 (1.313)	18.633*** (3.382)	4.654 (0.742)
Observations	132	132	132	132	132	132	132
R-squared	0.396	0.445	0.777	0.622	0.588	0.548	0.339
Number of households	66	66	66	66	66	66	66
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year* Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust *t*-statistics are in parentheses. ***, **, and * indicates the significance level at 1%, 5%, and 10%, respectively. Robust standard errors are clustered at community-level. Estimates are weighted by attrition weights. Other regressors included, but omitted from the table, are the same variables omitted from Table 9

References

- Abdulai A, Owusu V, Goetz R (2011) Land tenure differences and investment in land improvement measures: theoretical and empirical analyses. *J Dev Econ* 96(1):66–78. <https://doi.org/10.1016/j.jdeveco.2010.08.002>
- Amone C, Lakwo C (2014) Customary land ownership and underdevelopment in Northern Uganda. *Int J Social Sci Human Res* 2(3):117–125
- Bambio Y, Bouayad AS (2018) Land tenure security and investment: does strength of land right really matter in rural Burkina Faso. *World Dev* 111:130–147. <https://doi.org/10.1016/j.worlddev.2018.06.026>
- Bellemare MF (2013) The productivity impacts of formal and informal land rights: evidence from Madagascar. *Land Econ* 89(2):272–290. <https://doi.org/10.3368/le.89.2.272>
- Besley T (1995) Property rights and investment incentives: theory and evidence from Ghana. *J Political Econ* 103(5):903–937. <https://doi.org/10.1086/262008>
- Brasselle AS, Gaspard F, Platteau JP (2002) Land tenure security and investment incentives: puzzling evidence from Burkina Faso. *J Dev Econ* 67(2):373–418. [https://doi.org/10.1016/s0304-3878\(01\)00190-0](https://doi.org/10.1016/s0304-3878(01)00190-0)
- Busingye H (2002) Customary land tenure reform in Uganda: Lessons for South Africa. International Symposium on Communal Tenure Reform. Programme for Land and Agrarian Studies (PLAAS), Johannesburg. https://mokoro.co.uk/wp-content/uploads/customary_land_tenure_reform_uganda.pdf. Accessed 14 November 2021
- Chen Y, Xudong Z, Hongbo H, Hongtu X, Ying Y, Ping Z, Lichun W (2010) Carbon and nitrogen pools in different aggregates of a Chinese Mollisol as influenced by long-term fertilization. *J Soils Sediment* 10:1018–1026. <https://doi.org/10.1007/s11368-009-0123-8>
- Chenery EM (1960) An Introduction to the soils of the Uganda protectorate. Memoirs of the Research Division, Series 1- Soils, Number 1, Department of Agriculture, Kawanda Research Station, Uganda
- Deininger K, Ali DA (2008) Do overlapping land rights reduce agricultural investment? Evidence from Uganda. *Am J Agric Econ* 90(4):869–882. <https://doi.org/10.2307/20492341>
- Deininger K, Ali DA, Alemu T (2011) Impacts of land certification on tenure security, investment, and land market participation: evidence from Ethiopia. *Land Econ* 87(2):312–334. <https://doi.org/10.3368/le.87.2.312>
- Deininger K, Ali DA, Yamano T (2008) Legal knowledge and economic development: the case of land rights in Uganda. *Land Econ* 84(4):593–619. <https://doi.org/10.3368/le.84.4.593>
- Deininger K, Castagnini R (2006) Incidence and impact of land conflict in Uganda. *J Econ Behav Organ* 60(3):321–345. <https://doi.org/10.1016/j.jebo.2004.04.008>
- Deininger K, Jin S (2006) Tenure security and land-related investment: Evidence from Ethiopia. *Eur Econ Rev* 50(5):1245–1277. <https://doi.org/10.1016/j.euroecorev.2005.02.001>
- Dong W, Zhang X, Wang H, Dai X, Sun X, Qiu W, Yang F (2012) Effect of different fertilizer application on the soil fertility of paddy soils in Red Soil Region of Southern China. *PLoS ONE* 7(9):1–9. <https://doi.org/10.1371/journal.pone.0044504>
- FAO (2002) Land tenure and rural development. FAO Land Tenure Studies No.3. <https://fao.org/3/y4307e/y4307e.pdf>. Accessed 5 April 2021
- FAO (2015) The state of food and agriculture: Social protection and agriculture—Breaking the cycle of rural poverty. Acra. <http://www.fao.org/3/a-i4910e.pdf5d80-c277-4f12-be11-fb4b384cee35/>. Accessed 26 June 2017
- Feder G, Feeny D (1991) Land tenure and property rights: theory and implications for development policy. *World Bank Econ Rev* 135–154. <https://doi.org/10.1093/wber/5.1.135>
- Fenske J (2011) Land tenure and investment incentives: evidence from West Africa. *J Dev Econ* 95(2):137–156. <https://doi.org/10.1016/j.jdeveco.2010.05.001>
- Fitzgerald J, Gottschalk P, Moffitt R (1998) An analysis of sample attrition in panel data: the Michigan Panel Study of Income Dynamics. *J Hum Resour* 33(2):251. <https://doi.org/10.3386/t0220>
- Gavian S, Fafchamps M (1996) Land tenure and allocative efficiency in Niger. *Am J Agric Econ* 78(2):460. <https://doi.org/10.2307/1243717>
- Goldstein M, Udry C (2008) The profits of power: land rights and agricultural investment in Ghana. *J Political Econ* 116(6):981–1022. <https://doi.org/10.1086/595561>
- Gray CL (2011) Soil quality and human migration in Kenya and Uganda. *Glob Environ Change* 21(2):421–430. <https://doi.org/10.1016/j.gloenvcha.2011.02.004>
- Guo J, Liu XJ, Zhang Y, Shen J, Han W, Zhang W, Zhang FS (2010) Significant acidification in major Chinese croplands. *Science* 327(5968):1008–1010. <https://doi.org/10.1126/science.1182570>
- Hayes J, Roth M, Zepeda L (1997) Tenure security, investment and productivity in Gambian agriculture: a generalized Probit analysis. *Am J Agric Econ* 79:369–382. <https://doi.org/10.2307/1244136>
- Henaio J, Baanante CA (2006) Agricultural production and soil nutrient mining in Africa: implications for resource conservation and policy development. IFCD. <http://hdl.handle.net/10919/68832>. Accessed 2 January 2017
- Jacoby HG, Li G, Rozelle S (2002) Hazards of expropriation: tenure insecurity and investment in Rural China. *Am Economic Rev* 92(5):1420–1447. <https://doi.org/10.1257/000282802762024575>
- Jenny H (1995) Factors of soil formation. A system of quantitative pedology. Dover Publications, Inc. New York
- Kabubo-Mariara J (2007) Land conservation and tenure security in Kenya: Boserup's hypothesis revisited. *Ecol Econ* 64:25–35. <https://doi.org/10.1016/j.ecolecon.2007.06.007>
- Lal R (2006) Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural lands. *Land Degrad Dev* 17:197–209. <https://doi.org/10.1002/ldr.696>
- Liu Z, Rong Q, Zhou W, Liang G (2017) Effects of inorganic and organic amendment on soil chemical properties, enzyme activities, microbial community and soil quality in yellow clayey soil. *PLoS ONE*, 12(3). <https://doi.org/10.1371/journal.pone.0172767>
- Loveland P, Webb J (2003) Is there a critical level of organic matter in the agricultural soils of temperate regions: a review. *Soil Tillage Res* 70(1):1–18. [https://doi.org/10.1016/S0167-1987\(02\)00139-3](https://doi.org/10.1016/S0167-1987(02)00139-3)
- Mallarino P, Blackmer AM (1992) Comparison of methods for determining critical concentrations of soil test phosphorus for corn. *Agron J* 84(5):850. <https://doi.org/10.2134/agronj1992.00021962008400050017x>
- Marenya PP, Barrett CB (2009) State-conditional fertilizer yield response on Western Kenyan farms. *Am J Agric Econ* 91(4):991–1006. <https://doi.org/10.1111/j.1467-8276.2009.01313.x>
- Matsumoto T, Yamano T (2009) Soil fertility, fertilizer, and the maize Green Revolution in East Africa. World Bank. Policy Research Working Paper; No. 5158. World Bank, Washington, DC. <https://openknowledge.worldbank.org/handle/10986/19960>. Accessed 2 February 2017
- Michelson H, Muniz M, DeRosa K (2013) Measuring socio-economic status in the millennium villages: the role of asset index choice. *J Dev Stud* 49(7):917–935. <https://doi.org/10.1080/00220388.2013.785525>

- Morris M, Kelly VA, Kopicki RJ, Byerlee D (2007) Fertilizer use in African agriculture: Lessons learned and good practice guidelines. Directions in Development; Agriculture and Rural Development. Washington, DC: World Bank. <https://openknowledge.worldbank.org/handle/10986/6650>. Accessed 14 March 2017
- Mugizi FMP, Matsumoto T (2021) From conflict to conflicts: War-induced displacement, land disputes, and agricultural productivity in post-war Northern Uganda. *Land Use Policy*, Volume 101. <https://doi.org/10.1016/j.landusepol.2020.105149>
- Mugizi FMP, Matsumoto T (2021) A curse or a blessing? Population pressure, and soil quality in Sub-Saharan Africa: evidence from Rural Uganda. *Ecol Econ* Volume 179. <https://doi.org/10.1016/j.ecolecon.2020.106851>
- Mugizi FMP, Matsumoto T (2020) Population pressure and soil quality in Sub-Saharan Africa: panel evidence from Kenya. *Land Use Policy*, Volume 94. <https://doi.org/10.1016/j.landusepol.2020.104499>
- Musinguzi P, Ebanyat P, Tenywa JS, Basamba TA, Tenywa MM, Mubiru DN (2016) Critical soil organic carbon range for optimal crop response to mineral fertiliser nitrogen on a Ferralsol. *Exp Agric* 52(4):635–653. <https://doi.org/10.1017/s0014479715000307>
- Musinguzi P, Tenywa JS, Ebanyat P, Tenywa MM, Mubiru DN, Basamba TA, Leip A (2013) Soil organic carbon thresholds and nitrogen management in tropical agroecosystems: concepts and prospects. *J Sustain Dev* 6(12):31–43. <https://doi.org/10.5539/jsd.v6n12p31>
- Mwesigye F, Barungi M (2021) Land tenure insecurity, fragmentation and crop choice: Evidence from Uganda. AERC Research Paper 419. <https://africaportal.org/documents/Research-Paper-419.pdf>. Accessed 1 July 2021
- Mwesigye F, Matsumoto T, Otsuka K (2017) Population pressure, rural-to-rural migration and evolution of land tenure institutions: the case of Uganda. *Land Use Policy*, 65, 1–14. Mwesigye, Francis; Matsumoto, Tomoya; Otsuka, Keijiro (2017). <https://doi.org/10.1016/j.landusepol.2017.03.020>
- Namubiru-Mwaura E, Place F (2013) Securing land for agricultural production. In: Africa Agriculture Status Report: Focus on Staple Crops. Nairobi, Kenya: Alliance for a Green Revolution in Africa. https://agra.org/wp-content/uploads/2017/09/agra_africa_agriculture_status_report_2013.pdf. Accessed 15 May 2021
- Nkonya E, Kaizzi C, Pender J (2005) Determinants of nutrient balances in a maize farming system in eastern Uganda. *Agric Syst* 85:155–182. <https://doi.org/10.1016/j.agsy.2004.04.004>
- Otsuka K, Place F (ed) (2001) Land Tenure and Natural Resource Management: a Comparative Study of Agrarian Communities in Asia and Africa. Johns Hopkins University Press, Baltimore
- Pender J, Nkonya E, Jagger P, Sserunkuuma D, Ssali H (2004) Strategies to increase agricultural productivity and reduce land degradation: Evidence from Uganda. *Agric Econ* 31:181–195. <https://doi.org/10.1016/j.agecon.2004.09.006>
- Place F, Barrett CB, Freeman HA, Ramisch JJ, Vanlauwe B (2003) Prospects for integrated soil fertility management using organic and inorganic inputs: Evidence from smallholder African agricultural systems. *Food Policy* 28:365–378. <https://doi.org/10.1016/j.foodpol.2003.08.009>
- Place F, Hazell P (1993) Productivity effects of indigenous land tenure systems in Sub-Saharan Africa. *Am J Agric Econ* 75:10–19. <https://doi.org/10.2307/1242949>
- Place F, Otsuka K (2002) Land tenure systems and their impacts on agricultural investments and productivity in Uganda. *J Dev Stud* 38(6):105–128. <https://doi.org/10.1080/00220380412331322601>
- Sanchez PA, Shepherd KD, Soule MJ, Place FM, Buresh RJ, Izac AMN, Mokwunye AU, Kwesiga FR, Ndiritu CG, Woomer PL (1996) Soil fertility replenishment in Africa: An investment in natural resource capital. *Replenishing Soil Fert Afr* 6:1. <https://doi.org/10.2136/sssaspecpub51.c1>
- Sanchez PA (2002) Soil fertility and hunger in Africa. *Science*, 64–66. <https://doi.org/10.2307/3076259>
- Shepherd KD, Walsh MG (2002) Development of reflectance spectral libraries for characterization of soil properties. *Soil Sci Soc Am J* 66(3):988–998. <https://doi.org/10.2136/sssaj2002.9880>
- Srivastava S, Subba Rao A, Alivelu K, Singh KN, Raju NS, Rathore A, (2006) Evaluation of crop responses to applied fertilizer phosphorus and derivation of optimum recommendations using the Mitscherlich-Bray equation. *Communications in Soil Science and Plant Analysis* 37(5–6):847–858. <https://doi.org/10.1080/00103620600564182>
- Tully K, Sullivan C, Weil R, Sanchez P (2015) The state of soil degradation in Sub-Saharan Africa: Baselines, trajectories, and solutions. *Sustainability* 7:6523–6552. <https://doi.org/10.7916/D8HM5894>
- West H (1965) The mailo system in Buganda. The Government Printer, Uganda, Entebbe
- Wooldridge JM (2010) *Econometric Analysis of Cross Section and Panel data*. MIT Press, Cambridge, MA
- Yamano T, Kijima Y (2010) The associations of soil fertility and market access with household income: Evidence from rural Uganda. *Food Policy* 35(1):51–59. <https://doi.org/10.1016/j.foodpol.2009.09.005>
- Yamano T, Sserunkuuma D, Otsuka K, Omiat G, Ainembabazi JH, Shimamura Y (2004) The 2003 REPEAT survey in Uganda: Results. FASID Development Database. <https://www3.grips.ac.jp/~yamanota/REPEATinUgandaReport.pdf>. Accessed 20 April 2017