Scaling up Responsible Land Governance
ANNUAL WORLD BANK CONFERENCE ON LAND AND POVERTY
WASHINGTON DC, MARCH 14-18, 2016

To what extent does tenure security shape agroforestry investment and impacts on agriculture and livelihoods in strong customary land systems? Evidence from early agroforestry adopters in Zambia's Eastern Province

LAUREN PERSHA[1,2]*, HEATHER HUNTINGTON[2]
[1]Department of Geography, University of North Carolina at Chapel Hill, USA
[2]Cloudburst Consulting Group
*Corresponding Author
lpersha@email.unc.edu

Paper prepared for presentation at the
"2016 WORLD BANK CONFERENCE ON LAND AND POVERTY"
The World Bank - Washington DC, March 14-18, 2016

Abstract

Stronger land tenure security among rural smallholders in developing countries is widely hypothesized to facilitate agroforestry uptake, followed by anticipated agricultural and livelihoods benefits in turn. However, evidence is sparse, while the endogenous nature of tenure security and land investments presents substantial complications for empirical investigations. Further complications arise in land systems where informal customary user rights are discordant with formal land policies and administration. We draw on baseline data from an ongoing impact evaluation of a USAID land sector program in Zambia to examine: (1) characteristics of early agroforestry adopters operating in Zambia's strongly functional customary land system context, and how they differ from the general smallholder population; (2) current agroforestry impacts on agricultural productivity and household livelihoods across early adopters at baseline; and (3) the effect of tenure security on agroforestry investment outcomes. Qualitative and quantitative results suggest short-term term agroforestry impacts that may be discernable in this context, and contribute towards (1) understanding the role that enhanced tenure security may play in incentivizing agroforestry investments; and (2) stronger design of policy and programming to facilitate climate-smart land management and broader household benefits.

Key Words: agroforestry, Eastern Province, land rights, tenure security

Introduction

Amongst its proponents, agroforestry is widely viewed as an important strategy to meet climate adaptation, food security and broader agricultural development goals amongst poor rural smallholders in low-income countries (Verchot, Van Noordwijk et al. 2007; Mbow, Van Noordwijk et al. 2014; Luedeling, Smethurst et al. 2016). Its potential for beneficial impacts is especially highlighted for smallholders in sub-Saharan Africa (SSA), where it may serve as a viable solution to help mitigate the cumulative and interactive effects of persistent poverty and enduring reliance on small-scale and primarily non-mechanized farming to meet food and livelihoods needs. Moreover, addressing these issues for African smallholders has become increasingly urgent in the context of declining soil fertility, stagnant crop yields, and broader land degradation and emergent deleterious climate change effects (Palm, Smukler et al. 2010).

However, obtaining widespread agroforestry adoption at scale has long eluded programmatic and extension efforts on the continent (Jamnadass, Dawson et al. 2011). Several direct and underlying reasons for this have been proposed. Key amongst these, from a technical standpoint, are insufficient access to agroforestry inputs and implementation knowledge by the target beneficiary population, as well as disincentives associated with the anticipated longer time frame to realize benefits and outcome uncertainty stemming from the inherent complexity and variability of the many different components of agroforestry systems (Mbow, van Noordwijk et al. 2014; Luedeling, Smethurst et al. 2016). Together, these contribute to difficulties in predicting broader household effects of agroforestry uptake in any one context outside of highly controlled trials, much less understanding its viability across different landscape, agricultural, market, household or farm system contexts. While small-scale experiments in SSA generally suggest positive impacts on soil fertility, crop yields, and household welfare in turn, there are few large-scale studies quantifying actual or perceived benefits to smallholder households from agroforestry adoption.

More generally, and in addition to these technical issues, agroforestry represents a particular class of land investment for smallholder farmers for which a large body of conceptual and empirical micro-economic work has also sought to better understand factors related to uptake and potential benefits. An important and enduring question in this context has centered on property rights related to land, and particularly the role of and appropriate policy approaches to strengthening farmer security of tenure over land they use.

The concept of land tenure security is expressed in several different ways within the land economics literature (Arnot et al 2011). In broad terms, it is used to encompass either the legal or statutory form of property rights held by an individual or group; or, the landholder's perception of or uncertainty over their continued ability to access and benefit from the land, or otherwise hold statutory property rights to it. This latter use is sometimes referred to as an assurance-based definition of tenure security (Arnot et al 2011), and has been suggested to provide a more direct measure of the underlying issues that the concept attempts to capture (Arnot et al 2011; Sjastaad & Bromley 2000; Smith 2004).

Stronger land tenure security among rural smallholders in developing country contexts is widely hypothesized to play a key role in promoting agroforestry uptake and broader agricultural land investments, followed by anticipated agricultural and livelihoods benefits in turn (Holden, Deininger et al. 2009; Place 2009; Holden, Deininger et al. 2011). However, strong evidence to support this claim is sparse (Arnot, Luckert et al. 2011; Lawry, Samii et al. 2014), while the endogenous nature of tenure security and land investment practices - in which stronger tenure security can serve either as a mechanism to promote land investments, or a benefit to be derived from it - presents substantial complications for rigorous empirical investigations (Besley 1995; Brasselle, Gaspart et al. 2002; Deininger and Jin 2006). Parsing the contribution of tenure security towards agroforestry outcomes may also be further complicated in land systems where strong informal customary user rights and traditions overlap with discordant formal land policies and administration (Brasselle, Gaspart et al. 2002), as characterizes many areas of sub-Saharan Africa where increased agroforestry uptake is currently a key development interest.

Prevailing conceptual framings postulate that smallholder farmers in developing country contexts are more likely to undertake costly land improvements on land over which they have higher certainty of their right to continued use and access over the longer term (Deininger and Jin 2006). This framing has been used to support different types of land tenure strengthening activities, with the goal of promoting such land improvements and, ultimately, smallholder agricultural productivity, livelihoods and overall wellbeing. To date, however, no clear consensus has emerged from empirical studies across varying sub-Saharan Africa contexts on whether and how stronger land tenure security may, in general, incentivize farmer decision-making and pursuit of different land investment strategies on their farms (Lawry, Samii et al. 2014; Fenske 2011).

This paper aims to make an empirical contribution towards understanding: (1) characteristics of early agroforestry adopters amongst Zambian smallholders operating within a strongly functional customary land system context; (2) if and when different short and longer-term impacts from agroforestry adoption may be discernable in this farm system context; and (3) the potential role that enhanced tenure security may play in incentivizing farmer decisions to engage in agroforestry land investments. To do so, it draws on baseline data from an ongoing impact evaluation of a USAID land sector program in Zambia, a pilot activity of the Tenure and Global Climate Change project (TGCC), which couples customary land governance and tenure strengthening activities with agroforestry extension support. Our analyses (1) draw on integrated qualitative and quantitative data to characterize current agroforestry investment impacts on indicators of agricultural productivity and household livelihoods across a set of early agroforestry adopters in the baseline survey wave, and their potential variation with time since uptake; and (2) characterize the land tenure context for agroforestry adopters and non-adopters, and test for an effect of farmer perceived security of tenure over land they use on agroforestry investment outcomes in this customary land setting. In doing so, we ultimately aim to contribute knowledge that may be useful for stronger design of land-related policy and programming to facilitate uptake of climate-smart land management practices and their intended broader household benefits, particularly in contexts with relatively strong existing customary rights to land.

USAID's Tenure and Global Climate Change (TGCC) project

The Tenure and Global Climate Change (TGCC) activities in Zambia aim to increase tenure security at chiefdom, village, and household levels, as well as increase farmer knowledge of agroforestry practices and access to agroforestry seeds and related inputs. The pilot includes a set of tenure and agroforestry interventions implemented over two years (2014-2016) in five chiefdoms of Chipata District. The pilot is designed as a 4-arm randomized controlled trial, with villages across four chiefdoms selected at random to receive one of four treatments: agroforestry extension; land tenure strengthening; the combined agroforestry and land tenure interventions; or a control group in which none of these activities are implemented. Since the implementation of village and household level tenure activities requires basic engagement with chiefs around land and agricultural issues, a fifth treatment arm was also added in a fifth chiefdom to explore the impact of the agroforestry interventions absent chief-level land discussions. The evaluation design enables quantification of the relative contributions of stronger tenure security and agroforestry extension towards promoting CSA. TGCC's activities in Zambia contribute to broader USAID goals of improving an enabling governance environment and reducing rural poverty through increased smallholder agriculture productivity, improved natural resource management, and improved resilience of vulnerable households.

While the program aims to increase the adoption of climate-smart agriculture among smallholder farmers in the project area, a small number of surveyed households were already practicing agroforestry at the time of the baseline data collection, generally as a result of their involvement in earlier small-scale extension programs in the province. Time since agroforestry establishment within this group of early adopters ranges from several months to more than 15 years, providing an opportunity for qualitative and quantitative examination of agroforestry impacts over time. Most of these "early adopter" agroforestry households in the sample established trees on their farms within 1-3 years of data collection, however 40% of the agroforestry fields surveyed had been established 4 or more years prior to data collection. Given this timeframe, in this paper we first focus on assessing the impacts of agroforestry investment amongst these early agroforestry adopters, on three short and medium term household agricultural and livelihoods outcomes that are proposed to flow from this farm management strategy. The outcomes we focus on are crop yields, fertilizer use, and cash earnings from crop harvest. Secondly, given the conceptualized role of stronger land tenure security in promoting a greater likelihood of agroforestry adoption, we draw on household survey and short open-ended response data to characterize agroforestry adopters and non-adopters with respect to their prior land conflict experiences, formal land tenure status and perceived tenure security, and views around land documentation. We measure tenure security via parcel-level prior land conflict data and a household's perceived risk of expropriation from land that they customarily use, and also test for the effect of a household's perceived tenure security on each of the agroforestry outcomes of interest.

The ensuing paper is structured as follows: Section 1 provides context and theoretical framing around agroforestry as a key agricultural technology and land investment to improve smallholder agricultural productivity and household welfare in SSA, knowledge gaps and barriers to uptake, the hypothesized incentivizing role of stronger land tenure security for farmer decision-making around agroforestry and other land investments, and linkages to tenure strengthening policy and programmatic approaches. Section 2 details the data collection and sampling methods, outcome indicators, and our overall analytic strategy including the use of a matching approach to determine agroforestry impacts on agricultural productivity and livelihoods outcomes. Section 3 describes our quantitative and qualitative results. Section 4 contextualizes our findings in the context of existing work, highlights new contributions and discusses program implementation and policy implications that can be drawn from our results.

Context and Theoretical Framing

The agroforestry conundrum in SSA: Benefits and barriers to uptake

Agroforestry has long been heralded as a means to improve land use sustainability, household livelihoods, and broader development objectives in low-income countries (Verchot, Van Noordwijk et al. 2007; Jamnadass, Dawson et al. 2011; Minang, Duguma et al. 2014). The establishment of nitrogen-fixing shrubs or trees on cropland has been shown in several experimental or controlled settings to have significant positive effects on soil organic matter, soil fertility and ensuing crop yields (Ajayi, Franzel et al. 2003; Akinnifesi, Makumba et al. 2006). Agroforestry has therefore held strong promise as a solution to long-noted and widespread declines in soil fertility and stagnant crop yields across smallholder settings in sub-Saharan Africa (Franzel, Coe et al. 2001; Mercer 2004; Mbow, Van Noordwijk et al. 2014) -- often now additionally compounded by increased weather variability and other deleterious climate change effects (Cooper, Dimes et al. 2008; Müller, Cramer et al. 2011) -- with the expectation of eventual positive benefits to farmer livelihoods and overall household welfare via, for example, reduced variability in crop yields, more dependable farm income flows, improved food security, and direct provisioning of food, fuel, wood or fodder from agroforestry species planted on farms (Mbow, Van Noordwijk et al. 2014; Mbow, van Noordwijk et al. 2014).

Nevertheless, an agroforestry revolution has yet to materialize on the continent, suggesting there is scope for more nuanced examination of assumptions and potential barriers related to its uptake and realization of benefits. In Zambia, five percent of agricultural households engage in agroforestry nationally (RALS 2015). A large body of literature points to the many different factors that likely together influence farmer decisions to embrace new agricultural technologies or uncertain land investments. These include, for example, considerations across farmer preferences, including willingness to undertake risk; household and resource endowments such as labor and input availability, farm size, and extension knowledge around agroforestry systems; market incentives such as credit availability, fertilizer or seed subsidies, and staple crop price or demand; and biophysical characteristics such as existing soil quality on the farm, rainfall availability and the agro-ecological potential of the area in which the household is located (Feder, Just et al. 1985; Pattanayak, Mercer et al. 2003; Knowler and Bradshaw 2007; Marenya and Barrett 2007). While policy and institutional factors are also recognized as potential barriers, in general they have received less attention in existing empirical work related to agroforestry (Place and Otsuka 2001; Sirrine, Shennan et al. 2010).

Land tenure security and its conceptual role in spurring land investments to enhance agricultural productivity and household wellbeing

Land tenure insecurity has been widely hypothesized as a disincentive to agroforestry uptake, as well as smallholder likelihood to make agricultural land investments more generally. However, to date the empirical support for this relationship has remained contradictory and largely inconclusive in many SSA contexts (Place 2009; Lawry, Samii et al. 2014). Some of the reasons for this relate to data deficiencies, the complex and multi-faceted nature of both tenure security and land investments, and the many different and perhaps incompatible proxies that different empirical studies have used to capture them (Arnot, Luckert et al. 2011; Fenske 2011). Moreover, the endogenous nature of tenure security with respect to land investments, particularly in strong customary systems, confounds many empirical efforts to disentangle causality (Braselle et al 2002; Fenske 2011).

Though perhaps less overtly discernable, land governance issues, including formal land policies and the formal and informal institutions and processes for land documentation, allocation, transfer and dispute resolution, are also at the core of the incentive structure which underlies smallholder farmer decision-making and farm strategy behavior. In many SSA contexts, land cannot be outright owned, sold, or used as collateral (Wily 2000), thus rendering potentially less salient some of the conceptualized pathways by which stronger land tenure security might improve a farmer's economic outcomes (Bezu and Holden 2014). Moreover, long standing traditional or customary norms over the access, use, transfer and control of land are often still strongly followed in rural areas throughout SSA, although these customary processes do not always mesh well with more recent formal land policies introduced by governments.

State histories of land expropriation, as well as potentially uneven land allocation and conflict resolution processes within customary systems may also increase farmer uncertainty over their long-term rights to land they customarily use, hence potentially discouraging them to undertake costly or delayed-return land investments on land they use. At the same time, undertaking visible land investments or improvements on customarily held land can also function in many contexts to strengthen a farmer's claim to that land, especially where land documentation is either in dispute or does not exist, or where land governance norms or processes recognize the validity of such behavior for this purpose (Brasselle, Gaspart et al. 2002; Bromley 2009).

In addition, more emergent land governance issues have brought further attention to the vulnerabilities of rural smallholders with respect to land use, access and long term control. For example, land in Zambia and elsewhere in SSA continues to feed local and global appetites for new global cash crop commodities such as biofuels. More generally, recent work around the newly commodified nature of land itself in many places, often in response to changing government policies around land rental and sale, highlights how newer forms of expropriation may contribute to rural smallholder uncertainty over land (Schoneveld 2014; Schoneveld and German 2014; Cotula 2012). This can relate to changing rural-urban transitions, population growth, and new migration patterns that alter rural land use dynamics. However, case studies also document the dampening effects on smallholder tenure security of new or heightened forms of outside investment, covert sales of land that is traditionally used in common or customarily held, and rapid restructuring of formal land categories and policies by country governments, often in ways that appear to better position higher level actors in the system to engage in and benefit from these processes

(German, Schoneveld et al. 2013; Jayne, Chamberlin et al. 2014; Sitko and Jayne 2014). Already embedded somewhat precariously within these processes and the overarching statutory context, customary land and that held or used in common may be particularly vulnerable to these rapidly changing dynamics on the continent (Wily 2011).

Land tenure strengthening and programmatic approaches: Moving beyond individual freehold property rights and policy blueprints

Within SSA, much of the existing tenure strengthening work has focused on efforts to increase smallholder tenure security via a single channel – the conversion of customary land use rights by individuals to formally recognized property rights via land registration and titling programs (or, where land laws prohibit full ownership of land to rural citizens, via the provisioning of land certificates that formalize customary use and (in some cases) transfer rights). Broadly, land formalization is argued to lead to improved land investments, productivity and beneficial economic impacts for poor rural households. Results of such efforts have been positive in some contexts, although much of the existing evidence is from studies conducted outside of SSA. For example, Wiig (2013) reports substantial improvement in female decision-making and empowerment, particularly with respect to agricultural and land investment decisions, as a result of Peru's joint land registration and titling process. In Ethiopia, Ghebru and Holden (2015) found evidence of increased land productivity as a result of the country's land certification program, in which households obtain certification which formalizes their use rights to individual parcels of land.

But, several scholars caution that wholesale formalization and a focus on individual property rights may not always be the most suitable approach to strengthening land tenure or eliciting the desired land productivity and household economic benefits. It also may not necessarily lead to benefits for all intended beneficiaries (Deininger, Thorhurst et al 2014). For example, Jacoby and Minten (2007) found no effect of a land formalization program in Madagascar on agricultural productivity or land investment, and suggest that the informal customary system provides sufficient tenure security to facilitate productivity-enhancing land use decisions on the part of farmers. Pritchard (2013) suggests potentially negative tenure and food security impacts to subsistence households as a result of Rwanda's land formalization effort (Pritchard 2013). Elsewhere in SSA, formalization has also been criticized for, among others, increasing land conflict (at least over the short term); reinforcing elite capture, existing power structures and further disenfranchisement of already marginalized groups such as pastoralists, women, or newer migrants to an area; and for dismantling longstanding communal land systems that likely arose as means to efficient land use in resource-constrained settings (Musembi 2007; Benjaminson et al 2008; Sjaastad and Cousins

2009). Musembi (2007) notes several of the different ways that poorer or households with smaller landholdings may be less likely to be able to benefit from well-intentioned land registration and formalization programs, for example by having insufficient landholdings to be able to use the titles as collateral, or due to barriers that poorer households often face in navigating government bureaucracies needed to complete the titling and documentation process. Thus, critics suggest that in SSA such programs are more likely to benefit those who are already better off, ultimately bolstering pre-existing inequalities. The overall message from this line of critique tends to be a cautionary one around the pitfalls of uniform policy assumptions and program approaches with respect to links between land formalization via titling, expected gains to tenure security and concomitant improvements to household land decisions, investments and economic wellbeing.

More recent efforts have explored other tenure strengthening alternatives that tend to work more directly within the existing customary land context of a place. These can include, for example, communal land certification programs and recognition of collective use rights and land tenure. However, there is currently little empirical work which has examined the effects of such programs, and how they might differ from the more traditional land titling approaches to strengthening tenure security for rural smallholders (Lawry, Samii et al 2014).

Methods

Sampling & data collection

Data for this analysis are drawn from baseline household and village surveys conducted in July and August 2014 across 3,412 households in 294 villages in Chipata District in Zambia's Eastern Province. The data were collected as part of a prospective impact evaluation of a United States Agency for International Development (USAID) pilot project to increase adoption of climate-smart agriculture (CSA) practices in eastern Zambia. The pilot activities, which began after the baseline data collection wave, implement a set of tenure and agroforestry interventions that aim to strengthen customary land governance and agroforestry extension in five chiefdoms of Chipata District, in Eastern Province. The household survey was administered by enumerator teams, and included a comprehensive set of modules on household demographics, income and assets, agricultural activity, land conflict and conflict resolution, tenure and tenure security, and governance. Given the TGCC program and land tenure context of the study area, the household survey was designed to capture important formal and informal processes around customary and statutory land access, use, documentation, transfer and governance. To facilitate stronger identification of tenure strengthening impacts, household agricultural activity and a wide range of land conflict and tenure information were collected at the level of individual fields used by households.

Our data set draws on a large sample of households collected across a randomized set of villages, is supported by extensive qualitative data collected via key informants and village focus group discussions, which enables deeper interpretation of quantitative findings, and contains a comprehensive set of tenure security, land management, and associated information collected at the level of individual parcels used by households. This higher resolution data across a set of key factors allows for a more nuanced quantitative examination of land tenure factors and agroforestry outcomes than is often available through data collected at the level of individual households or farms. We aim to gain insights around current benefits that accrue to farmers as a result of agroforestry adoption on their farms, as well as to contribute new knowledge around the particular role that stronger tenure security can play in potentially facilitating these outcomes.

Outcome Variables

Drawing on the set of early agroforestry adopters in the baseline dataset, we test for the causal effect of agroforestry establishment on three expected short or medium-term indicators of agricultural productivity and household livelihoods impacts, each measured for the 2013-2014 agricultural season: (1) agricultural productivity as indicated by field-level crop yield in metric tonnes per hectare; (2) field level fertilizer use in kilograms of fertilizer applied per hectare, as an indicator of input demand; and (3) the actual or expected value of the main crop harvest that was sold, in Zambian kwacha per hectare, as an indicator of agricultural income contribution to household livelihoods.

To measure agricultural productivity, we calculate the amount of crop harvested per hectare over the 2013-2014 agricultural season. We convert harvest amounts reported in local or alternative units to metric tonnes[1], and take the log of harvest amount divided by the farmer-estimated area of the field in hectares. To measure field level fertilizer use, we take the log of farmer reported kilograms of fertilizer they applied on each field divided by the area of the field in hectares. To obtain a measure of the per hectare value of the main crop harvested during the 2013-2014 agricultural season, we draw on farmer reported earnings in Kwacha from selling the harvest obtained on the field, and divide by the area of the field in hectares. For fields that had not yet been harvested or products sold at market at the time of data

[1] Farmers primarily reported crop harvests in kilograms, tonnes or oxcarts, although a range of non-standard units were also used. Previous studies have used several different conversion factors for oxcarts to kilograms. In this study we use a conversion factor of 1 oxcart = 350 kilograms. We make the assumption that this is a reasonable estimate because it yielded a similar distribution in yields as fields that were reported in kilograms or tonnes. Given our already relatively low sample N and the typically high variability and uncertainty associated with farmer reporting of agricultural productivity and inputs, we chose to drop yield data reported in other non-standard units for this analysis, rather than introduce this additional source of uncertainty.

collection, the household survey asked respondents for the amount of Kwacha they anticipated earning from the field, which we use for such observations in lieu of actual profit[2]. This accounts for 8% of field observations (N=765).

To improve data consistency and comparability, we restrict our analyses to households with 20 hectares or less of land, and fields for which the main crop consisted of any of the six most commonly grown crops in the study area (local maize, hybrid maize, groundnuts, cotton, soybeans and sunflower). We also drop observations where the farmer reported yield was greater than 11 metric tonnes/ha, which is equivalent to the upper 1% of yield values in the data, and was considered very likely to be misreported (for example, even with fertilizer use, maize yields in Eastern Province for the 2013/14 agricultural season averaged around 2.5metric tonnes/ha, while other common crops tend to have lower average yields per hectare than this (RALS 2015). For agroforestry fields, we further restrict the observations to fields on which the three most common agroforestry species are established. These are *Faidherbia albida* (locally referred to as musangu), *Gliricidia spp*, and *Sesbania sesban*. In other words, we exclude from the analyses the relatively uncommon set of agroforestry fields in which agroforestry shrubs such as pigeon peas, cowpeas or *Tephrosia vogeli* (locally known as ububa) were grown, or the farmer did not know the agroforestry species which had been planted (overall N excluded = 53 fields, or 13% of agroforestry fields and 0.5% of all fields in the sample; these observations are also excluded from the potential control pool). We exclude plots with these agroforestry shrubs from the analyses for several reasons, including the different nature and time frame for potential benefits in contrast with the agroforestry tree species, which generally take many more years to become established and return benefits, low field N for each of these excluded species and the fact that the shrub species were more likely to be block or perimeter planted rather than intercropped with maize or other food or cash crops.

Empirical strategy

We use entropy weighting, a non-parametric matching approach, coupled with regressions, to estimate the impact of agroforestry investment on indicators of agricultural productivity and household livelihoods amongst the early adopters at baseline. The aim for pre-processing the data via entropy weighting is to generate a control set of observations that serves as a strong comparison group to determine the impacts of agroforestry establishment on a field. Under this process, a set of weights are obtained for observations

[2] We conducted tests of average differences in actual vs expected profits, by individual crop, and found that the reporting of expected profits tended to be higher, on average, than actual profits, for both local and hybrid maize but not the other 4 main crops that we focus on. This suggests that farmers may be somewhat optimistic about anticipated profits; however, the difference in mean expected and actual harvest earning was only statistically significant for hybrid maize. Still, to bolster robustness we run our analyses for outcome 3 on both the combined actual and expected earnings data, as well as only for actual earnings where the number of observations was sufficient to do so.

in the control group (non-agroforestry fields) such that potentially confounding field, household and village level characteristics among the non-agroforestry comparison group share a similar distribution as that of fields under agroforestry. That is, agroforestry fields and similar non-agroforestry fields are matched across an encompassing set of observable field- and household-level covariates that could confound the true impacts of agroforestry on the outcomes we assess. In doing so, the entropy weights generate a plausible counterfactual group of non-agroforestry fields, thus enabling stronger identification of the potential causal impact of agroforestry uptake on each of the three outcomes of interest.

Given our empirical focus, our analyses are conducted across the field-level observations in the dataset for any of the six main crops planted, in which yield data was reported in any of three standardizable units (kilograms, tonnes or oxcarts; 87% of observations), fertilizer inputs were reported, or the farmer reported expected or actual profits. As a robustness check, we also conducted the analyses on a restricted set of field observations in which full data was available across all three outcomes, for any of the six different main crops. This culminates to 22% of total baseline field observations or 2,008 fields.

We include in the regressions several control variables at field, household and village level. These are listed in Table 1, and include important field, household, and village characteristics that much existing literature from similar smallholder agricultural settings in Zambia or elsewhere in SSA suggest are likely to affect crop yield, fertilizer input, or harvest earnings outcomes. We particularly focus on indicators of key agricultural inputs that relate to fertilizer use and yields, including use of improved crop varieties, irrigation,[3] and farm power and tillage methods. Control variables include farming practices on each field, such as use of improved seed varieties, manuring, crop rotation, tillage method, and how crop residues are used; field area and land quality indicators, such as soil type; indicators of agricultural extension exposure, such as farmer participation in farming groups or cooperatives and whether the household has specifically received agroforestry advice; a set of household demographic indicators, including wealth status, off-farm income, education level, and household head age; and village distance to nearest urban center as proxy to capture market and information access.

In addition, we exploit variation in prior land conflict, subjective expropriation risk and time under agroforestry on the parcels to better understand how a household's security of tenure over the parcel relates to agroforestry uptake and field-level outcomes. We do so by including a measure of household

[3] Almost no farmers in our sample use field irrigation methods, thus we eventually disregard this as a potential control variable.

expropriation risk as an indicator of tenure security in our regression models, supported by a more qualitative examination of these relationships drawing on available data.

To generate a measure of field-level security of tenure that a farmer feels over land s/he uses, we construct an index of the household's perceived risk of dispossession from the field within the next 1-3 years across six different sources: extended family members, other households within the village, households from neighboring villages, village headman, chief, or other elites from outside the village. The index is constructed from respondent responses to each of six questions intended to measure their expectation of losing access to the parcel via reallocation or similar processes. The question asks: "How likely do you think it is that [expropriation source] will take this field without your permission or agreement?" "How likely do you think it is that [expropriation source] will re-allocate some or all of this field to another household or for other purposes?" Responses are ordered on a 6-level Likert-type scale ranging from "Impossible / would never happen" to "Highly unlikely";" Unsure"; "Likely"; "Very Likely"; and "Happening right now".

Agroforestry is very uncommon in the TGCC baseline dataset, representing less than 1% of fields in the sample. The so-called 'early adopters' in the sample are individuals scattered across several villages, who have established and maintained agroforestry on one or more of their fields due to earlier exposure to agroforestry extension efforts or voluntarily seeking out this uncommon agricultural technology. Because these early adopters are self-selecting rather than a random sample of smallholder farmers, we use a quasi-experimental approach to test for the causal impact of agroforestry adoption on productivity and livelihoods outcomes. Given existing challenges to widespread agroforestry uptake, it is likely that farmers who do so self-select into agroforestry adoption, and thus are likely to also share other characteristics which make them different from other households(the general smallholder population), on average, in ways that likely also influence the productivity or livelihoods outcomes they obtain under agroforestry. For example, if farmers who voluntarily pursue an agroforestry farming strategy also tend to be more educated than the typical smallholder, or have greater exposure to agroforestry or other farming extension services, such characteristics may also enable them to utilize information or knowledge skills around farming practices in ways that would be expected to translate to higher than average yields even without the establishment of agroforestry on the field. Under such confounding, quasi-experimental approaches to causal identification are particularly well-suited to generating less biased estimates of treatment effects, and significant results can be more confidently attributed solely to the intervention of interest rather than to such confounding factors.

In our sample, we indeed see evidence that the early agroforestry adopters in the sample also differ from the general smallholder population in other important ways that also correlate with agricultural yields and livelihoods outcomes. These factors thus are likely to confound estimates of agroforestry effects via traditional regression analyses. For example, agroforestry farmers in the sample have slightly larger household size and farm labor availability, and they tend also to have higher education levels in their household, practice agroforestry on plots that are larger than average in area, and are significantly more likely to practice crop rotation and manuring on their fields (Table 1). Under such confounding, traditional regression approaches are not well-suited to strong causal identification of treatment effects (here, the effects of agroforestry adoption), even with the inclusion of appropriate control variables (Dehejia and Wahba 1999; Imbens and Wooldridge 2009). We therefore employ a quasi-experimental analytic matching approach to better mitigate confounding effects due to selection biases around the kinds of households and farmers who choose to engage in agroforestry and the kinds of fields on which they tend to preference implementing this investment, and thereby enhance the ability to detect true casual effects from agroforestry use.

The quasi-experimental matching approach involves constructing a pool of non-agroforestry fields to serve as a counterfactual comparison group from which to derive an estimate of what the average impacts on agroforestry fields would have been in the absence of agroforestry establishment (Morgan and Harding 2006; Morgan and Winship 2007; Rubin 2007; Ravallion 2009). Under this framing, agroforestry establishment is the treatment[4] whose effects we are interested in estimating, and we use the presence of agroforestry on the field as the indicator for the treatment status of each field. We use a matching approach to generate a set of non-agroforestry fields to serve as the counterfactual, in which we aim to construct a comparison set of observations that is as similar as possible to observations in the treatment group (fields with agroforestry, in this case), across all relevant observable confounders, and differs only in agroforestry treatment status. Across the quasi-experimental literature, standard approaches to do this have typically drawn on matching treated and untreated observations on the basis of a similarity measure, such as the propensity score (Imbens and Wooldridge 2009; Stuart 2010), based on the likelihood of treatment conditional on a set of specified pretreatment covariates. Matching approaches are generally viewed as superior to standard regression analyses when selection biases are present, but they work best

[4] We note that our use of treatment here simply refers to the agroforestry establishment status across fields in the dataset at baseline, regardless of how such activities were introduced or obtained by the farmer. We highlight that any agroforestry activity which exists in this baseline data set is distinct from the intended TGCC program activities described in the paper introduction. By design, the TGCC agroforestry activities had not yet been implemented at the time of baseline data collection, and this study does not assess impacts stemming directly from TGCC project activities. Here, we simply aim to better understand shorter-term agroforestry impacts and the relationship between agroforestry uptake and land tenure security more generally, from the set of early agroforestry adopters that were present in the TGCC baseline dataset.

when there is a strong understanding of the selection process associated with obtaining treatment. Even in such situations, it can be difficult to obtain a balanced treatment and comparison group across all relevant potential confounders using just the propensity score or other more traditional matching approaches (Ho, Imai et al. 2007; Diamond and Sekhon 2013).

To create an appropriate pool of comparison fields, we use a more recently developed entropy balancing approach (Hainmueller 2012) to pre-process the data and generate weights across the set of potential control observations in our sample, such that the comparison groups of fields (or, fields without agroforestry) share similar means and variances as the treatment pool (fields with agroforestry) across the set of potential confounding variables that we specify. Entropy balancing employs a search algorithm to find a weight for each control observation such that treatment and control groups are similarly distributed across each covariate specified (Hainmueller 2012), thus ensuring a strongly balanced sample for analyses and more closely approximating a true randomized sample (Ho, Imai et al. 2007; Abadie and Imbens 2011). Through this process, entropy balancing creates a reweighted control group that is balanced with the treatment group across important covariates, and ensures less biased estimation of treatment effects via weighted regressions. A relatively new contribution to the quasi-experimental toolkit, entropy balancing has several favorable qualities over that of traditional propensity score matching or even newer matching methods such as genetic matching (Diamond and Sekhon 2013), including minimal computation time, no need to conduct iterative balance checking across different matching model specifications, and greater retainment of information from the control pool because observations are not dropped wholesale (Hainmueller and Xu 2013). In our sample, entropy balancing yielded full balance across all of the 21 potential confounding covariates that we specified (see Figure 1).

Given that we are examining field level outcomes, and our data consist of fields nested within households, which in turn are clustered within villages, we initially use both entropy-weighted Ordinary Least Squares (OLS) with robust standard errors clustered by village, and two-level mixed-effects linear models to estimate the effects of agroforestry adoption on each of the three outcomes of interest. The multi-level (ML) model more accurately adjusts for dependence among observations within the same cluster, and exploits the variance within and across household and village levels of the data to more precisely estimate covariate effects on the dependent variable (Rabe-Hesketh and Skrondal 2012). Ultimately we report results using the entropy-weighted OLS models, because the sub-set of relevant observations in the dataset for this analysis no longer retain a strongly hierarchical structure and there is little added-value to employing the multi-level modeling approach[5].

Results

3.1 Household and field descriptive statistics

Summary statistics of the data in our analyses are presented in Table 1. In general, households in the sample are subsistence or small-scale farmers who grow primarily maize or groundnuts. Households average 5.26 members, and the mean age of the head of household is 44 years old. The average education level for household heads is standard 3-4, and standard 5-6 is the average highest education level for any household member. The average total area of land that households use is just under 2 hectares, the mean field size is 0.68 hectares, and mean household labor availability for farming is 1 person per hectare of land farmed. Mean per capita annual off-farm income reported is 301 Zambian Kwacha. Around 43% of households in the sample participate in some form of a farmer's cooperative or agricultural group, although only 32% of households had received any agroforestry advice or extension exposure in the past year (and this proportion is not significantly different across households with any or no agroforestry fields). Lastly, 22% of the households in the sample are female-headed.

The data indicate that households who engage in agroforestry tend to differ from typical smallholder agricultural households in several ways. On average, households with any agroforestry fields have significantly higher household size (mean difference = -0.34; t = -2.19 P = 0.035), household labor availability (mean difference = -0.38; t = -3.45 P = 0.001), and level of household education (mean difference = -0.82; t = -4.08 P = 0.0001). Among households that use 20 hectares or less of land in total, agroforestry households also farm a slightly higher amount of land (mean difference = -0.34; t = -2.83 P = 0.005), and a lower proportion of such households had experienced a prior land reallocation event by village leaders or the Chief (although the overall percentage of such households was very low for both groups, at 1 and 2% of households respectively). A simple comparison of mean differences in outcomes point to significantly higher logged yields per hectare on agroforestry fields (mean difference = -0.21; t = -2.9 P = 0.004), significantly lower fertilizer use (mean difference = 0.25; t = 2.82, P = 0.005). A greater proportion of agroforestry fields are also planted with local maize or hybrid maize, and a lower proportion are planted with groundnuts, soybeans, or sunflower. Similarly, a t-test of mean differences indicates that agroforestry fields have significantly higher use of improved seed varieties, mean field size, use of manuring and crop rotation, and frequency of having had a prior land conflict on the field (Table 1).

[5] At the same time, the introduction of entropy weights to the ML model can introduce bias to the estimates. In practice, for this analysis, there was little material difference in estimates or significance across the OLS and ML models that we ran.

3.2 Agroforestry impacts: average treatment effect on the treated (ATT) results and robustness checks

Given the small sample of agroforestry fields in the data overall, which are further distributed across primarily three different crops, we test for agroforestry effects in entropy-weighted OLS models that combine all main crop types together (and include crop type dummies in the regressions), and we also test for effects in models run separately on the two most common crops that are grown on agroforestry fields, local maize and hybrid maize. We report results for each of these model families (all crops combined, local maize only, and hybrid maize only), for each of the three outcomes (yield, fertilizer use, and harvest value), noting smaller sample size and power in the individual crop models. This is particularly so for the harvest value outcome, where there are fewer observations to begin with. Given data limitations, analyses for each outcome are run on all available observations for the outcome. As a robustness check for the combined crops model, we also test for and report agroforestry effects on a restricted sample with full information for each field observation, across all three of the outcomes we examine (smaller observation N but also generally improved model fit with this sample).

Fields with agroforestry establishment have significantly higher average crop yields and significantly lower fertilizer use than non-agroforestry fields in a naïve comparison of means. However, this effect on crop yields and fertilizer use drops out in our ATT analyses with the addition of entropy-weighting to pre-process the control observations and account for selection biases around agroforestry uptake and appropriate controls on farming behavior. In addition, although we see anecdotal evidence that farmers are more likely to say they are experiencing greater soil fertility and yield benefits for fields that have had agroforestry for more than four years, we do not have a great number of such observations in the sample. We do not detect a significant effect of time under agroforestry through the regression analyses, when we include a continuous indicator of this in our outcome models. Indeed, more than half of the agroforestry fields in the sample were established within the past three years, and the majority of agroforestry farmers also indicated in open-ended questions on agroforestry benefits that they had not yet experienced any. We describe the OLS results below, and draw on additional qualitative and descriptive information around agroforestry benefits, tenure security, and land governance from the surveyed households to expand our interpretation of results.

3.2.1 Agroforestry treatment effects: all crops overall

As Table 2 indicates, we do not yet detect any average treatment effect at the field level, from agroforestry adoption across this set of early agroforestry adopters. This is the case for each of the three shorter term outcomes we tested, across our models that pool all crops planted with agroforestry together.

This is not entirely surprising, given that most of the agroforestry fields in the dataset were established within three years prior to the survey (and 8% were established within the year prior to survey), while each of the agroforestry species planted are generally not expected to generate benefits at the field level within this relatively short time period. Our quantitative estimate of treatment effects also generally agrees with anecdotal and qualitative information on benefits experienced to date that was provided by agroforestry respondents, as further discussed below. However, given the quite variable agroforestry survival rates across the fields on our sample, and that agroforestry for these fields at baseline were established through a variety of potentially inconsistent programs or practices, it may also be that such variation could mask any stronger impacts that could be present on some of the more successfully established fields. Nevertheless, the results suggest that studies of agroforestry impacts conducted within a few years of establishment should also consider drawing on complementary qualitative perceptions that farmers provide around if and how agroforestry establishment may affect their agricultural input use and resulting productivity, as well as their land use decisions as a whole. Furthermore, more uniform agroforestry or tenure strengthening activities that are implemented at scale across a larger number of villages and households, such as is planned for the TGCC program, may be better positioned to generate field-level impacts in early post-establishment years than was discernable with this more diverse sample of agroforestry households.

For the combined crop models, the strongest association with each of the yield, fertilizer use and harvest value outcomes is field size[6], in which larger fields have lower per hectare yields, lower per hectare fertilizer use, and lower per hectare value (Table 2). The use of improved seed varieties, manuring on the field, and ploughing are also significantly associated with higher yields, while the use of conventional hand hoeing as a field tillage method (over ploughing, for example), is associated with both lower fertilizer use and field harvest values.

In terms of the relationship between tenure security and each of the agroforestry outcomes, our results indicate that higher tenure security is associated with lower yields in the restricted data set that we use as a robustness check, but is not otherwise significant for crop yield in the combined crops model. Higher tenure security is associated with lower fertilizer use and crop harvest value per hectare in the entropy-

[6] Although beyond the scope of this study, we briefly note that our finding of a negative relationship between yield and field size is in agreement with several studies on the so-called farm size – productivity relationship in SSA, which through much more rigorous analyses than ours have tended to find evidence of the same (For example see: Barrett, Bellemare et al. 2010; Larson, Otsuka et al. 2014; Ali and Deininger 2015).

weighted models for both of those outcomes, which is contrary to expectations, although the effect is small for both.

3.2.2 Local Maize

Table 3 presents the agroforestry average treatment effect results for the subset of observations in which the primary crop grown on the field is local maize. For agroforestry fields intercropped with local maize, our results are similar in pattern to the combined crops model in Table 2. We did not detect a treatment effect from agroforestry on local maize crop yields. Results suggest that farmers apply significantly less fertilizer per hectare on agroforestry fields planted with local maize, but the agroforestry effect drops out once household level covariates are included in the model (Table 3, models 7-12).

Irrespective of agroforestry field status, the strongest associations with local maize crop yields are the field size (negatively associated with local maize yield), as well as using ploughing as the tillage method and practicing crop rotation (both resulting in relatively large positive impacts on yield). There is also a small positive effect of household education level on local maize crop yield.

The strongest associations with fertilizer use outcomes on local maize fields are field size, in which larger fields have a lower fertilizer input per hectare, as well as whether improved seed varieties and crop rotation are used. If yes for either, there is significantly lower fertilizer use. There is also a small negative association with household education level, where more educated households apply slightly less fertilizer per hectare. We find no effect of field-level tenure security on any of the three outcomes for local maize fields.

Ae show the results in Table 3 for the harvest value outcome for local maize fields, however we place lower confidence in this set of models (Table 3, columns 9-12) due to very few agroforestry treatment observations in this subset of the data. We also note that in general the number of agroforestry treatment N to work with for the local maize models is low, despite the relatively large overall number of local maize field observations, thus Table 3 results should be viewed with some caution. We consider the fertilizer use results in Table 3 to be more robust than the other two outcomes we examine, as the local maize field agroforestry treatment N is higher for this outcome.

3.2.3 Hybrid Maize

Table 4 presents the agroforestry average treatment effect results for the subset of fields planted with hybrid maize. For this set of observations, we find no effect of agroforestry establishment on any of the three outcomes we tested. However, we also note that we have generally few agroforestry treatment fields under hybrid maize. In terms of the effects of field and household level control covariates on hybrid maize crop yield, results indicate that the strongest associations with hybrid maize yield are the seed type used (higher yield with use of an improved seed variety), the field size (a similar negative association with outcome, as for each of the models discussed above), and the use of manuring or crop rotation on the field. The strongest association with fertilizer use is the field size (also a negative relationship, as for all models discussed above) and tillage by conventional hand hoeing, while there is a small positive association with household education level. As with the local maize model family, we have lower confidence in the hybrid maize harvest value model due to few agroforestry treatment observations in this subset of the data.

Qualitative integration

Agroforestry is practiced with some potentially important variations across the set of early adopters in our survey sample. The majority of farmers in this group intercrop with agroforestry trees (58% of agroforestry plots in the sample), while 19 and 23 percent of agroforestry plots instead use block or perimeter planting, respectively. The main agroforestry tree species planted is *Faidherbia albida* (known as musangu; 76% of plots with agroforestry trees planted), while the other two species typically introduced for CSA farming in Zambia, *Gliricidia spp.* and *Sesbania sesban*, account for 17 and 6% of plots in the sample with agroforestry trees, respectively. Farmers primarily intercrop with local maize (26% of agroforestry plots), hybrid maize (36% of agroforestry plots), or groundnuts (16% of agroforestry plots), on fields in which agroforestry trees are established. Cotton and sunflower are also grown on a small number of agroforestry fields.

Roughly half of the early agroforestry adopters in the dataset established agroforestry trees on their fields within 1-3 years of the survey (53% of agroforestry fields), while 8% of agroforestry fields were established within the year of sampling, and 39% had been established four or more years prior to the 2014 survey (Figure 2). Each of the three agroforestry species are represented in all time categories, though *Sesbania*, which is uncommon overall, seems to have been more commonly established in the earlier agroforestry plots relative to those more recently established. Given the variation in time under agroforestry present in the data and the longer time frames generally required for farmers to realize agroforestry benefits at scale, we expect that farmers who have had agroforestry established for a greater number of years, particularly more than 4 years, would be more likely to have realized yield or other noticeable benefits. This expectation was borne out to some extent in the qualitative data on benefits experienced to date, but it was not supported quantitatively (inclusion of either a continuous years under agroforestry variable, or a binary variable to indicate 4 or more years under agroforestry, were not significant for any outcome in the combined crop model). However, this is not surprising given the wide range of contributing factors to yield and other outcome variability and the smaller set of agroforestry observations in the dataset that had been established for more than four years.

From a more descriptive standpoint, it is important to note that early agroforestry adopters in the dataset also show wide variation in both the extent of establishment success and the benefits they feel they have received to date. For example, establishment success varies widely across this set of early adopter agroforestry fields (Figure 3). The combined mean survival rate across the three agroforestry species is 50% of seedlings planted (field N = 240 with sufficient information to calculate survival rates, SD = 0.30), with no significant variation across the three species. However, there is wide variation in establishment success overall, with 16% of fields reporting nearly 100% survival (N = 38 fields), but a nearly equal number experiencing survival rates below 10% (N = 32 fields, 13% of total), according to the data farmers provided. Such information could suggest a useful role for post-establishment extension efforts to help ensure greater survival of agroforestry investments that farmers make.

In response to the most important benefits that farmers say they've experienced to date, 52% of the early adopters indicated they had not received any benefits so far (N = 209 of 404 total agroforestry fields), while another 32% said they were benefitting from improved soil fertility (N = 129 fields). A small proportion said they were experiencing higher overall crop yields or improved crop growth (N = 33, or 8% of agroforestry fields), while some (4% of fields) also indicated that they benefited from the additional availability of food sources from the agroforestry species they had planted, which could potentially refer to sources of fodder for household livestock as well. This break down of benefits shows little variation across the three different agroforestry tree species that we focus on, with the exception that farmers with *Sesbania* planted on their fields tended to note actual crop yields and improved soil fertility in a higher proportion and less frequently said they had not experienced any benefits. However, the actual number of observations for this species is very low (N = 22 fields). Given that the *Sesbania* fields were also predominantly established more than 9 years prior to the survey, the greater benefits farmers noted could be as likely due to the longer time under establishment than an indication of superior benefits stemming from this particular species (indeed, if this were the case, we would expect to see increased *Sesbania* planting in more recent years as well – whether due to increased farmer demand or greater promotion by development and extension programs – rather than its very low establishment overall and much higher frequency of Musangu and *Gliricidia* in recently established agroforestry fields that is evidenced in the data).

For farmers who have not adopted agroforestry, the strongly predominant reasons that they cite for this are that they do not possess sufficient knowledge (40%, or N = 3,068 of 7,635 total non-agroforestry fields for which farmers responded to this question) or cannot obtain the seeds or seedlings (40%, or N = 3,016 fields). Another four percent of responses indicated that farmers did not plant agroforestry trees on the field because they did not see any benefit from doing so. These responses suggest that extension knowledge and inputs, rather than farmer disinterest, appear to serve as strong barriers to agroforestry uptake, thus suggesting a role for agroforestry extension support in promoting wider uptake.

Tenure status and security and land governance issues in the context of early agroforestry adoption

Although a detailed analysis goes beyond the scope of this paper, the data also provide a useful descriptive window into some of the important contextual factors that shape complex relationships among formal land documentation and tenure status, actual and anticipated sources of land conflicts and dispossession, perceived land tenure security, and concomitant relationships to agroforestry. In terms of formal tenure status, the overwhelmingly prevailing status on nearly all fields surveyed is a customary arrangement (N=8,765, or 99% of fields). Household possession of statutory tenure over land they use was only present in a small number of cases, where fields were located on state land (N=20 fields) or on land that was formerly customary but had been converted to state land (N=12 fields).

Eleven percent of fields in the dataset (N= 1,011 fields) have experienced a land conflict within the past three years. Outright land expropriation is less common, with less than two percent of households (N = 63 of 3,425 households) having experienced one of their fields reallocated to someone else by village authorities or the chief within the past 5 years. Household experience with land reallocation differs significantly for households with and without agroforestry fields (Likelihood ratio test, X^2 (1) = 3.23, P = 0.07), with agroforestry fields accounting for 2 and 7% of households that had or had not experienced a land reallocation event, respectively. Prior experience with conflict on the field is also not independent of agroforestry establishment, with a slightly higher proportion of agroforestry fields having also experienced a prior land conflict. Seven percent of fields with prior conflict have agroforestry established on them, compared to agroforestry establishment accounting for four percent of fields with no prior land conflict (Likelihood ratio test, X^2 (1) = 15.69, $P < 0.0001$).

Overall, farmers express a high level of perceived tenure security over fields that they use (combined mean is 5.3 for the tenure security index based on perceived expropriation risk, on a scale range from 1 to 6, SD 0.89, N = 8,652 fields), and ostensibly there is no significant difference in the tenure security index across agroforestry and non-agroforestry fields on the basis of a simple t-test for a difference in means (mean difference = 0.012, t=0.27, P = 0.79). Despite this relatively high level of perceived tenure security, household possession of paper documentation recognizing their land claims, such as a customary land certificate, was extremely uncommon, and applied to only 1% (N=106 fields) of fields. A full 81% of households (N = 2,753 households) expressed that they would like to obtain such documentation for fields that they use, if they could. In terms of reasons provided, households overwhelming said the primary reason they would like to obtain a paper document of their right to use the field was because it would reduce the likelihood of losing the land (main reason cited for 86% of fields, or N = 6,014 fields). The second most common reason cited was that it would strengthen the ability for their children to inherit the land (cited for 9% of fields, or N = 649 fields). Reasons related to proof of ownership (2% of fields) and to better protect investments made on the field (2%) were cited to a much lower extent. We note that such documentation in this Zambian context refers to customary land certificates to confirm use rights, rather than formal land titles associated with the conversion of customary use rights to freehold tenure.

In terms of actual benefits expressed around possessing land documentation, for the very uncommon set of fields for which such documentation had been obtained, respondents indicated that the most important benefits they had experienced to date from having a land certificate (customary certificate) was that they felt it had reduced the livelihood of losing their land (N=67 of 106 fields with some form of customary land documentation), while a stronger ability for their children to inherit the land was commonly mentioned as a secondary benefit (N = 37 fields). A small number of respondents indicated greater protection of investments made on the land, while many respondents in this category did not express any benefits received from their current land documentation.

In some smallholder contexts in SSA, possession of formal documentation of individual land rights has been linked to a higher likelihood of making land investments on fields that households use (Holden, Deininger et al. 2009; Deininger, Ali et al. 2011). However, the overall body of evidence on this for SSA is somewhat less definitive, while suggesting that both a strong pre-existing customary land governance system and other contextual factors may also be important moderators (Place 2009; Lawry, Samii et al. 2014). Here we simply note that respondents in our sample do not directly highlight the lack of formal land documentation as an investment barrier, saying that their current lack of formal documentation of their occupancy right to the field (i.e., customary land certificates) does not discourage them from making improvements on the field for 93% (N = 7,894 fields) of fields. However, the lack of variation around land documentation in the dataset precludes a formal test of its role. We do note a slightly but significantly higher proportion of fields with paper documentation also have agroforestry established on them (N = 13, or 13% of fields with paper documentation), relative to agroforestry establishment on 5% of fields without paper documentation (N = 383 fields; Likelihood ratio test, X^2 (1) = 10.6, P = 0.001).

Lastly, we note that household respondents generally expressed high confidence in land governance in their villages, as indicated through a series of survey questions to household respondents on the extent to which they felt that: (1) rules about land are clear and well-known in their village; (2) village leaders who make decisions about land are honest and can be trusted; (3) the extent to which decisions about customary land allocation in their village are transparent; (4) and fair; (5) that village leaders are accountable for land allocation decisions they make; and (6) their level of confidence that the chief will enforce their land rights in the event that they have a land dispute. Across the board, respondents expressed high confidence in village and chief leadership around land governance issues, with 71 - 90% of household respondents agreeing or strongly agreeing for each of the above.

Discussion & Conclusion

We use matching methods to examine short-term field-level impacts of agroforestry adoption on measures of agricultural productivity and household livelihoods. Given the focus in the literature on agroforestry as a beneficial agricultural technology with longer expected time frames for farmers to realize benefits, it is useful to undertake analyses that contribute towards a better understanding of typical characteristics of agroforestry adopters, how they may differ from smallholder farmers on average, and the magnitude and types of field-level impacts that might be discernible in early years post-adoption. Given the presence of varying time length of fields under agroforestry in the data, and different farmer statements and expectations around positive benefits and experiences, our results also contribute towards a stronger understanding of the extent to which perceived impacts may start to accrue in post-establishment years.

Our analysis is undertaken with a set of early agroforestry adopters that were present in the baseline wave of a randomized controlled trial study to assess land tenure strengthening and agroforestry impact. It is important to note that the impacts for such households that are assessed here derive at this stage from earlier agroforestry efforts that are distinct from the planned TGCC evaluation for which the baseline was conducted. Thus, they may not necessarily represent impacts that could be derived under the planned TGCC program. Moreover, high variation in agroforestry establishment and survival in this early adopter group could mask stronger or earlier impacts on more successfully established fields, as is also supported to some extent by farmer's qualitative perceptions of impacts. It is therefore possible that field-level results in early post-establishment years may be more detectable under a more widespread and uniformly implemented agroforestry or tenure strengthening program, such as is planned for the TGCC program.

Regardless of this, there are some important benefits to undertaking this analysis on the agroforestry adopters that were present at baseline. From a programming perspective, it provides a richer understanding of the kinds of agroforestry benefits that may have been experienced for households prior to program intervention -- and any detectable relationships with land tenure security -- amongst households who were early adopters under previous agroforestry extension efforts. It also provides a strong understanding of who early agroforestry adopters tend to be in this Zambian context, and how their farming practices, land governance experiences, and tenure security may differ from the overall smallholder population. Our analysis demonstrate self-selection of certain types of smallholder farmers into agroforestry, and point to the appropriateness of matching approaches and related alternatives to reduce the effects of such confounding in efforts to determine agroforestry impacts, especially in non-randomized settings. Findings point to the clear relevance of land tenure security and land documentation for household decisions to invest in and extent to which they benefit from agroforestry, despite that we cannot demonstrate the directionality of the relationship with these data. Lastly, our results suggest that studies which aim to assess agroforestry impacts over shorter time periods can benefit from drawing on complementary qualitative perceptions that farmers provide around if and how agroforestry establishment may affect their agricultural input use and resulting productivity, as well as their land use decisions as a whole.

We note there are few existing studies which have rigorously quantified field or household level impacts from agroforestry at scale (Sileshi, Akkinifesi et al. 2010), and highlight the complexity of data needs and analytic approaches required to do so. Although our sample of early adopters is limited in agroforestry observations, we benefit from the availability of extensive primary and field, household and village level data collected across a wide range of theoretically relevant data in order to test for potential short term impacts amongst this group. Our analyses also highlight that selection issues are relevant in the context of understanding agroforestry effects. Farmers who adopt this technology and maintain it for years are not necessarily the same, on average, as other farmers. Thus, to get at true impacts of agroforestry, a strong quasi-experimental design or a truly randomized analytic approach will be key. For efforts to marshal households that may be more likely to adopt or maintain agroforestry, our analyses also shed some light on types of farmers who may be more likely to respond to such efforts, at least in the Zambian context.

Although this analyses was aimed primarily at examining potential short term impacts from agroforestry adoption, it also provided some ability to look at the role of tenure security in this complex process. Other work (Persha, Huntington and Stickler, in prep) has examined determinants of tenure security and its role in land investment in this same Zambian context in more details. That work suggests that there is (1) a strong effect of prior land conflict on a field in dampening tenure security as measured via perceived expropriation risk; while (2) local level village institutions to deal with land governance issues can be an important way to bolster tenure security; but (3) was inconclusive to the role of tenure security in promoting land-related investments and could not detect an effect on agroforestry uptake specifically in this small and varied baseline sample of early agroforestry adopters (Persha, Huntington and Stickler, in prep). Still, as the results from our analyses here also suggest, related land conflict and tenure security issues are clearly important in the context of agroforestry investments, although robust linkages and their directionality are difficult to establish in this small and varied group of early adopters.

Lastly, although it is perhaps not surprising that we do not detect field-level impacts at this stage, given that tangible agroforestry benefits can take years to accrue at scale, our analyses are also subject to several notable constraints. These include variability stemming from different timing and extension sources amongst the agroforestry households in this sample, as well as multiple species planted and in combination with a range of crop types for inter-planting. We are also working with self-reported, farmer-estimated field size, yield, fertilizer application, and crop sale data, all of which are subject to fairly high measurement and reporting variability across respondents. Lastly, our measure of crop earnings as a short-term livelihood outcome is necessarily limited, but useful in this context. Jayne et al (2010) note that only 20-35% of smallholder households sell grain crops in Zambia in any year, and those that do often are wealthier households (Jayne, Mather et al. 2010). Overall, the majority of smallholders in the country buy staple crops to supplement the subsistence quantities that they produce on their own farms, and net buyers of grains tend to be poorer (Jayne, Mather et al. 2010). More generally, measures of cash income as a livelihood indicator are often critiqued for capturing only a narrow aspect of overall household wellbeing, while subsistence food contributions, durable assets and livestock, and other such livelihoods contributions are clearly as, if not more, important for sustaining many poor households. However, broader interests for improving the household welfare of African smallholders focus on, among others, improving farm-based income (Jayne, Chamberlin et al. 2014). Moreover, a longer term development goal of agroforestry is to raise yields such that smallholders are more likely to become net grain sellers rather than buyers, thus contributing towards broader farm-based income goals. As such, the measure of cash income from agroforestry fields that we do use, while certainly imperfect, may be informative with respect to the role of agroforestry in eliciting progress towards broader income growth for Zambian smallholders.

Agroforestry as a land management strategy is increasingly central to meeting concerns for rural smallholders around climate challenges, food security needs, and broader agricultural development goals. But, the complex interactions amongst different elements of agroforestry systems has also long been recognized, contributing to great uncertainty, variability and poor ability to predict outcomes in these systems across varied crop, agroforestry tree and soil interactions (Luedeling, Smethurst et al. 2016). A number of isolated agricultural experiments of Musangu, *Gliricidia* and other agroforestry tree species do provide evidence of changes in soil microbial fauna, soil organic matter, and other elements that should translate to improved crop yields (Heineman, Otieno et al. 1997; Akinnifesi, Makumba et al. 2006; Beedy, Snapp et al. 2010). However, to date there are few studies which rigorously quantify farmer input, yield and profit outcomes on agroforestry fields, and show unequivocal improvements (Sileshi, Akinnifesi et al. 2010).

Our analyses are important for their contributions towards understanding characteristics of early agroforestry adopters, if and when different shorter-term impacts may be discernable in this customary land system context, and the potential role that enhanced tenure security may play in incentivizing farmer decisions to engage in agroforestry land investments. It also has the potential to contribute towards theoretical clarity around the hypothesized causal role of stronger tenure security in eliciting certain kinds of land investments among rural smallholders in sub-Saharan Africa. Such knowledge – particularly from a customary land context prior to efforts to strengthen customary use rights *in situ* - is critical for practical applications amid contemporary land programming efforts by country governments, donors, and NGOs on the continent. Although these efforts focus on land tenure strengthening as a means to achieve improved household agricultural livelihoods, climate change mitigation, and broader development goals, they also tend to make a number of uniform assumptions around how different kinds of land formalization approaches affect farmer tenure security, and there are substantial knowledge gaps on the comparative effectiveness of converting customary rights to statutory freehold titles, relative to newer certification efforts to strengthen customary use rights within the existing land system. Ultimately, our results may contribute towards a better understanding of key design factors and how land tenure strengthening programs as a whole may be shaped to increase their likelihood of eliciting intended development outcomes for rural smallholders in customary land settings in sub-Saharan Africa.

Tables and Figures

Table 1. Descriptive summary statistics.

		Non-Agroforestry Households					Agroforestry Households								All Households		
Variable Name	Label	mean	sd	min	max	N	mean	sd	min	max	N	Mean Difference	T	P-value	mean	sd	N
age_head	HH head age	43.84	16.39	18	101	2695	44.61	17.12	19	94	327	-0.78	-0.78	0.436	43.9	16.5	3022
yrs_live_h~c	Head residency time in village (yrs)	41.74	17.8	0	101	2691	41.08	18.87	0	91	325	0.661	0.60	0.589	41.7	17.9	3016
hh_size	HH size	5.23	2.63	1	20	2722	5.57	2.82	1	20	337	-0.34**	-2.19	0.035	5.26	2.66	3059
hh_labor	HH labor: Number of HH members over age 12	2.93	1.63	0	15	2722	3.3	1.91	0	16	337	-0.38***	-3.45	0.001	2.97	1.66	3059
highest_educ	Highest education level of any HH member (1 = no formal schooling; 15 = post-secondary)	8.69	3.39	1	15	2722	9.51	3.49	1	15	337	-0.82***	-4.08	0.000	8.78	3.41	3059
ed_headc	Highest education level of any HH head(1 = no formal schooling; 15 = post-secondary)	6.74	3.75	1	15	2655	6.62	3.79	1	15	333	0.02	0.54	0.590	6.72	3.75	2988
landarea_own	HH land area owned (Hectares)	1.87	1.68	0	20	2718	2.21	2.1	0	20	336	-0.34***	-2.83	0.005	1.91	1.73	3054
landlabore~v	Total area cultivated in hectares per HH labor equivalent	1.07	13.69	0.02	612.6	2667	0.68	0.68	0.07	6.8	331	0.39	1.44	0.150	1.02	12.9	2998
incpercap	Per capita non-agricultural income (Zambian Kwacha)	306	1127	0	29333	2722	259	734	0	7000	337	47.56	1.05	0.296	301	1091	3059
off_farmincb	Hh has any off-farm income (Y/N) (salary or other non-agricultural income)	0.54	0.5	0	1	2722	0.52	0.5	0	1	337	0.02	0.74	0.457	0.54	0.5	3059
score_noli~k	Asset-based wealth index score	-0.07	1.75	-2.1	5.75	2718	0.04	1.82	-1.95	5.74	336	-0.11	-1.08	0.280	-0.06	1.76	3054
poor	1 = HH is in poorest quartile of households	0.25	0.43	0	1	2718	0.25	0.43	0	1	336	0.00	0.16	0.876	0.25	0.43	3054
farm_coop	HH participates in farmer groups / cooperatives (Y/N)	0.43	0.5	0	1	2722	0.42	0.49	0	1	337	0.02	0.67	0.502	0.43	0.5	3059
cfadvicec	In past yr HH received any advice on conservation farming? (Y/N)	0.37	0.48	0	1	2672	0.35	0.48	0	1	334	0.02	0.76	0.450	0.37	0.48	3006
agadvicec	In past year, HH received agroforestry advice specifically? (Y/N)	0.32	0.47	0	1	2672	0.3	0.46	0	1	334	0.02	0.56	0.576	0.32	0.46	3006
fhh	1 = Female-headed household	0.22	0.42	0	1	2722	0.23	0.42	0	1	337	-0.01	-0.38	0.706	0.22	0.42	3059
tt_50k_hours	Average travel time to nearest urban center (in hours)	3.80	2.55	0.23	14.78	2530	3.74	2.44	0.4	14.78	307	0.06	0.40	0.688	3.79	2.54	2837
reallocate	1 = HH had any land it was using reallocated by village or chief in past 5 years	0.02	0.14	0	1	2714	0.01	0.09	0	1	337	0.01*	1.78	0.076	0.02	0.13	3051
Variable Name	Label	Non-Agroforestry Fields					Agroforestry Fields								All Fields		
logYIELD1v2	Outcome 1: Logged crop yield in kilograms per hectare	6.68	1.27	0.3	9.3	6220	6.9	1.29	0.69	9.26	339	-0.21***	-2.94	0.004	6.7	1.27	6559
log_fertkg~a	Outcome 2: Logged amount of fertilizer applied per hectare	5.27	1.4	0	9.68	4265	5.02	1.39	0	9.47	259	0.25***	2.82	0.005	5.26	1.4	4524
log_harvpr~a	Outcome 3: Logged actual or expected harvest value per hectare from this field	6.84	1.44	0	17.26	2015	6.67	1.41	0	9.62	108	0.17	1.22	0.223	6.84	1.43	2123
YIELD_mt2	Crop yield in metric tonnes per hectare	1.39	1.45	0	10.94	6220	1.63	1.48	0	10.5	339	-0.24***	-2.906	0.004	1.4	1.45	6559
crop1	Main crop grown on field is Local maize	0.23	0.42	0	1	6220	0.3	0.46	0	1	339	-0.08***	-3.05	0.003	0.23	0.42	6559
crop2	Main crop grown on field is Hybrid maize	0.27	0.44	0	1	6220	0.39	0.49	0	1	339	-0.12***	-4.41	0.000	0.28	0.45	6559
crop3	Main crop grown on field is Groundnuts	0.26	0.44	0	1	6220	0.17	0.38	0	1	339	0.09***	4.30	0.000	0.26	0.44	6559
crop4	Main crop grown on field is Soybeans	0.05	0.22	0	1	6220	0.01	0.08	0	1	339	0.04***	8.60	0.000	0.05	0.21	6559
crop5	Main crop grown on field is Cotton	0.08	0.27	0	1	6220	0.07	0.25	0	1	339	0.01	0.84	0.400	0.08	0.27	6559
crop6	Main crop grown on field is Sunflower	0.11	0.32	0	1	6220	0.06	0.24	0	1	339	0.05***	3.76	0.000	0.11	0.31	6559
seedtype_2	1 = Hybrid variety seed type (improved seed)	0.49	0.5	0	1	6220	0.61	0.49	0	1	339	-0.13***	-4.59	0.000	0.49	0.5	6559
tot_cultiv	Field area in hectares	0.67	0.68	0.01	20	6220	0.87	0.81	0.05	10	339	-0.20***	-4.39	0.000	0.68	0.69	6559
tot_cultiv~g	Logged field area in hectares	0.48	0.31	0	7.8	7691	0.57	0.3	0.05	2.4	339	-0.10***	-5.79	0.000	0.48	0.26	6559
manure	1 = Manuring done on the field in past 5 years	0.17	0.38	0	1	6219	0.47	0.5	0	1	339	-0.30***	-11.02	0.000	0.19	0.39	6558
crop_rotatec	1 = Crop rotation done on the field in past 5 years	0.84	0.37	0	1	6220	0.93	0.25	0	1	339	-0.09***	-6.50	0.000	0.84	0.36	6559
tillagemeth1	1 = conventional hand hoeing	0.63	0.48	0	1	6220	0.63	0.48	0	1	339	0.00	0.14	0.886	0.63	0.48	6559
tillagemeth2	1 = ploughing	0.2	0.4	0	1	6220	0.2	0.4	0	1	339	0.00	-0.19	0.847	0.2	0.4	6559
tillagemeth3	1 = ridging	0.13	0.33	0	1	6220	0.11	0.31	0	1	339	0.02	0.91	0.362	0.12	0.33	6559
soil_typec	Soil type on the field (1 = Clay; 2 = Sandy loamy; 3 = Loamy; 4 = Silt or gravel)	2.62	1.01	1	4	6188	2.63	1	1	4	339	-0.01	-0.14	0.892	2.62	1.01	6527
tensec_f	Tenure security index (ranges from 0 to 6)	5.32	0.88	1.83	6	6131	5.27	0.9	2	6	338	0.05	1.00	0.317	5.31	0.88	6469
disputec	1 = HH experienced a conflict on this field	0.12	0.33	0	1	6130	0.21	0.41	0	1	338	-0.09***	-3.78	0.000	0.13	0.33	6468

Table 2. Agroforestry treatment effects, all crops combined.

	Outcome 1: Crop Yield (logged kilograms per hectare)							Outcome 2: Fertilizer Input Use (logged kgs of fertilizer applied per hectare)							Outcome 3: Harvest Value (Logged actual or expected ZK earned per hectare)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
LABELS	a	b	a	b	a	b	c	a	b	a	b	a	b	c	a	b	a	b	a	b	c
Agroforestry on field or not (treatment)	0.184**	-0.069	0.048	-0.077	0.021	-0.078	-0.008	-0.251**	-0.055	-0.079	-0.052	-0.045	-0.058	-0.012	-0.149	-0.124	-0.047	-0.102	0.001	-0.124	-0.087
	(0.078)	(0.105)	(0.074)	(0.101)	(0.094)	(0.101)	(0.172)	(0.102)	(0.124)	(0.098)	(0.113)	(0.116)	(0.113)	(0.189)	(0.153)	(0.187)	(0.132)	(0.161)	(0.158)	(0.160)	(0.230)
HH head age					0.002**	0.000	0.008**					-0.001	0.000	0.005					0.004	0.001	-0.000
					(0.001)	(0.003)	(0.004)					(0.002)	(0.004)	(0.006)					(0.002)	(0.005)	(0.006)
Total area cultivated per HH labor equivalent					0.006**	-0.019	-0.005					0.091	0.096	0.166					0.167**	0.264	0.245
					(0.003)	(0.041)	(0.153)					(0.071)	(0.065)	(0.186)					(0.065)	(0.161)	(0.203)
Highest education level of any HH member					0.013**	0.024	-0.011					0.056***	0.050***	-0.019					0.002	0.005	0.015
					(0.006)	(0.016)	(0.022)					(0.012)	(0.018)	(0.037)					(0.012)	(0.025)	(0.028)
log of Per capita non-agricultural income					-0.032**	0.018	-0.119***					-0.042*	-0.061	-0.129***					-0.034	0.078	0.074
					(0.013)	(0.036)	(0.044)					(0.025)	(0.037)	(0.048)					(0.025)	(0.049)	(0.075)
HH participates in farmer groups / cooperatives					0.071*	0.148*	0.023					-0.069	0.165	0.194					0.023	-0.088	0.172
					(0.041)	(0.088)	(0.157)					(0.078)	(0.132)	(0.265)					(0.083)	(0.165)	(0.186)
1 = Improved seed variety			0.349***	0.321***	0.346***	0.312**	-0.050			0.109**	0.343**	0.064	0.276**	0.169			0.459***	0.275	0.416***	0.293	0.085
			(0.036)	(0.122)	(0.044)	(0.121)	(0.209)			(0.051)	(0.140)	(0.063)	(0.138)	(0.186)			(0.068)	(0.215)	(0.082)	(0.218)	(0.370)
Log of 1 + field area in hectares			-1.117***	-0.755***	-1.141***	-0.769***	-1.638***			-1.290***	-0.866***	-1.484***	-1.044***	-1.060**			-1.117***	-0.553	-1.257***	-0.739**	-1.615***
			(0.079)	(0.167)	(0.095)	(0.167)	(0.328)			(0.085)	(0.194)	(0.103)	(0.200)	(0.459)			(0.129)	(0.367)	(0.169)	(0.310)	(0.446)
Manuring done in past 5 years?			0.163***	0.193**	0.226***	0.171*	0.093			0.047	-0.214*	0.025	-0.233**	-0.348**			0.110	-0.038	0.175*	0.016	-0.098
			(0.039)	(0.091)	(0.046)	(0.089)	(0.181)			(0.055)	(0.112)	(0.064)	(0.114)	(0.169)			(0.076)	(0.193)	(0.096)	(0.183)	(0.233)
Crop rotation done in past 5 years?			0.233***	0.747*	0.253***	0.711*	0.066			0.093	-0.023	0.119	-0.079	0.154			0.141	0.078	0.132	0.250	0.079
			(0.044)	(0.398)	(0.057)	(0.416)	(0.473)			(0.057)	(0.131)	(0.073)	(0.122)	(0.199)			(0.095)	(0.242)	(0.127)	(0.209)	(0.301)
Tillage method ==Conventional hand hoeing			-0.097**	0.023	-0.092*	0.042	0.168			-0.420***	-0.399***	-0.416***	-0.354**	-0.556**			-0.178**	-0.165	-0.261***	-0.232	-0.544*
			(0.041)	(0.189)	(0.052)	(0.190)	(0.185)			(0.066)	(0.141)	(0.078)	(0.139)	(0.245)			(0.072)	(0.213)	(0.093)	(0.200)	(0.290)
Tillage method ==Ploughing			0.159***	0.347*	0.150**	0.355*	0.417**			0.018	0.178	-0.000	0.184	-0.216			0.053	0.230	0.021	0.143	-0.054
			(0.051)	(0.205)	(0.061)	(0.202)	(0.187)			(0.072)	(0.178)	(0.084)	(0.173)	(0.257)			(0.082)	(0.261)	(0.104)	(0.250)	(0.337)
Soil type of field			-0.010	-0.019	-0.005	-0.021	-0.088			-0.052**	-0.056	-0.059*	-0.075	0.011			-0.010	-0.063	0.013	-0.076	-0.192*
			(0.014)	(0.048)	(0.018)	(0.048)	(0.065)			(0.025)	(0.055)	(0.031)	(0.057)	(0.076)			(0.029)	(0.086)	(0.036)	(0.086)	(0.102)
Tenure security index score			-0.023	-0.047	-0.025	-0.044	-0.216***			-0.072***	-0.110*	-0.043	-0.098*	0.072			-0.014	-0.134*	-0.038	-0.142*	-0.091
			(0.017)	(0.048)	(0.021)	(0.047)	(0.064)			(0.023)	(0.062)	(0.028)	(0.059)	(0.102)			(0.033)	(0.076)	(0.038)	(0.077)	(0.106)
Main crop == Local maize			0.547***	0.621***	0.551***	0.615***	0.630*			-0.449***	-0.252	-0.315***	-0.288*	0.254			-0.509***	-0.939**	-0.474***	-1.001**	-1.349***
			(0.059)	(0.219)	(0.073)	(0.227)	(0.343)			(0.074)	(0.170)	(0.091)	(0.165)	(0.241)			(0.121)	(0.402)	(0.145)	(0.392)	(0.503)
Main Crop == Hybrid maize			0.764***	0.779***	0.754***	0.763***	1.081***			-0.225***	-0.140	-0.139	-0.124	0.069			-0.092	-0.508	-0.043	-0.562	-0.735
			(0.054)	(0.163)	(0.068)	(0.175)	(0.220)			(0.072)	(0.164)	(0.086)	(0.160)	(0.164)			(0.096)	(0.374)	(0.127)	(0.394)	(0.467)
Main Crop == Groundnut			0.155***	0.264	0.170***	0.249	0.151			-0.048	0.336*	0.019	0.310	-0.048			-0.099	-0.480	0.044	-0.521	-0.697
			(0.048)	(0.179)	(0.063)	(0.189)	(0.211)			(0.075)	(0.190)	(0.099)	(0.200)	(0.253)			(0.082)	(0.382)	(0.112)	(0.392)	(0.470)
Main crop == Sunflower			-0.086	-0.013	-0.059	-0.017	-0.129			0.112	0.203	0.078	0.169	0.043			-0.640***	-1.195***	-0.573***	-1.252***	-1.438***
			(0.056)	(0.233)	(0.069)	(0.240)	(0.405)			(0.082)	(0.190)	(0.102)	(0.183)	(0.287)			(0.096)	(0.391)	(0.115)	(0.402)	(0.478)
Constant	6.685***	6.959***	6.639***	6.029***	6.545***	5.688***	8.695***	5.270***	5.203***	6.689***	6.575***	6.277***	6.409***	6.125***	6.844***	6.858***	7.372***	8.465***	7.365***	7.959***	8.862***
	(0.018)	(0.036)	(0.114)	(0.529)	(0.172)	(0.486)	(0.870)	(0.041)	(0.065)	(0.170)	(0.487)	(0.285)	(0.577)	(0.720)	(0.034)	(0.085)	(0.223)	(0.672)	(0.357)	(0.748)	(0.804)
Observations	6,520	3,661	6,399	3,661	4,155	3,661	817	4,495	2,528	4,425	2,528	2,875	2,528	539	2,115	1,154	2,081	1,154	1,369	1,154	805
R-squared	0.001	0.001	0.120	0.122	0.126	0.129	0.310	0.002	0.000	0.121	0.138	0.140	0.157	0.146	0.000	0.002	0.095	0.109	0.095	0.128	0.189

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

a = Unweighted OLS model; b = Entropy-weighted OLS model; c = Entropy-weighted OLS model using restricted sample (robustness check).

Table 3. Agroforestry treatment effects, local maize only.

	Outcome 1: Crop Yield (logged kilograms per hectare)						Outcome 2: Fertilizer Input Use (logged kgs of fertilizer applied per hectare)						Outcome 3: Harvest Value (Logged actual or expected ZK earned per hectare)					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
LABELS	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Agroforestry on field or not (treatment)	0.226	0.017	0.186	0.042	0.087	0.041	-0.296*	-0.285	-0.298*	-0.271	-0.195	-0.326	-0.375	-0.325	-0.299	-0.670***	-0.231	-0.570*
	(0.139)	(0.224)	(0.141)	(0.200)	(0.207)	(0.192)	(0.177)	(0.223)	(0.178)	(0.206)	(0.195)	(0.208)	(0.393)	(0.411)	(0.372)	(0.230)	(0.437)	(0.288)
HH head age					0.001	0.002					0.002	0.007					0.013*	0.008
					(0.002)	(0.004)					(0.003)	(0.005)					(0.008)	(0.011)
Total area cultivated per HH labor equivalent					0.008**	-0.010					0.093	0.090					0.151	-0.223
					(0.003)	(0.053)					(0.089)	(0.057)					(0.372)	(0.487)
Highest education level of any HH member					0.024*	0.080**					0.046***	0.061**					0.008	-0.030
					(0.013)	(0.036)					(0.016)	(0.028)					(0.042)	(0.086)
log of Per capita non-agricultural income					-0.039	-0.037					-0.076*	-0.059					-0.165*	-0.056
					(0.030)	(0.074)					(0.040)	(0.073)					(0.097)	(0.066)
HH participates in farmer groups / cooperatives					0.129	0.272*					0.100	0.508***					0.435*	0.526
					(0.088)	(0.151)					(0.104)	(0.192)					(0.245)	(0.402)
1 = Improved seed variety			0.175**	0.137	0.185*	0.112			0.452***	0.713***	0.408***	0.699***			0.768***	0.254	0.659***	0.319
			(0.087)	(0.199)	(0.107)	(0.195)			(0.092)	(0.247)	(0.119)	(0.236)			(0.206)	(0.308)	(0.242)	(0.290)
Log of 1 + field area in hectares			-1.081***	-0.567***	-1.100***	-0.570***			-1.266***	-0.815***	-1.572***	-0.870***			-1.021**	-0.002	-1.149**	0.457
			(0.147)	(0.202)	(0.188)	(0.180)			(0.171)	(0.286)	(0.257)	(0.316)			(0.423)	(0.237)	(0.492)	(0.745)
Manuring done in past 5 years			0.181**	0.134	0.237***	0.109			0.058	-0.331	-0.013	-0.304			0.073	0.476	0.324	0.341
			(0.073)	(0.173)	(0.087)	(0.175)			(0.099)	(0.208)	(0.136)	(0.191)			(0.259)	(0.352)	(0.307)	(0.402)
Crop rotation done in past 5 years			0.348***	0.927***	0.274**	0.590**			0.270**	0.288	0.343**	0.246			0.602**	1.731***	0.888**	1.635***
			(0.093)	(0.281)	(0.121)	(0.297)			(0.109)	(0.199)	(0.139)	(0.198)			(0.263)	(0.448)	(0.342)	(0.393)
Tillage method ==Conventional hand hoeing			-0.038	0.377	-0.003	0.473			-0.107	0.016	-0.110	0.054			0.186	-0.136	-0.201	-0.290
			(0.100)	(0.422)	(0.134)	(0.420)			(0.102)	(0.305)	(0.129)	(0.265)			(0.204)	(0.314)	(0.285)	(0.362)
Tillage method ==Ploughing			0.307**	0.927**	0.395**	0.916**			0.303**	0.417	0.304**	0.419			0.429	1.457***	0.428	1.370***
			(0.137)	(0.447)	(0.168)	(0.415)			(0.119)	(0.352)	(0.139)	(0.318)			(0.315)	(0.352)	(0.381)	(0.378)
Soil type of field			-0.014	0.098	-0.034	0.101			-0.057	-0.033	-0.086*	-0.070			0.034	0.497*	0.042	0.437*
			(0.034)	(0.099)	(0.042)	(0.098)			(0.041)	(0.125)	(0.048)	(0.107)			(0.110)	(0.254)	(0.138)	(0.230)
Tenure security index score			-0.020	-0.149	-0.056	-0.155			-0.060	-0.012	-0.010	-0.066			0.138	0.036	0.038	-0.045
			(0.042)	(0.123)	(0.048)	(0.111)			(0.044)	(0.106)	(0.054)	(0.105)			(0.139)	(0.103)	(0.123)	(0.135)
Constant	6.706***	6.812***	7.033***	6.274***	7.190***	5.777***	4.918***	5.009***	5.722***	5.198***	5.465***	4.699***	6.424***	6.525***	5.145***	2.939**	5.531***	3.603***
	(0.037)	(0.096)	(0.285)	(0.570)	(0.375)	(0.733)	(0.050)	(0.117)	(0.309)	(0.566)	(0.471)	(0.847)	(0.108)	(0.191)	(0.761)	(1.246)	(1.057)	(1.267)
Observations	1,493	880	1,480	880	944	880	991	571	983	571	629	571	218	133	218	133	146	133
R-squared	0.002	0.000	0.069	0.083	0.078	0.121	0.003	0.013	0.105	0.157	0.143	0.220	0.005	0.015	0.132	0.278	0.195	0.325

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
a = Unweighted OLS model; b = Entropy-weighted OLS model.

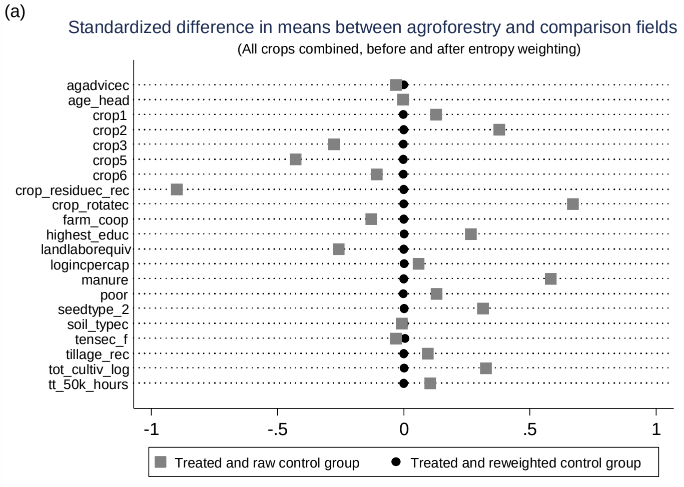
Table 4. Agroforestry treatment effects, hybrid maize only.

	Outcome 1: Crop Yield (logged kilograms per hectare)						Outcome 2: Fertilizer Input Use (logged kgs of fertilizer applied per hectare)						Outcome 3: Harvest Value (Logged actual or expected ZK earned per hectare)					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
LABELS	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Agroforestry on field or not (treatment)	-0.045	-0.223	-0.157	-0.249	-0.155	-0.249	-0.082	0.014	-0.042	-0.019	-0.074	-0.034	-0.249	-0.107	-0.246	-0.104	-0.030	-0.138
	(0.138)	(0.179)	(0.137)	(0.172)	(0.157)	(0.172)	(0.135)	(0.181)	(0.134)	(0.167)	(0.174)	(0.166)	(0.273)	(0.319)	(0.276)	(0.302)	(0.321)	(0.320)
HH head age					0.002	-0.003					-0.001	0.002					0.005	-0.005
					(0.002)	(0.005)					(0.003)	(0.005)					(0.005)	(0.008)
Total area cultivated per HH labor equivalent					-0.070	0.005					0.012	-0.104					0.211**	0.128
					(0.050)	(0.134)					(0.111)	(0.208)					(0.095)	(0.231)
Highest education level of any HH member					0.024**	0.020					0.051***	0.054*					-0.006	-0.036
					(0.012)	(0.030)					(0.018)	(0.029)					(0.028)	(0.063)
log of Per capita non-agricultural income					-0.020	0.038					-0.040	-0.058					0.003	0.213**
					(0.024)	(0.060)					(0.028)	(0.042)					(0.061)	(0.107)
HH participates in farmer groups / cooperatives					0.068	0.193					-0.086	-0.046					-0.013	0.134
					(0.074)	(0.162)					(0.090)	(0.195)					(0.163)	(0.301)
1 = Improved seed variety			0.830***	0.819***	0.828***	0.816***			0.266*	0.244	0.261	0.144			0.357*	-0.822	0.242	-0.927
			(0.111)	(0.220)	(0.149)	(0.219)			(0.158)	(0.422)	(0.186)	(0.390)			(0.199)	(0.769)	(0.282)	(0.735)
Log of 1 + field area in hectares			-0.586***	-0.679***	-0.616***	-0.767***			-0.975***	-0.698***	-1.023***	-0.723**			-0.716***	-0.756	-0.954***	-0.638
			(0.098)	(0.229)	(0.124)	(0.228)			(0.127)	(0.258)	(0.165)	(0.337)			(0.240)	(0.525)	(0.275)	(0.436)
Manuring done in past 5 years			0.153**	0.238*	0.200***	0.204			-0.013	-0.180	-0.092	-0.235			0.051	-0.021	0.126	0.021
			(0.067)	(0.141)	(0.074)	(0.139)			(0.076)	(0.172)	(0.100)	(0.173)			(0.149)	(0.275)	(0.192)	(0.266)
Crop rotation done in past 5 years			0.278***	0.619	0.344***	0.650			0.039	-0.133	0.034	-0.169			0.173	-0.052	0.056	0.355
			(0.072)	(0.537)	(0.092)	(0.535)			(0.084)	(0.154)	(0.115)	(0.160)			(0.183)	(0.329)	(0.216)	(0.296)
Tillage method ==Conventional hand hoeing			-0.224***	-0.062	-0.174*	-0.070			-0.492***	-0.411**	-0.463***	-0.367**			-0.587***	-0.207	-0.854***	-0.539
			(0.080)	(0.252)	(0.100)	(0.237)			(0.081)	(0.182)	(0.105)	(0.184)			(0.163)	(0.374)	(0.214)	(0.334)
Tillage method ==Ploughing			0.155*	0.295	0.098	0.283			0.119	0.297	0.117	0.317			-0.074	0.054	-0.170	-0.112
			(0.091)	(0.273)	(0.118)	(0.265)			(0.093)	(0.215)	(0.116)	(0.211)			(0.175)	(0.377)	(0.191)	(0.362)
Soil type of field			-0.046	-0.124	-0.027	-0.120			-0.121***	-0.021	-0.111**	-0.026			-0.048	-0.228*	-0.006	-0.245**
			(0.029)	(0.083)	(0.038)	(0.084)			(0.036)	(0.081)	(0.044)	(0.085)			(0.063)	(0.137)	(0.085)	(0.122)
Tenure security index score			-0.042	-0.028	-0.021	-0.026			-0.115***	-0.128	-0.118**	-0.115			-0.080	-0.148	-0.134*	-0.175
			(0.033)	(0.056)	(0.041)	(0.054)			(0.037)	(0.092)	(0.046)	(0.090)			(0.061)	(0.111)	(0.075)	(0.113)
Constant	7.134***	7.344***	6.903***	6.706***	6.508***	6.378***	5.123***	5.161***	6.615***	6.436***	6.410***	6.285***	6.967***	7.051***	7.807***	9.812***	8.080***	9.159***
	(0.032)	(0.055)	(0.230)	(0.705)	(0.321)	(0.706)	(0.048)	(0.085)	(0.271)	(0.788)	(0.406)	(0.834)	(0.072)	(0.130)	(0.474)	(1.192)	(0.771)	(1.232)
Observations	1,796	1,063	1,766	1,063	1,149	1,063	1,533	876	1,514	876	985	876	485	277	477	277	306	277
R-squared	0.000	0.007	0.075	0.100	0.086	0.109	0.000	0.000	0.103	0.089	0.115	0.109	0.002	0.001	0.062	0.105	0.096	0.161

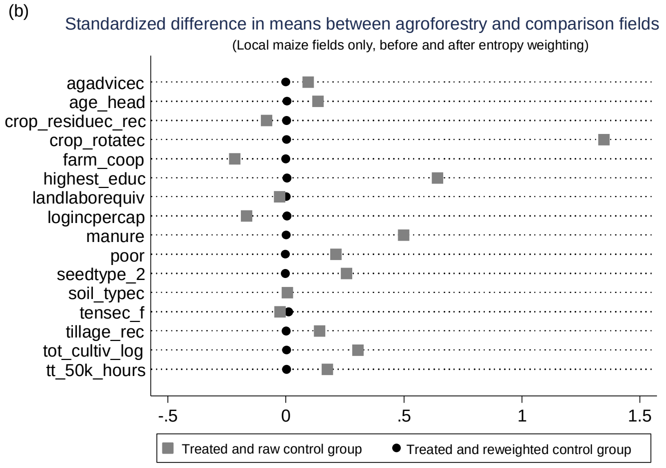
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
a = Unweighted OLS model; b = Entropy-weighted OLS model.

Figure 1. Entropy weighting balance summaries for (a) all crops combined, (b) local maize only, and (c) hybrid maize only.

(a)



(b)



(c)

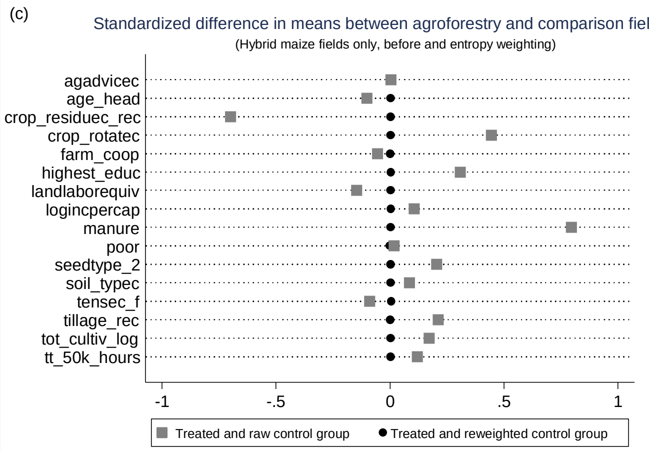


Figure 2. Distribution of time under agroforestry across agroforestry fields.

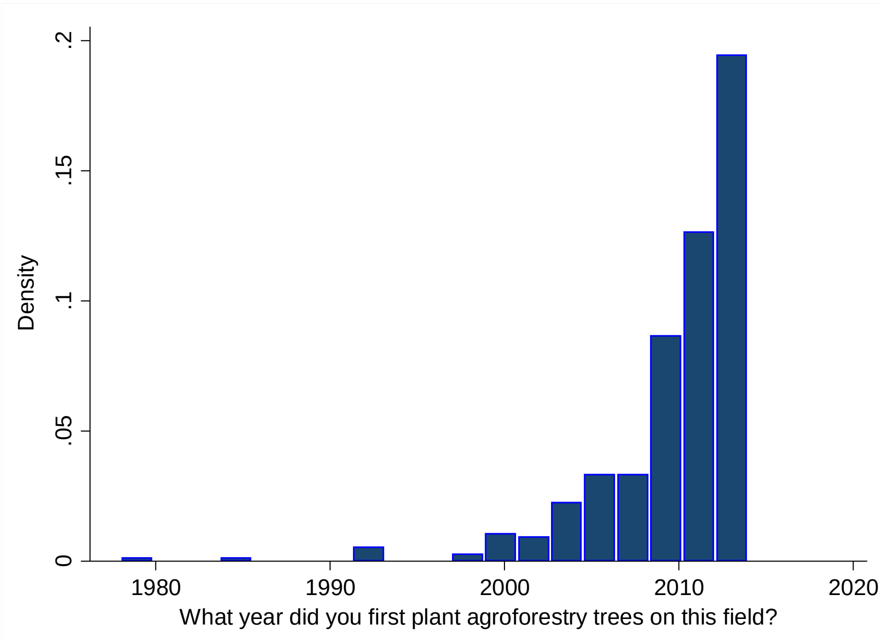
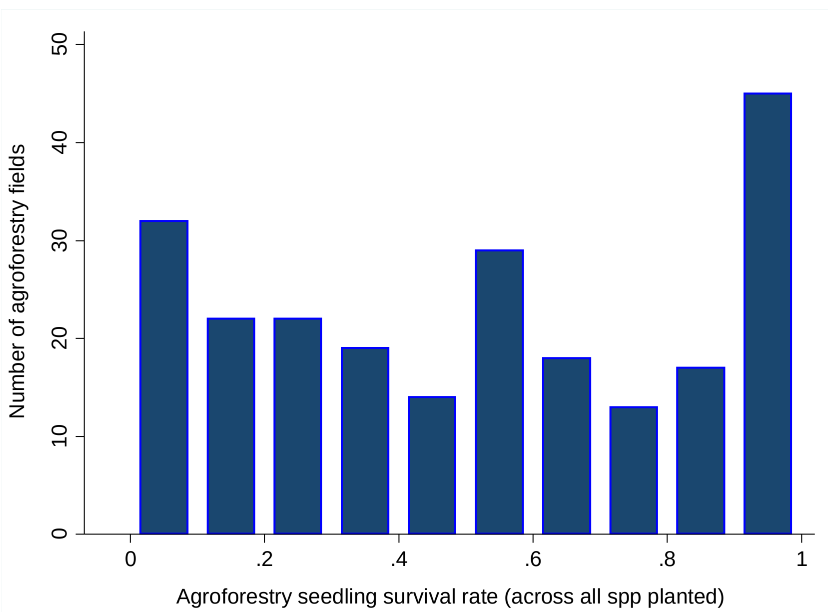


Figure 3. Agroforestry seedling survival rate



Literature Cited

Abadie, A. and G. W. Imbens (2011). "Bias-corrected matching estimators for average treatment effects." Journal of Business and Economic Statistics **29**(1): 1-11.

Ajayi, O. C., S. Franzel, et al. (2003). "Adoption of improved fallow technology for soil fertility management in Zambia: Empirical studies and emerging issues." Agroforestry Systems **59**(3): 317-326.

Akinnifesi, F. K., W. Makumba, et al. (2006). "Sustainable maize production using gliricidia/maize intercropping in southern Malawi." Experimental Agriculture **42**(4): 441-457.

Ali, D. A. and K. Deininger (2015). "Is there a farm size-productivity relationship in African agriculture? Evidence from Rwanda." Land Economics **91**(2): 317-343.

Arnot, C. D., M. K. Luckert, et al. (2011). "What is tenure security? Conceptual implications for empirical analysis." Land Economics **87**(2): 297-311.

Barrett, C. B., M. F. Bellemare, et al. (2010). "Reconsidering Conventional Explanations of the Inverse Productivity-Size Relationship." World Development **38**(1): 88-97.

Beedy, T. L., S. S. Snapp, et al. (2010). "Impact of Gliricidia sepium intercropping on soil organic matter fractions in a maize-based cropping system." Agriculture, Ecosystems and Environment **138**(3-4): 139-146.

Besley, T. (1995). "Property rights and investment incentives: theory and evidence from Ghana." Journal of Political Economy **103**(5): 903-937.

Brasselle, A. S., F. Gaspart, et al. (2002). "Land tenure security and investment incentives: Puzzling evidence from Burkina Faso." Journal of Development Economics **67**(2): 373-418.

Bromley, D. W. (2009). "Formalising property relations in the developing world: The wrong prescription for the wrong malady." Land Use Policy **26**(1): 20-27.

Cooper, P. J. M., J. Dimes, et al. (2008). "Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change?" Agriculture, Ecosystems and Environment **126**(1-2): 24-35.

Dehejia, R. H. and S. Wahba (1999). "Causal Effects in Nonexperimental Studies: Reevaluating the Evaluation of Training Programs." Journal of the American Statistical Association **94**(448): 1053-1062.

Deininger, K., D. A. Ali, et al. (2011). "Impacts of land certification on tenure security, investment, and land market participation: Evidence from Ethiopia." Land Economics **87**(2): 312-334.

Deininger, K. and S. Jin (2006). "Tenure security and land-related investment: Evidence from Ethiopia." European Economic Review **50**(5): 1245-1277.

Diamond, A. and J. S. Sekhon (2013). "Genetic matching for estimating causal effects: A general multivariate matching method for achieving balance in observational studies." Review of Economics and Statistics **95**(3): 932-945.

Feder, G., R. E. Just, et al. (1985). "Adoption of agricultural innovations in developing countries: a survey." Economic Development & Cultural Change **33**(2): 255-298.

Fenske, J. (2011). "Land tenure and investment incentives: Evidence from West Africa." Journal of Development Economics **95**(2): 137-156.

Franzel, S., R. Coe, et al. (2001). "Assessing the adoption potential of agroforestry practices in sub-Saharan Africa." Agricultural Systems **69**(1-2): 37-62.

German, L., G. Schoneveld, et al. (2013). "Contemporary Processes of Large-Scale Land Acquisition in Sub-Saharan Africa: Legal Deficiency or Elite Capture of the Rule of Law?" World Development **48**: 1-18.

Hainmueller, J. (2012). "Entropy balancing for causal effects: A multivariate reweighting method to produce balanced samples in observational studies." Political Analysis **20**(1): 25-46.

Hainmueller, J. and Y. Xu (2013). "Ebalance: A stata package for entropy balancing." Journal of Statistical Software **54**(7): 1-18.

Heineman, A. M., H. J. O. Otieno, et al. (1997). "Growth and yield of eight agroforestry tree species in line plantings in Western Kenya and their effect on maize yields and soil properties." Forest Ecology and Management **91**(1): 103-135.

Ho, D. E., K. Imai, et al. (2007). "Matching as nonparametric preprocessing for reducing model dependence in parametric causal inference." Political Analysis **15**(3): 199-236.

Holden, S. T., K. Deininger, et al. (2009). "Impacts of low-cost land certification on investment and productivity." American Journal of Agricultural Economics **91**(2): 359-373.
Holden, S. T., K. Deininger, et al. (2011). "Tenure insecurity, gender, low-cost land certification and land rental market participation in Ethiopia." Journal of Development Studies **47**(1): 31-47.
Imbens, G. W. and J. M. Wooldridge (2009). "Recent developments in the econometrics of program evaluation." Journal of Economic Literature **47**(1): 5-86.
Jamnadass, R. H., I. K. Dawson, et al. (2011). "Improving livelihoods and nutrition in sub-saharan africa through the promotion of indigenous and exotic fruit production in smallholders' agroforestry systems: A review." International Forestry Review **13**(3): 338-354.
Jayne, T. S., J. Chamberlin, et al. (2014). "Land pressures, the evolution of farming systems, and development strategies in Africa: A synthesis." Food Policy **48**: 1-17.
Jayne, T. S., D. Mather, et al. (2010). "Principal Challenges Confronting Smallholder Agriculture in Sub-Saharan Africa." World Development **38**(10): 1384-1398.
Jayne, T. S. and S. Rashid (2013). "Input subsidy programs in sub-Saharan Africa: A synthesis of recent evidence." Agricultural Economics (United Kingdom) **44**(6): 547-562.
Knowler, D. and B. Bradshaw (2007). "Farmers' adoption of conservation agriculture: A review and synthesis of recent research." Food Policy **32**(1): 25-48.
Larson, D. F., K. Otsuka, et al. (2014). "Should African rural development strategies depend on smallholder farms? An exploration of the inverse-productivity hypothesis." Agricultural Economics (United Kingdom) **45**(3): 355-367.
Lawry, S., C. Samii, et al. (2014). "The impact of land property rights interventions on investment and agricultural productivity in developing countries: a systematic review." Campbell Systematic Reviews **2014**(1).
Luedeling, E., P. J. Smethurst, et al. (2016). "Field-scale modeling of tree-crop interactions: Challenges and development needs." Agricultural Systems **142**: 51-69.
Marenya, P. P. and C. B. Barrett (2007). "Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya." Food Policy **32**(4): 515-536.
Mbow, C., M. Van Noordwijk, et al. (2014). "Agroforestry solutions to address food security and climate change challenges in Africa." Current Opinion in Environmental Sustainability **6**(1): 61-67.
Mbow, C., M. van Noordwijk, et al. (2014). "Knowledge gaps and research needs concerning agroforestry's contribution to Sustainable Development Goals in Africa." Current Opinion in Environmental Sustainability **6**(1): 162-170.
Mercer, D. E. (2004). "Adoption of agroforestry innovations in the tropics: A review." Agroforestry Systems **61-62**(1-3): 311-328.
Minang, P. A., L. A. Duguma, et al. (2014). "Prospects for agroforestry in REDD+ landscapes in Africa." Current Opinion in Environmental Sustainability **6**(1): 78-82.
Morgan, S. L. and D. J. Harding (2006). "Matching estimators of causal effects - Prospects and pitfalls in theory and practice." Sociological Methods & Research **35**(1): 3-60.
Morgan, S. L. and C. Winship (2007). Counterfactuals and Causal Inference: methods and Principles for Social Research. New York, Cambridge University Press.
Müller, C., W. Cramer, et al. (2011). "Climate change risks for African agriculture." Proceedings of the National Academy of Sciences of the United States of America **108**(11): 4313-4315.
Palm, C. A., S. M. Smukler, et al. (2010). "Identifying potential synergies and trade-offs for meeting food security and climate change objectives in sub-Saharan Africa." Proceedings of the National Academy of Sciences of the United States of America **107**(46): 19661-19666.
Pattanayak, S. K., D. E. Mercer, et al. (2003). "Taking stock of agroforestry adoption studies." Agroforestry Systems **57**(3): 173-186.
Place, F. (2009). "Land Tenure and Agricultural Productivity in Africa: A Comparative Analysis of the Economics Literature and Recent Policy Strategies and Reforms." World Development **37**(8): 1326-1336.
Place, F. and K. Otsuka (2001). "Tenure, agricultural investment, and productivity in the customary tenure sector of Malawi." Economic Development and Cultural Change **50**(1): 77-99.
Rabe-Hesketh, S. and A. Skrondal (2012). Multilevel and Longitudinal Modeling Using Stata (Third Edition). College Station, TX, Stata Press.
Ravallion, M. (2009). "Evaluation in the practice of development." World Bank Research Observer **24**(1): 29-53.

Rubin, D. B. (2007). "The design versus the analysis of observational studies for causal effects: Parallels with the design of randomized trials." Statistics in Medicine **26**(1): 20-36.
Schoneveld, G. C. (2014). "The geographic and sectoral patterns of large-scale farmland investments in sub-Saharan Africa." Food Policy **48**: 34-50.
Schoneveld, G. C. and L. German (2014). "Translating Legal Rights into Tenure Security: Lessons from the New Commercial Pressures on Land in Ghana." Journal of Development Studies **50**(2): 187-203.
Sileshi, G., F. K. Akinnifesi, et al. (2010). "Variation in maize yield gaps with plant nutrient inputs, soil type and climate across sub-Saharan Africa." Field Crops Research **116**(1-2): 1-13.
Sirrine, D., C. Shennan, et al. (2010). "Comparing agroforestry systems' ex ante adoption potential and ex post adoption: On-farm participatory research from southern Malawi." Agroforestry Systems **79**(2): 253-266.
Sitko, N. J. and T. S. Jayne (2014). "Structural transformation or elite land capture? The growth of "emergent" farmers in Zambia." Food Policy **48**: 194-202.
Stuart, E. A. (2010). "Matching methods for causal inference: A review and a look forward." Statistical Science **25**(1): 1-21.
Verchot, L. V., M. Van Noordwijk, et al. (2007). "Climate change: Linking adaptation and mitigation through agroforestry." Mitigation and Adaptation Strategies for Global Change **12**(5): 901-918.
Wily, L. A. (2011). "'The Law is to Blame': The Vulnerable Status of Common Property Rights in Sub-Saharan Africa." Development and Change **42**(3): 733-757.
Xu, Z., Z. Guan, et al. (2009). "Factors influencing the profitability of fertilizer use on maize in Zambia." Agricultural Economics **40**(4): 437-446.