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Joachim Vandercasteelen, Mekdim Dereje, Bart Minten, and Alemayehu Seyoum Taffesse

KU LEUVEN

Faculty of Economics and Business

LICOS Centre for Institutions and Economic Performance
Waaistraat 6 – mailbox 3511
3000 Leuven
BELGIUM

TEL:+32-(0)16 32 65 98
FAX:+32-(0)16 32 65 99
http://www.econ.kuleuven.be/licos

Scaling-up adoption of improved technologies: The impact of the promotion of row planting on farmers' teff yields in Ethiopia

Joachim Vandercasteelen*, Mekdim Dereje**, Bart Minten‡, and Alemayehu Seyoum Taffesse‡‡

ABSTRACT

Adoption of yield–increasing technologies is seen as a key driver to increase agricultural production in Sub-Saharan Africa. There is, however, a lack of empirical evidence on the impact of programs aiming to scale-up the adoption of improved technologies from research settings to the farm level. To fill this gap, this paper assesses the impact of the promotion of a new agricultural technology, i.e. row planting at reduced seed rate, on farmers' teff yields in Ethiopia. The results of a randomized control trial show that the program to scale-up row planting on average has a positive effect on teff yield. Depending on the measure of yield used, we find increases between 2 percent—but not statistically significant—and 22 percent. These findings are in contrast with larger yield increases found on village demonstration plots and in more controlled settings, as well as with the yield increase expected by teff farmers. The differences seemingly are linked to problems in implementation of the program and of its recommendations, methodological issues, and likely over-optimism on the potential of row planting in real farm settings.

Keywords: Ethiopia, teff yield, row planting, adoption of new technology

** Collaborator, Ethiopia Strategy Support Program, Development Strategy and Governance Division, International Food Policy Research Institute and PhD student at LICOS center of excellence, KU Leuven*

*** Research Officer, Ethiopia Strategy Support Program, Ethiopian Development Research Institute*

‡ Program Leader and Sr. Research Fellow, Development Strategy and Governance Division, International Food Policy Research Institute

‡‡ Sr. Research Fellow, Development Strategy and Governance Division, International Food Policy Research Institute

1. INTRODUCTION

The agricultural sector holds a prominent position in economic policies of most Sub-Saharan African (SSA) countries, with agricultural growth held to be a key driver for economic development, especially so in agriculture-based economies. Growth in the agricultural sector has generally been found to contribute to both poverty reduction and income growth by increasing food availability and rural incomes and providing surplus labor to industry, leading to spillover effects to the non-agricultural sector (De Janvry 2010; Christiaensen et al. 2012; Dethier and Effenberger 2012). Agricultural growth is commonly held to contribute to alleviate poverty and to spur the broader economy (World Bank 2008; Barrett 2008; McIntyre et al. 2009).

Yet, agricultural growth in SSA is considered to be low (World Bank 2008; De Janvry and Sadoulet 2010; Dethier and Effenberger 2012) and not much driven by technological change (Benin et al. 2011). SSA has not yet experienced a successful Green Revolution like Asia—which was based on the adoption of improved technologies. This lack of success in Africa has been attributed to underdeveloped agricultural research and extension systems, inefficient and missing markets, lack of infrastructure and institutions, and complex and heterogeneous agro-ecological systems (Otsuka 2006; Barrett 2008; World Bank 2008; Markelova and Mwangi 2010). The observed growth in agriculture has mainly been a result of unsustainable expansion of cultivated areas. Given the scarcity of suitable arable land and the rapidly growing population, it seems that SSA will need to scale-up the adoption of yield-increasing technical innovations to assure agricultural growth and food security for its citizens (Minten and Barrett 2008; De Janvry 2010; Godfray et al. 2010; Benin et al, 2011).

Ethiopia is a case in point. While Ethiopia has recently experienced one of the largest agricultural growth spurs in SSA (an average of six percent per year since 2000), maintaining this high growth rate will require successful adoption of new yield-increasing technologies (Dadi et al. 2004; Dorosh and Rashid 2012). To gain more insight in how the adoption of improved technologies can possibly increase land productivity in these settings, we study the case of row planting of teff in Ethiopia. Teff is Ethiopia's most important staple crop (at least in terms of area planted and value), but national average yield levels are low. One of the presumed reasons is that current agronomic practices constrain teff productivity. Farmers typically broadcast teff seeds, i.e. scattering seeds by hand, at high seed rates. This impedes teff yields because the uneven distribution of the seeds makes weeding difficult and increased competition with weeds and other teff plants lowers nutrient uptake by the individual teff plant (Berhe et al. 2011; Fufa et al. 2011). Technologies such as row planting and transplanting, where the seed rate is reduced and more space between seedlings is given, are assumed to be superior to traditional broadcasting because they allow for weeding, diminish competition between teff seedlings, and allow for better branching out (tillering) of teff plants.

To assess the potential of the reduced seed rate technologies, experiments were conducted in controlled settings where they showed large and positive impacts on teff yields (Berhe et al. 2011; Fufa et al. 2011). As a consequence, the Ethiopian government started rolling out these new technologies on a larger scale. In 2013, the technologies were promoted to almost 2.5 million teff farmers through large efforts by the national extension system and through farm radio partnerships (ATA 2013c). Similar promotion campaigns have been organized in the past with the aim to scale-up adoption of other improved agricultural technologies in Ethiopia, such as water harvesting and inorganic fertilizer use (Davis et al. 2010) or high input maize technologies (Howard et al. 2003). However, there are a lack of reliable and objective data that measure the impact of these widespread campaigns to promote the use of improved agricultural technologies. The goal of this paper is to fill this gap and provide evidence on the impact of the promotion of row planting on teff yields at the farm level.

In particular, we evaluate the impact of the government program during its 'pre-scale-up' phase in 2012/13. We collected data on almost 1,000 farmers from 36 villages exposed to the government's promotion campaign of these new technologies. Farmers were randomly selected to implement either row planting or broadcasting on an experimental plot, and all farmers received the same modern inputs (seeds and fertilizer) for free. As not all farmers could be selected randomly during implementation of the experiment, a matching exercise was required as well. Results from the randomized control trial and the matching exercise show that row planting increases teff yields by between 2 and 22 percent, depending on the measure of yield used. Similar experiments were carried out by extension agents at the village level and a significantly higher average yield increase of 26 percent was found. These results, however, contrast with much higher yield increases shown in research settings and more controlled environments (ATA 2013c). Our results indicate that the gap between teff yields in research environments and on-farm, a yield difference that is often found in such settings (e.g. Lobell et al. 2009), is explained by two effects – a first reduction between the research station level and the extension agents, and a second reduction between the level of the extension agents and farmers in their fields.

This research contributes to the literature in four ways. First, we extend the empirical literature on the impact of the adoption of improved technologies on yields at farm level (e.g. Feder et al. 1985; Duflo et al. 2008). While past literature has focused on the on-farm effect of newly introduced technologies, our contribution is to study the effect of a campaign promoting improved technologies on farm yields by implementing a large-scale randomized control trial. To our knowledge, this paper is the first to assess how scaling-up the adoption of technologies affects farmers' yield. Second, we measured impacts of the row planting promotion campaign simultaneously at the farm level and on village demonstration plots. The study finds that impacts are lower at the farm level compared to village demonstration plots, which, in turn, have much lower impacts than in research settings. The yield gaps found at each level might be explained by problems in program implementation and by methodological differences. As such, our findings contribute to the discussion on political agronomy (Sumberg et al. 2013). Third, we use different measurements of crop yields (crop-cuts of the plot; farmer assessments of plot output just before harvest, as well as after harvest and post-harvest operations), which is rarely done in the same study. The study finds strong correlations between these different measurements and our results are mostly robust with respect to the method used. Fourth, despite its importance in Ethiopia and Eritrea (teff is grown by 6.3 million smallholders in Ethiopia alone), teff has been largely ignored in international research, seemingly because of its localized importance in these countries. The research therefore contributes to the limited knowledge about the economics of teff productivity.

The rest of the paper is structured as follows. Background information on teff production and improved technologies in Ethiopia is presented in Section 2, whereas Section 3 discusses the set-up of the experiment at farm and village level. The methodologies and econometric strategies used in this study are described in Section 4. Section 5 and Section 6 respectively present the results and discuss the key findings . Lastly, conclusions and policy implications are provided in Section 7.

2. BACKGROUND

2.1. Teff

Teff (*Eragrostis tef*), a cereal crop that belongs to the grass family *Poaceae*, is endemic to Ethiopia and has been widely cultivated in the country for centuries (Teklu and Tefera 2005). The crop is found in most of the country —especially so in the highlands at altitude ranging from 1800 to 2100 meters above sea level—as it can be grown under diverse agro-ecological conditions. The main production areas are in Amhara and Oromia regions and, to a lesser extent, in Tigray and the Southern Nations, Nationalities and Peoples (SNNP) regions. Teff is resistant to extreme water conditions, as it is able to grow under both drought and waterlogged conditions (Teklu and Tefera 2005; Minten et al. 2013). Combined with its low vulnerability to pest and diseases, it is considered a low risk crop (Fufa et al. 2011; Minten et al. 2013). Teff is sown during the main *meher* rains between July and November, while harvesting is done in February. Seeds are broadcasted on a well ploughed soil and lightly covered with soil until germination. During the growing period, several weedings are often required (Assefa et al. 2011).

Teff is the country's most important staple crop in terms of both production and consumption, at least in value terms. During the 2012/13 *meher* rains, more than 6 million farmers allocated 22 percent of the national grain area to teff. On these teff lands, a total output of almost 4 million metric tons was obtained, accounting for 16 percent of all grain output. In 2013, the average teff yield reached 1.4 tons per hectare—an increase of eight percent from 2012 (CSA 2013). Although the recent increase was mainly due to an increase in production area, previous increases in teff production are attributed both to yield improvements and to expansion of the production area (Taffesse et al. 2011). Minten et al. (2013) evaluated national teff production for 2012 and estimated that teff is the most important food crop in the country. The value of its commercial surplus is second only to coffee. In addition to its importance as a staple food, teff straw is important for fodder and use in house construction (Teklu and Tefera 2005).

Teff is used in Ethiopia to produce the nation's staple dish *enjera*. Grinding teff grain into flour and mixing with water results in a spongy type of pancake. Teff is also used to brew local beer. It has high protein, fiber and complex carbohydrates content, a relatively low calorie content, and is gluten free (Berhane et al. 2011; ATA 2013c). It accounts for between 11 and 15 percent of all calories consumed in Ethiopia (Berhane et al. 2011, ATA 2013c) and provides about 66 percent of daily protein intake (Fufa et al. 2011). Almost two thirds of the Ethiopian population uses teff as their daily staple food. It is estimated that per capita consumption grew by four percent over the last 5 years (ATA, 2013c). Teff is considered an economically superior good, relatively more consumed by urban and richer consumers (Berhane et al. 2011; Minten et al. 2013). In urban areas, the share of per capita teff consumption in total food expenditure is 23 percent, while in rural area this is only six percent. In rural areas, teff is seen as a luxurious grain consumed only by elders or during special occasions. Growth in average incomes and faster urbanization in Ethiopia are likely to increase the demand for teff over time (Berhane et al. 2011).

2.2. Improved technologies and teff yields

Despite the importance of teff in Ethiopia, yields are remarkably low. While in 2012 - 2013, teff land productivity reached 1.4 ton per hectare, this is rather low when compared to other cereals such as maize (3.1 ton per hectare), rice (2.8 ton per hectare) and wheat (2.1 ton per hectare) (CSA 2013). Several factors explain this low yield. First, modern input use in teff production —such as inorganic fertilizer and improved seed—is low. Latest national estimates show that only two percent of teff farmers used improved seeds, although more than one third applied fertilizer for teff production (CSA 2012). Second, plant lodging, to which teff is susceptible, is perceived to be detrimental for teff grain production, especially during the grain-filling period (Berhe et al. 2011). Third, land is repeatedly ploughed before sowing to prepare the seedbed and control weeds, but this leads to increased erosion and lower soil fertility (Tulema et al. 2008; Fufa et al. 2011). Fourth, soil erosion has led to nutrient (mainly nitrogen and phosphorus) deficiencies in the drier areas of the country (Habtegebrial et al. 2007). Finally, there are significant post-harvest and processing losses (Fufa et al. 2011).

Overall, research on improved teff technologies has received limited international attention mainly because of the crop having only local importance (Berhane et al. 2011; Fufa et al. 2011). Not only has international funding for teff research been low, but national research also has been limited with institutions carrying out research on teff being understaffed. The crop therefore suffers from a lack of in-depth knowledge, which complicates extension efforts aimed at increasing teff production (ATA 2013b). However, some improved technologies have been identified to stimulate teff productivity. Experiments on genetic improvements and breeding achieved substantially higher teff grain yield (a 34 percent increase) in research settings. However, the improved teff varieties have not been widely accepted, seemingly associated with low consumer demand for the better performing varieties (Teklu and Tefera 2005; ATA 2013b). Later studies showed the potential of better land management for enhanced teff production—reduced tillage (Tulema et al. 2008), nitrogen fertilization (Habtegebrial et al. 2007), and water conservation measures (Araya et al. 2012)—but only in research settings.

It has been argued recently that low teff productivity is partly caused by the way farmers sow teff seed. Traditionally, farmers broadcast the seed using a rate of 25–50 kg per hectare (ATA 2013c). This practice reduces yields because of the uneven distribution of the seeds, higher competition between plants for inputs (water, light and nutrients), and difficult weeding once the plants have matured (Fufa et al. 2011). As a solution, it has been proposed to reduce seed rates and to plant seed in rows or to transplant seedlings (as is often done for rice, for example). Reducing the seed rate to between 2.5 and 3 kg per hectare allows for reduced competition between seedlings and optimal tillering of the teff plants. By row planting or transplanting the seeds, land management and especially weeding can also be done more readily and the incidence of lodging is reduced (Berhe et al. 2011, Chanyalew and Assefa 2013).

The belief in the potential of reduced seed rate technologies to increase teff productivity is the outcome of on-station agronomic research. The System of Teff Intensification (STI) —based on the insights of the System of Rice Intensification (SRI) experience (Moser and Barrett 2006) — assessed the impact of different planting methods on teff yield (World Bank 2012). Experiments in research settings[1] showed that when teff was transplanted in rows and appropriate types of fertilizer were used, teff yields were on average three times higher than yields obtained when using traditional broadcasting. Transplanting improved yields over broadcasting because it increased the number of plant tillers, produced stronger and fertile tiller culms, and the number of seeds per panicle increased (Berhe et al. 2011).

Given the positive results from on-station trials, the government initiated programs to promote the technologies at increasing scale (ATA 2013a). A technology package was offered to farmers that included the promotion of row planting (or transplanting) associated with a reduction of the seed rate to 5 kg/ha, a sowing depth of 2-3 cm and the provision of improved seed (*Quncho*) and recommended levels of fertilizer. Rather quickly, the focus shifted from transplanting to row planting, given widespread complaints from farmers of the high labor requirements for transplanting. In 2011, the Ministry of Agriculture (MoA), with the support of the Agricultural Transformation Agency (ATA), extended this teff package to 1,400 farmers. On-farm experiments were done in 90 Farm Training Centers (FTCs) in the four main teff producing regions (Tigray, Oromia, Amhara and SNNP). The results showed an increase of 75 percent in teff yield (ATA 2013). In 2012, the experiment was extended to almost 70,000 farmers from 1,337 FTCs. Data collected from 15,800 households indicated that teff yields had increased by 70 percent more than the national average (Berhe et al. 2011; ATA 2013c). In 2013, the program was rolled out nationwide to reach 2.5 million farmers (ATA 2013c).

However, not all research conducted on the yield effect of the row planting technique showed similar positive results. In 2011, several small-scale trials with farmers were run to assess the potential of row planting at reduced seed rate together with the application of blended fertilizers on teff yield. Most of the experiments showed promising results, but the

[1] At the Debre Zeit Agricultural Research Center, the first trial of STI compared traditional broadcasting with transplanting on three replications plots of 2 by 5 meters with two different types of seeds which were alternatively coated with fertilizer (Berhe and Zena 2009).

magnitude of the effect was lower than the earlier on-station results.[2] Moreover, the yield effect of row planting in some trials was only small or even negative and statistically not significant (due to different reasons; see e.g. Hiwot 2012; Feyiss 2012; Sahle 2012). The results of Ethiopian Institute of Agricultural Research (EIAR) trials showed that yield increases from implementing row planting were small and that changing the seed rate, planting depth and planting space did not affect teff yield significantly (Chanyalew and Assefa 2013). Even though ATA research tends to find (large) positive effects to row planting (even if it is scaled up), these alternative agronomic research findings cast some doubts on the claim that row planting is able to achieve enormous yield increases.

Overall, but there are doubts on the universal positive effect of row planting.

3. DESCRIPTION AND DESIGN OF THE INTERVENTION

3.1. Farm level

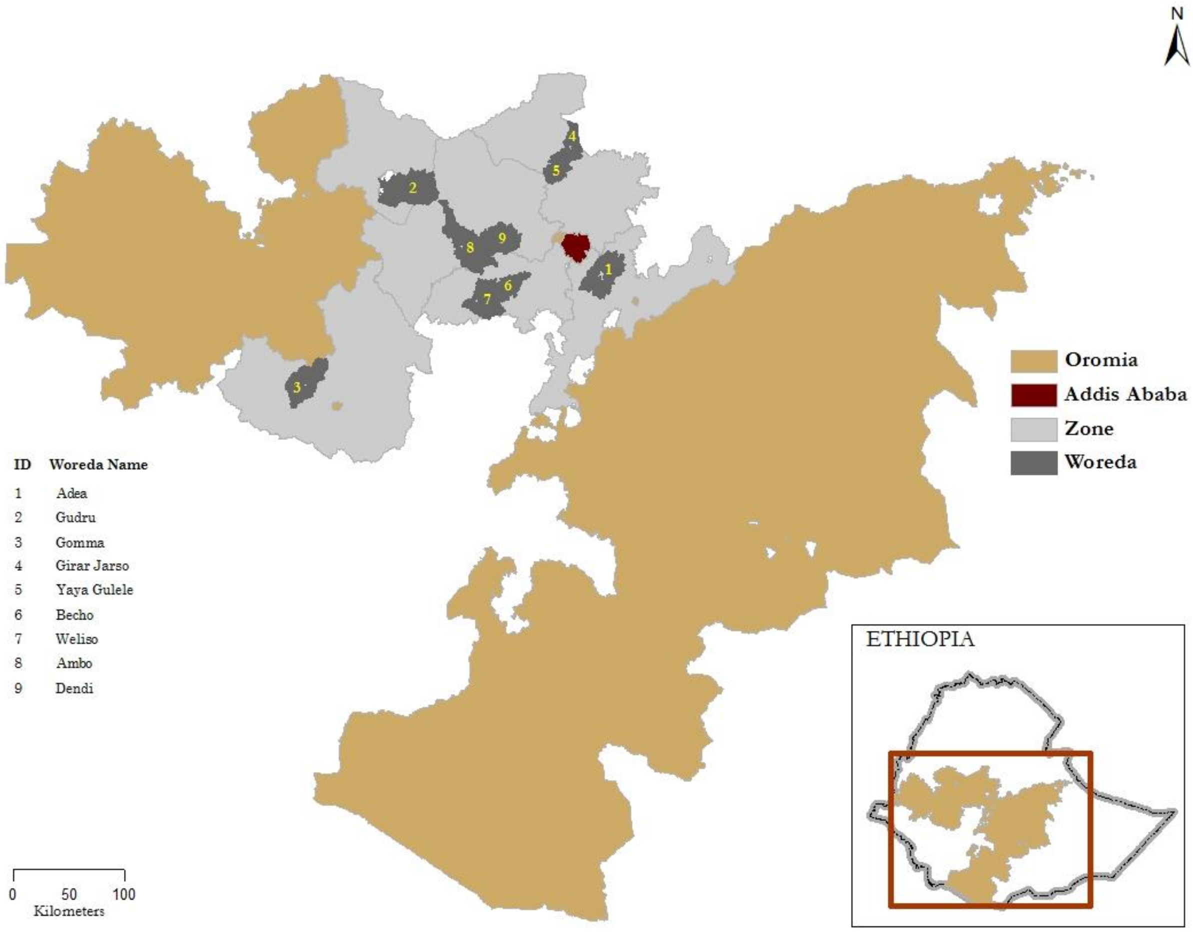
Our experiment evaluates the impact of the "pre-scale-up" program implemented in 2012, where reduced seed rate technologies were extended to a selected number of farmers. The design of the evaluation is in line with the roll-out of the program by the MoA in that year, with the support of ATA. However, some modifications were done to ascertain that the selection of farmers was done randomly and that an appropriate control group was constructed. The sample design followed a two-stage randomization approach. First, from the 23 Agricultural Growth Program (AGP)[3] *woredas* (communes) in the Oromia region (a major teff producing region), ten *woredas* were randomly selected. The ten selected *woredas* are shown in Figure 3.1 below. Four FTCs were then randomly selected out of all FTCs within a *woreda*, and in each FTC 25 farmers were randomly selected for the survey.[4] In the second stage, farmers were randomly allocated over treatment and control groups and ten farmers were selected to do either row planting or broadcasting. As few farmers showed interest in transplanting (given the heavy workload), five farmers were purposefully selected to implement that technology. Given the small sample, we will not present results of the analysis of the transplanting technology in this paper.

[2] Comparison of the sowing methods, i.e. broadcasting (at 25 kg per hectare) versus row planting (at 2.5 kg per hectare), showed in most trials that row planting increases grain yield and straw yield. The effect depends on the type of soil and the type of fertilizer use (blended fertilizer versus only DAP/urea) but varied between a 27—35 percent increase in teff yields and a 5–28 percent increase in straw yields (Abayu 2012; Tolosa 2012). Only Bezabih (2012) found grain yield increases of about 75%.

[3] AGP is a 5-year program aimed at reducing poverty by increasing agricultural productivity and improving market access for small holders in 83 woredas in Amhara, Oromia, SNNP and Tigray (Berhane et al. 2011).

[4] Initially, a total of 60 farmers was randomly selected – 5 to use transplanting, 10 to broadcast seed at the traditional seed rate by hand, 5 to broadcast seed at the traditional seed rate by machine, 35 to plant in rows by hand, and 5 to plant in rows by machine. From these 60 farmers, 25 were randomly selected to be interviewed.

Figure 3.1— Map of the intervention *woredas*



As in the program roll-out, the selection of farmers participating in the program within a FTC was done by the Development Agents (DAs). The DAs were also responsible for teaching and assisting farmers in implementing the new technologies. To facilitate this process, the MoA organized training for more than 5,000 DAs and distributed teff production manuals to all of them. We intentionally cooperated with the existing program roll-out and did not provide additional assistance towards the correct implementation of the technologies. The only difference in the selected *woredas* for the study was that DAs were trained on the inclusion of control farmers for the experiment. As per the program roll-out, all farmers were asked to grow teff using the allocated sowing technology on a small experimental plot of 300 m^2. Farmers assigned to row planting received 150 grams (5 kg per hectare) of improved teff seed (*Quncho*) for free, while the control group received 900 grams (30 kg per hectare) of the same seed, also for free. Finally, all groups received for free identical fertilizer packages (3 kg of both urea and DAP) to ensure that farmers used the same amount of inputs on the assigned experimental plot. The selected farmers in the survey area were visited three times, i.e. during the baseline survey (October 2012), the crop-cut measurement survey (November 2012 - January 2013), and the impact survey (February 2013). The set-up and implementation issues with each of the surveys are discussed below.

The baseline survey collected data from the farmers in the experiment on demography, agricultural and households assets, general agricultural production practices, experimental plot characteristics, teff farming practices (modern input use, tilling, and labor use) and teff production for the period 2011-2012. The baseline survey was not implemented completely as planned because several aspects of the experiment design were not achieved. One *woreda* did not follow the instructions for the intervention and was therefore dropped from the survey. In FTCs of other *woredas*, the DA was unable to achieve the planned 25 famers to implement the different technologies, mainly because of the lack of interest in new technologies (especially in transplanting). As a result of these problems, the baseline survey covered only 847 famers instead of the planned 1,000. Moreover, the assignment of farmers to row planting was not done randomly everywhere, despite clear instructions. In 17 FTCs, row-planters and control farmers were purposefully selected by the DA, resulting in 410 non-randomly selected farmers. Altogether, this left us with 437 randomly-selected farmers from 19 randomly-selected FTCs.

The second visit to the selected farmers was to measure teff output of the experimental plot just before harvesting. This exercise was done by enumerators of the Central Statistical Agency (CSA). The study benefitted from the experience of CSA in this area as their enumerators do this exercise annually in CSA's agricultural sample survey. Each experimental plot was subjected to 6 output measures during that survey: four sample crop-cut measurements (dry and wet weight measured by analog or digital scale), one total output measurement, and the farmer's expectations of teff output on the whole plot. Out of the 847 'baseline' farmers, 18 plot outputs could not be measured as farmers threshed their crop and sold it on the market before the survey team arrived. Additionally, no information on total output could be obtained from 12 farmers due to complete crop damage or because the teff from the experimental plot was mixed with teff from other plots. Finally, we were unable to collect data on sample measures for 261 farmers mainly because the sample plot was harvested before enumerators arrived or the sample could not be properly located within the experimental plot.

Finally, an impact survey was fielded after the teff harvest. This survey covered all 847 'baseline' farmers as well as 137 farmers initially selected for the experiment but which were dropped out of the baseline survey (the 'non-compliers'). This left a full sample of 984 farmers from 36 villages. The impact survey questionnaire was similar to the baseline survey, but collected information on input use, labor use, and production for the *meher* season 2012/2013. The survey also involved asking farmers to assess teff output on the experimental plot after harvest operations had been finalized. The impact survey only covered 967 of the 984 selected farmers because some farmers were not willing or were not able to cooperate and some farmers were intentionally dropped from the survey.[5] An overview of all respondents of the baseline and impact survey is given in Appendix 1.

To complement the quantitative surveys, qualitative and community data were collected to understand perceptions of participating and non-participating farmers on these teff technologies. After farmers harvested the teff from their experimental plot in the beginning of February 2013, focus group interviews were conducted in six FTCs which were part of the pre-scale-up phase, but not covered in the baseline survey. DAs were asked to gather a diverse group of ten farmers initially selected for the program and questions were asked about limiting factors of traditional production, program participation, perception on the new technologies, and assessments of the whole program. The qualitative insights helped to improve the design of the impact survey questionnaire. It also served as the basis of a community questionnaire that was fielded at the time of the impact survey. In each of the 36 'baseline' FTCs, ten farmers were selected by the DA to participate in this community interview. An informed group was gathered of mainly compliers (supplemented with two non-compliers), diversified over technologies, age, and gender. The last column of Appendix Table 1 shows the number of participants in the community survey. Questions were asked about the community, the cooperation with the DA and FTC, experiences with improved teff technologies, and participation in the program. This qualitative and community information is used for the interpretation of the impact findings at the farm level in Section 5.

3.2. FTC level

The reduced seed technology experiment was not only conducted at the farm level. DAs also implemented experiments on village demonstration plots (the FTC plots) and these experiments allowed to assess the impact of row planting on teff yield using alternative data. In each FTC, DAs were asked to roll out 10 experimental trials, each plot representing a unique combination of sowing technology and fertilizer application. DAs were instructed to use the improved seed, *Quncho*, on experimental plots of 100 m² and use fertilizer and seed in different combinations. Four plots were sown using the traditional broadcasting method with different combinations of DAP, urea, and number of weedings applied. Two plots were assigned to both row planting and transplanting with different quantities of fertilizer use. Two plots were allocated to broadcasting at reduced seed rate. Finally, two plots were assigned to either row planting or broadcasting at reduced seed rate, but sowing was done mechanically.

Each of the 36 FTCs should have implemented 10 experimental treatment combinations, resulting in data from 360 experimental plots at the FTC level. However, there were a number of implementation problems, resulting in a total of 331 trials only being successfully implemented.[6] Moreover, the described distribution of plots over different technology-fertilizer combinations and the associated specific applications of fertilizer and seed rate were not always achieved. An

[5] Nine 'baseline' farmers could not be interviewed: Three farmers were not willing or could not be reached to be interviewed and six farmers were purposely dropped from the survey because they did not practice the technology they were assigned to, but were forced by the DA to lie about an experimental plot that does not belong to them for both baseline and crop-cut survey. Ten non-compliers dropped out for different reasons – farmers could not be located or refused to be interviewed, migrated back to their homeland, etc.

[6] Data were missing for two kebeles, reducing the sample by 20 plots. All FTC plots in Dedo Warache were damaged and used as grazing land. Second, due to problems of communication, no information could be collected in Ganda Gorba. Within the other kebeles, the DA was not always able to successfully implement 10 trial plots. Some of the plots were completely destroyed by flooding or wild animals, while in S/ Chirecha the DA did not have enough land to implement all trials. Nine trials were not successfully implemented because of these reasons. Finally, several FTC plots faced some implementation problems because of pests, weeds or damage from cattle or wild animals, but data could be collected for these plots.

overview is given in Appendix 2.[7] As a result, all the FTC trials were pooled together according to the sowing technology that was used: traditional broadcasting, reduced seed rate broadcasting, row planting, and transplanting. To make straightforward comparisons with farm level data, only the information of the plots sown with traditional broadcasting and those plots allocated to row planting were used in the analysis here.

4. METHODOLOGY

4.1. Randomized control trial

The methodology and design described above provide a robust framework to measure the impact of row planting on teff productivity. The random assignment of farmers to different sowing practices and identical input distribution ensures that the difference in teff yield between the treated and non-treated farmers can be attributed solely to the sowing method. As a consequence, taking the mean difference between the two groups will give us an estimate of the effect of row planting on teff yield.[8] One parameter of interest is the effect of row planting on teff yield for those who actually implemented the technology on their experimental plot. This is the Average Treatment effect on the Treated (ATT), the average gain from using row planting for row-planters. Equation (1) shows the estimation set-up for the ATT, where Y_i is the teff yield, T_i is the treatment variable (T_i=1 if a farmer actually implemented row planting and 0 otherwise), and ε_i is the error term that contains all unobservable characteristics of farmers that affect teff yield:

$$Y_i = \alpha + \beta * T_i + \varepsilon_i \qquad (1)$$

The treatment variable in the ATT is subject to self-selection. Farmers that implement row planting on their experimental plot when assigned to do so, might systematically differ from those that refuse or are unable to adopt. Including the latter in our sample puts the results in the Intention-To-Treat (ITT) framework (Cameron and Trivedi 2005; Duflo et al. 2007; Khandker et al. 2010). All farmers initially assigned to do row planting are considered as treated, while all farmers selected for broadcasting are counted as controls, whether or not they actually implemented the assigned technology. The ITT makes sense, as nearly 24 percent of the farmers initially selected for implementing the assigned technology were not able to do so correctly. The ITT is also more policy relevant, as compliance with new technology adoption is imperfect. Even though the experiment might be scaled up to other teff farmers, some farmers will choose not to adopt even if they are offered the new technology.

The ITT measures the effect of row planting on teff yield for those farmers who were initially selected to participate in the experiment, irrespective of the actual implementation of the assigned technology on their experimental plot. The ITT is likely to underestimate the effect of row planting on those who actually implement it, because non-compliance introduces a downward bias in the impact of row planting. To get at the ITT, we re-estimate equation (1) on the full random sample but use now the initially selection S_i as the treatment variable. S_i takes the value of 1 if the farmer was initially randomly selected for the experiment, and zero if not.

$$Y_i = \alpha + \beta * S_i + \varepsilon_i \qquad (2)$$

If it is assumed that actual participation in the experiment is driven by unobservable factors that also affect farmers' behavior, initial selection can be used as an instrument for actual participation (Khandker et al. 2010). In this case, the Local Average Treatment Effect (LATE) is the impact of row planting for those farmers whose participation in the experiment is affected by the initial selection by the DA. The LATE is a valid measure of the treatment effect given that (i) when a farmer is initially selected to receive the technology, the probability to implement the technology is higher than when the farmer was not initially selected; and (ii) there are no defiers, i.e. farmers that did not implement row planting when selected and would make made the same decision if they were not selected for the experiment (Duflo et al. 2007; Khandker et al. 2010). As the experiment is part of the first year roll-out of the reduced seed rate technology, both assumptions are likely to hold.

4.2. Matching

For the previous analysis, we exclude those FTCs where the allocation of the technology over farmers was not done randomly. In such FTCs, farmers selected to implement row planting might systematically differ from control farmers because of the purposive selection by DAs. DAs might prefer certain farmers to implement the new technology based on

[7] In Appendix Table 2, only averages per kebele are given for seed rate, fertilizer application and the number of weedings. Even though specific recommendations were given for each plot, the table shows large variations in seed use, fertilizer application and number of weedings across kebeles. If the implementation of the different trials was done correctly, these should have been the same everywhere.
[8] The effect of row planting refers to the combined effect of sowing the seeds in rows and applying lower seed rates.

their farm characteristics, e.g. better teff yields in previous years, more educated or experienced household head, and closer distance to the FTC.[9] A selection bias occurs because the characteristics that determine farmers' selection for the technology also affect the level of their teff yield (Duflo et al. 2007). As a consequence, the expected difference in teff yield between the control and treated group may not be entirely attributed to the technology implemented but also is related to the factors that drive the selection of farmers. The selection bias is then a preexisting difference in yield between treated and non-treated groups due to other factors than the sowing method. If it is assumed that selection is based on observable characteristics—like age, education, household assets, etc.—it is still possible to get an unconfined estimate of the impact of row planting on land productivity (Duflo et al. 2007; Khandker et al. 2010). The selection bias can be minimized by matching farmers between the two groups that are similar in observable characteristics not affected by the experiment.

This is what the Propensity Scoring Matching (PSM) method does. It estimates the probability of participation in treatment using observed characteristics and uses this propensity score to match treated and non-treated farmers. In using PSM, the counterfactual[10] is identified by the average teff yield of the matched control group (Khandker et al. 2010). The ATT is then estimated as the average difference in teff yield between treated and matched non-treated farmers. To properly match farmers, the overlap assumptions condition should hold: that is, for each treated farmer there exists a non-treated farmer that is similar in observable characteristics, i.e. has a similar propensity score (Cameron and Trivedi 2005). Implicitly, the PSM method assumes selection on observable characteristics only and hence unobserved characteristics should not affect the program treatment. This implies that the expected yield from treatment is the same for treated and control farmers, when two farmers are compared with the same propensity score (Khandker et al. 2010). In our analysis, it is safe to assume that the DA uses observable farmer characteristics (age, education, location, etc.) to decide on the allocation of technologies over farmers. Moreover, the variables used for matching farmers were collected during the baseline survey and are therefore unaffected by the program itself.

4.3. Yield measurement

Teff yields are the main outcome variable in our experiment. However, measuring yields in these settings is not straightforward. Yields are calculated as output divided by area and measurement errors might occur in both variables (De Groote and Traore 2005; Carletto et al. 2013). By using alternative methods and measures for yields, we aim to assure robustness in our findings. An overview is given below on how data on output and area were collected in the different surveys, and all tables and figures in this section describe the correlation between the different measures. Detailed descriptive statistics on distribution patterns for output and area are presented in Appendix Table 3.

If the guidelines had been followed correctly, all experimental plots should have had a standardized area of 300m². However, there were both small and large deviations from these guidelines. Data on area were collected through measurements during the baseline survey and during the crop-cut exercise. Enumerators were instructed on area measurement methods during the training for the baseline survey and received ropes and measurement tapes to measure the length and width of the plot at the time of the baseline survey.[11] Additionally, the area of the experimental plot was again measured by CSA using a compass and rope method during the crop-cut survey. All corners of the experimental plot were identified and both the distance and angle between two consecutive corners was measured. This information was used to calculate the area in square meters. The study finds strong—but not perfect —correlation of these two measures, i.e. 88 percent. In further analysis, we used the measurement during the crop-cut, as it was closer to the actual area, and we only relied on the area measured during the baseline (or impact) survey if the crop-cut measurement was missing.

Data on teff output were collected at two different periods and a total of seven different measures of output were obtained. First, just before harvest, enumerators visited each farmer to measure output from a 4 by 4 meter area within the experimental plot. A rigorous sampling procedure was followed to randomly determine the location of the sample area within the plot. Just before the teff was ready to be harvested, a crop-cut of that area within the plot was done. After the output from this sample area was harvested and threshed, wet weight was measured using both analog and digital balances. The teff from that sample area was then dried and weighed, again using the two types of weighing balances. Table 4.1 shows the very high correlation between the wet and dried measures and the analog and digital weights. As expected, dried weights are lower than the wet weights, but the differences are small, reflecting the limited moisture retention capacities of teff due to the small size of its seed. Analog weights are higher than digital ones, but the differences are not significant. Finally, when farmers harvested and threshed their experimental plots, enumerators

[9] Informal and focus groups discussions revealed that in the 17 non-random FTCs, DA purposefully selected better farmers to do row planting to be able to present substantial yield increases to their *woreda* officials.
[10] The teff yield of treated farmers in the case that they would not have implemented row planting
[11] Non-compliers were only interviewed in the impact survey, hence plot areas were measured at that point.

measured the teff output for the whole plot after drying using the digital balance. Dividing the output by area gives us the "yield from crop-cut" and this variable is our preferred crop-cut yield measure. There is a rather strong correlation (70 percent) between the crop-cut yield measured from the whole plot and the sample crop-cut, but the latter could not be collected for all farmers (as described in section 3.1). Whole plot crop-cut measures are also preferred because they do not suffer from sampling errors.

Table 4.1—Correlation matrix of crop-cut measures for farmers in the randomized control trial

		Correlation coefficients (in %)		
	mean (kg)	analog wet	digital wet	analog dried
Sample crop-cut				
analog wet	1.77			
digital wet	1.75	99.4		
analog dried	1.72	99.6	99.2	
digital dried	1.71	99.2	99.7	99.3
Crop-cut whole plot				
analog dried	48			

Source: Authors' calculations.

Second, farmers were asked to assess the output they expected to get from the whole experimental plot at the time of the crop-cut exercise, i.e. just before harvest. In further analysis, we refer to this measure, divided by the area of the experimental plot, as the "yield assessment before harvest".

Third, at the time of the impact survey, after the harvesting, drying, and threshing operations were finished, all farmers were asked to estimate the teff output of the experimental plot. In further analysis, we refer to this output assessment, divided by the relevant area of the plot, as the "reported yield after harvest". The first column in Table 4.1 shows that the yield assessment before harvest was on average the highest (1.38 ton/ha) followed by the yield reported after harvest (1.30 ton/ha) while the crop-cut yield (1.15 ton/ha) was the lowest. The declared measures are on average at least 10 percent higher than the crop-cut measures of yield, which might indicate over-optimism by farmers in output assessment.[12]

Table 4.2—Comparison of the three yield measures for farmers in the randomized control trial

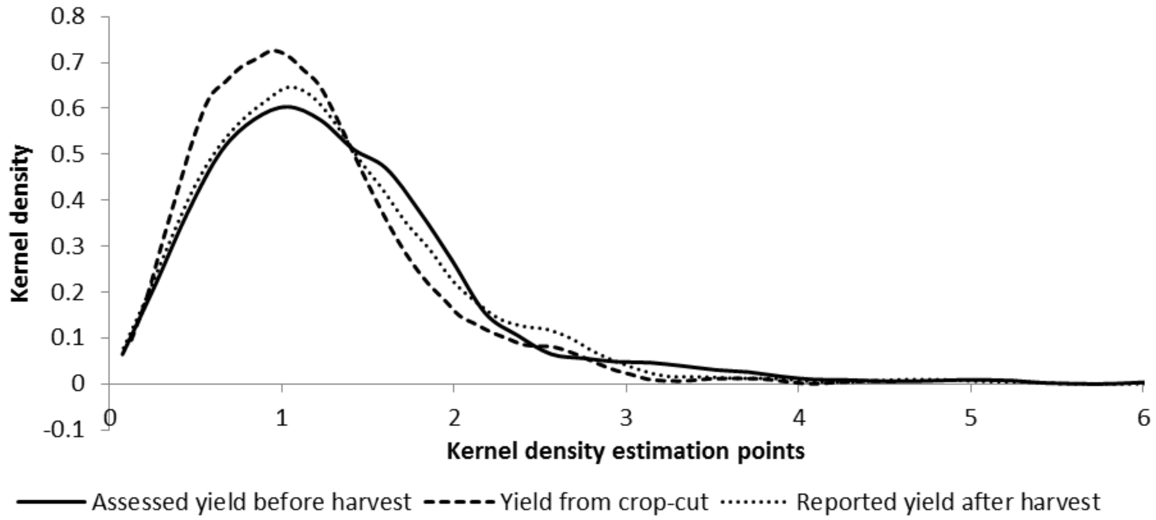
		Correlation coefficients (%)		t- value of paired t-test	
	mean (ton/ha)	Assessed yield before harvest	Yield from crop-cut	Assessed yield before harvest	Yield from crop-cut
Assessed yield before harvest	1.38				
Yield from crop-cut	1.15	28.9		3.91***	
Reported yield after harvest	1.30	31.1	75.1	1.39	5.72***

Source: Authors' calculations.
Notes: Asterisks represent level of statistical significance: * (10% significance), ** (5% significance), *** (1% significance)

Each of these measures has its own benefits and drawbacks. While crop-cuts generate seemingly the most objective measure of yield, farmers' output estimates for whole plots might be preferred as farmers' output for the whole plot take into account losses during harvest, transport, and threshing. Moreover, the latter has more observations and allows estimation of the ITT and LATE. While yields assessments after harvest are seemingly better as they measure effective outputs, it can also be argued that assessments just before harvest and crop-cuts might be a better approximation of true land productivity. This is because harvesting and post-harvest activities—such as transporting teff from field to home, drying, as well as threshing—often lead to important losses in the actual output obtained from a plot. Moreover, enumerators were present at the field of the farmer during the pre-harvest assessment and they might therefore have been in a better position to validate the farmer's assessment (Fermont and Benson 2011). Previous research in this area has shown that crop-cut data do not outperform farmers' estimates as both measures might suffer from biases (Murphy et al. 1991; Fermont and Benson 2011).

[12] There is no indication that row-planters overestimate their yield more than control farmers to impress enumerators or DAs. Row-planters and control farmer tend to overestimate yields before harvest by 45 and 30 percent, respectively, while they overestimate yields after harvest by 24 and 14 percent, respectively. However, the overestimation is not significantly different between the two groups (the t-value of mean-comparison test is -1.4 in both cases).

Figure 4.1—Kernel estimates of different measures of teff yields for random farmers



Source: Authors' calculations.

Table 4.2 and Figure 4.1 present different measures to compare the three yield variables described above after clear outliers were removed. Table 4.2 show that the yield measured during crop-cut and assessed after harvest are strongly correlated, while the relation of both measures with the expected yield is weaker (3rd and 4th column). The last two columns of Table 4.2 assess the equality in distributions of the yield variables by comparing their means using the paired t-test. The tests show that the distribution of reported yield after harvest and assessed yield before harvest are statistically not different. Finally, the distribution of the three yield measurements is shown in Figure 4.1. Crop-cut measurement seems to have a tighter distribution than the two other estimates, which are seemingly more correlated.

5. IMPACT ANALYSIS

The impact analysis of the program to promote row planting on teff yields presented here is split in three sections. In the first section, we limit the analysis to the farmers that were randomly assigned to treatment and control. Second, we use all the data collected at farm level, including from those farmers who were not randomly selected, and analyze the impact by using matching methods. Finally, we rely on the data from the trial implemented by DAs in experimental demonstration plots at the village level.

5.2. Randomized control trial

The Randomized Control Trial (RCT) uses data from these villages/FTCs where the DA allocated the different technologies over farmers in a random manner.[13] First, we restrict the sample to the compliers—for control and treatment farmers—only. Farmers that did not implement the assigned technology or failed to comply with the recommendations are dropped in this first stage of analysis.[14] The difference in teff yield between the control and treatment group is a valid estimate of the treatment effect assuming that both groups are balanced in characteristics that determine teff yield. The balancedness test in Table 5.1 indicates that both groups of farmers are indeed similar in almost all of the measured characteristics as shown by insignificant t-values for most of the coefficients.[15] The observed difference in teff yield between control and treated farmers in the RCT is therefore assumed to be caused by the assigned technology only. A significant difference between control and treated farmers, however, is the area allocated to the experimental plot, since control farmers tend to have larger experimental plots than row-planting farmers. It seems that famers experimenting with reduced seed rate technologies were willing to implement the technology, but only on a small experimental plot.

[13] More precisely, the only ones willing to participate in the experiment were model farmers, who tend to be more educated and better-off farmers. Although this makes it more difficult to generalize our findings to all teff farmers in Oromia, it does not affect our evaluation of the reduced seed rate technology program because model farmers were specifically targeted by the government to adopt the new technologies first (ATA, 2013b).
[14] However, during the impact survey it was observed that many farmers did not follow the guidelines of the experiment or what the DA had told them, resulting in seed use, fertilizer use and experimental plot areas that was out of line with the recommendations. When DAs did not assist farmers in measuring the experimental plot or did not distribute inputs on time, problems with implementing the experiment were exacerbated.
[15] Although all selected farmers are model farmers and hence should be similar in characteristics, we performed balancedness tests to check whether there are no differences between treated and control farmers. Both groups are similar in age, literacy level, distance to FTC, agricultural assets, livestock holdings, non-farm activities, soil quality, number of weedings and organic inputs but not in gender, area and urea usage.

Table 5.1—Balancedness of control versus treated farmers

Variable		Control		Treatment	
		Mean	se	Coefficient	t-value
Household head characteristics	Age (years)	43.6	(0.94)	-0.44	-0.37
	Gender (male=1)	99.4	(1.23)	-2.90**	-1.85
	Literacy (yes=1)	69.9	(3.56)	4.93	-1.09
	Primary education (yes=1)	66.7	(3.68)	4.99	1.07
Household characteristics	Distance to FTC (minutes)	33.7	(2.04)	0.13	-0.05
	Total household assets value (ln of Birr)	7.2	(0.16)	0.15	0.73
	Total agricultural assets value (ln of Birr)	6.8	(0.08)	-0.07	-0.72
	Income from other activities (yes=1)	79.5	(6.98)	-11.00	-1.24
	Area (m²)	572.5	(28.50)	-199.80***	-3.70
Experimental plot	Red colored soil (yes=1)	31.4	(3.69)	-1.88	-0.40
	Brown colored soil (yes=1)	9.6	(2.24)	-1.74	-0.61
	Black colored soil (yes=1)	57.7	(3.96)	0.18	0.04
	Tan colored soil (yes=1)	1.3	(1.45)	3.44**	1.87
	Sloped plot (yes=1)	16.7	(2.81)	-3.67	-1.03
	Improved Quncho seed used (yes=1)	99.4	(0.68)	-0.15	-0.17
	Distance to plot from house (minutes)	10.8	(0.80)	-0.25	-0.24
	Number of tilling (number)	4.9	(0.13)	0.09	0.60
	Organic input used (yes=1)	12.8	(2.56)	-2.19	-0.68
	Inorganic fertilizer used (yes=1)	99.4	(0.40)	0.64	1.28
	Number of weedings (number)	2.0	(8.14)	0.12	1.19
	Amount of urea used (g/m²)	9.1	(0.34)	1.22***	2.43
	Amount of DAP used (g/m²)	11.4	(0.51)	0.40	0.57
	Value of herbicide used (birr/ha)	196.0	(17.70)	17.30	0.51

Source: Authors' calculations.

Notes: se – standard error; Asterisks represent level of statistical significance: * (10% significance), ** (5% significance), *** (1% significance).

Table 5.2 presents the results of the impact of the program to promote row planting measured through the data of the RCT. The table reports the different measures of treatment (ATT, ITT, and LATE) for different yield measurements (assessed yield just before harvest, crop-cut yield, and the reported yield after harvest). Within each of these columns, the first part reports the average teff yield for the control group (the "constant"). The second part is the point estimate of the treatment effect on teff yield. The different row blocks refer to different measurements of the treatment effect. The first block represents the ATT for the different yield measures while the middle and last block report respectively the ITT and LATE on farmers' declared yield after harvest. These latter measures take into account possible selection bias by including the sample of farmers that were initially selected to be part of the experiment, irrespectively of whether they actually implemented the technology (correctly). In total we encountered 127 such non-compliers.[16]

[16] Eighteen row-planters did not implement the assigned technology and shifted to broadcasting, mainly because they did not receive appropriate training or the inputs did not arrive or were delivered too late. Thirty-seven farmers were not covered in the baseline because the area of their experimental plot was ether too small or too large compared to the recommendations or seedlings were damaged. More worrisome are the non-compliers for which we were unable to retrieve their reason for non-compliance. Thirteen farmers reported that they did not implement the technology, but provided information about the assigned technology on the experimental plot. Fifty-eight other non-compliers reported that they did not face any implementation problem, and it is unclear why they were then dropped from the baseline.

Table 5.2—Effect of row planting on farmers' teff yield in the randomized control trial

Treatment effect		Yield from crop-cut		Assessed yield before harvest		Reported yield after harvest	
		constant	row planting	constant	row planting	constant	row planting
ATT	Coefficient	1.142***	0.020	1.249***	0.215**	1.214***	0.144*
	se	(0.052)	(0.066)	(0.076)	(0.098)	(0.063)	(0.081)
	Observations	383		395		394	
ITT	Coefficient					1.202***	0.153*
	se					(0.066)	(0.081)
	Observations					486	
LATE	Coefficient					1.204***	0.158*
	se					(0.065)	(0.084)
	Observations					486	

Source: Authors' calculations.

Notes: ATT= Average Treatment effect on the Treated, ITT=Intention-To-Treat, LATE=Local Average Treatment Effect. Standard errors (se) in parentheses under coefficient. Asterisks represent level of statistical significance: * (10% significance), ** (5% significance), *** (1% significance).

When focusing on the crop-cut data, we do not find a significant impact of the row planting promotion program on teff yield. Implementing row planting on the experimental plot increases farmers' yield by two percent, but this effect is not statistically different from zero. In the case of assessed yields just before harvest, a stronger effect of row planting is found as sowing the seeds in rows increases the teff yield by 21.5 percent. This effect is significant at the 5 percent level. The teff yield declared by farmers after harvest also shows positive impacts. The different measurements of treatment effect (ATT, ITT and LATE) show that row planting increases declared teff yield on average by between 14 and 16 percent. The farmers that actually implemented row planting on their experimental plot realized an increase in teff yield of 14 percent compared to those who used traditional broadcasting (the ATT estimate). For farmers initially selected to do row planting in the experiment, teff yield increased by 15 percent (the ITT estimate).[17] Finally, if the participation in the experiment is influenced by farmers' initial selection for the program, row planting increased teff yield by 16 percent (the LATE estimate). In short, we find evidence that row planting improves teff yield, but its effect is moderate and much lower than the yield increases found in experimental settings.[18]

In the previous analysis, we assumed that the effect of row planting is the same for each of the treated farmers. However, the treatment effect might be heterogeneous and vary among individuals (Cameron and Trivedi 2005). To check for such heterogeneous effects, we now control for additional variables that might explain different treatment effects over treated farmers. After controlling for the age, education, and gender of the household head; household size; farm size; previous teff experience and knowledge of row planting; whether the experimental plots were larger or smaller than the recommended size; and the interactions of these factors with treatment, none of the variables has a significant heterogeneous effect. Table 5.3 does show that having a larger experimental plot (negative) and a larger household size (positive) affects teff land productivity, but this effect is the same for all participants.

[17] The small difference between the ATT and the ITT point estimates is however not significant (t-test=-1.65), so there is no indication of a downward or upward bias in the ATT estimate.

[18] Several robustness checks confirmed our results. Estimation without controlling for outliers, using area and output from the same source and individual sample crop-cuts (dry/wet and analog/digital) gave similar results.

Table 5.3—Heterogeneous effects of row planting on teff yield

		Assessed yield before harvest		Yield from crop-cut harvest		Reported yield after harvest	
Variables		**Level**	**Interaction treatment**	**Level**	**Interaction treatment**	**Level**	**Interaction treatment**
Row planting (yes=1)	Coeff.	0.619		0.047		-0.040	
	se	(1.134)		(0.793)		(0.933)	
Age of household head (years)	Coeff.	0.001	-0.008	0.002	-0.002	0.006	-0.001
	se	(0.007)	(0.009)	(0.005)	(0.006)	(0.006)	(0.007)
Primary education household head (yes=1)	Coeff.	-0.055	0.161	0.046	-0.089	0.190	-0.090
	se	(0.166)	(0.218)	(0.120)	(0.154)	(0.138)	(0.180)
Gender of household head (male=1)	Coeff.	0.006	0.083	0.028	-0.006	-0.022	0.067
	se	(0.080)	(0.100)	(0.056)	(0.070)	(0.067)	(0.084)
Farm size (ln of ha)	Coeff.	0.280	-1.164	-0.753	0.367	-0.785	0.402
	se	(0.903)	(0.957)	(0.622)	(0.659)	(0.743)	(0.788)
Size of the household (number of persons)	Coeff.	-0.012	0.052	0.051**	-0.048	0.061**	-0.069
	se	(0.035)	(0.045)	(0.025)	(0.032)	(0.029)	(0.037)
Previous experience with teff (yes=1)	Coeff.	-0.009	0.381	-0.087	0.176	0.120	0.067
	se	(0.460)	(0.552)	(0.323)	(0.384)	(0.382)	(0.457)
Previous knowledge of row planting (yes=1)	Coeff.	0.572	-0.391	0.270	-0.158	0.300	-0.148
	se	(0.413)	(0.479)	(0.284)	(0.327)	(0.340)	(0.395)
Too large experimental plot w.r.t. guidelines (yes=1)	Coeff.	-0.291*	-0.099	-0.257**	0.142	-0.283**	-0.064
	se	(0.162)	(0.211)	(0.155	(0.149)	(0.134)	(0.175)
Too small experimental plot w.r.t. guidelines (yes=1)	Coeff.	0.214	0.299	0.057	0.189	0.309	0.058
	se	(0.242)	(0.288)	(0.170)	(0.202)	(0.200)	(0.237)
Constant	Coeff.	0.653		1.219*		1.060	
	se	(1.021)		(0.716)		(0.841)	
Observations		395		383		394	

Source: Authors' calculations.

Notes: for each yield measure, the first column reports the point estimate of the covariate while the second column reports the interaction effect with treatment. Standard errors (se) in parentheses under coefficient (Coeff.). Asterisks represent level of statistical significance: * (10% significance), ** (5% significance), *** (1% significance)

5.3. Matching

In the RCT, our analysis focused on those farmers that were randomly selected to be a treatment or control farmer. We now look at the full sample of farmers that were interviewed in both baseline and impact survey, irrespectively whether the DA allocated technologies over the participating farmers randomly. This imperfect randomization implies that the impact of the reduced seed rate technologies is no longer simply the difference between the mean of the treated and control groups. We therefore match row-planters that were either randomly or purposefully selected with controls from all 36 villages. The matching exercise based on several household and experimental plot characteristics is reported in Table 5.4. The PSM probit estimation results indicate that being a male increases the probability of being treated, while having a plot with some slope has the reverse effect. Several balancing tests (presented in Appendix Table 4) show that the balancing properties are fulfilled.[19]

[19] We assess the quality of the matching exercise using the procedures described in Caliendo and Kopeining (2008). All balancing tests show that the distribution of covariates between treated and control does not significantly differ after conditioning on the propensity score. Appendix 4 also shows the distribution of the propensity score and the common support region. The figure indicates the proper distribution of the propensity score over treated and non-treated farmers.

Table 5.4—Estimation of the propensity score

Probability of being a row-planter	Coefficient	Standard Error
Age of household head (years)	-0.003	(0.004)
Primary education household head (yes=1)	0.096	(0.101)
Gender of household head (male=1)	0.541**	(0.227)
Size of the household (number of persons)	0.001	(0.022)
Household is a model farmer (yes=1)	-0.081	(0.092)
Black colored soil (yes=1)	-0.057	(0.111)
Tan colored soil (yes=1)	0.122	(0.316)
Brown colored soil (yes=1)	-0.004	(0.178)
Sloped plot (yes=1)	-0.236*	(0.130)
Household asked for a loan (yes=1)	-0.085	(0.093)
Household had non-agricultural income (yes=1)	-0.073	(0.055)
Household is an iqub member (yes=1)	0.100	(0.135)
Household owns a mobile phone (yes=1)	0.100	(0.113)
Distance to road (minutes)	-0.036	(0.181)
Total value of household assets (ln of birr)	0.018	(0.023)
Total value of agricultural assets (ln of birr)	0.026	(0.041)
Livestock earnings (ln of birr)	-0.005	(0.016)
Constant	-0.306	(0.439)

Source: Authors' calculations.
Notes: Asterisks represent level of statistical significance: * (10% significance), ** (5% significance), *** (1% significance)

Table 5.5 reports the ATT for the three different measures of teff yield. The first block reports the results for the Nearest Neighbor Matching (NNM) algorithm and the second for the Kernel Matching (KM) algorithm, the two most commonly used procedures for PSM. The matching results are broadly in line with the results from the RCT. The effect of row planting on crop-cut yield is insignificant in the crop-cut data. The effect of row planting on assessed yields before harvest is similar to before: row planting increases yield significantly by 20 percent and 12 percent in the NNM and KM specification respectively. In the last column, the ATT on the declared yield after harvest confirms our earlier finding that using row planting on the experimental plot increases teff yield significantly by 17 percent for both matching algorithms.

Table 5.5—Effect of row planting on farmers' teff yield in matching exercise

Matching algorithm		Yield from crop-cut	Assessed yield before harvest	Reported yield after harvest
Nearest Neighbor Matching (NNM)	Number of row-planters	428	435	495
	Number of controls	190	198	215
	ATT	0.112	0.205***	0.167***
	Standard error	(0.072)	(0.099)	(0.077)
	Constant	1.221***	1.382***	1.316***
Kernel Matching (KM)	Number of row-planters	428	435	495
	Number of controls	275	283	316
	ATT	0.100	0.115*	0.166***
	Standard error	(0.065)	(0.063)	(0.071)
	Constant	1.239***	1.472***	1.317***

Source: Authors' calculations.

Notes: ATT= Average Treatment effect on the Treated. Asterisks represent level of statistical significance: * (10% significance), ** (5% significance), *** (1% significance)

5.4. FTC plots

In this section, we analyze the FTC plots, i.e. the demonstration plots at the village level managed by the DAs themselves. In this case, we expect the treatment effect of row planting to be higher because of the better technology knowledge of the DA, better land management, and the DA's motivation to realize yields in line with expectations of their supervisors. Yields were measured using the crop-cut sample method. The first column in Table 5.6 confirms our hypothesis: implementing row planting on the FTC plots increased teff yield significantly by 26 percent. However, as we pooled together data from plots with the same technology but different input application, it is difficult to ascertain whether this increase in yield is entirely due to row planting.[20]

Table 5.6—Effect of row planting on FTC teff yield

Treatment effect		Yield from crop-cut	
ATT	Coefficient	0.255**	0.260**
	Standard error	(0.125)	(0.123)
DA was not well informed about the row planting technique (yes = 1)	Coefficient		-0.272**
	Standard error		(0.133)
Constant	Coefficient	1.143***	1.219***
	Standard error	(0.077)	(0.085)
Observations		168	168

Source: Authors' calculations.

Notes: ATT= Average Treatment effect on the Treated. Standard errors (se) in parentheses under coefficient. Asterisks represent level of significance: * (10% significance), ** (5% significance), *** (1% significance)

The higher yield increments found at FTC level are attributed to better management of row planting plots by DA compared to the experimental plots managed by farmers. The magnitude of the treatment effect is estimated to be much higher (and statistically significant) compared to the point estimate for crop-cut yield at the farm level. To test whether the assumed knowledge and experience of DA about the reduced seed rate technology is driving our results, we include a dummy variable which is one if during the community questionnaire farmers responded that the DA in their village was not well informed about the new technologies. Column 2 of Table 5.6 shows that in *kebeles* where DAs were not well informed about row planting, row planting does not affect teff yield at village level.[21]

6. DISCUSSION

The study empirically assesses the impact on land productivity of a government program to promote row planting of teff . The results mostly indicate that row planting increases teff yield compared to the traditional practice of broadcasting at a high seed rate. When output is measured by farmers' declaration after harvest, row planting increased yield by 12 to 16 percent. This statistically significant increase in yield is found in both the random and the matched sample. The effect of row planting is the strongest on the yield expected by farmers, as yield increases of over 20 percent are found. When estimating the effect of row planting on teff yield measured through crop-cuts, however, the point estimate becomes insignificant, indicating no impact.

In contrast, alternative measures in more controlled settings (ATA 2013b; McGuire 2013; Abayu 2012; Tolosa 2012) indicate larger impacts and claim that row planting in itself is able to achieve much larger yield increases. Our research provides at least three arguments that assure the robustness of our finding over those of the other researchers.

First, our paper analyzes the direct effect of row planting on teff yield rather than estimating the impact of a whole package, including improved seeds and chemical fertilizer. We were able to isolate the effect of the sowing technology from other elements within the package by setting up a randomized control trial. Farmers similar in characteristics (as indicated in our balancedness tests) were randomly assigned to a row planting or a control group and both groups received the same inputs. As the only difference—by design—between the two groups of farmers is the sowing technology, yield differences in our experiment are solely driven by the technique of row planting and not by confounding factors. In other studies, an estimation bias due to self-selection is likely to occur that prohibits isolating the row planting effect on yields.[22]

Second, we analyze the impact of the promotion program of a new technology rather than focusing on the agronomic impact of the technology at the farm level. The latter has been the focus in other studies and, as a consequence, farmers

[20] At farm level we do not report the effect of transplanting on teff yield, because of the purposive selection of transplanters by DAs and severe implementation problems. At FTC level, transplanting data is available. Transplanting teff seedlings on the demonstration fields significantly increased teff yield by 33 percent.
[21] The ATA (2013c) survey also looked at the effect of the different components of the technology package at FTC level. Row planting increased teff yield by 18 percent; which is in line with our findings.
[22] More precisely, ATA (2013c) compared yields from the exposed farmers to the national average. Data for a control group that grew teff the traditional way (i.e. broadcasting) and received the same assistance and inputs was not collected. As a consequence the results of this exercise did not show the exact contribution of row planting compared to improved access to modern inputs and agricultural extension. This might be a valid concern, as the community questionnaire revealed that farmers do not think that broadcasting is hampering teff production, but at the same time they believed that row planting or transplanting is useful to increase yield. This could indicate that farmers consider the technologies as a package, and they conceive the yield increases mainly as the result of improved access to improved seeds and fertilizer.

were assisted carefully or researchers themselves were managing experimental trials in order to assure that the row planting technique was correctly implemented. However, when these technologies are scaled up using the existing extension system, the implementation of the promotion campaign tend to differ significantly with respect to the quality of technological support provided. The program we analyze was characterized by large diversity in the quality of the efforts of the extension agent, in the time availability of DAs to properly explain and train farmers on the new technology, and in seemingly more restricted access to modern inputs.[23] These factors explain much of why a project implemented by One-Acre Fund in the Amhara region found teff yield increases of at least twice conventional yields. By design, farmers were visited regularly by private extension agents and access to inputs was ensured. However, when conducting compliance surveys in the following year, the project found that the row planting techniques taught by DAs to farmers differed from governments' recommendations, resulting in lower yields than expected (McGuire, 2013).

Finally, farmers in our study were interviewed by enumerators that had no incentive but to report the findings as expressed by farmers or as found in the crop-cut. In the case of other surveys (e.g. ATA 2013c), data were collected by DAs themselves. Some of the DAs might have felt that their performance was to be judged by how well the new technology was implemented in the region for which they were responsible. A perceived conflict of interest could have existed, leading to higher and non-truthful estimates of the performance of the technologies. Even if this was not done at the DA level, people at higher levels might have similar incentives to misrepresent findings, as data were transferred relying on bureaucratic hierarchies. Such an argument on the 'political economy of agricultural data' has recently been proposed by Jerven (2013).

The moderate effect of the promotion campaign not only stands in contrast to agronomic research, it also conflicts with expectations of farmers about the yield benefit of row planting. Farmers might be too optimistic about the effect of reduced seed rate technologies. Part of this seemingly is explained by inaccurate yield assessment of farmers themselves. Farmers might base their expectations on those parts of the teff plots where the seedlings branch out optimally under the reduced seed rate technology. This might lead to a false generalization to the plot as a whole. Also, it appears that farmers have exaggerated expectations, as farmers in focus groups after the experiment stated that row planting would on average double yields compared to traditional broadcasting. Such statements are puzzling given the results on their experimental plots. Several explanations might exist for this. First, some farmers might face difficulties in disentangling the effect of the technology itself and the additional effects of access to improved seeds and fertilizer.[24] Second, given the lack of alternative information sources, farmers' opinion might be influenced by what they hear from extension agents, media, and training. In all instances, farmers were told that it was possible to achieve large yield increases if the technology was implemented correctly. Moreover, all of the participating farmers were model farmers, who receive privileged access to information and sometimes inputs. To retain their status, model farmers might have an incentive to prove to their supervisors that they were capable of implementing the technology and achieving the promised results. They might have felt that showing skepticism of a newly introduced technology might hamper their prospects as a model farmer.

Even though the superiority of row planting over broadcasting is not always significant in our sample, and given that other projects found much higher effects, yield increases in the range of 10 to 20 percent have considerable monetary value. Using the annual value of teff production as a reference (Minten et al. 2013), an increase of teff yield of 15 percent corresponds to an increase in the value of national production of 240 million USD. Moreover, our research is not the first to show that the effect of a technology (package) is lower than those found in on-station results. For example, it is interesting to look at the experience with SRI, the improved technology package for rice. While SRI has been widely praised for its ability to increase yields in Madagascar (Stoop et al. 2002), others claim that the success of SRI cannot be generalized (Sheehy et al. 2004, McDonald et al. 2006) and highly depends on local conditions (Dobermann 2004).

7. CONCLUSION

Widespread adoption of improved agricultural technologies is needed for countries in SSA to achieve or maintain agricultural growth and to improve food security. However, there is a lack of empirical knowledge on the potential and

[23] Farmers felt that they were poorly supervised (44 percent of the *kebeles* in field reports), DAs were too busy or had a lack of training (66 percent and 51 percent of the *kebeles* in the community questionnaire, respectively). In these *kebeles*, farmers did not understand the technology properly. In the extreme case, this caused farmers to replant their experimental plots with chickpea. On top of this, the supply of inputs was late or otherwise problematic in 22 percent of the surveyed FTCs. Moreover, the flow of information from woreda experts to DAs was imperfect and inefficient. For example, our focus group interviews showed that *woreda* experts seemed to visit and support DAs less where the distance between the *kebele* and *woreda* was great.

[24] Our measure of expectations from the crop-cut largely does not suffer from this. Compared to the general expectations, it is far lower. This can be explained by the fact that the farmers were explicitly asked to form their expectations based on the experimental plot that they managed last year. Hence, it is more likely that farmers will take into account their implementation problems and predict lower yields.

impact of scaling-up programs that promote new technologies at farm level. We fill this gap by looking at a program promoting improved technologies to increase teff productivity in Ethiopia. Teff is the most important staple crop in the country, but teff yield is low. To address this low yield, the government has recently started to scale-up the promotion of reduced seed rate technology packages. Traditionally, teff seed is broadcast at high seed rates (typically 30 kg per hectare). It is believed that this impedes teff production because the uneven seed distribution makes weeding more difficult and increases competition between seedlings. Experimental trials on-station and on-farm have shown that when the seed is transplanted in rows and when improved seeds and appropriate level of fertilizer are applied, yield increases by between two and four times. In field demonstrations, row planting achieved a yield increase of 75 percent (ATA 2013c).

Yet, independent and reliable data to test the impact of this teff technology promotion program at the farm level have not been collected. We therefore conducted a study to rigorously measure the on-farm effect of the program that promotes row planting on teff land productivity, controlling for both modern input use and the characteristics of the farmer. To do so, we collected data from almost 1,000 farmers in the Oromia region, one of the most important teff producing regions in the country. Farmers were assigned to implement either row planting or broadcasting in a randomized control trial. The selection of farmers, however, was not always done randomly by the DA and, so, a matching exercise was done as well to construct a control group that is similar in its characteristics as the group of treated farmers. We collected data for three measures of yields, i.e. crop-cuts, assessed plot yields before harvest, and reported plot yields after harvesting and threshing. We also collected data from demonstration plots that were implemented by extension agents in 36 *kebeles*.

The results of the randomized control trial indicate that growing teff in rows mostly improves teff land productivity compared to the traditional practice of broadcasting. Most robust results are found from farmers' yield declaration: row planting increased teff yield on farmers' experimental plot by 12 to 16 percent. Findings from the matching exercise are in line with the randomized control trial. However, the effect on teff yields of row planting is smaller and statistically not significant when yields are measured through data collected from crop-cuts. Even if yield does not improve very much overall, farmers that practice row planting will still benefit from the lower seed rates and associated cost savings. The data of the demonstration plots at the village level show a larger effect of row planting, as teff yield increases by 26 percent when DAs implement row planting. This larger effect can be explained by the better knowledge and motivation of DAs compared to individual farmers. The results indicate that the gap in yields between research settings and the farm that is often found in these settings is explained by two effects, i.e. a first reduction between research settings and the extension agents and a second reduction between extension agents and farmers.

The moderate increase in teff yield found at the farm level is in contrast with findings from demonstration plots, from research station trials, and from farmers' declared expectations. The discrepancy is attributed to several factors. First, our methodology is an improvement over previous estimates because we control for potential confounding factors, i.e. access to inputs and extension and farmer characteristics. This allows us to estimate the direct effect of row planting and not the combined effect of the whole package. Second, farmers' exaggerated optimism is puzzling and seems related to improper yield assessments and possible incentives for misrepresentations. Third, we estimate the impact of a program designed to roll out the improved technologies at a large scale. The implementation of such a program might be constrained by issues related to technological support, distribution of modern inputs, and the quality of the extension agents overseeing the program implementation. We believe that an intensive support program provided in experimental settings would require public resources that are not readily available. As such, the results of our impact evaluation likely approach the impact that would be achieved if a national program would be rolled out along these lines.

The results of our research point to several important implications. While we have no evidence to disprove the agronomic superiority of the row planting technology, our results indicate that significant effort should be put into the design and implementation of the promotion campaigns for such improved technologies. It especially seems that learning by the farmers is required and continuous efforts in extension of field assistance are needed.[25] There is often a big gap between the supply of new technologies and their efficient adoption, as innovations spread slowly and require different management skills (Moser and Barrett 2006; Duflo et al. 2008; Collier and Dercon 2011). Our results indicate that widespread adoption and large yield increases cannot be expected after the first year that the row planting technology for teff is rolled out.[26] Moreover, an important yardstick for farmers' adoption is not increased land productivity but labor productivity (Moser and Barrett 2006), as a large number of farmers complained particularly about the workload required for employing these new technologies. On-farm constraints towards adoption should therefore be further assessed and careful monitoring, learning, and evaluation is required to improve extension approaches for successful scaling-up of adoption of the row planting technology for teff.

[25] Qualitative questions from the impact survey show that 35 percent of farmers reported that row planting was difficult to implement.
[26] Not only the sowing technology was new to the farmers, some of them also had to learn to apply the recommended seed rate and fertilizer usage.

APPENDIX

Appendix Table 1—Number of compliers, non-compliers, and community questionnaire participants per FTC/kebele in Oromia

zone	woreda	FTC name	Random selection	compliers baseline	compliers impact	non compliers	total farmers	communities
North Shoa	Y/Gulale	Y/Guda Warqi	no	25	25		25	10
		K/Dhangoo	no	25	25		25	10
		G/Qxala	no	25	25		25	10
		D/Xiqi	no	25	25		25	10
	G/Jarso	G/ Boneya	no	25	25		25	10
		K/safani	no	23	23		23	10
		Amato Kiro	no	19	13		13	10
		Wertu	yes	25	25	12	37	10
H/guduru Welega	Guduru	Ula Gutto	yes	25	25	6	31	9
		Tokuma Biyaa	yes	25	25	3	28	9
		Yeronama Tole	yes	25	25	2	27	7
		Gobbu	yes	25	25	7	32	8
East Shoa	Adea	Katila	yes	22	22	11	33	8
		G/Gorba	yes	20	20	17	37	10
		Gobasi	no	12	12		12	10
		Bekejo	yes	21	21	6	27	8
Jimma	Gommaa	Kaso Iti	yes	15	15	13	28	8
		Qatta	no	24	24		24	6
		Dedo warache	no	21	20		20	6
		Omoo Funtule	yes	24	24	12	36	7
South West Shoa	Weliso	D/Kata	yes	23	23	6	29	7
		D/Eebicha	yes	25	25	11	36	8
		Guro Rabaca	no	25	25		25	7
		Badessa Qorecha	yes	25	25	1	26	7
	Becho	Kobo	no	25	25		25	10
		Jato	yes	25	24		24	9
		A/Bune	yes	25	25	5	30	10
		S/Chirecha	no	25	24		24	10
West Shoa	Ambo	Amano	no	25	25		25	10
		B/Qumbi	yes	24	24	7	31	10
		Awaro	yes	25	25	4	29	7
		Boji Gebissa	no	25	25		25	8
	Dendi	G/Dilbata	no	25	25		25	9
		Chelelka bobe	no	26	26		26	10
		Wamera Sako	yes	24	24		24	9
		Gollele Bole	yes	24	24	6	30	10
Total number				**847**	**838**	**129**	**967**	**317**

Source: Authors' calculations.

Appendix Table 2—Distribution of different planting technologies, seed use, fertilizer application, and number of weedings at FTC/kebele level

kebele	row planting by hand	row planting by machine	transplanting	traditional broad-casting	RSR* broad-casting by hand	RSR* broad-casting with machine	Seed use (gram)	DAP use (kg)	Urea use (kg)	Weeding (number)
Kaso Iti	2	0	2	3	2	1	141	0.90	0.45	3
Qatta	2	0	3	4	0	1	143	0.90	0.45	5
D/ Warache					no observations					
Omoo Funtule	2	0	2	3	2	1	121	0.95	0.45	3
Amano	3	0	2	3	1	1	175	0.90	0.90	2
B/Qumbi	2	1	2	3	1	1	121	0.90	0.90	1
Awaro	2	0	1	3	2	1	161	0.78	0.78	0
Boji Gebissa	2	0	2	3	2	1	161	0.85	0.85	2
G/Dilbata	3	0	2	4	0	1	127	0.90	0.90	2
C/Bobe	2	0	2	5	0	1	165	0.90	0.90	3
W/ Sako	2	0	1	5	1	0	161	0.89	0.89	2
Gollele Bole	2	0	2	5	0	1	200	0.90	0.80	1
G/Boneya	1	1	2	5	0	1	160	0.90	0.89	2
K/Safani	2	1	2	3	1	1	200	0.90	0.44	1
Amato Kiro	2	0	2	4	0	1	300	0.78	1.00	1
Wertu	1	1	2	4	1	1	135	1.00	1.00	2
Y/Guda Warqi	1	1	2	4	1	1	95	0.90	0.90	3
K/Dhangoo	1	1	2	3	2	1	170	0.80	0.90	2
G/Qxala	1	1	2	3	2	1	120	0.90	0.89	2
D/Xiqi	1	0	2	4	1	2	170	0.90	0.90	1
Katila	2	0	2	3	2	1	128	0.90	0.90	2
G/Gorba					no observations					
Gobasi	2	0	2	3	2	0	41	0.89	0.89	2
Bekejo	2	0	2	0	5	1	600	3.00	3.00	3
D/Kata	2	0	2	4	1	1	165	0.90	0.85	2
D/Eebicha	2	0	2	4	1	1	151	0.85	0.85	2
Guro Rabaca	2	0	2	4	1	1	144	0.80	0.80	2
B/Qorecha	2	0	2	4	1	1	180	0.90	0.85	2
Kobo	2	0	2	4	0	2	150	0.90	0.90	2
Jato	2	0	2	4	0	1	133	0.89	0.89	2
A/Bune	0	0	2	2	5	1	130	0.90	0.90	4
S/Chirecha	1	0	1	2	1	1	137	1.00	1.00	2
Ula Gutto	1	1	2	3	2	1	143	0.90	0.43	2
T/ Biyaa	2	0	2	4	2	0	163	0.63	0.80	2
Y/ Tole	2	0	2	3	2	1	141	0.90	0.40	4
Gobbu	2	0	2	4	1	1	151	1.10	0.13	3

Source: Authors' calculations.
Notes: RSR*= Reduced Seed Rate; the last four column are FTC averages.

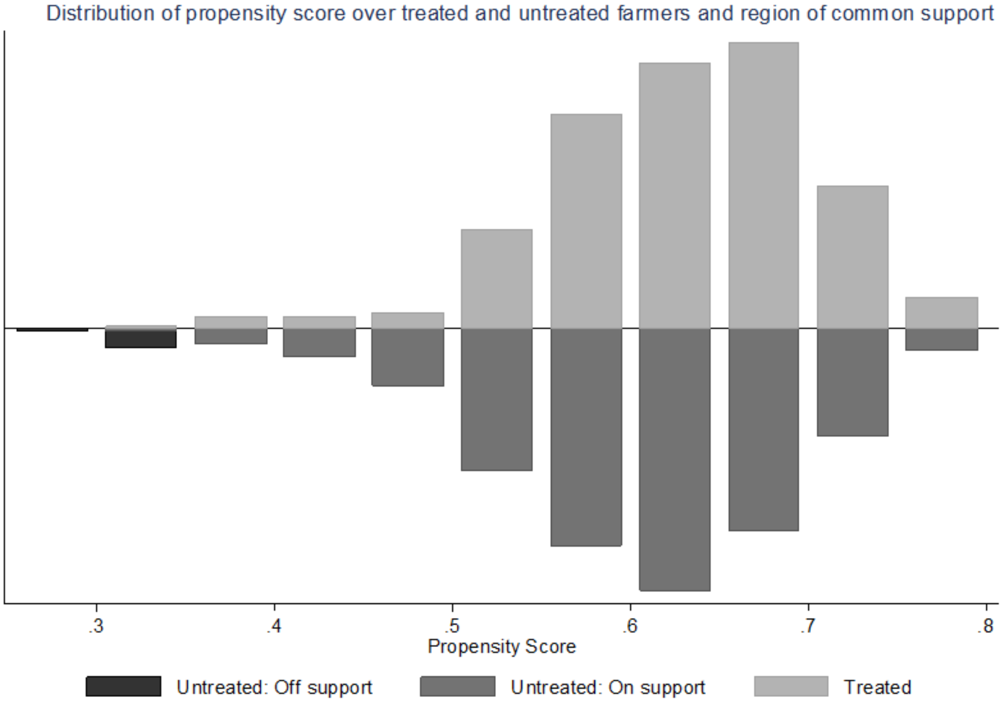
Appendix Table 3—Overview of different area, output, and yield measurements

		Area measurement (m^2)			Output measurements (kg)							Yield measurement (ton/ha)		
					sample plot				experimental plot			Crop-cut		declared
		Crop-cut data	declared data	analysis	wet sample weight analog	wet sample weight digital	dry sample weight analog	dry sample weight digital	expected output	total output	Declared total output	expected	actual	actual
Random sample: compliers	obs	445	446	446	336	336	336	336	442	438	445	442	438	445
	mean	472	477	471	1.77	1.75	1.72	1.71	56	48	52	1.38	1.11	1.28
	median	320	313	320	1.58	1.55	1.50	1.47	40	36	40	1.18	1.01	1.14
	s.d.	325	335	324	1.04	1.05	1.03	1.04	45	41	42	1.01	0.68	0.84
	min	57	0	57	0.10	0.04	0.04	0.04	0	1	0	0.01	0.02	0.01
	max	1,850	2,186	1,850	6.66	6.88	6.64	6.86	250	229	240	9.27	4.43	6.61
Random sample: non-compliers	obs		128	128							123			122
	mean		1,103	1,103							99			1.17
	median		300	300							25			0.75
	s.d.		2,235	2,235							207			2.03
	min		0	0							0			0
	max		15,000	15,000							1,500			20
Non-random farmers	obs	390	393	401	249	249	249	248	371	386	397	371	386	397
	mean	321	339	319	2.15	2.14	2.12	2.07	50	40	42	1.84	1.44	1.57
	median	291	300	292	2.00	2.04	1.97	1.95	45	34	35	1.56	1.29	1.32
	s.d.	226	246	224	1.08	1.07	1.07	1.04	35	32	34	1.41	0.95	1.17
	min	40	14	40	0.08	0.04	0.07	0.08	3	1	1	0.05	0.02	0.029
	max	1,785	2,620	1,785	6.62	6.56	6.52	6.45	200	205	300	16.38	8.02	10.15

Source: Authors' calculations.

Notes: obs=observations, s.d.=standard deviation, min=minimum, max=maximum

Appendix Table 4—Balancing properties of the Propensity Score Matching



t-test for equality of means for all variables after matching	
For all covariates, we cannot reject the null hypothesis that the mean of the covariate is different between treated and control farmers	
Standardized % bias	
before matching	9.0
after matching	2.2
total % bias reduction	78.0
Pseudo R^2 of propensity score estimation	
before matching	0.021
after matching	0.003
Likelihood-ratio test of the joint significance of all covariates	
before matching	25.27 ($p>chi^2=0.089$)
after matching	3.43 ($p>chi^2=0.999$)

Source: Authors' calculations.

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