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Does Integrated Soil Fertility Management increase returns to land and labor? Plot-level evidence from Ethiopia

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Abstract

Integrated Soil Fertility Management (ISFM) is widely promoted to enhance soil fertility, yields and livelihoods among smallholders, and ultimately combat environmental degradation. Its core is the combined use of organic and inorganic fertilizers with improved crop varieties. Yet, farmers face adoption barriers, such as additional monetary and labor investments. To date, much of the evidence on ISFM effects comes from experimental field trials instead of micro-level farmer data. In particular, studies on labor outcomes are scarce, but important to assess the viability of ISFM in smallholder settings. This study addresses this gap by providing a comprehensive analysis of ISFM effects on land productivity, net crop value, labor demand, labor productivity and returns to unpaid labor using survey data from over 6,000 teff, maize and wheat plots and 2,000 households in Ethiopia. We employ a multinomial endogenous switching model to account for endogeneity from observed and unobserved heterogeneity. We find that both partial and complete ISFM adoption lead to significant increases in land productivity and net crop value, in particular when improved seeds are used. In moister regions, complementing improved varieties with inorganic fertilizer seems most important, while in drier regions, enhancing it with organic fertilizer appears crucial. ISFM is related to higher labor demand, but also significantly increases labor productivity and financial returns to labor. These findings imply that ISFM can contribute to improve farmers' livelihoods by breaking the nexus between low productivity, environmental degradation and poverty.

Key words: Technology adoption, land productivity, labor productivity, crop value, agroecological heterogeneity, multinomial endogenous switching

JEL codes: J23, J24, O 13, O 33, Q 16

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1. Introduction

Achieving stable food security is still one of the major challenges the global community has to face, even more in the light of on-going population growth, projected to be particularly strong in Sub-Saharan Africa (SSA) (UN, 2017). However, agricultural productivity in many African countries remains low and agricultural growth in the past was often attributed to an expansion in area rather than an intensification of production, resulting in severe threats for ecosystems and a depletion of the natural resource base. Climate change and increasing competition for land further exacerbate the pressure on the environment as well as on food systems, and call for strategies that increase food production in a sustainable way on the same (or even smaller) area of land (Godfray, 2010). One of the major bottlenecks to a sustainable intensification of agricultural productivity is the high level of land degradation, mainly caused by excessive deforestation and unsuitable agricultural practices (Barrow, 1991). Land degradation commonly goes along with a loss in soil fertility, resulting in yield deficits which are particularly threatening to the livelihoods of rural communities in developing countries (Barrow, 1991).

Both land degradation and low soil fertility can be causes of self-reinforcing negative feedback loops for the rural poor (Barbier & Hochard, 2018; Barrett & Bevis, 2015). Studies show that high levels of degradation are likely to decrease agricultural labor productivity; as coping mechanisms, farm households try to farm their land even harder, or increasingly capitalize nearby natural resources, which over time aggravates environmental deterioration (Barbier & Hochard, 2018). Along the same lines, low initial soil fertility has been shown to prevent farmers from investing in an improvement of the soil's productive capacity, which may lead to a steady decrease of both land and labor productivity. Hence, strategies to overcome these downward spirals of land degradation, poor soil fertility and low land as well as labor productivity are urgently needed.

The concept of 'Integrated Soil Fertility Management' (ISFM) is a system technology that has been promoted by governments and donors in SSA to tackle soil degradation and improve productivity and livelihoods among smallholder farmers. ISFM consists of a set of soil fertility practices including the integrated application of inorganic and organic fertilizers and the use of improved seeds, coupled with the knowledge on how to adapt these practices to a specific local context (Vanlauwe et al., 2010). Hence, it is important to understand ISFM as a site-specific concept that may vary according to local conditions, for instance with respect to locally available organic materials, water-harvesting practices or measures to correct soil acidity (Vanlauwe et al., 2015). Additionally, ISFM aims at a general improvement of agronomic techniques, like targeted application of seeds and fertilizers, and the complementary use of practices such as cereal-legume intercropping, reduced tillage, or agroforestry (Place et al., 2003). Yet, the use of ISFM is still limited since smallholder farmers face a series of barriers to adoption. Apart from knowledge constraints, ISFM involves substantial up-front investments of labor and capital (Hörner et al., 2019; Jayne et al., 2019; Takahashi et al., 2019).

The positive effects of ISFM on soil fertility and yields are well documented by a comprehensive series of studies using experimental field trials (Agegnehu et al., 2016; Bationo et al., 2012; Gnahoua et al., 2017; Nezomba et al., 2015; Tabo et al., 2007; Vanlauwe et al., 2012; Zingore et al., 2008). However, in most of these cases, field trials are managed according to best practices in terms of input quantities, timing and agronomic management (Jayne et al., 2019), while studies on combinations of key ISFM practices using micro-level data from farmer surveys are scarce (with the exception of Adolwa et al. (2019)).

A well-established body of literature deals with plot- or household level effects of green-revolution, sustainable agricultural intensification or soil conservation practices on crop output, income or similar measures, mostly using matching or switching techniques to tackle endogeneity (e.g. Abro et al., 2017, 2018; Barrett et al., 2004; Di Falco et al., 2011; Jaleta et al., 2016; Kassie et al., 2008, 2010, 2015; Khonje et al., 2015, 2018; Manda et al., 2016, 2018; Noltze et al., 2013; Takahashi & Barrett, 2014; Teklewold et al., 2013). Some of these studies analyze combinations of practices that can be classified as part of ISFM, e.g. legume intercropping, conservation tillage and improved varieties in Teklewold et al. (2013), Kassie et al. (2015) or Arslan et al. (2015). There are also studies specifically analyzing the effects of organic and inorganic fertilizers. For instance, Kassie et al. (2009) show that both chemical fertilizer as well as compost lead to yield gains for major cereal crops in semi-arid areas of Ethiopia, but the effect of compost outperforms that of inorganic fertilizer and is consequently more profitable for farmers, although the authors do not analyze their joint use. Similarly, Asfaw et al. (2016) find that both inorganic fertilizer and improved seeds, as well as organic fertilizer go along with increased crop productivity and income in Niger, but do also not estimate the joint effect of all practices. In general, few studies look into the combined impact of inorganic and organic fertilizers with improved seeds, the core concept of ISFM. Interestingly, Wainaina et al. (2018) find that improved seeds coupled with chemical fertilizer have no significant effect on income among Kenyan maize farmers, nor is there an effect when the package is enhanced by organic manure. Yet, when improved varieties are combined with organic manure only, income effects are positive, and even more so when the two technologies are complemented by reduced tillage. One study by Adolwa et al. (2019) explicitly assesses the effect of ISFM on maize yields among farmers in two regions in Ghana and Kenya. They find positive effects of partial or full ISFM adoption on crop yields, albeit increasing the number of adopted ISFM components does not further enhance yields. However, the authors do not analyze interactions of particular ISFM practices, but only look at partial or complete adoption in terms of number of components, nor do they analyze effects on labor outcomes.

As Takahashi et al. (2019) conclude in their recent review article, to date evidence on ISFM is mostly limited to its effects on yields or, at best, income. By contrast, studies looking into other outcomes, in particular the returns to unpaid family, labor are scarce. This is problematic considering that ISFM is often linked to higher labor investments, which are mostly covered by unpaid household labor and not accounted for in traditional outcome measures. Hence, it remains unclear whether yield benefits make up for additional labor input and thus, whether ISFM overall is a profitable technology.

This study aims at filling this gap by providing comprehensive evidence on the effects of ISFM in resource-constrained smallholder settings. We assess plot-level effects of organic fertilizer, inorganic fertilizer, improved seeds and combinations thereof on land productivity and net crop value as well as labor demand, labor productivity and financial returns to unpaid labor. To do so, we use survey data from 2,040 households and 6,247 maize, wheat and teff[1] plots in the Ethiopian highlands. We employ a multinomial endogenous switching model to address issues of self-selection stemming from different technology choices. We differ from previous studies mainly by assessing effects of distinct combinations of ISFM practices and looking into a broader range of outcome indicators. To the best of our knowledge, no study has yet addressed labor demand, labor productivity and financial returns to labor in the context of ISFM adoption. Finally, since previous studies point towards the importance of accounting for differences in climatic, soil and other conditions (Adolwa et al., 2019; Jayne et al., 2019; Kassie et al., 2008, 2010; Marenya & Barrett, 2009), we look into heterogeneous treatment effects for two different agroecological zones.

The remainder of this article proceeds as follows: The next section outlines the ISFM concept and its potential effects on yields and labor in more detail. Subsequently, we describe the study context and data used for analysis as well as our estimation framework, followed by the empirical results. The last section discusses findings and draws conclusions.

[1] Teff is a small cereal grain (annual grass) originating from the Northern Ethiopian highlands. While it is hardly grown in other parts of the world, it presents a major staple in Ethiopian and Eritrean diets (Baye, 2010).

2. The concept and implications of ISFM

The first core ISFM principle – the combined use of organic and inorganic fertilizers – is based on several arguments. Firstly, in many smallholder environments, neither of the two is available or affordable in adequate quantities. Secondly and more importantly, both sources comprise different sets of nutrients and/or carbon, which consequently address different soil fertility constraints in a complementary manner. Organic inputs alone, when applied at realistic levels, are unlikely to release enough nutrients to raise yield levels sufficiently on depleted African soils (Vanlauwe et al., 2010, 2015). On the other hand, marginal productivity of inorganic fertilizers, i.e. the additional crop yield per unit of fertilizer applied, is often substantially reduced on degraded soils that exhibit low levels of soil organic matter (SOM), low soil moisture, or high deficiencies of other yield-limiting nutrients (Barrett & Bevis, 2015; Jayne et al., 2019; Place et al., 2003; Vanlauwe et al., 2015). More precisely, both soil moisture as well as SOM levels – the latter closely linked to soil carbon stocks – regulate the solubility and hence, the availability of added inorganic nutrients for plant uptake. Recycling organic resources presents a strategy to improve SOM levels in the medium to long term, conserve soil moisture and supply additional nutrients, which can substantially increase the soil's responsiveness to chemical fertilizers (Marenya & Barrett, 2009). Efficient use of inorganic fertilizers, in turn, can itself contribute to increasing the availability of organic materials and consequently, building organic matter through enhanced on-farm biomass production (Vanlauwe et al., 2013). Hence, the ISFM concept goes beyond substitution effects, but claims substantial positive interactions and complementarities between inorganic and organic nutrient sources with the potential to increase crop productivity and long-term soil health (Place et al., 2003).

In terms of local adaptation of inorganic nutrient application, Vanlauwe et al. (2015) argue that crop response to fertilizers is often suboptimal, as many inorganic fertilizers are not suited to specific nutrient deficiencies prevailing in an area. In fact, the most commonly applied fertilizers used in SSA consist of the macronutrients nitrogen (N), phosphorus (P) or potassium (K), which fail to replenish secondary or micronutrients, such as sulfur (S), boron (B), calcium (Ca), zinc (Zn), or iron (Fe), that are particularly often lacking in densely populated areas where fallow periods are insufficient (Chianu et al., 2012; Vanlauwe et al., 2015). Hence, enriching standard fertilizers with locally deficient nutrients is important to increase their yield response.

The second core principle of ISFM is the use of crop varieties with locally required improved traits, such as higher-yielding, drought- or disease tolerant seeds, to ensure adequate matching of nutrient supply with demand, higher resilience to shocks, and increased production potential (Vanlauwe et al. 2015). Improved crop varieties are seen as key technology for boosting agricultural productivity and have proven positive effects on crop yields and welfare in numerous studies (Takahashi et al., 2019), but need to go along with adequate soil management strategies to deploy their full productivity-enhancing potential (Sanchez, 2002).

Building on these theoretical ISFM premises, we expect that the use of ISFM practices will lead to enhanced land productivity. In particular, we hypothesize that the full integrated package will have the strongest effect due to the synergistic potential of organic fertilizer, inorganic fertilizer and improved seeds. Yet, for smallholder farmers, the application of ISFM may involve substantial opportunity costs in terms of financial resources, such as for the purchase of improved seeds and mineral fertilizers, and in terms of time, since in particular the preparation and transportation of bulky organic fertilizers and the targeted application of inputs are labor-intensive activities (Jayne et al., 2019; Takahashi et al., 2019). We therefore expect ISFM adoption to increase labor demand. Furthermore, the effects on net crop value as well as on labor productivity and returns to unpaid labor are ambiguous, as they depend on whether increased land productivity makes up for higher input costs and labor demand.

3. Materials and methods

3.1 Study area and context

Around three-fourths of the Ethiopian population reside in rural areas and depend on agriculture as their main livelihood (CIA, 2020). Three cereal crops – maize, wheat and teff – make up for over half of the country's cultivated area and represent main staples in rural diets, but agricultural productivity remains comparatively low with average cereal yields of below 2.5 metric tons per hectare (CSA, 2019; FAO, 2020). In addition, over a quarter of the rural population lives below the national poverty line (FAO, 2020). Despite considerable prevention efforts, land degradation and declining soil fertility are still among the most severe threats to the Ethiopian agricultural sector and the livelihoods of smallholder farmers (Nyssen et al., 2015).

In order to combat environmental degradation, low agricultural productivity and rural poverty, the Ethiopian government, in cooperation with international donor agencies, has implemented a large-scale campaign to prevent further erosion and restore natural resources in large parts of the country's highland area over the past three decades (Schmidt & Tadesse, 2019). The core of the 'Sustainable Land Management Programme' (SLMP) was the stabilization of hillsides through physical soil conservation measures. Building on the SLMP achievements, the main focus has now been shifted to the intensification of smallholder farming practices. In 2017, ISFM has been integrated into the 'Ethiopian Soil Health and Fertility Improvement Strategy' (MoANR, 2017).

Against this background, in mid-2015 the German Agency for International Cooperation (GIZ) launched the 'Integrated Soil Fertility Management Project' (ISFM+ project) in areas where erosion control measures had already been introduced via the SLMP. The project's main goal is the promotion of ISFM practices among small-scale farmers, in particular for the three main staples wheat, maize and teff. It is implemented in close cooperation with the Ethiopian Ministry of Agriculture and Natural Resources, local extension staff, and farmers themselves via a community-based participatory extension strategy (Hörner et al., 2019). The ISFM+ project operates in 18 districts (in Ethiopia called Woredas) in the three Ethiopian highland regions Amhara, Oromia and Tigray.

Woredas within the three regions differ along agroecological characteristics. In terms of altitude, they cover the 'wenya dega' (1500 to 2,300 m a.s.l.) as well as 'dega' zones (over 2,300 to 3,200 m a.s.l.). In terms of rainfall, all districts in Tigray are classified as dry (less than 900 mm of annual rainfall), while those in Amhara and Oromia cover moist (over 900 to 1,400 mm) and wet (over 1,400 mm) zones, pointing towards substantial agroecological heterogeneity (Hurni, 1998).[2]

3.2 Sampling and data collection

We base our analysis on primary data from households residing in ISFM+ project Woredas. In order to rigorously assess the project's effectiveness in inducing ISFM adoption, the extension interventions have been implemented as a randomized controlled trial (RCT) (Hörner et al., 2019). Since the interventions were implemented in a community-based way, the primary randomization units of the RCT were microwatersheds, which are typical implementation entities for natural resource related projects in Ethiopia. Microwatersheds are water catchment areas, usually comprising 200 to 300 households in one or more villages that share a common rainwater outlet. In each of the three regions, six Woredas were selected, and within each Woreda, four treatment microwatersheds were randomly assigned. Furthermore, a total of 89 microwatersheds in the same Woredas did not receive any intervention and thus, serve as control microwatersheds. In each of the 161 microwatersheds, approximately 15 households were then randomly chosen from administrative lists to be included in the sample. While the total sample

[2] The average altitude of our study districts in Amhara is 2,450 m a.s.l., the average annual rainfall is 1,229 mm; in Oromia: 1,992 m a.s.l and 1,426 mm; and in Tigray: 2,130 m a.s.l and 661 mm.

consists of 2,382 farm households, we restrict our analysis to those farmers that grow maize, wheat or teff on at least one of their plots, leading to a sample of 6,247 plots managed by 2,040 farm households.

We conduct our empirical analyses using the RCT endline data collected in treatment and control microwatersheds. Data were gathered in the first half of 2018 using tablet-based structured questionnaires. Amongst others, we collected detailed plot-level data on agricultural technology adoption, labor input and crop output in retrospective for the 2017 main cropping season. In addition, community-level data was assessed during interviews with key informants at the Woreda and microwatershed levels.

3.3 Description of treatment variable

Our treatment variable of interest is the adoption of ISFM practices. We focus on the three core practices of ISFM, i.e. the use of organic and inorganic fertilizers as well as improved varieties.[3] To account for differences in locally available resources, organic fertilizer refers to having applied either animal manure, compost, mulching or green manuring on a plot. Regarding inorganic fertilizer, the most common compound fertilizer types used in our sample are NPS fertilizers (in few cases NPK), mostly enriched with one or several locally deficient nutrients such as boron, zinc or iron.[4] These locally adapted 'blended fertilizers' have mostly replaced Diammonium-Phosphate (DAP), previously used as main compound fertilizer (ATA, 2019).[5] Improved seeds refer to higher-yielding open-pollinated (wheat and teff) or hybrid (maize) varieties, which in some cases also carry improved traits regarding disease (mostly wheat) or drought resistance (mostly maize). As we are particularly interested in the combined effects, we account for six possible practices and packages farmers can choose from: organic fertilizer only (OF), inorganic fertilizer only (IF), organic and inorganic fertilizers jointly (OF + IF)[6], organic fertilizer plus improved seeds but no inorganic fertilizer (OF + IS), inorganic fertilizer plus improved seeds but no organic fertilizer (IF + IS), and the full ISFM package (OF + IF + IS).[7]

[3] We leave aside additional, locally-varying components of ISFM in order to reduce the number of possible combinations of practices and hence, reduce analytical complexity to a reasonable level.

[4] In our definition of inorganic fertilizers, we refer to these 'compound' fertilizers which supply at least three key nutrients, as opposed to so-called 'straight' fertilizers containing only one nutrient type, such as Urea.

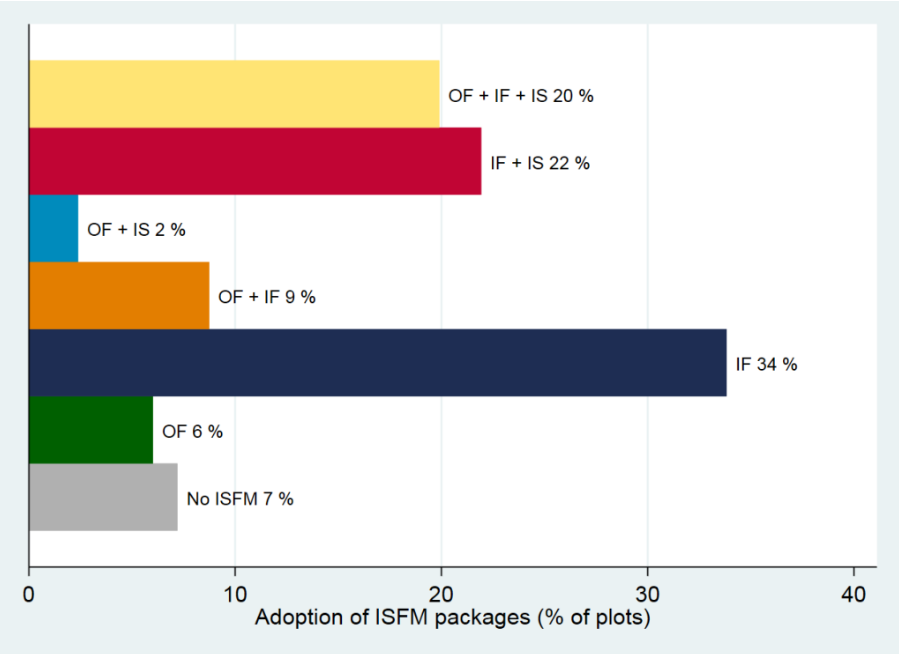
[5] In Ethiopia, the predominant belief in the past was that DAP supplemented by Urea fertilizer supply all necessary nutrients, resulting in blanket recommendations for the whole country. With the introduction of the 'Ethiopian Soil Information System' in 2012, currently the whole country is being mapped with regards to local availability and deficiencies of soil nutrients, which has led to area-specific fertilizer recommendations (ATA, 2019).

[6] In options one to three, OF, IF or OF + IF are coupled with the use of local landraces instead of improved seeds.

[7] We exclude plots on which only improved seeds were used, i.e. without organic or inorganic fertilizer, which is the case on only 58 plots. This small sub-sample size results problematic for econometric estimations, in particular that of heterogeneous treatment effects.

Figure 1 depicts the distribution of our treatment variable, the partial or complete adoption of the ISFM package. On around 7% of plots, none of the three technologies is used, while on about 6% respectively 9%, organic fertilizer is used solely (OF) or in combination with inorganic fertilizer (OF + IF). The most common practice is inorganic fertilizer, which is used in isolation (IF) on 34% of all fields. The least common combination of practices is OF + IS, applied on only 2% of plots, while farmers supplement improved seeds with inorganic fertilizer only (IF + IS) on 22% of their fields. The full ISFM package (OF + IF + IS) is used on 20% of maize, wheat and teff plots. These results confirm findings by Lambrecht et al. (2015): while farmers indeed engage in ISFM activities, adoption of components occurs rather sequentially than simultaneously, and large-scale complete adoption is yet to be attained.

Figure 1. Adoption of ISFM packages at the plot level.



Note: OF stands for organic fertilizer only, IF for inorganic fertilizer only, IS for improved seeds, while + indicates joint adoption of components.

3.4 Description of outcome variables

Our first core outcome variable is *land productivity*, measured as crop output in kilogram per hectare (kg/ha) over the three main cereal crops maize, wheat and teff.[8] Secondly, we assess the effects of ISFM adoption on profitability, defined as *net crop value* in Ethiopian Birr per hectare (ETB/ha). To do so, we calculate the monetary value of farmers' crop produce minus all costs for inputs such as seeds, fertilizers, pesticides and costs for hired labor. Since input and output prices vary between study districts, we use price information obtained at the Woreda

[8] In order to obtain more accurate data, we assessed this information using a broad range of local measurement units for both land area and yield quantities, and then converted into standard measurement units using conversion factors acquired from key informants at the community level, as well as from the Ethiopian Central Statistical Agency.

level.[9] It is important to note that we do not study true economic profit, but rather 'quasi profits', since we do not value owned land, equipment or household labor monetarily. *Labor demand* was assessed in detail by asking respondents which household member and how many hired or exchange laborers had been involved in farming activities during each of the following cropping stages: land preparation and sowing, 'general cultivation' (includes e.g. weeding, application of most inputs), and harvesting and threshing. Following Di Falco et al. (2011), we convert labor input into adult male equivalents with the factors 0.8 for adult females and 0.3 for children. Assuming one labor-day has about seven hours, we calculate labor demand in labor-days per hectare (labor-days/ha). Next, we are interested in effects on *labor productivity*, which describes the amount of crop output in kilogram produced per labor-day (kg/labor-day). Ultimately, we calculate the *returns to unpaid labor*[10] in Ethiopian Birr per labor-day (ETB/labor-day). Table 1 provides descriptive statistics of all outcome variables. In addition to full sample statistics, we distinguish between those plots on which the full package (OF + IF + IS) is used and those on which ISFM is only partially or not at all applied.

Table 1. Descriptive statistics of all outcome variables.

	Not adopted complete ISFM		Adopted complete ISFM			Full sample	
Outcome variables	Mean	SD	Mean	SD	p	Mean	SD
Land productivity (kg/ha)	1948.35	1648.89	3092.43	2035.11	0.000	2175.99	1791.64
Land productivity maize (kg/ha)	2914.05	2149.41	3514.53	2193.36	0.000	3146.82	2185.69
Land productivity wheat (kg/ha)	2432.35	1541.14	2544.20	1503.52	0.224	2455.83	1533.55
Land productivity teff (kg/ha)	1188.78	865.38	1701.50	1062.15	0.000	1209.24	879.57
Net crop value (ETB/ha)	17598.05	13939.66	18635.12	14299.35	0.020	17804.40	14016.92
Labor demand (labor-days/ha)	139.38	68.24	169.23	80.65	0.000	145.32	71.87
Labor productivity (kg/labor-day)	15.49	13.68	20.16	13.23	0.000	16.41	13.72
Returns to unpaid labor (ETB/labor-day)	151.87	186.55	133.56	125.52	0.001	148.24	176.26
N	5,004		1,243			6,247	

Note: SD stands for standard deviation. Exchange rate during survey period: 1 US-$ ~ 27 ETB; p-value indicates statistical significance of differences in means between those who adopt complete ISFM and those who do not.

3.5 Econometric framework

When modelling the effects of adoption of a certain technology (package) on outcomes of interest, one has to deal with potential endogeneity stemming from farmers' self-selection into different plot management regimes. Farmers' choice of technology might be influenced by both observed and unobserved factors, which at the same time may be correlated with outcomes such as yields or labor input. In order to address these issues and to disentangle the effects of ISFM

[9] Regarding wages for hired laborers, we follow Vandercasteelen et al. (2016) and use average daily wage rates for each production activity over all microwatersheds in a Woreda.

[10] Including household and non-monetarily rewarded labor from outside the household.

adoption, we follow Teklewold et al. (2013) and Kassie et al. (2015) and employ a multinomial endogenous switching regression model (MESR). This approach allows for the modelling of alternative choices of technologies and their combinations, and thus, allows capturing interactions between different options in the selection process (Mansur et al., 2008; Wu & Babcock, 1998).[11]

The MESR entails a two-step simultaneous estimation procedure. The first stage estimates farmers' selection of alternative ISFM technologies (and their combinations) using a multinomial logit model which accounts for inter-relationships between alternatives. In the second stage, effects of the individual or combined ISFM practices on land productivity, net crop value as well as on labor demand, labor productivity and returns to labor are estimated via ordinary least squares (OLS), including selectivity correction terms obtained from the first stage.

3.5.1 Multinomial selection model

The analysis takes place at the plot level. Farmers are assumed to adopt a package of ISFM practices that maximizes their utility over all alternative combinations. We consider a latent model for the unobserved expected utility U_{jik}^* that farmer *i* derives from adopting ISFM combination *j* (with *j = 1, 2, ..., 7*) on plot *k* (Kassie et al., 2015; Teklewold et al., 2013):

$$U_{jik}^* = \beta_j X_{jik} + \varepsilon_{jik} \tag{1}$$

in which X_{jik} is a vector of observed household, plot and location characteristics, while ε_{jik} are unobserved factors. While farmers' utility is not observable, their adoption decision *I* is. A rational farmer is expected to choose technology *j*, and not any alternative combination *m*, if:

$$I = \begin{cases} 1\ if U_{1ik}^* > max_{m \neq 1}(U_{mik}^*)\ or\ \eta_{1ik} < 0 \\ \vdots \qquad\qquad \vdots \qquad\qquad \vdots \\ J\ if U_{Jik}^* > max_{m \neq J}(U_{mik}^*)\ or\ \eta_{Jik} < 0 \end{cases} \quad for\ all\ m \neq j \tag{2}$$

with $\eta_{jik} = max_{m \neq j}\left(U_{mik}^* - U_{jik}^*\right) < 0$, which implies that the ith farmer will adopt ISFM combination *j* on plot *k* if it provides greater expected utility than any alternative *m* (Bourguignon et al., 2007).

[11] Bourguignon et al. (2007) show that the model provides a fairly good correction for endogeneity in the outcome equation even if the independence of irrelevant alternatives (IIA) assumption is violated in the selection process.

Assuming an independent and identical Gumbel distribution of ε, the probability that farmer i with characteristics X adopts technology package j on plot k is expressed by a multinomial logit model, which is estimated using maximum likelihood (McFadden, 1973).

$$P_{jik} = Pr(\eta_{jik} < 0 | X_{jik}) = \frac{exp(\beta_j X_{jik})}{\sum_{m \neq 1}^{J} exp(\beta_m X_{jik})} \quad (3)$$

3.5.2 Multinomial endogenous switching model

In the second stage, the relation between the outcome variables and a set of explanatory variables Z is estimated for each of the ISFM choices, i.e. OF *(j = 2)*, IF *(j = 3)*, OF + IF *(j = 4)*, OF + IS *(j = 5)*, IF + IS *(j = 6)* and OF + IF + IS *(j = 7)*, in which *j = 1* (no ISFM) is the reference category. For all outcomes Q, the equations for each possible adoption regime j is given as follows:

$$\begin{cases} Regime\ 1: Q_{1ik} = \alpha_1 Z_{1ik} + u_{1ik} & if\ I = 1 \\ \quad\vdots \qquad\qquad \vdots & j = 2, 3, 4, 5, 6, 7 \\ Regime\ J: Q_{Jik} = \alpha_J Z_{Jik} + u_{Jik} & if\ I = J \end{cases} \quad (4)$$

in which Q_{jik} denotes the outcome of farmer i on plot k in regime j, and u_{jik} the error terms distributed with $E(u_{jik}|XZ) = 0$ and $var(u_{jik}|XZ) = \sigma^2$. Q_{jik} is only observed if package j is used on plot k. If the error terms u are correlated with those from the first stage ε, OLS estimates in equation (4) are likely to be biased. In order to obtain consistent estimates of α_j, we have to augment outcome equations (4) by including selection correction terms (Bourguignon et al. 2007):

$$\begin{cases} Regime\ 1: Q_{1ik} = \alpha_1 Z_{1ik} + \sigma_1 \hat{\lambda}_{1ik} + \omega_{1ik} & if\ I = 1 \\ \quad\vdots \qquad\qquad \vdots \qquad\qquad \vdots & \\ Regime\ J: Q_{Jik} = \alpha_J Z_{Jik} + \sigma_J \hat{\lambda}_{Jik} + \omega_{Jik} & if\ I = J \end{cases} \quad (5)$$

where ω_{jik} is the error term with an expected value of zero, σ_j the covariance of the ε*'s* and *u's*, and λ_j the inverse Mills ratio computed from the estimated probabilities in (3) as:

$$\lambda_{jik} = \sum_{m \neq j}^{J} \rho_j \left[\frac{\hat{P}_{mik} ln(\hat{P}_{mik})}{1 - \hat{P}_{mik}} + ln(\hat{P}_{jik}) \right] \quad (6)$$

with ρ_j denoting the correlation coefficients of ε and u. In this multinomial choice framework, *J-1* selection correction terms have to be included, i.e. one for each alternative technology choice. In order to account for heteroscedasticity arising from the generation process of λ, standard errors are bootstrapped.

We base the empirical specification of the variables included in X and Z on previous theoretical and empirical adoption literature (e.g. Kassie et al., 2009, 2015; Khonje et al., 2018; Knowler & Bradshaw, 2007; Marenya & Barrett, 2009; Teklewold et al., 2013, 2019; Wollni et al., 2010). Table 2 provides an overview of all plot and household-level characteristics included in the models as explanatory variables. In addition, we include total labor use in the models for land productivity and net crop value.

For the model to be identified correctly, it is important to use at least one selection instrument, i.e. a variable that directly affects the adoption decision, but not the outcome variables (except via adoption). This instrumental variable is included in X, but not in the Z variables. Building on the RCT design, we employ the random assignment to the ISFM+ project interventions as an instrument, which fulfils the necessary properties of a valid instrumental variable (Angrist et al., 1996). Firstly, exposure to the treatment is random, which is satisfied given the experimental set-up. Secondly, exposure to the treatment indeed influences the uptake of ISFM practices. And finally, outcomes are not directly affected by the random assignment to the ISFM+ project interventions, but only through ISFM adoption. Tables A1 and A2 in the Appendix confirm that these assumptions hold in the empirical case, as living in an ISFM+ community significantly influences ISFM uptake, while it does not affect any of the outcome variables beyond ISFM adoption.

3.5.3 Estimating average treatment effects

Finally, the above described estimation procedure is used to compute the average treatment effects on the treated (ATT), hence, the expected effects of applying a certain ISFM package on a plot. To do so, one has to obtain a valid counterfactual, i.e. the outcome a farmer would obtain on an ISFM plot, assuming she or he had not adopted any ISFM practice. Following a well-established approach in the impact literature (e.g. Di Falco et al., 2011; Kassie et al., 2015; Teklewold et al., 2013), we estimate actual and counterfactual cases as follows:

Adopters with adoption (observed in sample)

$$E\left(Q_{jik} \middle| I = j\right) = \alpha_j Z_{jik} + \sigma_j \hat{\lambda}_{jik} \tag{7}$$

Non-adopters with non-adoption (observed in sample)

$$E(Q_{1ik} | I = 1) = \alpha_1 Z_{1ik} + \sigma_1 \hat{\lambda}_{1ik} \tag{8}$$

Adopters with non-adoption (counterfactual)

$$E(Q_{1ik} | I = j) = \alpha_1 Z_{jik} + \sigma_1 \hat{\lambda}_{jik} \tag{9}$$

Non-adopters with adoption (counterfactual)

$$E(Q_{jik}|I=1) = \alpha_j Z_{1ik} + \sigma_j \hat{\lambda}_{1ik} \tag{10}$$

Equations (7) and (8) model the actual expected outcomes for ISFM adopters and non-adopters, respectively, which are observed in the data. By contrast, equations (9) and (10) represent the counterfactual outcomes; that is, the outcomes that adopters would achieve without adoption, and that non-adopters would achieve under adoption. The ATT is calculated as the difference between equations (7) and (9):

$$ATT = E(Q_{jik}|I=j) - E(Q_{1ik}|I=j) = Z_{jik}(\alpha_j - \alpha_1) + \hat{\lambda}_{jik}(\sigma_j - \sigma_1) \tag{11}$$

The first term (Z_{jik}) on the right-hand side of equation (11) models the expected change in adopters' mean outcomes assuming their characteristics and endowments had the same returns as those of non-adopters, while the second term $(\hat{\lambda}_{jik})$ corrects for selection bias originating from unobserved factors.

Table 2. Descriptive statistics of all explanatory variables used in analysis.

	Not adopted complete ISFM		Adopted complete ISFM			Full sample	
	Mean	SD	Mean	SD	p	Mean	SD
Panel A: Household characteristics							
Gender HH head (1 = male)	0.86		0.90		0.002	0.88	
Age HH head (in years)	48.84	14.29	47.51	13.35	0.031	48.21	13.87
HH head has formal education (1 = yes)	0.39		0.42		0.191	0.40	
No. of HH members	5.26	2.03	5.31	1.81	0.541	5.28	1.93
No. of TLU owned	3.57	3.01	4.50	3.02	0.000	4.01	3.05
Farm size (in ha)	1.36	1.07	1.38	0.95	0.743	1.37	1.02
HH has access to formal credit (1 = yes)	0.59		0.63		0.050	0.61	
No. of social organizations HH is involved	3.20	1.92	3.68	1.91	0.000	3.43	1.93
Talked to extension agent (1 = yes)	0.49		0.67		0.000	0.58	
Walking distance to nearest FTC (in min)	33.24	25.57	31.04	23.65	0.044	32.20	24.71
Walking distance to nearest village market (in min)	75.31	49.85	67.03	43.13	0.000	71.42	46.99
Agri-input dealer in Kebele (1 = yes)	0.60		0.63		0.194	0.62	
HH lives in ISFM+ community (1 = yes)	0.42		0.54		0.000	0.48	
Pest and disease stress (1 = yes)	0.12		0.11		0.858	0.12	
Weather stress (drought/flood/frost/storm) (1 = yes)	0.35		0.28		0.001	0.32	
Average annual rainfall (in mm)	1054.63	457.96	1203.19	361.75	0.000	1124.40	422.03
N	1,082		958			2,040	
Panel B: Plot characteristics							
Plot distance from homestead (in min)	14.92	22.15	4.91	11.20	0.000	12.93	20.83
Plot owned (1 = yes)	0.68		0.83		0.000	0.71	
Plot size (in ha)	0.24	0.21	0.20	0.18	0.000	0.23	0.20
Footslope (1 = yes)	0.46		0.46		0.873	0.46	
Hillslope (1 = yes)	0.13		0.11		0.065	0.12	
Shallow soil (1 = yes)	0.21		0.16		0.000	0.20	
Deep soil (1 = yes)	0.52		0.60		0.000	0.53	
Poor soil quality (1 = yes)	0.26		0.14		0.000	0.23	
Good soil quality (1 = yes)	0.36		0.49		0.000	0.38	
Herbicide used (1 = yes)	0.33		0.09		0.000	0.28	
Pesticide used (1 = yes)	0.13		0.17		0.000	0.14	
Lime used (1 = yes)	0.02		0.11		0.000	0.04	
Urea used (1 = yes)	0.68		0.93		0.000	0.73	
Maize plot (1 = yes)	0.25		0.64		0.000	0.33	
Wheat plot (1 = yes)	0.26		0.28		0.190	0.27	
Teff plot (1 = yes)	0.49		0.08		0.000	0.41	
N	5,004		1,243			6,247	

Note: SD stands for standard deviation. HH stands for household; FTC stands for farmer training center; TLU stands for tropical livestock unit; Kebele is the lowest administrative unit in Ethiopia; formal credit refers to bank, microfinance institution, government or agri-input dealer; footslope/hillslope compared to midslope; shallow/deep soil compared to medium soil depth; poor soil/good soil compared to average soil quality; p-value indicates statistical significance of differences in means between those who adopt complete ISFM and those who do not.

4. Empirical results

4.1 Average treatment effects in the full sample

Table 3 depicts the average treatment effects on the treated plots for each of the six ISFM combinations.[12] Results show that, averaged over the three crop types, adoption of all individual as well as combined ISFM practices leads to increased land productivity.[13] In the case of fertilizer use without improved seeds, we find that inorganic fertilizer is associated with more pronounced yield gains than organic fertilizer when the two are applied in isolation (546 kg/ha vs. 320 kg/ha), while the ATT of their combined use is only modestly higher than that of inorganic fertilizer alone (603 kg/ha). Combining any kind of fertilizer with improved seeds increases the magnitude of the ATT substantially. This is not surprising considering that improved seeds for all crop types carry higher-yielding traits. On average, the full ISFM package leads to the highest yield effect (1,561 kg/ha). While the ATT magnitude of the combination IF + IS (1,300 kg/ha) is relatively close to that of the complete package, the package OF + IS on average leads to smaller, but still substantial effects (947 kg/ha). The treatment effects of these three packages reflect average changes in land productivity between 66% and 138% compared to the hypothetical yields that farmers would achieve under traditional farming practices (no ISFM) on the same plots.

Looking at net crop value suggests that on average, the combinations OF + IF + IS (6,995 ETB/ha) and OF + IS (6,868 ETB/ha) lead to the highest increase in profitability for farmers, followed by the IF + IS package (6,457 ETB/ha). These effects are equivalent to mean increases of 67% to 82% in comparison to the counterfactual scenarios of no ISFM on the same plots. Overall, effects of the three packages that involve improved seeds on net crop value are quite similar, despite the smaller effect of the OF + IS combination on land productivity. This is most likely the case because farmers do hardly incur expenses for organic fertilizer, which is typically sourced on-farm. In contrast, inorganic fertilizer use involves substantial monetary costs that on average do not seem to be compensated by its additional yield effect. Regarding the use of fertilizers without improved seeds, organic fertilizer alone is associated with the smallest, yet positive and significant effect on net crop value (1,851 ETB/ha), reflecting the finding that OF

[12] Since the ATT of ISFM adoption on yield- and labor-related outcomes are our primary interest in this article, we do not discuss the empirical results of the adoption and outcome equations; Tables A3 to A8 in the Appendix show estimation results of the first and second stage regressions.

[13] Small sub-sample sizes for some categories of the treatment variable do not allow separate estimations for each crop type. While averaging productivity over different crop types makes the interpretation of the absolute magnitude of results less straightforward, relative effect sizes still provide important implications. Focusing on aggregated effects for main food crops in subsistence agriculture settings, while controlling for crop types grown, is also supported by other studies (Di Falco et al., 2011; Kassie et al., 2010).

alone is related to the smallest yield increase. The use of inorganic fertilizer alone as well as combined with organic fertilizer lead to higher average effects on net crop value (4,932 ETB/ha and 3,723 ETB/ha). Hence, here it seems that the stronger effect of inorganic fertilizer on land productivity outweighs the additional expenses, compared to the use of organic fertilizer alone.

Table 3. Average ISFM adoption effects on the treated plots.

ISFM combination	Land productivity (kg/ha)			Net crop value (ETB/ha)			Labor demand (labor-days/ha)			Labor productivity (kg/labor-day)			Returns to unpaid labor (ETB/labor-day)			N
	ATT		p	ATT		p	ATT		p	ATT		p	ATT		p	
OF	320.30	(65.70)	0.000	1850.53	(494.39)	0.000	9.81	(3.19)	0.002	1.53	(0.31)	0.000	6.76	(3.44)	0.050	376
IF	545.95	(20.80)	0.000	4932.26	(213.93)	0.000	6.10	(1.00)	0.000	4.27	(0.17)	0.000	35.49	(1.69)	0.000	2,113
OF + IF	602.65	(40.03)	0.000	3722.66	(417.61)	0.000	24.21	(2.73)	0.000	3.26	(0.24)	0.000	13.96	(3.07)	0.000	546
OF + IS	947.24	(122.33)	0.000	6868.43	(850.03)	0.000	24.39	(6.10)	0.000	5.22	(0.59)	0.000	36.19	(4.24)	0.000	149
IF + IS	1299.74	(35.57)	0.000	6456.63	(245.32)	0.000	26.71	(1.34)	0.000	8.43	(0.25)	0.000	37.21	(1.91)	0.000	1,370
OF + IF + IS	1560.61	(38.66)	0.000	6995.02	(245.24)	0.000	40.38	(1.73)	0.000	8.06	(0.19)	0.000	31.56	(1.77)	0.000	1,243

Note: Exchange rate during survey period: 1 US-$ ~ 27 ETB; reduced sample size stems from logarithmic transformation of outcomes during estimation procedure; standard errors in parentheses; p-values indicate statistical significance of ATT.

As expected, using any of the ISFM practices as well as any combination thereof is associated with an increase in labor demand. On average, applying only organic fertilizer on a plot increases labor requirements by around 10 labor-days/ha, while using inorganic fertilizer leads to around 6 additional labor-days/ha. The difference in ATT magnitude between OF and IF is likely to be explained by the fact that both transportation and application of organic inputs are more cumbersome compared to inorganic fertilizers, which are applied in much lower quantities.[14] More detailed analyses reveal that increased labor demand associated with all ISFM packages that contain organic fertilizer mainly stems from the 'general cultivation' stage, i.e. the phase between planting and harvesting, in which inputs such as organic fertilizers are mainly applied (results available upon request). The use of improved seeds also seems to be associated with substantial increases in average labor demand, as suggested by the significant ATT between 24 and 40 labor-days/ha of the packages containing improved seeds (equivalent to average increases of 17% to 34% compared to the counterfactual). Contrary to our expectations, this does not primarily stem from the fact that improved seeds are mostly sown in lines, which should increase labor demand during the planting stage (compared to local seeds which are commonly broadcasted). By contrast, we find that much of this effect occurs during the stage of 'general cultivation' (results available upon request). This could indicate that farmers pay special attention to fields planted with improved seeds, e.g. they invest more time in weeding and pest control, since a loss of harvest would be costlier compared to produce obtained from local seeds.

Despite substantial increases in labor demand, results in Table 3 also show positive and significant ATT on labor productivity for all ISFM combinations, ranging between 1.5 kg/labor-day (+17%) for OF, 4 kg/labor-day for IF (+61%), 3 kg/labor-day OF + IF (+45%), 5 kg/labor-day for OF + IS (+57%), and around 8 additional kg/labor-day for IF + IS and the full ISFM package (+80 to 90%). Hence, higher requirements in terms of labor input appear to be offset by enhanced land productivity.

Ultimately, we assess ISFM effects on the profitability of unpaid labor investments. For all practices and combinations, we find positive and significant ATT for the returns to unpaid labor. The largest average effects stem from IF alone and the three packages that involve improved seeds, leading to ATT between 32 and 37 ETB/labor-day. These effects reflect increases in returns to labor between 36% and 56% compared to the counterfactuals of no ISFM on the

[14] The average application rate of manure and compost is 1,869 kg/ha, compared to inorganic fertilizer with 158 kg/ha.

same plots, and are equivalent to slightly less than half of the average daily wage rate for agricultural laborers in our study area (around 80 ETB).

4.2 Differential effects by agroecological zone

Due to the substantial agroecological differences in our sample, we assess heterogeneous treatment effects by type of agroecology, differentiating between the regional states of Amhara and Oromia, classified as moist or wet areas (Panel A of Table 4), and that of Tigray, which covers dry areas (Panel B).

Regarding the effects of fertilizers alone on land productivity of the three crops, the pattern found in the two disaggregated samples is fairly similar to the one in the full sample: Applying inorganic fertilizer alone leads to somewhat higher yield increases than organic fertilizer alone, while combining the two fertilizer types leads to a modestly stronger effect than inorganic fertilizer only. Yet, when we look into the different combinations of fertilizers and improved seeds within each subsample, the picture changes. In the moister regions, the combinations IF + IS (1,603 kg/ha) as well as OF + IF + IS (1,741 kg/ha) lead to more pronounced ATT on land productivity than OF + IS (979 kg/ha), underlining the relevance of complementing improved seeds with inorganic fertilizer. In the drier region of Tigray, by contrast, the combinations OF + IS (858 kg/ha) and OF + IF + IS (1,016 kg/ha) clearly outperform the effect of the IF + IS package (492 kg/ha). This points towards the importance of using improved seeds combined with organic fertilizer in dryer areas, probably due to its moisture-conserving effect.

In terms of net crop value, the ATT estimates for Amhara and Oromia indicate an approximately similar effect of the three packages containing improved seeds (ranging between 7,011 ETB/ha and 7,533 ETB/ha), despite the fact that OF + IS on average has a substantially smaller effect on land productivity. Again, this finding presumably reflects the reduced expenses when only organic fertilizer is used and hence, no additional costs for inorganic fertilizer are incurred. In Tigray, the combinations that include organic fertilizer and improved seeds, i.e. OF + IS (6,467 ETB/ha) and OF + IF + IS (5,582 ETB/ha), are superior to the IF + IS package (3,590 ETB/ha) in terms of net crop value (although the effect size of the OF + IS package in Tigray should not be over-interpreted due to the small sample size).

Regarding labor demand, in both subsamples the full ISFM package on average goes along with the largest increase in labor input (40 respectively 43 additional labor-days/ha). In general, magnitudes of the ATT indicate that labor requirements associated with ISFM are larger in Tigray than in the other two regions, probably because the terrain is more rugged and hence, transporting and applying inputs more cumbersome. In Amhara and Oromia, applying only one fertilizer type leads to insignificant, albeit positive ATT. Results further show that on average, labor productivity in Amhara and Oromia increases the strongest when both improved seeds and inorganic fertilizer are used together (9 to 11 kg/labor-day), while in Tigray the largest average effects come from the combinations that involve improved seeds and organic fertilizer (4 to 5 kg/labor-day). Overall, ATT magnitudes for labor productivity are substantially smaller in Tigray, since ISFM there is related to higher labor demand, yet somewhat smaller increases in land productivity. Considering returns to unpaid labor, in Tigray only the three packages including improved seeds lead to significant positive ATT, whereas packages including inorganic fertilizer but no improved seeds are even associated with negative (though insignificant) effects. This suggests that in Tigray, investments of unpaid labor only pay off when improved varieties are used, and even more when they are combined with organic fertilizer. By contrast, in Amhara and Oromia, all ISFM practices and combinations go along with substantial positive and significant ATT on labor returns.

Table 4. Average ISFM adoption effects on the treated plots by agroecological zone.

ISFM combination	Land productivity (kg/ha)		Net crop value (ETB/ha)		Labor demand (labor-days/ha)		Labor productivity (kg/labor-day)		Returns to unpaid labor (ETB/labor-day)		N
Panel A: Amhara & Oromia (moist/wet)											
	ATT	p	ATT	p	ATT	p	ATT	p	ATT	p	
OF	382.79 (81.06)	0.000	2282.13 (585.35)	0.000	4.30 (3.38)	0.204	2.07 (0.39)	0.000	8.72 (3.54)	0.014	225
IF	600.77 (23.46)	0.000	5552.99 (232.20)	0.000	0.95 (0.99)	0.338	5.01 (0.20)	0.000	45.13 (1.94)	0.000	1,687
OF + IF	706.18 (52.81)	0.000	5207.72 (571.62)	0.000	14.57 (3.20)	0.000	4.24 (0.33)	0.000	25.85 (4.19)	0.000	320
OF + IS	979.02 (125.86)	0.000	7010.74 (851.64)	0.000	22.66 (5.86)	0.000	5.61 (0.65)	0.000	39.15 (4.44)	0.000	110
IF + IS	1602.94 (40.47)	0.000	7533.05 (260.34)	0.000	26.57 (1.42)	0.000	10.64 (0.27)	0.000	49.22 (2.30)	0.000	996
OF + IF + IS	1741.49 (45.01)	0.000	7464.45 (279.61)	0.000	39.61 (1.79)	0.000	9.16 (0.22)	0.000	34.58 (2.11)	0.000	933
Panel B: Tigray (dry)											
	ATT	p	ATT	p	ATT	p	ATT	p	ATT	p	
OF	227.20 (108.50)	0.037	1207.41 (850.81)	0.157	18.01 (5.97)	0.003	0.73 (0.41)	0.073	3.83 (6.68)	0.567	151
IF	328.89 (43.58)	0.000	2474.13 (521.59)	0.000	26.51 (2.70)	0.000	1.33 (0.25)	0.000	-2.69 (2.84)	0.344	426
OF + IF	456.06 (59.76)	0.000	1619.93 (556.86)	0.004	37.86 (4.68)	0.000	1.88 (0.29)	0.000	-2.88 (3.83)	0.453	226
OF + IS	857.61 (302.05)	0.006	6467.05 (2197.68)	0.004	29.28 (16.52)	0.080	4.12 (1.21)	0.001	27.86 (9.88)	0.006	39
IF + IS	492.28 (44.90)	0.000	3590.02 (538.38)	0.000	27.09 (2.95)	0.000	2.54 (0.32)	0.000	5.22 (3.03)	0.085	374
OF + IF + IS	1016.23 (63.85)	0.000	5582.19 (485.57)	0.000	42.69 (4.34)	0.000	4.77 (0.29)	0.000	22.45 (2.98)	0.000	310

Note: Exchange rate during survey period: 1 US-$ ~ 27 ETB; reduced sample size stems from logarithmic transformation of outcomes during estimation procedure; standard errors in parentheses; p-values indicate statistical significance of ATT.

4.3 Robustness checks

Even though we control for the type of crop grown on a plot in our regression framework, we re-estimate the ATT on land productivity excluding one crop type at a time in order to check robustness of our results with regards to crop choice.[15] Since cropping patterns are somewhat different between regions, we do that for the two agroecologies separately.[16] Focusing only on the effects of the joint application of improved seeds and different types of fertilizers, Table A9 in the Appendix confirms that results for land productivity are largely robust to crop choice in Amhara and Oromia. Here, the combinations entailing inorganic fertilizers (IF + IS and OF + IF + IS) still lead to higher ATT than that of improved seeds and organic fertilizer alone (OF + IS) in all three cases. Similarly, in Tigray, the full ISFM package (OF + IF + IS) is associated with substantially higher yield gains than the IF + IS combination in each of the three subsamples, which is in line with results from the full Tigray sample. The same can be said for the ATT of OF + IS when either wheat or teff are excluded. Yet, when maize plots are omitted from the ATT estimations, the ATT of OF + IS for Tigray drops sharply. While this may point towards differential effects of the OF + IS combination in Tigray for different crop types, this finding relies on a fairly small sample size and should not be over-interpreted. In any case, we can safely conclude that complementing the joint use of inorganic fertilizer and improved seeds by organic fertilizer is more relevant in drier than in moister areas when it comes to increasing land productivity.

5. Discussion and conclusion

In recent years, ISFM is increasingly promoted as a strategy to sustainably improve soil fertility, increase returns to land and labor of rural farm households, and ultimately combat natural resource depletion. ISFM is a system technology comprising the joint application of organic and inorganic fertilizer and improved crop varieties, which are supposed to bear synergistic effects. Yet, since ISFM typically goes along with higher demand for capital and labor, it is important to assess whether these additional investments pay off for smallholders. In this study, we assessed the plot-level effects of different combinations of ISFM practices.

In line with our expectations, we find that both partial as well as full ISFM adoption is associated with significant increases in land productivity over the three major staples maize, wheat and teff. On average, the largest effect stems from adopting complete ISFM, followed

[15] Very small sample sizes for some combinations of ISFM practices and crop types do not allow estimating the ATT for each crop type separately.

[16] Amhara/Oromia: 38% maize plots, 24% wheat, 37% teff; Tigray: 18% maize, 33% wheat, 49% teff.

by combining improved seeds only with inorganic fertilizer, and only with organic fertilizer. Using either fertilizer type alone or jointly but with local instead of improved seeds, still leads to positive, yet substantially smaller yield benefits. Likewise, we find positive and significant effects of all ISFM practices and packages on net crop value, suggesting that ISFM is profitable despite additional input costs. On average, the strongest increases in net crop value stem from the adoption of either one or both fertilizer types with improved seeds. This is in spite of the lower yield effects of using only organic fertilizer with improved seeds, most likely since it does not involve costs for externally sourced inorganic fertilizer.

Further, as expected, results also show that ISFM is related to significant increases in labor demand of up to 34%. In the case of fertilizers, this most likely stems from their transportation and application, while higher labor demand for improved seeds probably originates from more weeding, pest control or other measures taken to prevent crop damage. Yet, on average, increased labor demand seems to be outweighed by enhanced crop yields and net crop value, since ISFM adoption goes along with significantly positive effects on labor productivity as well as returns to unpaid labor.

Yet, we find substantial heterogeneity regarding the effects on land productivity in different agroecological zones. In moister regions, combining inorganic fertilizer with improved seeds – whether complemented by organic fertilizer or not – clearly outperforms the combination of improved seeds and organic fertilizer only. By contrast, in drier areas, the joint uptake of organic fertilizer with improved seeds (with or without inorganic fertilizer) has a substantially larger effect on yields than the package improved seeds plus inorganic fertilizer only. This finding seems robust to the choice of crop type when the package of organic fertilizer and improved seeds is applied jointly with inorganic fertilizer. Most likely, this is because organic fertilizer increases the solubility, and thus, plant uptake of inorganic nutrients, and consequently also the potential of improved seeds to convert nutrients into biomass. The relevance of moisture-retaining technologies in drier agroecological areas is also supported by other studies (Kassie et al., 2008, 2010).

These results have important implications. Firstly, though fertilizer application is important to raise smallholders' yields, its combined uptake with improved seeds appears crucial to exploit more of the soil's productive potential. Considering that in some SSA countries improved seed adoption is still low (in Ethiopia, for instance, only around 30% of the maize area is cultivated with improved seeds), sustained efforts to promote their use appear crucial, e.g. via strengthening local seed networks, infrastructure and access to credit (Jayne et al., 2019; Sheahan & Barrett, 2017).

Secondly, despite the fact that the largest average effect on land productivity stems from the full integrated package, the difference to the package comprising only inorganic fertilizer and improved seeds is not as strong as expected. These findings are in line with Adolwa et al. (2019), who find significant effects of partial or full ISFM adoption on maize yields, but not of increasing the number of adopted components. This may question the fundamental idea of ISFM that the full synergistic potential can only be reaped by using organic and inorganic nutrients jointly, as demonstrated by numerous field trials. However, as mentioned above, while ISFM in this study is only conceptualized with a binary variable indicating adoption of each technology (combination), other factors such as the *how* and the *how much* are also crucial, especially when using data from micro-level farmer surveys instead of well-managed demonstration fields (Bationo et al., 2008; Jayne et al., 2019). In addition, the quality of applied inputs may vary, in particular when it comes to self-produced organic fertilizers. For instance, whereas around 50% of the households in our data set produce compost, a compost quality index reveals that on average, farmers do not even apply half of the best-practice recommendations for compost production, which most likely has implications for the quality of the end product. In addition, changes in soil organic matter through organic fertilizer application do usually not occur within one season, but rather build over time (Jayne et al., 2019; Marenya & Barrett, 2009). Our RCT baseline data reveals that organic fertilizer use was less prevalent among the same households in 2015, so that in 2017, some plots probably received organic fertilizer for the first or second time. Hence, mid- or long-term effects of integrated application of organic and inorganic fertilizers might be much more pronounced than those we captured with our data. In addition, our study areas have already benefitted from soil conservation through the SLMP, including physical structures, terracing or contour planting. These erosion control measures are beneficial for the accumulation of organic matter and preserving soil moisture, and hence, for the effect of inorganic fertilizer. The combination of organic and inorganic fertilizers might therefore be more crucial in other areas of Ethiopia or SSA, where soils still suffer from higher erosion levels.

Thirdly, the positive ISFM effects on land productivity, net crop value, labor productivity and returns to labor suggest that overall, ISFM is a profitable technology for smallholder farmers, at least when assessed at the plot level. Nonetheless, increased labor demand – in particular when the full ISFM package is applied – can present a prohibitive barrier to adoption, especially for labor-constrained households. In moister regions, using improved seeds solely with inorganic fertilizer may – at least in the shorter run – appear more viable. On the other hand, while combining only organic fertilizer and improved seeds leads to lower average increases in land productivity in moister zones, this combination has still substantial positive effects even in these areas, leading to an equally strong effect on net crop value. Hence, for more cash-constrained households, substituting costly inorganic fertilizers with renewable, locally available organic resources may constitute a more attractive option. In dryer areas, however, using improved seeds with organic fertilizer (either with or without inorganic fertilizer) seems vital, despite the higher labor requirements. In this context, communal labor exchange schemes might gain even more importance in order to make ISFM implementation feasible for farmers. In addition, emerging initiatives to enhance the use of labor-sparing mechanization in SSA are certainly well targeted (Jayne et al., 2019).

Lastly, despite its central role in dry regions, organic fertilizer adoption is still limited (in our sample to around 37% of plots), probably also due to its competing purposes; for instance, crop residues are often used to feed livestock, or manure as fuel. Promoting alternatives, such as planting fodder crops around plot borders and using energy-saving stoves, might lead to a higher availability of organic material to be used as fertilizer. Moreover, involving public or private sector actors to develop markets and distribution services for organic manure and compost seems important in this regard (Jayne et al., 2019).

Our study exhibits some limitations. Firstly, we apply a rather narrow definition of ISFM, only looking into the effects of the three main components, while ignoring other 'local adaptation' measures. Yet, it may be important to analyze the effects of further agricultural inputs and technologies, which might be adopted as substitutes or complements for fertilizers and improved seeds. Secondly, in the absence of plot-level panel data, we only capture farmers' plot management behavior in a cross-section, without accounting for previous input use or management decisions. In particular the application of organic resources in a previous period might have important implications for organic matter accumulation and consequently, lead to heterogeneous effects of different ISFM combinations in the season under consideration. Future studies should shed more light on these effects using longitudinal plot-level data. And finally, we only consider ISFM effects on outcomes directly related to farmers' livelihoods, while we do not capture potential positive externalities on the environment. For instance, enhanced soil organic matter levels and soil health can, in the longer run, improve the provision of vital ecosystem services, such as the storing of soil carbon and erosion control, while higher productivity may prevent further deforestation and thus, contribute to conserving natural resources (Adhikari &

Hartemink, 2016). These environmental benefits can, in turn, lead to positive feedback effects on smallholders' livelihoods, as well as on society as a whole.

All in all, our evidence suggests that ISFM can contribute to overcoming the downward spiral of poor soils, poor agricultural performance and perpetuated poverty by increasing both land and labor productivity. To initiate this process, recommendations need to be carefully targeted to heterogeneous conditions, both in terms of agroecological environments as well as resources available at the farm level.

Appendix

Table A1. Association between instrumental variable and selection variable (adoption of ISFM practices).

	OF	IF	OF + IF	OF + IS	IF + IS	OF + IF + IS
HH lives in ISFM+ community (1 = yes)	0.259*	0.388***	0.476***	0.421**	0.397***	0.771***
	(0.147)	(0.133)	(0.153)	(0.204)	(0.134)	(0.136)
Constant	-0.288***	1.378***	-0.018	-1.290***	0.941***	0.645***
	(0.098)	(0.087)	(0.100)	(0.144)	(0.087)	(0.089)
Wald $\chi2$ (6) = 46.96, P > $\chi2$ = 0.000; Pseudo R^2 = 0.003						
Observations	6,247	6,247	6,247	6,247	6,247	6,247

Note: 'No ISFM' is reference category; robust standard errors in parentheses, clustered at the household level; *** p<0.01, ** p<0.05, * p<0.1.

Table A2. Associations between instrumental variable and outcome variables.

	Log of land productivity (kg/ha)		Log of net crop value (ETB/ha)		Log of labor demand (labor-days/ha)		Log of labor productivity (kg/labor-day)		Log of returns to unpaid labor (ETB/labor-day)	
HH lives in ISFM+ community (1 = yes)	0.017	-0.011	-0.004	-0.016	0.003	0.014	0.015	-0.021	-0.012	-0.027
	(0.031)	(0.025)	(0.035)	(0.028)	(0.017)	(0.014)	(0.032)	(0.027)	(0.035)	(0.030)
ISFM adoption included	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Control variables included	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Constant	6.572***	2.778***	9.118***	5.986***	4.609***	3.553***	1.965***	0.469	4.584***	3.942***
	(0.044)	(0.336)	(0.042)	(0.385)	(0.023)	(0.166)	(0.043)	(0.341)	(0.046)	(0.395)
	F (7, 2030) =157.71***	F (32, 2030) = 147.02***	F (7, 2015) = 19.48***	F (32, 2015) = 54.07***	F (7, 2039) = 63.77***	F (31, 2039) = 93.31***	F (7, 2030) = 84.95***	F (31, 2030) = 74.93***	F (7, 2012) = 20.39***	F (31, 2012) = 36.33***
R-squared	0.168	0.461	0.021	0.277	0.069	0.361	0.102	0.334	0.025	0.189
Observations	6,195	6,195	6,058	6,058	6,247	6,247	6,195	6,195	6,038	6,038

Note: Reduced sample sizes because outcome variables are in logarithms. Control variables are the same as in selection and outcome models. Robust standard errors in parentheses, clustered at the household level; *** p<0.01, ** p<0.05, * p<0.1.

Table A3. First stage regression estimates: multinomial selection model.

	OF	IF	OF + IF	OF + IS	IF + IS	OF + IF + IS
Gender HH head (1 = male)	0.383	0.583**	0.246	0.985**	0.538*	0.480
	(0.297)	(0.266)	(0.288)	(0.437)	(0.285)	(0.312)
Age HH head (in years)	-0.020**	-0.019***	-0.022***	-0.022**	-0.021***	-0.030***
	(0.008)	(0.007)	(0.007)	(0.009)	(0.007)	(0.008)
HH head has formal education (1 = yes)	0.082	-0.459***	-0.442**	-0.338	-0.350*	-0.449**
	(0.207)	(0.175)	(0.201)	(0.276)	(0.189)	(0.200)
No. of HH members	-0.038	-0.047	0.021	-0.060	0.023	0.024
	(0.050)	(0.043)	(0.049)	(0.069)	(0.048)	(0.050)
No. of TLU owned	0.121***	0.124***	0.155***	0.191***	0.133***	0.183***
	(0.037)	(0.033)	(0.036)	(0.043)	(0.036)	(0.037)
Log of farm size (in ha)	-0.374*	-0.364**	-0.502***	-0.924***	-0.696***	-0.834***
	(0.193)	(0.164)	(0.190)	(0.238)	(0.174)	(0.186)
HH has access to formal credit (1 = yes)	0.190	-0.150	0.159	0.573**	0.120	0.166
	(0.193)	(0.171)	(0.192)	(0.274)	(0.183)	(0.192)
No. of social organizations HH is involved	0.021	-0.041	0.014	0.060	0.069	0.131***
	(0.055)	(0.046)	(0.051)	(0.078)	(0.049)	(0.051)
Talked to extension agent (1 = yes)	0.250	-0.115	0.330*	0.784***	0.040	0.433**
	(0.194)	(0.177)	(0.194)	(0.260)	(0.185)	(0.199)
Log of walking distance to nearest FTC (in min)	0.242**	-0.040	0.228*	0.393**	-0.073	0.128
	(0.117)	(0.108)	(0.123)	(0.157)	(0.114)	(0.123)
Log of walking distance to nearest village market (in min)	-0.147	0.014	-0.073	-0.130	-0.050	-0.080
	(0.123)	(0.099)	(0.117)	(0.149)	(0.108)	(0.118)
Agri-input dealer in Kebele (1 = yes)	0.785***	0.592***	1.604***	1.120***	0.911***	1.264***
	(0.252)	(0.222)	(0.269)	(0.341)	(0.248)	(0.261)
HH lives in ISFM+ community (1 = yes)	-0.016	0.273*	0.191	0.068	0.214	0.444**
	(0.183)	(0.158)	(0.177)	(0.241)	(0.170)	(0.179)
Pest and disease stress (1 = yes)	0.004	0.111	-0.123	-0.007	-0.129	-0.062
	(0.292)	(0.270)	(0.280)	(0.355)	(0.278)	(0.284)
Weather stress (drought/flood/frost/storm) (1 = yes)	0.387*	0.162	0.463**	-0.099	0.233	0.283
	(0.216)	(0.178)	(0.197)	(0.272)	(0.189)	(0.202)

Log of av. annual rainfall (in mm)	0.706**	2.822***	2.025***	1.687***	3.714***	2.693***
	(0.311)	(0.256)	(0.297)	(0.372)	(0.286)	(0.306)
Log of walking distance to plot (in min)	-0.824***	0.097	-0.676***	-1.081***	0.165**	-0.701***
	(0.092)	(0.062)	(0.077)	(0.143)	(0.067)	(0.073)
Plot owned (1 = yes)	0.469**	-0.253	0.366*	0.703**	0.001	0.655***
	(0.206)	(0.168)	(0.197)	(0.298)	(0.180)	(0.202)
Footslope (1 = yes)	-0.439**	-0.492***	-0.293	-0.183	-0.049	-0.134
	(0.194)	(0.162)	(0.183)	(0.249)	(0.172)	(0.180)
Hillslope (1 = yes)	0.120	0.299	0.168	-0.123	0.096	0.061
	(0.305)	(0.232)	(0.274)	(0.428)	(0.254)	(0.267)
Shallow soil (1 = yes)	0.371	0.309	0.234	0.147	0.135	0.043
	(0.254)	(0.210)	(0.235)	(0.326)	(0.227)	(0.244)
Deep soil (1 = yes)	-0.023	0.170	-0.026	-0.110	0.128	0.356*
	(0.217)	(0.165)	(0.195)	(0.288)	(0.178)	(0.192)
Poor soil quality (1 = yes)	0.026	-0.268	-0.304	-0.390	-0.363*	-0.529**
	(0.226)	(0.172)	(0.198)	(0.300)	(0.189)	(0.209)
Good soil quality (1 = yes)	0.303	-0.089	0.002	0.417	0.199	0.282
	(0.221)	(0.177)	(0.199)	(0.264)	(0.187)	(0.194)
Herbicide used (1 = yes)	-0.791***	0.115	-0.079	-1.725***	-0.506**	-0.887***
	(0.278)	(0.174)	(0.219)	(0.594)	(0.201)	(0.239)
Pesticide used (1 = yes)	1.142***	0.713*	0.865**	0.989*	1.460***	1.438***
	(0.426)	(0.369)	(0.394)	(0.505)	(0.379)	(0.397)
Lime used (1 = yes)	1.780	1.279	2.853***	0.958	1.955*	3.369***
	(1.122)	(1.090)	(1.087)	(1.467)	(1.092)	(1.080)
Urea used (1 = yes)	-0.389	3.646***	3.321***	0.611**	4.645***	4.336***
	(0.259)	(0.229)	(0.241)	(0.296)	(0.246)	(0.249)
Maize plot (1 = yes)	1.635***	-3.371***	0.215	3.829***	1.302***	2.396***
	(0.272)	(0.318)	(0.284)	(0.621)	(0.270)	(0.276)
Wheat plot (1 = yes)	0.368	-0.386**	0.319	3.612***	1.481***	2.248***
	(0.287)	(0.194)	(0.221)	(0.617)	(0.216)	(0.238)
Log of total labor use (in labor-days/ha)	0.650***	0.553***	0.691***	0.915***	0.724***	0.945***
	(0.233)	(0.190)	(0.213)	(0.289)	(0.199)	(0.207)

Log of plot size (in ha)	-0.036	0.190	0.147	0.284	0.466***	0.627***
	(0.142)	(0.118)	(0.129)	(0.175)	(0.125)	(0.131)
Constant	-8.720***	-20.937***	-18.965***	-21.082***	-31.408***	-26.132***
	(2.609)	(2.163)	(2.458)	(3.252)	(2.365)	(2.492)
Wald $\chi2$ (192) = 3771.97, P > $\chi2$ = 0.000; Pseudo R^2 = 0.381						
Observations	6,247	6,247	6,247	6,247	6,247	6,247

Note: 'No ISFM' is reference category. HH stands for household; FTC stands for farmer training center; TLU stands for tropical livestock unit; Kebele is the lowest administrative unit in Ethiopia; formal credit refers to bank, microfinance institution, government or agri-input dealer; footslope/hillslope compared to midslope; shallow/deep soil compared to medium soil depth; poor soil/good soil compared to average soil quality. Robust standard errors in parentheses, clustered at the household level; *** p<0.01, ** p<0.05, * p<0.1.

Table A4. Second stage regression estimates: land productivity.

	Log of land productivity (kg/ha)						
	No ISFM	OF	IF	OF + IF	OF + IS	IF + IS	OF + IF + IS
Gender HH head (1 = male)	-0.195	0.289**	0.182**	0.249**	0.310	0.098	0.041
	(0.135)	(0.135)	(0.073)	(0.121)	(0.491)	(0.075)	(0.088)
Age HH head (in years)	-0.007**	-0.004	-0.002	-0.001	0.007	-0.002	-0.007***
	(0.004)	(0.003)	(0.001)	(0.003)	(0.007)	(0.002)	(0.002)
HH head has formal education (1 = yes)	0.006	-0.133	-0.242***	-0.178**	0.176	-0.067	-0.098**
	(0.102)	(0.103)	(0.036)	(0.075)	(0.191)	(0.048)	(0.048)
No. of HH members	-0.038*	0.007	-0.039***	-0.004	0.027	-0.035***	-0.040***
	(0.021)	(0.024)	(0.008)	(0.022)	(0.065)	(0.009)	(0.013)
No. of TLU owned	0.016	0.058***	0.046***	0.035**	0.061	0.037***	0.067***
	(0.018)	(0.019)	(0.007)	(0.016)	(0.037)	(0.008)	(0.010)
Log of farm size (in ha)	0.098	-0.096	-0.070	-0.196**	-0.342	-0.069*	-0.095**
	(0.071)	(0.104)	(0.048)	(0.089)	(0.272)	(0.041)	(0.048)
No. of social organizations HH is involved	-0.113*	-0.054	-0.006	0.003	0.367	0.011	0.050
	(0.063)	(0.080)	(0.036)	(0.076)	(0.240)	(0.038)	(0.046)
Log of walking distance to nearest FTC (in min)	0.018	0.009	0.029***	0.022	0.048	0.002	0.025*
	(0.023)	(0.026)	(0.010)	(0.023)	(0.068)	(0.015)	(0.014)
Talked to extension agent (1 = yes)	0.044	-0.067	0.067*	0.018	0.140	0.026	0.052
	(0.083)	(0.097)	(0.036)	(0.087)	(0.282)	(0.042)	(0.060)
Log of walking distance to nearest village market (in min)	-0.017	-0.045	-0.055**	-0.086	-0.154	-0.056**	-0.043

	(0.047)	(0.061)	(0.022)	(0.059)	(0.147)	(0.025)	(0.035)
Agri-input dealer in Kebele (1 = yes)	-0.071	-0.037	0.027	-0.055	0.110	0.029	-0.053*
	(0.047)	(0.044)	(0.020)	(0.045)	(0.127)	(0.024)	(0.028)
HH has access to formal credit (1 = yes)	0.037	-0.194	0.253***	-0.122	0.135	-0.006	0.070
	(0.248)	(0.215)	(0.047)	(0.116)	(0.401)	(0.068)	(0.088)
Pest and disease stress (1 = yes)	0.020	0.132	-0.099*	-0.085	-0.062	-0.168***	0.058
	(0.101)	(0.103)	(0.055)	(0.135)	(0.271)	(0.057)	(0.060)
Weather stress (drought/flood/frost/storm) (1 = yes)	-0.187**	-0.088	-0.212***	-0.198**	-0.556	-0.271***	-0.180***
	(0.079)	(0.106)	(0.040)	(0.095)	(0.408)	(0.043)	(0.047)
Log of av. annual rainfall (in mm)	-0.112	0.504*	0.270***	0.331	-0.445	0.065	0.039
	(0.392)	(0.303)	(0.088)	(0.214)	(0.596)	(0.105)	(0.163)
Log of walking distance to plot (in min)	-0.028	0.144	-0.022	0.062	-0.123	0.069	-0.017
	(0.066)	(0.098)	(0.028)	(0.101)	(0.256)	(0.050)	(0.098)
Plot owned (1 = yes)	-0.006	0.048	-0.111***	-0.051	0.215	-0.067	0.036
	(0.083)	(0.132)	(0.032)	(0.106)	(0.346)	(0.048)	(0.076)
Footslope (1 = yes)	0.185**	0.006	-0.058	-0.137*	-0.002	0.017	0.019
	(0.094)	(0.084)	(0.039)	(0.075)	(0.192)	(0.043)	(0.055)
Hillslope (1 = yes)	0.044	0.146	-0.081*	0.165	0.311	0.109*	0.120
	(0.165)	(0.139)	(0.044)	(0.107)	(0.283)	(0.058)	(0.093)
Shallow soil depth (1 = yes)	-0.364***	-0.154	-0.058	-0.147	0.324	0.018	-0.140**
	(0.121)	(0.122)	(0.049)	(0.094)	(0.294)	(0.055)	(0.067)
Deep soil (1 = yes)	-0.002	0.025	0.164***	0.122	0.224	0.015	0.097
	(0.078)	(0.097)	(0.037)	(0.087)	(0.234)	(0.043)	(0.072)
Poor soil quality (1 = yes)	-0.031	-0.189**	-0.259***	-0.017	-0.314	-0.157***	-0.270***
	(0.091)	(0.096)	(0.036)	(0.075)	(0.318)	(0.054)	(0.077)
High soil quality (1 = yes)	0.117	0.228**	-0.019	0.121	0.148	0.013	0.060
	(0.081)	(0.113)	(0.037)	(0.091)	(0.336)	(0.044)	(0.055)
Applied herbicide on plot	0.214*	0.108	0.190***	0.228*	-0.420	0.310***	-0.017
	(0.130)	(0.225)	(0.045)	(0.120)	(1.045)	(0.077)	(0.098)
Pesticide used (1 = yes)	0.130	0.390***	0.053	-0.006	0.109	-0.033	-0.069
	(0.172)	(0.151)	(0.063)	(0.136)	(0.339)	(0.074)	(0.089)
Lime used (1 = yes)	0.439	-0.028	-0.183	-0.502**	0.473	-0.100	0.044

	(0.465)	(0.522)	(0.121)	(0.244)	(1.216)	(0.136)	(0.131)
Urea used (1 = yes)	-0.344	-0.161	0.179*	-0.002	-0.726	-0.052	0.149
	(0.491)	(0.818)	(0.100)	(0.230)	(1.766)	(0.156)	(0.227)
Maize plot (1 = yes)	0.413	0.904**	0.684**	0.227	1.654	0.834***	0.934***
	(0.379)	(0.376)	(0.337)	(0.426)	(2.300)	(0.321)	(0.224)
Wheat plot (1 = yes)	0.372**	0.344	0.613***	0.416	1.229	0.534***	0.629***
	(0.173)	(0.209)	(0.105)	(0.292)	(2.009)	(0.181)	(0.182)
Log of total labor use (in labor-days/ha)	0.318***	0.496***	0.297***	0.362***	0.174	0.275***	0.441***
	(0.111)	(0.116)	(0.044)	(0.090)	(0.265)	(0.044)	(0.058)
Log of plot size (in ha)	-0.319***	-0.364***	-0.217***	-0.165**	-0.130	-0.173***	-0.156***
	(0.069)	(0.091)	(0.035)	(0.084)	(0.229)	(0.041)	(0.051)
$\lambda 1$		-0.910*	-0.005	0.319	-0.054	0.439	0.309
		(0.521)	(0.186)	(0.506)	(1.090)	(0.400)	(0.281)
$\lambda 2$	0.113		-0.762**	-0.220	0.455	-0.254	-0.234
	(0.499)		(0.381)	(0.509)	(1.426)	(0.537)	(0.437)
$\lambda 3$	0.183	0.845*		0.208	0.263	-0.048	-0.135
	(0.457)	(0.489)		(0.498)	(2.000)	(0.282)	(0.268)
$\lambda 4$	0.081	-2.259**	0.175		0.098	0.237	-0.232
	(0.767)	(1.089)	(0.345)		(4.105)	(0.454)	(0.582)
$\lambda 5$	-0.254	-0.346	1.280***	0.219		0.352	0.297
	(0.691)	(0.568)	(0.491)	(0.543)		(0.627)	(0.425)
$\lambda 6$	-0.771	1.540***	-0.380	-0.154	-1.090		-0.113
	(0.647)	(0.507)	(0.263)	(0.621)	(1.412)		(0.480)
$\lambda 7$	0.618	0.839	-0.248	-0.260	0.132	-0.669**	
	(0.871)	(0.791)	(0.254)	(0.386)	(1.762)	(0.293)	
Constant	6.211**	-0.838	2.891***	3.132*	6.107	4.995***	4.258***
	(2.949)	(2.323)	(0.750)	(1.609)	(6.274)	(1.169)	(1.201)
R-squared	0.400	0.464	0.455	0.325	0.494	0.414	0.317
Observations	436	367	2,102	537	148	1,366	1,239

Note: Standard errors in parentheses, bootstrapped with 100 replications; *** p<0.01, ** p<0.05, * p<0.1.

Table A5. Second stage regression estimates: net crop value.

	Log of net crop value (ETB/ha)						
	No ISFM	OF	IF	OF + IF	OF + IS	IF + IS	OF + IF + IS
Gender HH head (1 = male)	-0.192	0.304**	0.203**	0.269*	0.237	0.189*	0.158
	(0.143)	(0.152)	(0.094)	(0.161)	(0.408)	(0.098)	(0.121)
Age HH head (in years)	-0.007*	-0.006	-0.002	-0.002	0.004	-0.005***	-0.008***
	(0.004)	(0.004)	(0.001)	(0.004)	(0.007)	(0.002)	(0.003)
HH head has formal education (1 = yes)	0.029	-0.159	-0.247***	-0.132	0.125	-0.156***	-0.171**
	(0.104)	(0.118)	(0.041)	(0.098)	(0.171)	(0.050)	(0.070)
No. of HH members	-0.033	-0.000	-0.036***	-0.012	0.036	-0.035***	-0.025*
	(0.022)	(0.027)	(0.010)	(0.023)	(0.052)	(0.012)	(0.013)
No. of TLU owned	0.009	0.061**	0.054***	0.045**	0.056	0.045***	0.061***
	(0.019)	(0.024)	(0.008)	(0.021)	(0.042)	(0.011)	(0.011)
Log of farm size (in ha)	0.083	-0.064	-0.136***	-0.234**	-0.298	-0.111*	-0.119**
	(0.067)	(0.137)	(0.051)	(0.097)	(0.252)	(0.066)	(0.050)
No. of social organizations HH is involved	-0.092	-0.071	0.045	-0.058	0.271	0.039	0.070
	(0.076)	(0.096)	(0.036)	(0.105)	(0.228)	(0.051)	(0.064)
Log of walking distance to nearest FTC (in min)	0.026	0.017	0.018	0.013	0.050	0.017	0.037*
	(0.022)	(0.034)	(0.013)	(0.029)	(0.065)	(0.017)	(0.020)
Talked to extension agent (1 = yes)	0.062	-0.060	0.067*	0.133	0.036	0.024	0.073
	(0.069)	(0.116)	(0.038)	(0.118)	(0.254)	(0.064)	(0.078)
Log of walking distance to nearest village market (in min)	-0.007	-0.024	-0.057**	-0.047	-0.133	-0.058*	-0.055
	(0.042)	(0.061)	(0.024)	(0.076)	(0.164)	(0.030)	(0.053)
Agri-input dealer in Kebele (1 = yes)	-0.081*	-0.037	0.038	-0.078	0.127	0.036	0.004
	(0.048)	(0.050)	(0.026)	(0.050)	(0.120)	(0.025)	(0.036)
HH has access to formal credit (1 = yes)	-0.028	-0.125	0.293***	-0.004	0.395	0.125	0.125
	(0.237)	(0.273)	(0.060)	(0.145)	(0.287)	(0.083)	(0.100)
Pest and disease stress (1 = yes)	-0.028	0.148	-0.061	-0.121	-0.225	-0.275***	-0.100
	(0.108)	(0.124)	(0.066)	(0.168)	(0.205)	(0.077)	(0.075)
Weather stress (drought/flood/frost/storm) (1 = yes)	-0.178**	-0.146	-0.240***	-0.304***	-0.285	-0.333***	-0.225***
	(0.090)	(0.122)	(0.051)	(0.104)	(0.336)	(0.058)	(0.072)
Log of av. annual rainfall (in mm)	-0.544*	0.163	0.156	0.275	-0.538	0.125	0.226
	(0.302)	(0.404)	(0.122)	(0.356)	(0.487)	(0.144)	(0.231)

Log of walking distance to plot (in min)	-0.069	0.036	-0.018	0.088	-0.217	0.053	0.068
	(0.070)	(0.129)	(0.034)	(0.149)	(0.298)	(0.071)	(0.137)
Plot owned (1 = yes)	0.037	0.087	-0.092**	-0.071	0.329	-0.043	0.045
	(0.097)	(0.147)	(0.044)	(0.136)	(0.359)	(0.064)	(0.109)
Footslope (1 = yes)	0.154	-0.055	-0.098**	-0.034	0.056	0.021	0.050
	(0.096)	(0.110)	(0.049)	(0.106)	(0.148)	(0.059)	(0.058)
Hillslope (1 = yes)	0.024	0.131	-0.070	0.238	0.294	0.110*	0.171*
	(0.156)	(0.152)	(0.054)	(0.162)	(0.309)	(0.065)	(0.099)
Shallow soil depth (1 = yes)	-0.312**	-0.078	-0.135**	-0.136	0.238	0.051	-0.248***
	(0.145)	(0.136)	(0.064)	(0.129)	(0.226)	(0.087)	(0.096)
Deep soil (1 = yes)	0.048	0.062	0.103**	0.148	0.352	0.043	0.048
	(0.084)	(0.110)	(0.048)	(0.097)	(0.215)	(0.060)	(0.081)
Poor soil quality (1 = yes)	-0.039	-0.128	-0.296***	-0.071	-0.148	-0.244***	-0.341***
	(0.100)	(0.154)	(0.044)	(0.100)	(0.329)	(0.076)	(0.096)
High soil quality (1 = yes)	0.088	0.296**	0.016	-0.019	0.082	-0.000	0.077
	(0.099)	(0.119)	(0.046)	(0.111)	(0.261)	(0.051)	(0.060)
Applied herbicide on plot	0.154	0.180	0.177***	0.216	-0.150	0.283***	-0.109
	(0.128)	(0.249)	(0.047)	(0.135)	(0.808)	(0.109)	(0.132)
Pesticide used (1 = yes)	0.139	0.461**	0.116	-0.045	0.070	0.015	0.063
	(0.220)	(0.191)	(0.076)	(0.145)	(0.416)	(0.096)	(0.100)
Lime used (1 = yes)	0.426	-0.264	-0.316*	-0.606*	0.299	-0.286	-0.218
	(0.571)	(0.640)	(0.183)	(0.354)	(0.959)	(0.241)	(0.202)
Urea used (1 = yes)	-0.694	-0.731	0.102	0.035	-0.569	-0.079	0.424
	(0.447)	(0.949)	(0.109)	(0.370)	(1.357)	(0.215)	(0.351)
Maize plot (1 = yes)	-0.237	0.286	-0.362	-1.082**	0.316	-0.372	-0.264
	(0.334)	(0.432)	(0.364)	(0.470)	(1.703)	(0.372)	(0.348)
Wheat plot (1 = yes)	-0.086	-0.111	0.018	-0.524	0.067	-0.129	-0.071
	(0.141)	(0.281)	(0.120)	(0.335)	(1.609)	(0.229)	(0.246)
Log of total labor use (in labor-days/ha)	0.275**	0.503***	0.321***	0.436***	0.276	0.312***	0.384***
	(0.109)	(0.134)	(0.045)	(0.122)	(0.256)	(0.060)	(0.062)
Log of plot size (in ha)	-0.372***	-0.409***	-0.245***	-0.215**	-0.199	-0.193***	-0.181***
	(0.056)	(0.099)	(0.046)	(0.106)	(0.209)	(0.059)	(0.061)
λ1		-0.829	-0.156	0.319	-0.092	0.285	0.225
		(0.638)	(0.229)	(0.674)	(0.859)	(0.528)	(0.530)

λ2	0.576		-0.887**	-0.070	0.811	-0.925	-0.837*
	(0.530)		(0.445)	(0.678)	(1.361)	(0.600)	(0.436)
λ3	-0.201	0.832		0.403	-0.151	-0.018	0.144
	(0.387)	(0.576)		(0.602)	(1.799)	(0.350)	(0.423)
λ4	-0.334	-2.627**	0.315		0.927	0.236	-0.467
	(1.016)	(1.256)	(0.435)		(3.124)	(0.612)	(0.689)
λ5	-0.196	-0.301	1.836***	0.020		1.219	0.472
	(0.724)	(0.647)	(0.585)	(0.748)		(0.799)	(0.476)
λ6	-0.746	1.333**	-0.411	-0.087	-2.160		0.367
	(0.586)	(0.670)	(0.308)	(0.773)	(1.551)		(0.633)
λ7	0.817	1.111	-0.567*	-0.507	0.660	-0.719*	
	(0.898)	(0.902)	(0.326)	(0.480)	(1.796)	(0.384)	
Constant	11.886***	3.625	6.200***	5.717**	9.876*	6.937***	5.397***
	(2.134)	(3.067)	(0.999)	(2.316)	(5.566)	(1.535)	(1.570)
R-squared	0.269	0.385	0.335	0.337	0.506	0.255	0.252
Observations	434	366	2,054	517	146	1,342	1,199

Note: Standard errors in parentheses, bootstrapped with 100 replications; *** p<0.01, ** p<0.05, * p<0.1.

Table A6. Second stage regression estimates: labor demand.

	Log of labor demand (person-days/ha)						
	No ISFM	OF	IF	OF + IF	OF + IS	IF + IS	OF + IF + IS
Gender HH head (1 = male)	0.105	0.119	-0.044	0.030	-0.327	0.021	0.050
	(0.085)	(0.087)	(0.042)	(0.053)	(0.274)	(0.044)	(0.048)
Age HH head (in years)	0.004*	0.005***	0.005***	0.004***	0.004	0.005***	0.004***
	(0.002)	(0.002)	(0.001)	(0.001)	(0.005)	(0.001)	(0.001)
HH head has formal education (1 = yes)	0.004	0.035	0.009	-0.029	-0.061	0.015	-0.012
	(0.051)	(0.070)	(0.018)	(0.040)	(0.126)	(0.029)	(0.025)
No. of HH members	0.025**	0.010	0.028***	0.033***	0.034	0.030***	0.014**
	(0.012)	(0.014)	(0.005)	(0.012)	(0.037)	(0.007)	(0.007)
No. of TLU owned	-0.010	-0.003	-0.009***	0.005	-0.002	0.003	0.012**
	(0.010)	(0.011)	(0.003)	(0.007)	(0.028)	(0.005)	(0.005)
Log of farm size (in ha)	0.033	-0.047	0.025	-0.066*	0.079	-0.016	-0.071**
	(0.049)	(0.046)	(0.020)	(0.035)	(0.176)	(0.031)	(0.031)

No. of social organizations HH is involved	-0.015	0.060	-0.017	0.064*	0.080	-0.013	0.063**
	(0.035)	(0.046)	(0.018)	(0.038)	(0.178)	(0.026)	(0.027)
Log of walking distance to nearest FTC (in min)	-0.010	0.002	-0.004	0.011	-0.002	-0.008	0.005
	(0.011)	(0.015)	(0.006)	(0.012)	(0.037)	(0.009)	(0.008)
Talked to extension agent (1 = yes)	-0.003	0.014	0.020	0.030	0.066	0.042	0.019
	(0.051)	(0.056)	(0.015)	(0.040)	(0.193)	(0.028)	(0.034)
Log of walking distance to nearest village market (in min)	-0.020	0.032	0.018	0.054**	0.063	0.026	-0.010
	(0.024)	(0.040)	(0.012)	(0.024)	(0.098)	(0.017)	(0.021)
Agri-input dealer in Kebele (1 = yes)	0.024	-0.010	-0.022*	-0.028	-0.164**	-0.009	-0.031*
	(0.027)	(0.029)	(0.012)	(0.024)	(0.082)	(0.013)	(0.016)
HH has access to formal credit (1 = yes)	0.103	0.029	0.020	0.071	0.123	0.018	0.026
	(0.137)	(0.136)	(0.028)	(0.054)	(0.212)	(0.040)	(0.050)
Pest and disease stress (1 = yes)	-0.069	-0.030	-0.001	-0.044	0.022	0.046	-0.022
	(0.063)	(0.071)	(0.029)	(0.061)	(0.173)	(0.039)	(0.034)
Weather stress (drought/flood/frost/storm) (1 = yes)	-0.004	-0.107**	-0.017	-0.056	0.132	-0.033	0.010
	(0.047)	(0.052)	(0.021)	(0.042)	(0.210)	(0.029)	(0.032)
Log of av. annual rainfall (in mm)	0.046	-0.275*	-0.014	0.139	-0.562	-0.032	0.005
	(0.223)	(0.158)	(0.045)	(0.109)	(0.390)	(0.066)	(0.103)
Log of walking distance to plot (in min)	-0.012	-0.061	-0.000	-0.002	-0.068	0.008	0.027
	(0.036)	(0.061)	(0.015)	(0.048)	(0.200)	(0.030)	(0.056)
Plot owned (1 = yes)	0.068	0.035	-0.025	0.079*	0.230	-0.025	0.005
	(0.043)	(0.077)	(0.021)	(0.048)	(0.255)	(0.033)	(0.047)
Footslope (1 = yes)	-0.085	-0.007	-0.051***	-0.028	-0.158	-0.054*	-0.041
	(0.057)	(0.062)	(0.019)	(0.044)	(0.102)	(0.030)	(0.033)
Hillslope (1 = yes)	-0.210***	0.005	0.010	0.009	0.122	0.028	-0.035
	(0.081)	(0.084)	(0.025)	(0.058)	(0.185)	(0.034)	(0.039)
Shallow soil depth (1 = yes)	-0.067	-0.159***	-0.047**	-0.017	0.087	0.013	0.011
	(0.055)	(0.061)	(0.021)	(0.046)	(0.133)	(0.037)	(0.036)
Deep soil (1 = yes)	0.054	-0.038	0.005	-0.062	0.081	0.001	0.053
	(0.057)	(0.059)	(0.020)	(0.040)	(0.128)	(0.030)	(0.034)
Poor soil quality (1 = yes)	0.077*	0.008	-0.043*	-0.024	0.168	0.009	-0.010
	(0.044)	(0.054)	(0.023)	(0.042)	(0.139)	(0.033)	(0.034)
High soil quality (1 = yes)	0.118**	0.002	-0.023	0.057	-0.264	-0.047*	-0.020
	(0.048)	(0.062)	(0.020)	(0.047)	(0.176)	(0.027)	(0.031)

Applied herbicide on plot	-0.019	0.111	-0.065***	-0.039	0.763	0.026	-0.022
	(0.076)	(0.144)	(0.023)	(0.053)	(0.642)	(0.057)	(0.063)
Pesticide used (1 = yes)	0.109	0.032	0.065*	0.077	-0.337	0.051	0.089*
	(0.121)	(0.093)	(0.034)	(0.070)	(0.231)	(0.056)	(0.045)
Lime used (1 = yes)	-0.486*	-0.474	-0.035	-0.147	0.160	-0.120	-0.008
	(0.290)	(0.329)	(0.076)	(0.100)	(0.842)	(0.101)	(0.085)
Urea used (1 = yes)	-0.237	-0.706	0.049	0.111	-0.678	-0.049	0.112
	(0.312)	(0.480)	(0.051)	(0.136)	(1.087)	(0.108)	(0.126)
Maize plot (1 = yes)	0.241	0.171	-0.215	0.090	-1.594	-0.181	0.039
	(0.197)	(0.209)	(0.166)	(0.178)	(1.451)	(0.199)	(0.159)
Wheat plot (1 = yes)	-0.063	0.055	-0.226***	-0.116	-1.912	-0.323***	-0.210
	(0.085)	(0.133)	(0.053)	(0.122)	(1.327)	(0.117)	(0.131)
Log of plot size (in ha)	-0.244***	-0.275***	-0.289***	-0.333***	-0.534***	-0.296***	-0.318***
	(0.038)	(0.033)	(0.017)	(0.038)	(0.115)	(0.025)	(0.030)
λ1		0.515*	0.067	-0.098	-0.021	0.214	-0.294*
		(0.311)	(0.097)	(0.251)	(0.690)	(0.246)	(0.168)
λ2	0.308		-0.058	0.059	0.930	-0.117	0.172
	(0.326)		(0.182)	(0.236)	(0.746)	(0.261)	(0.230)
λ3	-0.258	-0.255		-0.151	0.075	0.262	-0.006
	(0.239)	(0.259)		(0.229)	(0.863)	(0.170)	(0.152)
λ4	-0.414	-0.139	0.059		1.977	0.002	0.077
	(0.489)	(0.675)	(0.164)		(2.051)	(0.304)	(0.343)
λ5	-0.236	0.776**	0.195	-0.036		-0.124	-0.015
	(0.365)	(0.335)	(0.223)	(0.295)		(0.332)	(0.207)
λ6	0.137	-0.253	-0.077	0.315	-1.569		0.095
	(0.349)	(0.435)	(0.121)	(0.297)	(1.086)		(0.277)
λ7	0.391	-0.708**	-0.232*	-0.117	-1.165	-0.217	
	(0.455)	(0.352)	(0.119)	(0.181)	(1.021)	(0.200)	
Constant	3.276**	5.744***	4.201***	2.551***	10.360***	4.471***	4.075***
	(1.459)	(1.126)	(0.377)	(0.797)	(3.427)	(0.712)	(0.787)
R-squared	0.338	0.351	0.337	0.450	0.517	0.322	0.361
Observations	450	376	2,113	546	149	1,370	1,243

Note: Standard errors in parentheses, bootstrapped with 100 replications; *** p<0.01, ** p<0.05, * p<0.1.

Table A7. Second stage regression estimates: labor productivity.

	Log of labor productivity (kg/labor-day)						
	No ISFM	OF	IF	OF + IF	OF + IS	IF + IS	OF + IF + IS
Gender HH head (1 = male)	-0.237*	0.222	0.214***	0.219	0.671	0.082	0.020
	(0.138)	(0.164)	(0.082)	(0.137)	(0.585)	(0.076)	(0.087)
Age HH head (in years)	-0.010***	-0.007*	-0.005***	-0.003	0.003	-0.006***	-0.009***
	(0.003)	(0.004)	(0.001)	(0.003)	(0.008)	(0.002)	(0.002)
HH head has formal education (1 = yes)	-0.017	-0.146	-0.248***	-0.160*	0.240	-0.075	-0.094**
	(0.101)	(0.123)	(0.036)	(0.091)	(0.198)	(0.049)	(0.046)
No. of HH members	-0.056***	0.001	-0.058***	-0.027	-0.006	-0.057***	-0.048***
	(0.020)	(0.023)	(0.010)	(0.022)	(0.056)	(0.010)	(0.013)
No. of TLU owned	0.026	0.057***	0.052***	0.031*	0.066	0.033***	0.059***
	(0.018)	(0.021)	(0.007)	(0.018)	(0.046)	(0.009)	(0.011)
Log of farm size (in ha)	0.072	-0.049	-0.086*	-0.147*	-0.455	-0.050	-0.059
	(0.077)	(0.098)	(0.051)	(0.087)	(0.297)	(0.040)	(0.051)
No. of social organizations HH is involved	-0.102	-0.090	0.005	-0.041	0.339	0.018	0.015
	(0.072)	(0.101)	(0.039)	(0.080)	(0.304)	(0.047)	(0.050)
Log of walking distance to nearest FTC (in min)	0.021	0.002	0.033***	0.013	0.053	0.007	0.023
	(0.024)	(0.028)	(0.012)	(0.021)	(0.054)	(0.016)	(0.016)
Talked to extension agent (1 = yes)	0.047	-0.086	0.052	-0.007	0.129	-0.007	0.040
	(0.078)	(0.086)	(0.039)	(0.079)	(0.316)	(0.047)	(0.062)
Log of walking distance to nearest village market (in min)	-0.003	-0.066	-0.068***	-0.120*	-0.188	-0.077***	-0.040
	(0.048)	(0.068)	(0.021)	(0.062)	(0.174)	(0.028)	(0.036)
Agri-input dealer in Kebele (1 = yes)	-0.087	-0.033	0.042	-0.035	0.240*	0.036	-0.036
	(0.056)	(0.052)	(0.026)	(0.048)	(0.126)	(0.028)	(0.032)
HH has access to formal credit (1 = yes)	-0.004	-0.239	0.237***	-0.175	-0.025	-0.032	0.045
	(0.235)	(0.227)	(0.057)	(0.144)	(0.336)	(0.073)	(0.086)
Pest and disease stress (1 = yes)	0.072	0.149	-0.098*	-0.058	-0.068	-0.199***	0.074
	(0.105)	(0.111)	(0.059)	(0.133)	(0.260)	(0.064)	(0.059)
Weather stress (drought/flood/frost/storm) (1 = yes)	-0.178**	-0.015	-0.201***	-0.167*	-0.717	-0.249***	-0.191***
	(0.082)	(0.100)	(0.046)	(0.089)	(0.442)	(0.050)	(0.057)
Log of av. annual rainfall (in mm)	-0.051	0.623*	0.288***	0.232	-0.002	0.068	0.057
	(0.371)	(0.319)	(0.105)	(0.256)	(0.665)	(0.103)	(0.186)

Log of walking distance to plot (in min)	-0.019	0.183*	-0.021	0.074	-0.143	0.073	-0.018
	(0.076)	(0.111)	(0.032)	(0.136)	(0.315)	(0.058)	(0.109)
Plot owned (1 = yes)	-0.054	0.025	-0.094**	-0.112	0.068	-0.055	0.026
	(0.084)	(0.128)	(0.043)	(0.123)	(0.346)	(0.060)	(0.096)
Footslope (1 = yes)	0.220**	-0.008	-0.021	-0.120	0.129	0.061	0.048
	(0.104)	(0.095)	(0.047)	(0.091)	(0.209)	(0.049)	(0.050)
Hillslope (1 = yes)	0.180	0.143	-0.087*	0.163	0.144	0.091	0.140*
	(0.120)	(0.153)	(0.051)	(0.105)	(0.338)	(0.061)	(0.079)
Shallow soil depth (1 = yes)	-0.318**	-0.052	-0.026	-0.135	0.235	0.008	-0.149*
	(0.124)	(0.126)	(0.056)	(0.099)	(0.250)	(0.067)	(0.078)
Deep soil (1 = yes)	-0.044	0.046	0.161***	0.154*	0.163	0.012	0.069
	(0.082)	(0.110)	(0.042)	(0.082)	(0.251)	(0.050)	(0.076)
Poor soil quality (1 = yes)	-0.088	-0.187	-0.228***	0.003	-0.450	-0.158***	-0.266***
	(0.093)	(0.119)	(0.042)	(0.086)	(0.367)	(0.058)	(0.079)
High soil quality (1 = yes)	0.037	0.225**	-0.003	0.082	0.433	0.044	0.072
	(0.085)	(0.112)	(0.043)	(0.098)	(0.292)	(0.044)	(0.051)
Applied herbicide on plot	0.232**	0.047	0.233***	0.267**	-1.307	0.298***	-0.008
	(0.117)	(0.267)	(0.043)	(0.105)	(1.005)	(0.091)	(0.108)
Pesticide used (1 = yes)	0.086	0.376**	0.010	-0.070	0.443	-0.080	-0.113
	(0.194)	(0.161)	(0.075)	(0.122)	(0.407)	(0.069)	(0.084)
Lime used (1 = yes)	0.832*	0.158	-0.162	-0.433	0.199	-0.027	0.034
	(0.443)	(0.592)	(0.153)	(0.289)	(1.149)	(0.156)	(0.145)
Urea used (1 = yes)	-0.038	0.135	0.149	-0.086	-0.490	-0.088	0.101
	(0.523)	(0.849)	(0.108)	(0.263)	(1.572)	(0.159)	(0.229)
Maize plot (1 = yes)	0.160	0.722*	0.843**	0.105	3.462*	0.950***	0.913***
	(0.387)	(0.425)	(0.399)	(0.348)	(2.056)	(0.294)	(0.295)
Wheat plot (1 = yes)	0.390**	0.240	0.775***	0.447**	3.225	0.754***	0.758***
	(0.173)	(0.269)	(0.122)	(0.228)	(2.014)	(0.165)	(0.234)
Log of plot size (in ha)	-0.150**	-0.243***	-0.014	0.043	0.320	0.040	0.029
	(0.063)	(0.076)	(0.034)	(0.085)	(0.199)	(0.041)	(0.046)
$\lambda 1$		-1.162**	-0.067	0.453	-0.103	0.526	0.517
		(0.593)	(0.214)	(0.500)	(1.240)	(0.375)	(0.358)
$\lambda 2$	-0.185		-0.698**	-0.284	0.010	-0.288	-0.401
	(0.630)		(0.350)	(0.520)	(1.327)	(0.683)	(0.421)

λ3	0.442	1.156**		0.360	0.253	-0.254	-0.098
	(0.450)	(0.491)		(0.417)	(1.899)	(0.298)	(0.290)
λ4	0.447	-2.204*	0.106		-2.242	0.192	-0.370
	(1.065)	(1.173)	(0.323)		(3.580)	(0.488)	(0.573)
λ5	-0.082	-0.845	1.149**	0.202		0.436	0.346
	(0.801)	(0.656)	(0.478)	(0.557)		(0.759)	(0.419)
λ6	-0.883	1.710***	-0.313	-0.364	0.247		-0.115
	(0.654)	(0.583)	(0.299)	(0.632)	(1.862)		(0.489)
λ7	0.314	1.060	-0.087	-0.238	1.335	-0.565*	
	(0.936)	(0.793)	(0.273)	(0.438)	(1.658)	(0.319)	
Constant	3.453	-3.545	-0.121	1.644	-3.009	1.952**	1.844
	(2.471)	(2.207)	(0.840)	(1.647)	(6.666)	(0.967)	(1.293)
R-squared	0.264	0.288	0.376	0.212	0.350	0.379	0.192
Observations	436	367	2,102	537	148	1,366	1,239

Note: Standard errors in parentheses, bootstrapped with 100 replications; *** p<0.01, ** p<0.05, * p<0.1.

Table A8. Second stage regression estimates: returns to unpaid labor.

	Log of returns to labor (ETB/labor-day)						
	No ISFM	OF	IF	OF + IF	OF + IS	IF + IS	OF + IF + IS
Gender HH head (1 = male)	-0.187	0.264	0.231**	0.224	0.601	0.170*	0.061
	(0.147)	(0.168)	(0.099)	(0.187)	(0.553)	(0.099)	(0.139)
Age HH head (in years)	-0.009**	-0.008*	-0.005***	-0.005	0.000	-0.007***	-0.010***
	(0.004)	(0.004)	(0.002)	(0.004)	(0.008)	(0.002)	(0.003)
HH head has formal education (1 = yes)	-0.016	-0.140	-0.248***	-0.125	0.197	-0.159***	-0.151**
	(0.121)	(0.147)	(0.037)	(0.111)	(0.158)	(0.061)	(0.060)
No. of HH members	-0.076***	-0.013	-0.056***	-0.039	0.001	-0.054***	-0.039**
	(0.023)	(0.028)	(0.011)	(0.027)	(0.062)	(0.014)	(0.016)
No. of TLU owned	0.038*	0.062**	0.064***	0.038*	0.065	0.042***	0.058***
	(0.023)	(0.026)	(0.008)	(0.021)	(0.056)	(0.011)	(0.014)
Log of farm size (in ha)	0.016	-0.033	-0.170***	-0.186*	-0.423	-0.086	-0.065
	(0.102)	(0.148)	(0.048)	(0.096)	(0.358)	(0.074)	(0.062)
No. of social organizations HH is involved	-0.099	-0.123	0.051	-0.086	0.255	0.018	0.021

	(0.078)	(0.111)	(0.047)	(0.114)	(0.264)	(0.058)	(0.059)
Log of walking distance to nearest FTC (in min)	0.022	0.012	0.031**	0.012	0.060	0.017	0.029
	(0.027)	(0.031)	(0.014)	(0.023)	(0.053)	(0.021)	(0.020)
Talked to extension agent (1 = yes)	0.053	-0.084	0.052	0.084	0.044	-0.012	0.066
	(0.094)	(0.112)	(0.043)	(0.107)	(0.384)	(0.065)	(0.074)
Log of walking distance to nearest village market (in min)	0.005	-0.039	-0.068***	-0.088	-0.138	-0.074**	-0.036
	(0.057)	(0.078)	(0.023)	(0.091)	(0.178)	(0.036)	(0.051)
Agri-input dealer in Kebele (1 = yes)	-0.140**	-0.047	0.039	-0.072	0.243**	0.038	0.020
	(0.060)	(0.065)	(0.026)	(0.060)	(0.115)	(0.029)	(0.033)
HH has access to formal credit (1 = yes)	-0.058	-0.184	0.251***	-0.098	0.262	0.079	0.110
	(0.253)	(0.310)	(0.069)	(0.201)	(0.331)	(0.095)	(0.117)
Pest and disease stress (1 = yes)	0.050	0.163	-0.039	-0.066	-0.236	-0.297***	-0.066
	(0.110)	(0.124)	(0.067)	(0.182)	(0.221)	(0.086)	(0.089)
Weather stress (drought/flood/frost/storm) (1 = yes)	-0.192*	-0.047	-0.235***	-0.248**	-0.433	-0.304***	-0.195**
	(0.100)	(0.122)	(0.053)	(0.125)	(0.402)	(0.057)	(0.078)
Log of av. annual rainfall (in mm)	-0.449	0.255	0.196	0.231	-0.138	0.117	0.126
	(0.472)	(0.466)	(0.136)	(0.337)	(0.450)	(0.151)	(0.228)
Log of walking distance to plot (in min)	-0.062	0.082	-0.002	0.102	-0.290	0.068	0.053
	(0.072)	(0.125)	(0.041)	(0.172)	(0.354)	(0.081)	(0.147)
Plot owned (1 = yes)	-0.046	0.057	-0.091*	-0.076	0.222	-0.037	0.043
	(0.092)	(0.158)	(0.049)	(0.144)	(0.349)	(0.080)	(0.110)
Footslope (1 = yes)	0.168	-0.056	-0.062	0.025	0.184	0.047	0.084
	(0.124)	(0.106)	(0.045)	(0.097)	(0.196)	(0.056)	(0.060)
Hillslope (1 = yes)	0.119	0.112	-0.078	0.282**	0.138	0.072	0.184*
	(0.131)	(0.184)	(0.056)	(0.134)	(0.317)	(0.075)	(0.096)
Shallow soil depth (1 = yes)	-0.308**	0.026	-0.118**	-0.178	0.166	0.052	-0.269***
	(0.150)	(0.148)	(0.057)	(0.118)	(0.257)	(0.082)	(0.093)
Deep soil (1 = yes)	-0.053	0.099	0.093**	0.153	0.254	0.046	0.009
	(0.112)	(0.126)	(0.044)	(0.101)	(0.197)	(0.064)	(0.079)
Poor soil quality (1 = yes)	-0.126	-0.111	-0.282***	-0.067	-0.276	-0.251***	-0.313***
	(0.104)	(0.178)	(0.055)	(0.107)	(0.326)	(0.075)	(0.103)
High soil quality (1 = yes)	-0.002	0.325**	0.018	-0.073	0.344	0.029	0.068
	(0.091)	(0.153)	(0.049)	(0.111)	(0.356)	(0.060)	(0.061)
Applied herbicide on plot	0.211	0.093	0.227***	0.311**	-1.034	0.281**	-0.012

	(0.136)	(0.288)	(0.052)	(0.155)	(1.264)	(0.127)	(0.138)
Pesticide used (1 = yes)	0.164	0.495***	0.070	-0.107	0.360	-0.046	-0.006
	(0.217)	(0.174)	(0.092)	(0.181)	(0.356)	(0.114)	(0.096)
Lime used (1 = yes)	1.197**	-0.097	-0.214	-0.621*	-0.141	-0.235	-0.223
	(0.519)	(0.650)	(0.220)	(0.351)	(1.264)	(0.239)	(0.196)
Urea used (1 = yes)	-0.228	-0.560	0.081	0.017	-0.604	-0.179	0.305
	(0.655)	(1.162)	(0.135)	(0.335)	(1.784)	(0.236)	(0.374)
Maize plot (1 = yes)	-0.763*	0.081	-0.240	-1.238***	2.097	-0.368	-0.428
	(0.438)	(0.532)	(0.387)	(0.476)	(2.538)	(0.457)	(0.343)
Wheat plot (1 = yes)	-0.169	-0.277	0.186	-0.492	2.021	0.015	-0.058
	(0.170)	(0.298)	(0.135)	(0.344)	(2.370)	(0.275)	(0.249)
Log of plot size (in ha)	-0.141**	-0.284***	-0.022	-0.007	0.206	0.014	0.014
	(0.069)	(0.084)	(0.041)	(0.090)	(0.173)	(0.053)	(0.063)
λ1		-1.197	-0.270	0.444	-0.231	0.503	0.463
		(0.805)	(0.238)	(0.621)	(0.688)	(0.480)	(0.499)
λ2	0.119		-0.755*	-0.189	0.450	-1.114	-1.023**
	(0.613)		(0.433)	(0.653)	(1.271)	(0.680)	(0.471)
λ3	0.343	1.268**		0.594	-0.004	-0.188	0.089
	(0.449)	(0.618)		(0.564)	(1.694)	(0.405)	(0.439)
λ4	0.074	-2.725*	0.116		-1.199	0.184	-0.247
	(0.999)	(1.591)	(0.513)		(4.066)	(0.634)	(0.859)
λ5	-0.076	-0.872	1.689***	-0.057		1.405*	0.479
	(0.584)	(0.692)	(0.562)	(0.612)		(0.843)	(0.591)
λ6	-0.956	1.689**	-0.266	-0.281	-0.988		0.169
	(0.748)	(0.721)	(0.376)	(0.943)	(1.407)		(0.716)
λ7	0.533	1.303	-0.368	-0.422	1.608	-0.695	
	(0.936)	(0.909)	(0.330)	(0.488)	(1.980)	(0.472)	
Constant	9.335***	1.076	3.208***	4.310*	1.329	4.342***	3.877**
	(3.123)	(3.176)	(1.058)	(2.349)	(5.552)	(1.523)	(1.688)
R-squared	0.206	0.248	0.231	0.275	0.326	0.205	0.159
Observations	434	366	2,048	514	146	1,338	1,192

Note: Standard errors in parentheses, bootstrapped with 100 replications; *** p<0.01, ** p<0.05, * p<0.1.

Table A9. Robustness check: crop type effects per agroecological zone.

Panel A: Amhara & Oromia (moist/wet)												
ISFM combination	Land productivity w/o maize (kg/ha)				Land productivity w/o wheat (kg/ha)				Land productivity w/o teff (kg/ha)			
	ATT		p	N	ATT		p	N	ATT		p	N
OF	156.48	(152.76)	0.309	44	405.12	(85.74)	0.000	205	409.55	(86.10)	0.000	201
IF	598.57	23.51)	0.000	1,670	371.13	(17.81)	0.000	1,253	1246.91	(49.59)	0.000	451
OF + IF	711.16	(55.84)	0.000	244	568.08	(55.46)	0.000	237	904.38	(82.14)	0.000	159
OF + IS	472.06	(277.17)	0.101	13	1046.97	(136.37)	0.000	97	979.02	(125.86)	0.000	110
IF + IS	1137.99	(48.81)	0.000	432	1740.66	(54.64)	0.000	659	1725.14	(40.66)	0.000	901
OF + IF + IS	1177.60	(70.31)	0.000	210	1843.80	(51.92)	0.000	762	1786.74	(45.77)	0.000	894
Panel B: Tigray (dry)												
ISFM combination	Land productivity w/o maize (kg/ha)				Land productivity w/o wheat (kg/ha)				Land productivity w/o teff (kg/ha)			
	ATT		p	N	ATT		p	N	ATT		p	N
OF	73.00	(74.28)	0.328	57	254.43	(113.83)	0.026	141	274.80	(139.23)	0.050	104
IF	319.39	(40.60)	0.000	409	259.95	(42.61)	0.000	335	578.67	(106.17)	0.000	108
OF + IF	465.46	(60.13)	0.000	129	389.08	(75.17)	0.000	162	515.93	(73.82)	0.000	161
OF + IS	225.71	(147.96)	0.134	23	1577.82	(458.58)	0.001	19	881.22	(319.36)	0.007	36
IF + IS	472.82	(42.61)	0.000	368	305.82	(54.11)	0.000	198	734.49	(71.58)	0.000	182
OF + IF + IS	819.04	(49.00)	0.000	243	1131.22	(126.63)	0.000	129	1149.64	(73.15)	0.000	248

Note: Reduced sample size stems from logarithmic transformation of outcomes during estimation procedure; standard errors in parentheses; p-values indicate statistical significance of ATT.

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