Impacts of Cash Crop Production on Land Management and Land Degradation: The Case of Coffee and Cotton in Uganda

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Abstract

We investigate the impacts of coffee and cotton production on land management and land degradation in Uganda, based on a survey of 851 households and soil measurements in six major agro-ecological zones, using matching and multivariate regression methods. The impacts of cash crop production vary by agro-ecological zones and cropping system. In coffee producing zones, use of organic inputs is most common on plots growing coffee with other crops (mainly bananas), and least common on mono-cropped coffee. Both mono-cropped coffee and mixed coffee plots have lower soil erosion than other plots in coffee producing zones because of greater soil cover. Potassium depletion is much greater on mixed banana-coffee plots. In the cotton production zone, few land management practices or investments are used, especially on cotton plots. Soil erosion and soil nutrient depletion are lower in the cotton zone than in coffee producing zones because of flatter terrain and lower crop yields. Soil erosion is much higher on cotton than non-cotton plots in this zone. These results imply that promotion of cash crop production will not halt land degradation, and in some cases will worsen it, unless substantial efforts are made to promote adoption of sustainable land management practices.

Key words: land management, land degradation, soil nutrient depletion, soil erosion, agricultural commercialization, cash crops, Uganda

JEL: Q13, Q16, Q17

Introduction

Land degradation is a severe problem in Uganda, as elsewhere in sub-Saharan Africa. The rate of soil nutrient depletion in Uganda in among the highest in Africa (Henao and Baanante 2006) because of very limited use of organic or inorganic sources of fertility. The rate of fertilizer use in Uganda is among the lowest in the world, averaging only 1 kg of soil nutrients per hectare in the 1990s (NARO and FAO 1999). Soil erosion is severe in many sloping areas. For example, Rücker (2005) estimated that net soil loss since the 1960s averaged 21 tons/ha/year in a cultivated site in the eastern highlands, with rates as high as 45 tons/ha/year on the more steeply sloping portions of the site, while similar erosion rates have been measured in erosion plots on sloping lands in central Uganda (Zake and Nkwiine 1995).

Land degradation is contributing to low and declining productivity in Uganda, and hence is undermining efforts to reduce poverty. According to one recent study, Ugandan farmers deplete on average about 1.2 percent of the soil nutrient stock in their topsoil each year, causing a productivity decline of 0.3 percent (Nkonya, et al. 2005). Ugandan farmers depend on soil nutrient mining for about one-fifth of their farm income on average (Ibid.).[1]

The main response to low agricultural productivity and rural poverty by policy makers in Uganda (and many other African countries) is to promote agricultural modernization and commercialization. Promotion of high value cash crop production[2] is often seen as the solution to land management problems since farmers are expected to have more incentive and ability to finance use of fertilizer and organic inputs and to make land improving investments on cash crops than on subsistence food crops.

There is significant evidence supporting this presumption. For example, Tiffen, Mortimore and Gichuki (1994) found that farmers in the Machakos district of Kenya adopted higher value cash crops and more intensive soil and water conservation practices, resulting in higher incomes and less erosion as population grew and access to market opportunities improved over a 50 year period. Place, et al. (2006) found a similar pattern of improving land management and incomes in the highlands of central Kenya associated with shifts to production of higher value commodities, including coffee, tea and dairy production; in contrast to

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[1] This is the value of soil nutrient depletion with nutrients valued at their replacement cost, using the cheapest available fertilizers.

[2] We define a cash crop as a crop grown primarily for sale, as distinct from food crops, which are consumed at home as well as (in most cases) sold by farm households.

continuing land degradation in subsistence food production systems of western Kenya. In Uganda, Pender, et al. (2004) found that adoption of organic land management practices and perceived improvements in resource and welfare conditions were greater where coffee and banana production were expanding than in other development pathways. Nkonya, et al. (2004) also found favorable impacts of cash crop production on adoption of several land management practices in Uganda, while Pender, et al. (2001) found similar favorable impacts of perennial cash crop production in the Ethiopian highlands. In West Africa, Mortimore (2005) found improving land management in rural areas around the city of Kano in Nigeria, associated with production of cash crops such as groundnuts, livestock and increasing off-farm employment opportunities.

Positive impacts of market development and cash crop production on land management are by no means a universal finding, however. For example, in a review of several studies of land management in the East African highlands, Pender, Place and Ehui (2006) found many examples in which better market access or cash crop production was associated with less adoption of improved land management practices. For example, Benin (2006) found that farmers in the Amhara region were less likely to use reduced tillage or contour plowing closer to roads; Pender and Gebremedhin (2007) found less use of contour plowing closer to towns in Tigray; and Jagger and Pender (2006) found less incorporation of crop residues or use of mulch closer to towns in Uganda.

Furthermore, better market access and cash crop production can contribute to land degradation even if these promote greater adoption of improved land management practices, because better access and greater market orientation can increase the outflows of nutrients from the farm through crop sales, and because cash crops may be more erosive than food crops. For example, de Jager, et al. (1998) found that more market oriented farms had much more negative soil nutrient balances in three districts of Kenya, even though they used more inorganic fertilizer. They found that nutrient balances varied substantially across types of crops, with maize and beans plots having higher rates of nutrient depletion than coffee or tea plots (though the differences weren’t statistically significant given their small sample), while depletion was much larger on napier grass plots than plots growing other crops. Nkonya, et al. (2004) found that soil nutrient depletion in maize systems of eastern Uganda was greater in villages closer to markets, mainly because the outflows of harvested products were much greater in these areas and not compensated by increased nutrient inflows.

Clearly, the question of what impacts production of cash crops and commercialization of food crops have on land management and land degradation is not a settled issue. In this paper, we investigate the first part of this question, focusing on the impacts of cash crop production on land management and land degradation in Uganda. We investigate the impacts of coffee and cotton production because these are the two most important cash crops grown in Uganda. We contribute to the literature on this issue is several ways. First, unlike previous studies, our analysis is based on a large survey (851 households and more than 3,700 plots) conducted in several important farming systems of Uganda. Secondly, we investigated not only land management practices or perceptions of changes in resource conditions, as in several studies, but also estimated soil erosion and nutrient balances at the plot level based on detailed information collected in the survey and measurements and soil samples collected from each plot, and then related these outcomes to the choice of crop at the plot level. Although such work has been done in some studies such as de Jager, et al. (1998) and Nkonya, et al. (2004), those studies were much smaller in scale and did not identify comparable counterfactual (non-cash crop) plots for comparison to cash crop plots. In this study, we analyzed these data using several econometric matching and regression methods to control for selection biases, and investigated the robustness of our findings to alternative methods.

The remainder of the paper is organized as follows. Section 2 presents information on the agro-ecological zones and farming systems in Uganda, section 3 discusses the methods of data collection and analysis used, section 4 presents the results, and section 5 concludes.

1. Agro-ecological zones and farming systems in Uganda

Wortmann and Eledu (1999) classified 14 major agro-ecological zones in Uganda (Figure 1). These categories are largely determined by the amount of rainfall, which drives agricultural potential and farming systems in each category. Our surveys were conducted in eight districts representing six of the most populated zones:

(i) The Lake Victoria Crescent zone has a high level of rainfall (above 1200 mm/year) distributed throughout the year in a bimodal pattern. Agricultural production is dominated by the banana-coffee farming system. The zone runs along the vicinity of

Lake Victoria from the east in Mbale district, through the central region to Rakai district in southwestern Uganda along the shores of Lake Victoria.

(ii) Northwest farmland zone: This area is characterized by unimodal low to medium rainfall and covers the west Nile districts of Arua, Nebbi and Yumbe. Common crops grown in the zone are coarse grain (sorghum, millet, bulrush, etc), maize, tubers, and tobacco. The region covers areas with high rainfall in the highlands (above 1200 mm/year) and medium rainfall in the lowlands plans (900 – 1200mm/year).

(iii) North-moist farmland: This zone is also characterized by unimodal low to medium rainfall (700 – 1200 mm/year) and covers most of the northern districts. The area has sandy soils with low inherent fertility. The common crops grown are coarse grain, maize, tubers, cotton, and a variety of legumes.

(iv) Mount Elgon farmlands: This zone is on the slopes of Mount Elgon in the east and is characterized by unimodal high (above 1200 mm/year) and well distributed rainfall, high altitude and hence cooler temperatures, and relatively fertile volcanic soils. The main districts in this zone are Mbale and Kapchorwa. The major crops in this zone include maize, bananas and coffee.

(v) Southwestern grass-farmland: This zone receives medium to low rainfall (900 – 1200 mm/year) in a bimodal distribution. The region is along the cattle corridor area with mainly Savannah vegetation suitable to livestock grazing. Farmers in this zone keep large herds of cattle and grow bananas, coffee, coarse grains, maize and tubers.

(vi) Southwestern highlands (SWH) zone. This zone receives bimodal high rainfall (above 1200 mm/year) and has high altitude, hence cooler climate, and relatively fertile volcanic soils. Some areas in the lowlands receive medium rainfall ranging from 900 – 1200 mm/year. The common crops in the southwestern highlands are bananas, Irish potatoes and other tubers, sorghum, maize, and vegetables.

Our analysis focuses on the zones where coffee and cotton are primarily produced: the Lake Victoria Crescent, Mt. Elgon Farmlands, and Southwest Grasslands for coffee, and the Northern Moist Farmlands for cotton.

3. Methods

In this section we discuss the sources of data and methods of analysis used.

3.1. Data

The data used in this study included data collected from the Uganda Bureau of Statistics (UBOS) and data from a community, household and plot level survey. The surveys were conducted with a sub-sample of the enumeration areas and households included in the UBOS 2002/03 Uganda National Household Survey (UNHS). A stratified two-stage sample was drawn for the UNHS. Using the 56 districts as strata, 972 enumeration areas (565 rural and 407 urban) were randomly selected at the first stage sampling, from which a total of 9,711 households were randomly selected in the second stage sampling. Some of the data used in the econometric analysis in this study are from the UNHS and the Uganda 2002 Population Census.

Most of the data used in this study are derived from a smaller survey conducted by IFPRI and UBOS in 123 communities in 2003, which were drawn from the 565 rural enumeration areas that were covered by the UNHS. This smaller survey drew a sample using the rural enumeration areas in eight districts as the sampling frame. The districts selected for the IFPRI-UBOS survey were: Arua, Iganga, Kabale, Kapchorwa, Lira, Masaka, Mbarara, and Soroti. These districts were selected to represent different levels of poverty and natural resource endowments, and major agro-ecologies and farming systems in Uganda. Figure 1 shows the spatial distribution of the sampled communities.

In each selected enumeration area, we randomly selected seven of the UNHS sample households for the IFPRI-UBOS survey. The survey focused on questions that were not already available from the UNHS, particularly issues related to land management and land degradation. For each household, information was collected on all plots operated by the household, including the location of the plot, land use and types of crops, use of land management practices and land investments, inputs into and outputs from the plot, and others.

For crop plots, detailed measurements were taken in the field, including measurements of the plot size (using Global Positioning Units), slope (using clinometers), and topsoil depth. Soil samples were collected from the top 20 cm of the soil and analyzed by soil scientists at the soils laboratory of the Uganda National Agricultural Research Organization (NARO). These data, together with the survey data, were used to estimate soil nutrient stocks, inflows and outflows of soil nutrients from each plot, using the methods described by Smaling, et al. (1993) and de Jager, Nandwa and Okoth (1998).[3] In estimating soil nutrient outflows, soil erosion rates were estimated using the Revised Universal Soil Loss Equation (RUSLE) (Renard, et al. 1991), which has been calibrated and validated in several studies in Uganda (Lufafa, et al., 2003; Mulebeke, 2003; Majaliwa, 2003; Tukahirwa, 1996).

3.2. Analysis

We analyzed the differences in land management practices, soil erosion and soil nutrient depletion across plots growing coffee, cotton and other crops using simple descriptive statistics and econometric methods to account for differences in the characteristics of the plots and in agro-ecological and socioeconomic environments that may affect these outcomes. The econometric methods that we used included matching estimators and multivariate regression methods.

Matching methods are designed to identify the impacts of a discrete factor on outcomes of interest by selecting comparable "treatment" and "control" observations in terms of observable characteristics expected to jointly influence the selection of observations into these categories and the outcomes. Although often used to evaluate impacts of programs (e.g., Heckman, et al. 1997; Ravallion 2005), such methods can also be used to assess impacts of other discrete factors, such as impacts of land management practices (Kassie, et al. 2008). In our case, we used matching estimators to assess the impacts of plot level crop choice on land management and land degradation indicators.

The matching estimators used in our analysis include propensity score matching (PSM) (Rosenbaum and Rubin 1983) and the bias-corrected nearest neighbor matching (NN) estimator developed by Abadie, et al. (2004). Both methods use a distance metric based on observed covariates to select comparable "treatment" vs. "control" observations for comparison. PSM uses the predicted probability of an observation being in the "treated" vs. "control" category as the distance metric. NN uses a distance metric based on the magnitudes of differences in the values of the covariates, weighted by the inverse of the variance matrix, which accounts for differences in scale of the covariates.

Each of these methods has advantages and disadvantages. An advantage of PSM is that its distance metric gives greater weight to factors that influence the selection process, which are

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[3] The methods used to estimate soil nutrient flows and balances are described in detail in Kaizzi, Ssali and Kato (2004).

the factors that are most important to match to reduce potential selection bias in comparing the "treated" vs. "control" groups. By contrast, the distance metric of the NN estimator is more arbitrary. Two disadvantages of PSM relative to the NN estimator are 1) that the estimated impacts are biased to the extent that perfect matching is not achieved (i.e., there are still differences in the covariates among the matched samples), and 2) that the estimated standard errors are not correct because the propensity scores are estimated (Abadie and Imbens 2006). Analysts often use bootstrapping to estimate standard errors with propensity score matching, but this has been shown to be invalid in the case of PSM with nearest neighbor selection (Ibid.). By contrast, the NN estimator with bias correction corrects for bias using auxiliary regressions, and the estimated standard errors are correct (Abadie, et al. 2004). Since each method has advantages as well as disadvantages, we use both and check the robustness of our conclusions to the choice of method.

Matching methods also have advantages and disadvantages relative to other methods of estimating impacts, such as multivariate regression methods. Compared to parametric methods such as linear ordinary least squares (OLS), matching methods have the advantage of being less dependent upon parametric assumptions to identify impacts, and they can reduce the bias that can result from estimating impacts by comparing non-comparable observations in regression analysis (Heckman, et al. 1998).[4] On the other hand, matching estimators rely upon the untestable conditional independence assumption – the assumption that the outcome for the "control" group is independent of its treatment status, conditional upon the observed covariates (Ibid.). This assumption is similar to the assumption in OLS models that the error term is uncorrelated with the explanatory variables, and violation of either assumption can result in a bias due to "selection on unobservables" (Ibid.). This problem can be tested for and addressed using instrumental variables (IV) estimation if suitable instrumental variables can be identified. Thus, we estimate models using IV estimation as well as OLS to estimate determinants of soil nutrient balances and erosion. We use generalized method of moments – instrumental variables estimation (GMM-IV), which is efficient under heteroskedasticity (Davidson and MacKinnon

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[4] To reduce this bias, "treatment" and "control" observations used in the matching procedure are selected from the observations in the two groups that have "common support", meaning that observations from one group that have values of the covariates that are outside of the range of values observed for the other group are dropped from the comparison.

2004). For land management practices, we use probit models to predict impacts because these are discrete (yes/no) dependent variables.[5]

For the land management probit regression models, the specification is the following:

$$LM^{i}_{hp} = 1 \quad if\ b^{i}_{c}C_{hp} + b^{i}_{x}X_{hp} + u^{i}_{hp} > 0; LM^{i}_{hp} = 0\ otherwise. \tag{1}$$

LM^{i}_{hp} reflects adoption of land management practice i by household h on plot p, C_{hp} refers to the type of crop mix grown by household h on plot p, X_{hp} is a vector of plot, household and community characteristics affecting land management decisions, u^{i}_{hp} is an error term assumed to be distributed N(0,1) and uncorrelated with the explanatory variables, and b^{i}_{c} and b^{i}_{x} are vectors of parameters to be estimated.

We separate the analysis between coffee producing zones and cotton producing zones. In our sample, coffee is produced primarily in three zones: the Lake Victoria Crescent, the Mt. Elgon highlands, and the Southwest Grasslands zones (Figure 2). Cotton is produced primarily in the Northern Moist Farmlands zone. We thus focus the analysis of impacts of coffee production on the first three zones and the analysis of impacts of cotton on the last zone. In the coffee zones, C_{hp} reflects whether the plot is growing mono-cropped coffee, coffee mixed with other crops (usually bananas), or other crops. In the cotton zone, C_{hp} reflects whether the plot is used to grow cotton.

Consistent with many other studies of determinants of adoption of land management practices in Uganda and elsewhere in Africa (e.g., Clay, et al. 1998; Adesina and Chianu 2002; Freeman and Coe 2002; Kazianga and Masters 2002; Mekuria and Waddington 2002; Place, et al. 2002; Nkonya, et al. 2004; Benin 2006; Jagger and Pender 2006; Pender and Gebremedhin 2007), we assume that land management decisions are determined by household endowments, land quality characteristics, and community or higher level factors such as population density, access to markets and agro-ecological characteristics. We assume that X_{hp} includes plot quality characteristics including the plot size (acres), slope (percent), soil depth (cm) and texture (percent sand), and distance of the plot to the household residence (km); the household's

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[5] We also tried to use bivariate probit estimation to jointly estimate the determinants of crop choice and the impacts of crop choice on land management practices. However, this was not feasible due to convergence/identification problems, even when explanatory variables that were jointly insignificant in the univariate probit models were dropped from the second stage of the bivariate probit models.

endowments of land (area operated), livestock (tropical livestock units), equipment (value of equipment owned), education (proportion each of female and male household members with primary, secondary, or post-secondary education), and family labor (household size); gender (gender of head of household and share of land owned by women); the agro-ecological zone (dummy variables for each zone); population density of the village (persons per square km in 2002); and access to markets (measured by the potential market integration (PMI) index, an inverse measure of travel time to the nearest five urban centers weighted by the population size of each center (Wood, et al. 1999)) and roads (distance of the plot to the nearest all-weather road in km).[6] To reduce problems of outliers and nonlinearities in the models, we used natural logarithmic transformations (lnX) of all continuous positive variables in the regression analysis (Mukherjee, et al. 1998). For continuous variables taking zero or positive values, we used the transformation (lnX+1). The definitions and descriptive statistics of the explanatory variables used in the analysis are reported in Annex 1 for coffee producing zones and Annex 2 for the cotton zone.

Land management practices refer to decisions made in the current crop year, such as whether or not to apply manure or mulch to the plot. We also investigate the impacts of crop choice on land investments (LI^j_{hp}), such as construction of terraces or planting trees. In this case, we include only explanatory variables that are fixed or slowly changing as determinants of investments (Z_{hp}), including the size and slope of the plot, the depth and texture of the topsoil, the population density of the village, PMI, and the agro-ecological zone, since these investments were made in the past and could have affected other components of X_{hp}. As for land management practices, probit models are used to estimate impacts of crop choice on land investments:

$$LI^j{}_{hp} = 1 \quad if\ b^j{}_c C_{hp} + b^j{}_x Z_{hp} + u^j{}_{hp} > 0; LI^j{}_{hp} = 0\ otherwise. \qquad (2)$$

The specification for determinants of land degradation indicators (soil erosion and soil nutrient depletion, LD^j_{hp}) is quite similar to equation (1), except that uncensored regression models are used since the dependent variables are continuous and uncensored:

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[6] To avoid problems with endogenous explanatory variables, we do not include factors such as participation in technical assistance programs, access to credit or livelihood strategies as determinants of land management.

$$LD^{k}_{hp} = b^{k}_{c} C_{hp} + b^{k}_{x} X_{hp} + u^{k}_{hp} \tag{3}$$

Both OLS and GMM-IV estimation were used to estimate equation (3). For the GMM-IV estimation, the model was identified by using as instrumental variables predicted values of the probability of crop choice from a first stage discrete choice regression (multinomial logit for mono-cropped coffee and mixed coffee vs. non-coffee plots in coffee producing zones; probit for cotton vs. non-cotton plots in the cotton zone). The explanatory variables used to predict cotton choice in the cotton zone included all of X_{hp}. For the coffee regressions, we predicted coffee choice using only fixed or slowly changing variables (Z_{hp}), as in equation (2). The GMM-IV models could be identified using only these instrumental variables, but this relied solely on the nonlinear nature of the first stage regressions for identification, and resulted in weak identification. To improve identification, we also used as instrumental variables components of X_{hp} that were jointly statistically insignificant in both the OLS and the unrestricted GMM-IV models for equation (3). As will be noted further in the discussion of results below, this still resulted in weak identification of the land degradation regressions in coffee zones.

In addition to testing for weak identification, we tested the validity and exogeneity of the instrumental variables using Hansen's J test (Davidson and MacKinnon 2004). In all but one case (noted in the discussion of results below), this test failed to reject the null hypothesis that the instruments were valid and exogenous. We also tested for exogeneity of the crop choice variables using a C test (Baum, Schaffer and Stillman 2003), and in all cases failed to reject exogeneity. These results argue that the OLS model should be preferred to the GMM-IV model, since in the absence of endogeneity bias associated with the crop choice variables, OLS is more efficient than GMM-IV, and likely less biased due to the problem of weak identification (Bound, et al. 1995). Nevertheless, we report the results of both models.

We tested for heteroskedasticity in estimating equation (3) and found it to be a present. Thus, in the OLS regressions we used the Huber-White estimator of the covariance matrix, which is robust to heteroskedasticity, while the GMM estimator is consistent and efficient in presence of heteroskedasticity. In all regressions we accounted for possible non-independence of observations from different plots of the same household using Stata's "cluster" option. The regressions were also adjusted for the sample weights. We tested for multicollinearity and found it not to be a serious concern (the maximum variance inflation factor was 8.72 in the coffee regressions and 2.95 in the cotton regressions).[7]

For the PSM estimations, we used kernel matching with the epanechnikov kernel function (the default for Stata's PSMATCH2 command). For the NN estimations, we used the default weighting matrix for the distance metric (inverse variance of the covariates) and the five nearest neighbors in matching. In the matching estimations for coffee producing zones, we used pairwise matching, comparing mono-cropped plots to non-coffee plots in one estimation, then comparing mixed coffee plots to non-coffee plots in another estimation for each outcome variable. For cotton, a single pairwise estimation comparing cotton vs. non-cotton plots was used for each outcome. The covariates used in the matching estimators were the same as those used to predict crop choice in the GMM-IV regressions; i.e., we used X_{hp} as the vector of covariates for the cotton matching estimators, and the more restricted set of covariates Z_{hp} for the coffee matching estimators. After the PSM, we conducted balancing tests of how well the matching reduced differences in the covariates between the "treatment" and "control" groups. The results of these balancing tests are reported in Annexes 3 and 4. In all cases, the mean differences in covariates between the matched groups are statistically insignificant and quantitatively small, despite large differences in covariates in the unmatched groups in some cases. This indicates that PSM performs well to eliminate systematic differences between the different groups with respect to the covariates.

4. Results

We first present descriptive statistics on the land management practices and land degradation indicators in coffee and cotton producing zones, respectively, followed by our econometric results.

4.1. Land management practices in coffee zones

As noted earlier, the coffee producing zones in our sample include the Lake Victoria crescent, the Mount Elgon zone, and the Southwest grasslands zone. Of the 294 coffee plots in our survey sample, 286 were in these three zones. Hence, we limit our analysis of coffee production to

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[7] For most variables, the variance inflation factor (VIF) was much less than 5 in the coffee regressions; only the agro-ecological zone variables had VIF > 5 in these regressions. The coffee crop choice variables (for mono-cropped coffee and mixed coffee) had had VIF < 1.1, while in the cotton regressions, the cotton choice variable had VIF=1.1. These results indicate that multicollinearity had very little impact on the estimated standard errors of the coefficients for the crop choice variables.

these zones. In these zones, about one fifth of farmers' plots are growing coffee (Table 1). Most of these plots are mixed crop plots, including other crops as well as coffee, usually bananas (80 percent of coffee plots include bananas).

The most common land management practices used in coffee producing zones include use of organic materials to manage soil fertility, soil moisture and/or weeds (manure, compost, household refuse, mulch, crop residues); slash and burn or slashing only to clear the plot for cultivation; fallowing, crop rotation or cover crops to improve soil fertility; alternative tillage practices such as zero tillage and deep tillage; planting and plowing along slope contours to conserve soil and water; and inorganic fertilizer. None of these practices is very common; the most common is application of manure, which is used on less than one fifth of plots. Inorganic fertilizer is used on less than 2% of plots in these zones.[8]

There are substantial differences in the land management practices used on mono-cropped coffee, mixed coffee and other crop plots. In general, application of organic materials is much more common on mixed coffee plots than on either mono-cropped coffee or other crops. This is undoubtedly due to the importance of banana production on mixed coffee plots, for which use of manure, household refuse and mulch is fairly common. This finding is consistent with findings of other studies on use of land management practices in mixed coffee-banana production in Uganda (e.g., Pender, et al. 2004; Nkonya, et al. 2004). On mono-cropped coffee plots, by contrast, use of household refuse and mulch is much less common than on mixed coffee plots, and even less common than on other crop plots.

Not surprisingly, slash and burn and crop rotation are less common on perennial mono-cropped coffee and mixed coffee plots than on non-coffee plots, while contour planting and plowing are virtually non-existent on coffee plots. However, we do find some of these practices (slash and burn and crop rotation) on some coffee plots; these are probably associated with the annual crops grown on these plots. Even plots that we have classified as mono-cropped coffee may only have been mono-cropped in the cropping year covered by our survey. Other annual crops may be planted on those plots among the coffee trees in other years as part of a crop rotation or fallow system. This also explains how we find fallowing and tillage practices on

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[8] We exclude discussion of other even less common land management practices and land investments, found on less than 1 percent of plots of any type (i.e., mono-cropped coffee, mixed coffee or other crops). Examples of such rare practices include alley cropping, improved fallows, and green manures.

some coffee plots. We do not find inorganic fertilizer used on any of the mono-cropped coffee plots and on less than 2 percent of mixed coffee and non-coffee plots.

In addition to these types of regular land management practices, farmers invest in various types of land improvements. The most common land improvements used are drainage trenches (found on 27 percent of plots) and planting trees on the plot boundary (on 14 percent).[9] The relatively common use of drainage trenches indicates that managing excess water is a concern in many areas of the high rainfall coffee producing zones. Drainage trenches are more common on coffee plots than on non-coffee plots, suggesting that excess water is a particular concern for coffee. Other less common investments include grass strips, terraces, soil bunds, irrigation canals and live barriers; all of these are found on 3 percent or fewer of plots in coffee producing zones. We find no soil bunds, irrigation canals or live barriers on mono-cropped coffee plots, but these are also relatively rare on other plots. Other investments, such as trees on the plot boundary, grass strips and terraces are similarly common on coffee and non-coffee plots.

4.2. Land management practices in cotton zones

In our sample, cotton is produced primarily in the Northern Moist Farmlands zone, with 34 of the 42 cotton plots in our sample in this zone. About 5 percent of the plots in this zone are cotton plots (Table 2).

The most common land management practices used in the Northern Moist Farmlands zone include fallow (29 percent of plots) and crop rotation (21 percent). Other practices used on at least 1 percent of plots include slash and burn, burning or slashing only, incorporation of crop residues, deep tillage, fallow strips, and application of manure or household refuse. Inorganic fertilizer is very rarely used on this zone (0.1 percent of plots). Few of these practices are used on cotton plots. Only fallow, crop rotation and slashing are used on any cotton plots, and crop rotation is less common on cotton than on non-cotton plots.

Land investments are also rare in this zone. The only investment that we find on more than 1 percent of plots is tree planting on the plot. A higher percentage of non-cotton plots have planted trees than cotton plots, though the difference is not statistically significant.

4.3. Land degradation indicators in coffee and cotton zones

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[9] In plots growing coffee and other tree crops, farmers of course also plant trees within the plot. We do not include this as a land investment since this is already implied as part of the cropping system.

The average estimated soil nutrient balances are negative for N, P and K on all types of plots in the coffee producing zones, with mean soil nutrient depletion rates of -88 kg/ha/yr for N, -9 kg/ha/yr for P and -113 kg/ha/yr for K (Table 3). These depletion rates are larger than those estimated for Uganda as a whole by Stoorvogel and Smaling (1990) and Henao and Baanante (2006), but are more comparable to rates estimated in more micro level studies in East Africa, which tend to be more negative than the macro scale estimates (Smaling, et al. 1993; Van den Bosch, et al. 1998; Wortmann and Kaizzi 1998; Nkonya, et al. 2004).

The differences in depletion rates of N and P are statistically insignificant across mono-cropped coffee, mixed coffee and other crops. However, depletion of K is substantially greater on mixed coffee plots than on either non-coffee or mono-cropped coffee plots. This is mainly due to depletion of K through harvests of bananas, which have a high level of K. Thus, even though organic inputs are most common on mixed coffee plots, as shown in Table 1, and even though erosion is lower on these plots than non-coffee plots because of their greater soil cover, potassium depletion is still greater.

Average estimated soil nutrient depletion rates and soil erosion rates are lower in the Northern Moist Farmland zone than in the coffee producing zones, but still indicate relatively high rates of soil nutrient depletion – averaging -56, -5 and -35 kg/ha/yr of N, P and K, respectively (Table 4). Lower erosion is due to the flatter terrain in this zone than in coffee production zones, despite production of more erosive annual crops. Lower nutrient depletion in this zone is due to less erosion and lower crop yields, limiting nutrient outflows, despite very little inflows of organic or inorganic sources of soil nutrients. We find no statistically significant differences between plots growing cotton vs. other crops in terms of soil nutrient balances. However, estimated erosion is larger on cotton plots. This is not surprising since soil cover is low in cotton production due to tillage and intensive weeding of cotton plots.

4.4. Impacts of coffee on land management practices – matching and econometric results

The differences in land management practices between mono-cropped coffee, mixed coffee and non-coffee plots reported in Table 1 do not control for differences in the nature of the plots, the households operating them, or the local agro-ecological or socioeconomic environment. Hence these differences may not reflect the true effects of coffee production on land management. In Table 5, we present results of comparisons of land management practices on these different types of plots using the matching and econometric estimators discussed in section 3.

Most of the differences reported in Table 5 are consistent with the simple descriptive results in Table 1, and are in most cases robust to the estimator used, especially in comparing mixed coffee and non-coffee plots. The findings of the different estimators are less robust when comparing mono-cropped coffee and non-coffee plots, probably due to the relatively small number of mono-cropped coffee plots, which limits the ability to estimate impacts in some cases. For practices that were used on no mono-cropped coffee plots (e.g., inorganic fertilizer, contour planting, contour plowing, soil bunds, irrigation canals and live barriers), it was not possible to estimate the impact of mono-cropped coffee using a probit estimator, and for a few of these the NN estimator was also not estimable. For several other practices that were used on only a few mono-cropped coffee plots (e.g., slash and burn, crop rotation), the results were not robust between the PSM and NN estimator.

Statistically significant results that are robust across all three estimators include the following: use of household refuse and mulch are less likely on mono-cropped coffee than non-coffee plots; use of manure and household refuse are more likely on mixed coffee than non-coffee plots; and use of slash and burn, slashing or burning only, and fallow are less likely on mixed coffee than non-coffee plots. Results that are robust across the two matching estimators but not estimable or not significant in the probit model include: crop rotation is less likely on mono-cropped coffee or mixed coffee plots than on non-coffee plots; deep tillage is less likely on mono-cropped coffee than non-coffee plots; mulching is more likely on mixed coffee plots than non-coffee plots; incorporating crop residues, and contour planting and contour plowing are less likely on mixed coffee plots than non-coffee plots. Some results are estimable and significant only in the PSM model: inorganic fertilizer, slash and burn, contour planting, contour plowing, soil bunds and irrigation canals are less likely on mono-cropped coffee than non-coffee plots. A few results are significant only in the probit models: slashing only and cover crops are more likely on coffee mono-cropped plots than non-coffee plots.

These results confirm that there are significant differences in land management practices used on mono-cropped vs. mixed coffee vs. non-coffee plots. Use of organic inputs is most likely on mixed coffee plots and use of some organic inputs is least likely on mono-cropped coffee plots. Practices associated with annual crops, such as slash and burn, fallow, crop rotation, incorporation of crop residues and tillage practices are, not surprisingly, less common on coffee plots than non-coffee plots.

4.5. Impacts of cotton on land management practices – matching and econometric results

The estimated differences between use of land management practices on cotton vs. non-cotton plots in the Northern Moist Farmlands zone, using the two matching estimators and probit estimation, are reported in Table 6. For most land management practices, probit estimation could not estimate this difference because they were not used on any of the cotton plots in our sample.

Our results are less robust across the three estimators for cotton vs. non-cotton plots than our results for coffee vs. non-coffee plots. This is likely because of the small number of cotton plots in our sample. None of the findings were robust across all three estimators, and the only result that is robust across both matching estimators is that use of household refuse is less likely on cotton than on non-cotton plots. We find that slashing is more likely on cotton plots using both the NN matching estimator and the probit estimator. Several other results are significant only using one estimator: manure use less likely on cotton plots (NN); slash and burn, burning only, fallow strips, incorporation of crop residues and deep tillage are less likely on cotton plots (PSM); and tree planting more likely on cotton plots (NN).

Overall, these results support the conclusion that many land management practices are less common on cotton than non-cotton plots. The one exception is planted trees, for which a positive association with cotton was found using the NN estimator; but this result was not robust.

4.6. Impacts of coffee and cotton production on land degradation

The estimated impacts of mono-cropped and mixed coffee production on land degradation indicators relative to non-coffee plots, using the PSM and NN matching estimators as well as ordinary least squares (OLS) and generalized method of moments/instrumental variables regressions (GMM-IV), are shown in Table 7. The results are quite consistent across the two matching estimators and the OLS model, showing that soil erosion is significantly lower on both mono-cropped coffee (by 33 – 40 percent, depending on the estimator) and mixed coffee plots (by 17 – 19 percent) than on non-coffee plots, and that the K balance is more negative on mixed coffee plots than on non-coffee plots (by -77 to -105 kg of K/ha/year). The negative impact of mixed coffee on the K balance is also confirmed in the GMM-IV model.

Except for the weakly statistically significant impact of mixed coffee on the K balance in the GMM-IV model, the estimated impacts of mono-cropped or mixed coffee production on land degradation indicators in the GMM-IV models are statistically insignificant, despite the coefficients being substantially larger in this model than in the other models in all cases. This is due to weak identification of these models, leading to much larger standard errors and biased coefficients (Bound, et al. 1995).[10] Since our diagnostic tests with the GMM-IV model support the validity of the instrumental variables and exogeneity of the explanatory variables, OLS is preferred over the GMM-IV model as more efficient and subject to less bias.[11]

These results confirm our observations in Table 3 that potassium depletion is greater on mixed coffee plots than non-coffee plots, despite lower erosion on these plots, after controlling for differences between plot characteristics and agro-ecological and socio-economic conditions. We also find that erosion is lower on mono-cropped coffee than non-coffee plots, consistent with the estimated mean levels of erosion reported in Table 3 (although the result in Table 3 was not statistically significant). Hence, we find that coffee production has favorable impacts in reducing soil erosion due to better soil cover and less tillage than with annual crops. However, mixed coffee (usually with banana) production has a negative impact on potassium depletion, despite greater use of organic inputs, primarily due to the effects of banana harvests.

For cotton, we find that erosion is significantly greater on cotton plots than non-cotton plots (by 49 to 64 percent) using both matching estimators and OLS, while the impact on erosion in the GMM-IV model is statistically insignificant. We find no statistically significant differences in soil nutrient depletion on cotton vs. non-cotton plots using the different estimators, except a weakly significant (10 percent level) impact of cotton production on the P balance using GMM-IV. As for the coffee regressions, the exogeneity of the explanatory variables was not rejected in the GMM-IV models for cotton, so OLS is preferred over GMM-IV estimation.[12] Except for the GMM-IV results, these results are consistent with the descriptive findings in Table 4, showing that cotton is more erosive than other crops planted in cotton producing areas.

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[10] In the first stage of the GMM-IV models, the partial R^2 for mono-cropped coffee and mixed coffee variables were only 0.0058 and 0.0048, respectively, and Wald tests of the instrumental variables were statistically insignificant (p = 0.2645 and 0.6161 for mono-cropped coffee and mixed coffee, respectively). Under-identification of these models could not be rejected using the Kleibergen-Paap rk LM statistic (p levels = 0.4062). For an explanation of these diagnostic tests, see Baum, Schaffer and Stillman (2007). Full regression and diagnostic results are available from the authors upon request.

[11] The validity of the instrumental variables was not be rejected in any model using Hansen's J test (p levels = 0.1583, 0.5054, 0.9796, and 0.7597, respectively, for the N balance, P balance, K balance and soil loss regressions). Exogeneity tests of the mono-cropped coffee and mixed coffee variables did not reject exogeneity (p levels = 0.4383, 0.5895, 0.1261, and 0.3769, respectively, for the N balance, P balance, K balance and soil loss regressions).

[12] Exogeneity of the cotton production variable was not rejected in any of the land degradation regressions (p levels = 0.6402, 0.2200, 0.6050, and 0.9687, respectively, for the N balance, P balance, K balance and soil loss regressions). Full regression and diagnostic results are available upon request.

5. Conclusions

We find that cash crop production has significant impacts on land management and land degradation indicators, though the impacts vary by agro-ecological zones and cropping system. In coffee producing zones, use of organic inputs such as manure, household refuse and mulch are most common on plots growing coffee with other crops (mainly bananas), but least common on mono-cropped coffee. Practices associated with annual crops, such as slash and burn, fallowing, crop rotation, incorporation of crop residues and tillage practices are less common on coffee plots, though are still found in some cases because coffee is sometimes planted with annual crops. Estimated soil erosion is moderate in these areas, averaging less than 10 tons/ha/year, while soil nutrient depletion rates are high, averaging more than 200 kg of N, P and K per ha per year. Both mono-cropped coffee and mixed coffee production are associated with lower (at least 17 percent) estimated soil erosion than other plots in coffee producing zones because of greater soil cover provided by these perennial crops. Nevertheless, depletion of potassium is much (at least 75 kg/ha/year) greater on mixed coffee plots than other plots. This is due to banana production rather than coffee production on these plots, however.

In the lower rainfall and less densely populated cotton producing zone, few land management practices or investments are used on a significant share of plots. Only fallowing, crop rotation and, to a lesser extent, tree planting are used on more than 10 percent of plots in this zone. These were the only land management practices that were practiced on the cotton plots in our sample. Despite the lack of adoption of land management practices, soil erosion and soil nutrient depletion are lower in this zone than in coffee producing zones, because of the flatter terrain and lower crop yields. Nevertheless, soil nutrient depletion rates are still fairly high, averaging nearly 100 kg of N, P and K per ha per year. We found no statistically significant difference in soil nutrient balances on cotton vs. non-cotton plots. However, soil erosion is significantly (at least 48 percent) higher on cotton plots.

These results suggest that promoting cash crop production could help reduce land degradation in some contexts and worsen it in others. In particular, shifting from coffee-banana production to coffee production likely would reduce depletion of soil potassium, even though this is likely to reduce use of organic land management practices commonly used for bananas. By contrast, promoting cotton production likely would increase erosion and not improve soil nutrient depletion. Land degradation will continue at a rapid pace in Uganda, even with efforts to promote cash crop production, unless substantial efforts are made to promote increased use of soil fertility enhancing inputs and control erosion. Addressing land degradation in Uganda will require more concerted efforts to promote improved land management practices.

Our results imply that policy makers and researchers should be cautious in interpreting signs of agricultural commercialization or even more intensive land management as evidence that land degradation is becoming less of a problem, notwithstanding the recently heralded "success stories" in African agriculture. As we have seen, cash crops such as cotton may be more erosive, while adoption of intensive land management practices may be insufficient to offset high rates of nutrient outflows, as in the coffee – banana system. Further careful empirical research is needed in different agro-ecologies and farming systems to identify the extent to which agricultural commercialization and intensification are solving or exacerbating land degradation problems, and the implications of this for achieving sustainable improvements in productivity and reductions in poverty.

Table 1. Land management practices and investments in coffee producing zones[13] (% of plots)

Practice or investment	All plots	Mono-crop coffee	Mixed coffee	Other crops
Annual practices				
Manure	18.4	17.8	32.4***	15.7
Compost	2.6	4.4	3.7	2.3
Household refuse	14.4	2.2***	24.1***	12.9
Mulch	14.5	6.7*	22.4***	13.2
Incorporate crop residues	12.1	8.9	10.0	12.7
Inorganic fertilizer	1.8	0.0***	1.7	1.9
Slash and burn	12.4	6.7*	6.2***	13.8
Slashing only	9.8	22.2*	5.0***	10.3
Fallow	8.9	11.1	1.2***	10.4
Crop rotation	10.0	2.2***	6.2***	11.0
Cover crop	5.5	13.3	7.1	4.9
Contour planting	3.4	0.0***	0.0***	4.2
Contour plowing	3.3	0.0***	0.4***	4.0
Zero tillage	5.2	4.4	5.8	5.1
Deep tillage	15.9	6.7**	16.6	16.2
Land investments on plot				
Terrace	2.4	4.4	3.3	2.2
Soil bunds	0.9	0.0***	0.4	1.1
Drainage trenches	18.6	26.7	24.1**	17.2
Grass strips	3.0	2.2	3.7	2.8
Irrigation canals	0.7	0.0***	1.7	0.6
Live barriers	0.6	0.0**	1.7	0.4
Trees on plot boundary	13.6	13.3	12.4	13.9
Number of plots	1488	45	241	1202

*, **, ***: the reported statistic is statistically significantly different from the corresponding statistic for non-coffee plots at the 10%, 5%, or 1% level, respectively.

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[13] The main coffee producing zones in our sample include the Lake Victoria Crescent, Mt. Elgon zone, and Southwest grasslands zones. Of the 294 plots with coffee in our sample, 286 were in these zones.

Table 2. Land management practices in cotton producing zone[14] (% of plots)

Practice	All plots	Cotton	Other crops
Annual practices			
Manure	1.4	0.0***	1.5
Household refuse	1.2	0.0***	1.2
Inorganic fertilizer	0.1	0.0	0.2
Slash and burn	8.1	0.0***	8.5
Burning only	4.3	0.0***	4.6
Slashing only	4.0	11.8	3.6
Fallow	29.3	26.5	29.4
Fallow strips	1.6	0.0***	1.7
Crop rotation	21.4	11.8*	21.9
Incorporate crop residues	6.8	0.0***	7.1
Deep tillage	4.2	0.0***	4.4
Land investments on plot			
Planted trees	12.3	8.8	12.4
Number of plots	693	34	659

*, **, ***: the reported statistic is statistically significantly different from the corresponding statistic for non-cotton plots at the 10%, 5%, or 1% level, respectively.

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[14] The main cotton producing zone in our sample is the Northern Moist Farmlands. Of 42 cotton plots in our sample, 34 were in this zone.

Table 3. Land degradation indicators in coffee producing zones (means, standard errors in parentheses)

Indicator	All plots	Mono-crop coffee	Mixed coffee	Other crops
Soil nutrient balances (kg/ha/yr)				
- Nitrogen	-87.6 (3.9)	-77.4 (24.1)	-97.9 (9.7)	-86.0 (4.3)
- Phosphorus	-9.22 (0.64)	-6.66 (3.35)	-9.85 (1.58)	-9.18 (0.71)
- Potassium	-113.3 (6.2)	-65.9 (31.0)	-168.6*** (15.6)	-104.0 (6.9)
Soil erosion (tons/ha/yr)	9.66 (0.35)	7.49 (1.52)	8.19*** (0.56)	10.06 (0.41)
Number of plots	1488	45	241	1202

*, **, ***: the reported statistic is statistically significantly different from the corresponding statistic for non-coffee plots at the 10%, 5%, or 1% level, respectively.

Table 4. Land degradation indicators in cotton producing zone (means, standard errors in parentheses)

Indicator	All plots	Cotton	Other crops
Soil nutrient balances (kg/ha/yr)			
- Nitrogen	-56.2 (5.2)	-61.0 (10.0)	-55.9 (5.5)
- Phosphorus	-5.27 (0.55)	-6.20 (0.97)	-5.22 (0.57)
- Potassium	-35.0 (5.2)	-26.5 (5.1)	-35.4 (5.5)
Soil erosion (tons/ha/yr)	3.09 (0.09)	5.28*** (0.62)	2.96 (0.09)
Number of plots	693	34	659

*, **, ***: the reported statistic is statistically significantly different from the corresponding statistic for non-cotton plots at the 10%, 5%, or 1% level, respectively.

Table 5. Differences in land management practices on coffee vs. non-coffee plots in coffee zones using propensity score matching (PSM), nearest neighbor (NN) matching, and probit regressions

	Monocrop coffee – non-coffee plots			Mixed coffee – non-coffee plots		
Practice	PSM	NN	Probit[a]	PSM	NN	Probit[a]
Manure	0.0174 (0.0570)	0.0212 (0.0605)	-0.0029 (0.0760)	0.1455*** (0.0309)	0.1487*** (0.0315)	0.0967*** (0.0401)
Compost	0.0174 (0.0310)	0.0091 (0.0368)	NE	-0.0004 (0.0120)	0.0012 (0.0150)	NE
Household refuse	-0.1004*** (0.0267)	-0.0744* (0.0400)	-0.1092** (0.0218)	0.1069*** (0.0312)	0.1142*** (0.0300)	0.0852*** (0.0354)
Mulch	-0.0746* (0.0442)	-0.0990* (0.0530)	-0.0795* (0.0304)	0.0777** (0.0323)	0.0773** (0.0307)	0.0379 (0.0316)
Inorganic fertilizer	-0.0110*** (0.0029)	-0.0053 (0.0107)	NE	-0.0133 (0.0107)	-0.0167 (0.0127)	NE
Slash and burn	-0.0807** (0.0387)	-0.0512 (0.0511)	-0.0543 (0.0272)	-0.0926*** (0.0190)	-0.0616*** (0.0228)	-0.0554*** (0.0169)
Slashing only	0.1161* (0.0643)	0.0884 (0.0608)	0.1459*** (0.0623)	-0.0610*** (0.0170)	-0.0612*** (0.0221)	-0.0478** (0.0189)
Fallow	0.0074 (0.0508)	-0.0339 (0.0586)	0.0146 (0.0368)	-0.0892*** (0.0114)	-0.1024*** (0.0193)	-0.0865*** (0.0115)
Crop rotation	-0.0828*** (0.0254)	-0.0994** (0.0461)	-0.0649 (0.0277)	-0.0424** (0.0192)	-0.0424* (0.0230)	-0.0310 (0.0220)
Incorporate crop residues	-0.0243 (0.0400)	-0.0430 (0.0555)	-0.0152 (0.0499)	-0.0404* (0.0225)	-0.0666*** (0.0256)	-0.0325 (0.0219)
Cover crop	0.0810 (0.0496)	0.0516 (0.0475)	0.0641** (0.0422)	0.0080 (0.0194)	-0.0121 (0.0217)	0.0130 (0.0158)
Contour planting	-0.0199*** (0.0045)	NE	NE	-0.0548*** (0.0106)	-0.0704*** (0.0146)	NE
Contour plowing	-0.0182*** (0.0044)	NE	NE	-0.0480*** (0.0094)	-0.0646*** (0.0144)	NE
Zero tillage	-0.0123 (0.0329)	-0.0140 (0.0406)	0.0071 (0.0354)	0.0024 (0.0167)	0.0178 (0.0174)	0.0186 (0.0167)
Deep tillage	-0.1069** (0.0419)	-0.1187** (0.0590)	-0.0588 (0.0414)	-0.0271 (0.0261)	-0.0391 (0.0298)	-0.0052 (0.0273)
Terrace	0.0298 (0.0284)	0.0444* (0.0254)	0.0709 (0.0831)	0.0179 (0.0113)	0.0257** (0.0109)	0.0576 (0.0564)
Soil bunds	-0.0092*** (0.0032)	-0.0038 (0.0082)	NE	-0.0039 (0.0051)	-0.0024 (0.0059)	NE
Drainage trenches	0.0803 (0.0659)	0.0389 (0.0682)	0.0803 (0.0680)	0.0381 (0.0274)	0.0203 (0.0307)	0.0330 (0.0393)
Grass strips	0.0005 (0.0212)	0.0050 (0.0249)	0.0207 (0.0352)	0.0012 (0.0135)	0.0115 (0.0134)	0.0028 (0.0097)
Irrigation canals	-0.0071*** (0.0026)	-0.0164 (0.0162)	NE	0.0082 (0.0091)	0.0044 (0.0089)	NE
Live barriers	-0.0036* (0.0020)	-0.0050 (0.0082)	NE	0.0125 (0.0091)	0.0039 (0.0098)	NE
Trees on plot boundary	0.0208 (0.0448)	0.0712 (0.0494)	0.1060 (0.0826)	0.0022 (0.0216	-0.0175 (0.0251)	-0.0029 (0.0305)

*, **, ***: the difference is statistically significant at the 10%, 5%, or 1% level, respectively.

[a] Marginal effects of the dummy variables for monocropped coffee and mixed coffee plots from probit regressions are reported in the table. Full probit regression results available upon request.

NE: Not estimable.

Table 6. Differences in land management practices on cotton vs. non-cotton plots in cotton zone using propensity score matching (PSM), nearest neighbor (NN) matching, and probit regressions

Practice	PSM	NN	Probit[a]
Manure	-0.0208 (0.0169)	-0.0300** (0.0143)	NE
Household refuse	-0.0092* (0.0053)	-0.0980*** (0.0342)	NE
Inorganic fertilizer	-0.0006 (0.0005)	NE	NE
Slash and burn	-0.0839*** (0.0240)	0.0044 (0.0113)	NE
Burning only	-0.0341** (0.0145)	0.0092 (0.0155)	NE
Slashing only	0.0394 (0.0544)	0.0886* (0.0506)	0.0764*** (0.0485)
Fallow	0.0076 (0.1018)	0.0263 (0.0845)	-0.0695 (0.0691)
Fallow strips	-0.0148* (0.0081)	0.0023 (0.0218)	NE
Crop rotation	-0.0931 (0.0765)	0.0415 (0.0613)	-0.0782 (0.0492)
Incorporate crop residues	-0.0438*** (0.0144)	-0.0234 (0.0153)	NE
Deep tillage	-0.0222*** (0.0067)	NE	NE
Planted trees	0.0002 (0.0557)	0.1091** (0.0554)	-0.0465 (0.0593)

*, **, ***: the difference is statistically significant at the 10%, 5%, or 1% level, respectively.

[a] Marginal effects of the dummy variable for cotton plots from probit regressions are reported in the table. Full probit regressions available upon request.

NE: Not estimable.

Table 7. Differences in land degradation in coffee producing areas

Indicator	PSM	NN	OLS	GMM-IV
Monocrop coffee – non-coffee plots				
N balance	10.04 (25.09)	12.29 (28.80)	16.47 (31.99)	-263.18 (380.80)
P balance	3.00 (3.41)	2.48 (5.93)	1.57 (4.50)	-49.20 (57.44)
K balance	31.46 (31.85)	26.66 (33.53)	31.34 (35.20)	-351.35 (550.60)
Ln(soil erosion)	-0.397* (0.225)	-0.508*** (0.188)	-0.396* (0.213)	5.68 (4.43)
Mixed coffee – non-coffee plots				
N balance	-11.59 (10.08)	-9.63 (12.68)	-25.13* (13.18)	152.56 (178.38)
P balance	0.04 (1.68)	-1.07 (1.95)	-2.47 (2.17)	-17.01 (31.80)
K balance	-76.93*** (16.38)	-74.85*** (17.94)	-104.91*** (20.67)	-487.96* (278.52)
Ln(soil erosion)	-0.186*** (0.064)	-0.204*** (0.072)	-0.209** (0.080)	0.288 (0.890)

*, **, ***: the difference is statistically significant at the 10%, 5%, or 1% level, respectively.

Table 8. Differences in land degradation in cotton producing areas

Indicator	PSM	NN	OLS	GMM-IV
Cotton – non-cotton plots				
N balance	-11.30 (13.50)	-21.53 (25.93)	-16.30 (14.99)	-69.62 (55.38)
P balance	-0.81 (1.30)	-2.94 (2.54)	-1.94 (1.73)	-12.42* (6.45)
K balance	2.50 (7.63)	-5.14 (23.69)	-3.92 (11.96)	-40.54 (50.27)
Ln(soil erosion)	0.407*** (0.136)	0.497*** (0.104)	0.398*** (0.150)	0.162 (0.350)

*, **, ***: the difference is statistically significant at the 10%, 5%, or 1% level, respectively.

Figure 1: Agro-climatic zones of Uganda

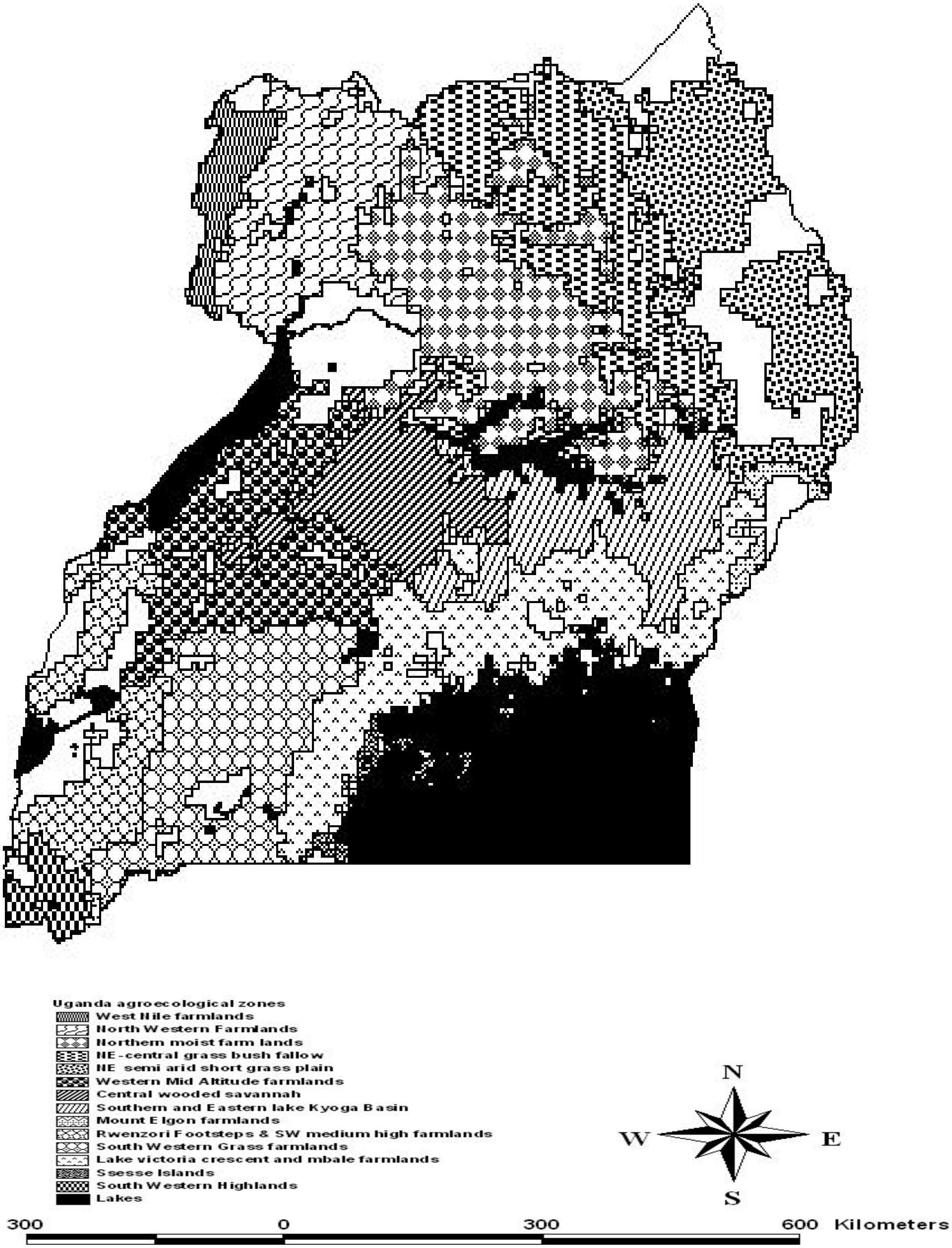
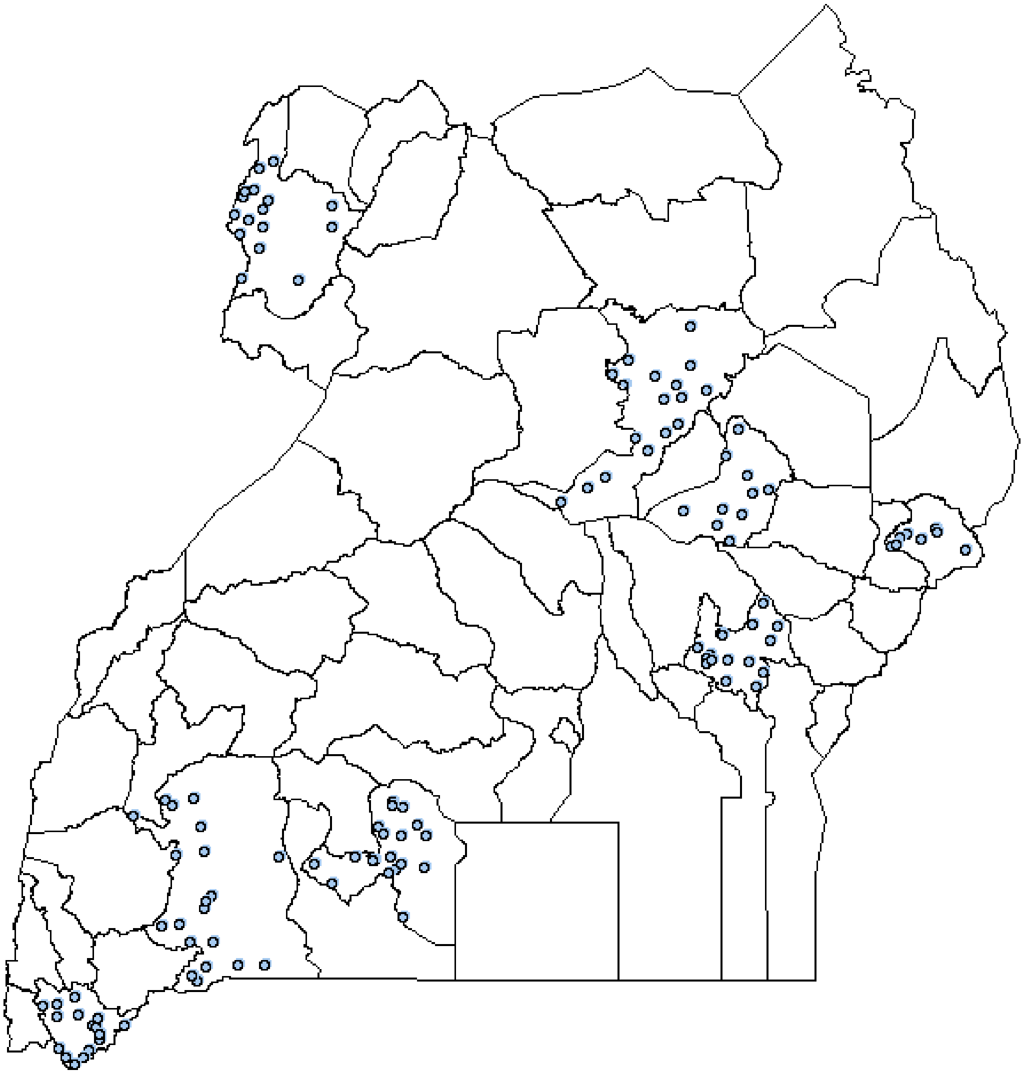


Figure 2. Spatial distribution of communities sampled



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Annex 1. Descriptive statistics of explanatory variables used in coffee regressions

Variable	Definition	Number of Observations	Mean	Std. Dev.	Min	Max
Coffeemixed	Coffee mixed with other crops on plot (dummy)	1488	0.162	0.369	0.000	1.000
Coffeemono	Coffee mono-cropped on plot (dummy)	1488	0.030	0.171	0.000	1.000
Avgslope	Ln(average slope of the plot in %)	1488	1.955	0.771	0.000	3.932
Soildepth	Ln(depth of topsoil in cm.)	1474	3.264	0.467	1.609	4.331
Sand	% of sand in the topsoil	1488	58.903	13.458	16.760	91.120
Logplotarea	Ln(area of plot in acres)	1483	-0.310	1.000	-2.303	5.110
Logfarm	Ln(area of farm in acres)	1481	0.763	1.064	-2.303	3.181
TLU	Ln(size of livestock herd in tropical livestock units)	1488	0.798	0.912	0.000	4.777
Valequip	Ln(value of farm equipment in 1,000 USh)	1488	2.412	2.153	0.000	9.210
Propeducfem2	Proportion of female household members with primary education	1488	0.405	0.447	0.000	1.000
Propeducfem3	Proportion of female household members with secondary education	1488	0.132	0.307	0.000	1.000
Propeducfem4	Proportion of female household members with post secondary education	1488	0.041	0.182	0.000	1.000
propeducmal2	Proportion of male household members with primary education	1488	0.454	0.456	0.000	1.000
propeducmal3	Proportion of male household members with secondary education	1488	0.168	0.337	0.000	1.000
propeducmal4	Proportion of male household members with post secondary education	1488	0.098	0.265	0.000	1.000
Sexhhd	Household head is male (dummy)	1488	0.846	0.361	0.000	1.000
Hhdsize	Ln(number of household members)	1488	1.791	0.440	0.693	2.890
propareawom	Proportion of household land owned by women	1488	0.127	0.317	0.000	1.000
Dist_res	Ln(distance from plot to residence in km + 1)	1488	0.366	0.557	0.000	5.017
PMI	Potential market integration index[15]	1488	215.517	92.167	26.907	415.073
Dist_road	Ln(distance from plot to nearest all-weather road in km + 1)	1488	0.985	0.711	0.000	3.801
Popdense	Ln(population density of the village in 2002 in persons/km^2)	1488	2.480	1.078	0.543	5.997

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[15] The potential market index is an index of market integration based on the travel times to the nearest five towns, weighted by the population of those towns (Wood, et al. 1999). A higher value of the index means better market access.

Annex 2. Descriptive statistics of variables used in the cotton regressions

Variable	Number of observations	Mean	Std. Dev.	Min	Max
Cotton (dummy)	693	0.049	0.216	0.000	1.000
Avgslope	693	0.997	0.355	0.000	1.946
Soildepth	323	3.003	0.376	1.609	4.025
Sand	693	69.784	8.685	41.840	89.840
Logplotarea	681	0.143	0.872	-2.303	3.335
Logfarm	686	1.441	0.889	-2.303	3.296
TLU	693	0.803	0.811	0.000	3.408
Valequip	693	2.712	1.936	0.000	7.626
propeducfem2	693	0.333	0.455	0.000	1.000
propeducfem3	693	0.061	0.209	0.000	1.000
propeducfem4	693	0.017	0.106	0.000	1.000
propeducmal2	693	0.490	0.464	0.000	1.000
propeducmal3	693	0.119	0.280	0.000	1.000
propeducmal4	693	0.062	0.209	0.000	1.000
Sexhhd	693	0.827	0.379	0.000	1.000
Hhdsize	693	1.756	0.399	0.693	2.639
Propareawom	693	0.114	0.302	0.000	1.000
Dist_res	693	0.285	0.497	0.000	3.718
PMI	693	161.183	90.284	9.745	337.894
Dist_road	693	0.688	0.512	0.000	3.560
Popdense	693	2.220	0.994	0.234	4.392

Annex 3. Balancing tests for coffee PSM estimations

Variable	Sample	Treated	Control	%bias	% reduction |bias|	t	p>|t|
Monocropped coffee vs. non-coffee							
PMI	Unmatched	229.4900	193.4600	41.7		2.790	0.005
	Matched	236.2000	224.3700	13.7	67.2	0.650	0.519
Logplotarea	Unmatched	-0.2908	-0.5322	24.0		1.560	0.119
	Matched	-0.3090	-0.3119	0.3	98.8	0.010	0.989
Logfarm	Unmatched	1.0055	0.7251	26.4		1.750	0.080
	Matched	1.0207	0.8888	12.4	52.9	0.630	0.531
Avgslope	Unmatched	1.7548	1.8757	-14.0		-1.030	0.302
	Matched	1.7709	1.9014	-15.2	-8.0	-0.730	0.469
Soildepth	Unmatched	3.2416	3.2654	-5.5		-0.380	0.702
	Matched	3.2351	3.2578	-5.2	4.7	-0.230	0.818
Sand	Unmatched	59.1600	60.1900	-7.2		-0.500	0.619
	Matched	58.9120	58.9510	-0.3	96.2	-0.010	0.988
Popdense	Unmatched	2.2162	2.2728	-5.5		-0.360	0.722
	Matched	2.2382	2.3577	-11.7	-111.1	-0.580	0.566
SWgrasszone	Unmatched	0.1754	0.1310	12.3		0.980	0.325
	Matched	0.2222	0.2878	-18.1	-47.6	-0.700	0.484
Lakevictzone	Unmatched	0.6140	0.2248	85.4		6.970	0.000
	Matched	0.7778	0.6775	22.0	74.2	1.060	0.293
Mixed coffee vs. non-coffee							
Pmi	Unmatched	235.0300	190.9000	50.7		7.460	0.000
	Matched	235.6900	235.3200	0.4	99.2	0.050	0.963
Logplotarea	Unmatched	-0.2779	-0.5475	25.3		3.790	0.000
	Matched	-0.2820	-0.2854	0.3	98.8	0.040	0.971
Logfarm	Unmatched	0.7266	0.7292	-0.2		-0.040	0.972
	Matched	0.7317	0.7475	-1.4	-507.5	-0.160	0.875
Avgslope	Unmatched	2.0011	1.8644	16.8		2.440	0.015
	Matched	2.0071	2.0095	-0.3	98.3	-0.030	0.972
Soildepth	Unmatched	3.2596	3.2655	-1.3		-0.200	0.838
	Matched	3.2617	3.2614	0.1	94.5	0.010	0.994
Sand	Unmatched	56.4360	60.4540	-28.5		-4.050	0.000
	Matched	56.7380	57.6150	-6.2	78.2	-0.750	0.452
Popdense	Unmatched	2.3858	2.2635	11.1		1.670	0.095
	Matched	2.4009	2.4371	-3.3	70.4	-0.370	0.711
SWgrasszone	Unmatched	0.1603	0.1295	8.7		1.420	0.155
	Matched	0.1765	0.1849	-2.4	72.7	-0.240	0.813
Lakevictzone	Unmatched	0.6489	0.1994	102.0		17.300	0.000
	Matched	0.7059	0.7125	-1.5	98.5	-0.160	0.874

Annex 4. Balancing tests for cotton PSM estimations

Variable	Sample	Treated	Control	%bias	% reduction |bias|	t	p>|t|
Avgslope	Unmatched	1.3374	1.8805	-70.5		-4.190	0.000
	Matched	1.1063	1.0695	4.8	93.2	0.400	0.691
Sand	Unmatched	68.1500	60.0760	62.8		3.510	0.000
	Matched	68.9600	69.1600	-1.6	97.5	-0.100	0.918
Logplotarea	Unmatched	0.5337	-0.5416	95.1		6.470	0.000
	Matched	0.4476	0.3714	6.7	92.9	0.310	0.760
Logfarm	Unmatched	1.6529	0.7179	105.6		5.430	0.000
	Matched	1.5866	1.5572	3.3	96.9	0.180	0.859
TLU	Unmatched	0.6936	0.7859	-11.9		-0.680	0.494
	Matched	0.5230	0.6026	-10.3	13.7	-0.460	0.650
Valequip	Unmatched	2.9241	2.1105	43.0		2.510	0.012
	Matched	2.5555	2.6850	-6.8	84.1	-0.270	0.789
propeducfem2	Unmatched	0.3095	0.3841	-17.7		-1.080	0.282
	Matched	0.1936	0.2606	-15.9	10.1	-0.650	0.516
propeducfem3	Unmatched	0.0159	0.0911	-38.8		-1.910	0.056
	Matched	0.0215	0.0380	-8.5	78.1	-0.450	0.652
propeducfem4	Unmatched	0.0079	0.0286	-19.7		-0.960	0.338
	Matched	0.0108	0.0147	-3.7	81.1	-0.190	0.851
propeducmal2	Unmatched	0.5873	0.4658	26.7		1.720	0.086
	Matched	0.6882	0.6147	16.1	39.6	0.640	0.527
propeducmal3	Unmatched	0.1667	0.1467	6.0		0.410	0.681
	Matched	0.0645	0.1008	-10.9	-81.9	-0.560	0.575
propeducmal4	Unmatched	0.0635	0.0724	-4.2		-0.250	0.803
	Matched	0.0538	0.0522	0.7	82.3	0.030	0.976
Sexhhd	Unmatched	0.7619	0.8269	-16.0		-1.110	0.269
	Matched	0.8065	0.7875	4.7	70.8	0.180	0.857
Hhdsize	Unmatched	1.8975	1.7675	32.9		1.980	0.047
	Matched	1.7789	1.7771	0.4	98.7	0.020	0.985
Propareawom	Unmatched	0.1458	0.1287	5.4		0.340	0.731
	Matched	0.1054	0.1275	-7.0	-29.2	-0.290	0.776
Dist_res	Unmatched	0.3757	0.4139	-7.7		-0.480	0.630
	Matched	0.2723	0.3246	-10.5	-37.0	-0.450	0.656
PMI	Unmatched	189.5900	194.0100	-5.1		-0.320	0.752
	Matched	171.7700	170.3000	1.7	66.7	0.070	0.948
Dist_road	Unmatched	0.6797	0.9181	-33.0		-2.240	0.025
	Matched	0.6935	0.6610	4.5	86.4	0.180	0.861
Popdense	Unmatched	2.1672	2.2733	-9.1		-0.620	0.537
	Matched	1.7882	1.8882	-8.6	5.7	-0.360	0.720