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Article

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Performance of women-managed plots compared to men-managed plots among smallholder maize farmers in western and central Ethiopia

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ABSTRACT

A more targeted approach towards improving women's access to agricultural innovations is key to increase the overall agricultural productivity. This paper uses gender-disaggregated household and plot-level survey data from Ethiopia to explore the impacts of multiple agronomic practices disaggregated by the sex of the plot manager. Using a multinomial endogenous switching regression methodology, after controlling for endogeneity arising from observed and unobserved heterogeneity, we found that multiple agronomic practices have a positive and significant effect on maize yields and maize income. Crucially, subject to demographics, plot quality and agronomic practices (among others), we found that women-managed plots (WMP) had treatment effects (yields) that were statistically the same as those of men-managed plots (MMP) (and nominally higher in a number of cases).

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Technology adoption; gender, heterogeneity; endogenous switching regression; welfare; Ethiopia

1. Introduction

In agrarian circumstances, gender inequalities in access to services, market opportunities and resources disfavour women, undermine rural economic transformation (Food and Agriculture Organization (FAO), 2011; von Braun & Webb, 1989) and weaken development aspirations (Doss, Meinzen-Dick, Quisumbing, & Theis, 2018; Peterman, Quisumbing, Behrman, & Nkonya, 2011). Gender issues in Africa and the developing world continue to generate interest among researchers and policymakers in particular because African women play a key role in farm and non-farm intra-household resource allocation and production (Meinzen-Dick et al., 2010). Gender inequalities in agriculture are manifested in many ways. These range from lower access to land (Doss et al., 2015), to public services such as extension and, reduction in market participation as the net sellers of produce (Kassie, Jaleta, Teklewold, & Erenstein, 2015; Marenya, Kassie, Jaleta, & Rahut, 2016; Quisumbing, 1995).

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The potential of the agriculture sector is tied to the performance of smallholder men and women farmers, who make up to 81% of farmers in Ethiopia (Salami, Kamara, & Brixiova, 2010). The literature shows that, particularly in Africa, women constitute 25–60% of the labour supplied into agriculture (Food and Agriculture Organization (FAO), 2011). The proportion of women who are landowners and farm operators are estimated at 22% in Africa and 18% in Ethiopia, respectively (Doss et al, 2015). Nevertheless, the agricultural yields and productivity of women's plots (those under their exclusive control) is often less than that of their male counterparts (Quisumbing, 1996). The share of agricultural incomes that they control is often estimated at 30.5% (Aromolaran, 2004). Where women have access to land, these are often 30–50% smaller landholdings than the average land sizes owned by male farmers (Food and Agriculture Organization (FAO), 2011).

This paper uses intra-household production data to compare the yield performance of plots under different combinations of multiple agronomic technologies (MATs) dissagregated by whether the plots are managed by female and male household members separately, as well as those managed jointly. The reason for this disaggregation is that the majority of women and, therefore, the core of gender issues are found in dual (or multi-adult) households (Doss et al., 2018; Peterman, 2011) and 75% in Ethiopia. By comparing women-managed plots (WMP), men-managed plots (MMP) and jointly-managed plots (JMP), this study provides evidence that women's disadvantage in agriculture arises not so much from some perceived lack of capacity but from constrained access to agricultural inputs and services. There is some evidence, albeit not universal, that women fare relatively better in cases where they are household heads. (Quisumbing, Haddad, & Peña, (2001), in a survey of 10 developing countries, found no statistically significant higher incidence of poverty in households headed by women in two-thirds of those countries. This may arise from the greater control these women have, highlighting the fundamental issue of access and control in generating gender issues in development (Food and Agriculture Organization (FAO), 2011). A 1999 IFAD assessment of poverty in the West and Central Africa (cited in Food and Agriculture Organization (FAO), 2011) reported results from a study on 19 countries and found that the rate of poverty was lower among households headed by women as compared to those headed by men in 9 of those 19 countries.

In many developing countries, agricultural production is a complex process that involves multiple household members managing land and sharing household resources (Haider, Smale, & Theriault, 2018). Members of the household cultivate a mixture of individually and collectively managed plots. These distinctions have important policy implications. First, women's access to inputs should be an important agricultural policy goal, which can be pursued through better intra-household targeting of extension and training, input access and related programmes. Second, if social norms constrain women's access to inputs, and if these norms can be shown to hurt social development through serious empirical work, it follows that reforming such norms would advance overall agricultural productivity and development. We come back to these issues in the final sections of this study.

This study is consonant with the on-going interest in the sources and consequences of agricultural productivity differences between male and female farmers (Peterman et al., 2011). As we have posited, the main drivers of lower agricultural productivity among female farmers are associated with women's limited access to agricultural innovations, technologies and markets (Peterman et al., 2011; Quisumbing, 1995; von Braun & Webb, 1989). A study by FAO, IFAD and WFP (FAO, IFAD, & WFP, 2015) revealed that if female farmers were given the same access to resources and opportunities as male ones, their productivity would be increased by about 20–30%, which would increase aggregate agricultural productivity (FAO, 2014; Juma, Tabo, Wilson, & Conway, 2013). A more targeted approach to improving women's access to agricultural innovations is, therefore, key to increase the overall agricultural productivity. It should be recalled that this refers to all the women, the majority of whom are members of households headed by men.

The contribution of this study is, therefore, at least twofold. First, we examined the differential effects of agronomic practices on maize yield and maize income based on the gender of the plot manager, as observed within each household. Despite its social and economic significance, a limited number of studies have shown the link between the gender of the plot manager and the adoption and impacts of better technologies. To our understanding, ours is the first to examine the heterogeneous effects of the gender of the plot manager on the productivity in Ethiopia. Second, we have also used a rich plot- and household-level data, combined with the weather data extracted from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS), allowing us to test the gender differentiated impacts of MATs on productivity under varying rainfall conditions.

The rest of this paper is organised as follows. Section 2 outlines the methods used and describes in detail the econometric approach and why it is appropriate. Section 3 presents the sampling and data sources and describes the key variables used in the analyses including the demographic and other covariates. Section 4 presents the results from the empirical model after describing the data and provides a broad discussion of the results with a focus on the relative impact of gender and rainfall heterogeneities in the econometric results. Section 5 concludes the study.

2. Empirical strategy

In this study, the three pillars of MATs considered were maize-legume diversification (D), fertilizer application (F) and soil and water conservation measures (S). We defined the MATs as binary variables that take the value one if the plot manager uses the MATs or zero otherwise. The empirical strategy used in this study was derived from discrete choice models common in the agricultural technology adoption literature (Khonje, Manda, Mkandawire, Tufa, & Alene, 2018; Teklewold, Kassie, Shiferaw, & Köhlin, 2013; Teklewold, Mekonen, Köhlin, & Di Falco, 2017).[1] The choice of whether a plot manager adopted a particular combination was not by random assignment, as would be achieved in a controlled social experiment. Farmers themselves self-selected into different adoption categories, thereby raising econometric challenges around self-selection. When the analyst tries to determine the factors that influence technology adoption and

[1]Considering these three MATs, it is possible to generate eight (23) combinations of packages the plot manager could potentially choose from based on what works best for her, subjected to perceived utility.

impact, the issues such as factors of influence need to be disentangled. These relate to both observable (but unmeasured) and unobservable characteristics (such as managerial skills, risk attitudes, innovativeness, motivation, entrepreneurial ability, taste preferences, etc.). The latter may be correlated with the outcome variables of interest – in our case, maize yield and maize income (Wooldridge, 2010). Unobserved biophysical confounders can also lead to heterogeneities in the returns to the adoption of agricultural technologies (Suri, 2011).

In adoption and impact evaluation, correcting for self-selection bias is critical. Without a randomisation and an identification strategy, common regression techniques will generate biased estimates of impact, perhaps exaggerating the impact if unobserved factors positively affect the outcome (Heckman, 1979) or vice versa. Self-selection bias can be corrected by the use of instrumental variables (IV), Heckman selection or propensity score matching (PSM) methods (Wooldridge, 2010). As a parsimonious alternative to IV, Heckman and matching approaches, we employed a switching regression approach by using the multinomial endogenous switching regression framework (MESR) to control for both observed and unobserved heterogeneity (Lokshin & Sajaia, 2011). In the MESR framework, the correction for selection bias was achieved by including the inverse Mills ratio (IMR), which is based on the notion of truncated normal distribution (Khonje et al., 2018;). The adoption and the consequential impact were modelled in the following two stages: first, adoption was estimated using the multinomial logit selection (MNLS) mode.[2] Second, the relationship between the different combinations of packages and the outcome variables of interest were estimated using an Ordinary Least Square (OLS). Additionally, IMRs were also included.

The regression model which estimates the impact of MATs on plot level yields (W_{ij}) by regressing the observed outcome on j^{th} specific plot with plot, farm, household and village specific variables(S_{ij}). The Mundlak (1978) and Wooldridge (2010) strategy of using the mean values of plot-level varying characteristics ($\bar{S}$) (e.g, plot soil fertility, plot manager, plot distance from home, etc.) was implemented here. The regime switching regression is specified as follows:

$$\begin{cases} Regime0: W_{i0} = S_{i0}\alpha_0 + S_{i0}\theta_0 + \nu_{i0}, ifj = 0 \\ \quad\quad\quad\quad\quad\quad .. \\ \quad\quad\quad\quad\quad\quad ..j = 1,2,3,4 \\ \quad\quad\quad\quad\quad\quad .. \\ RegimeJ: W_{iJ} = S_{iJ}\alpha_J + \bar{S}_{ij}\theta_J + \nu_{iJ}, ifJ = 5 \end{cases} \quad (1)$$

The ν_{ij} constituted a composite error term that accounted for unobserved effects from the plot and household effects as well as a random error. The resulting estimates from (using OLS) may be biased in the cases where (ε_{ij}) and the outcome (ν_{ij}) equations are correlated. To get consistent estimates of the parameters α_j and θ_j, a selection correction variable recovered from the adoption estimation step was included in the regression in the following manner

[2]Please see online supplementary material for details of the adoption and impact models described in this section. Those supplementary materials also have more details on some of the results.

$$Regime0: W_{i0} = S_{i0}\alpha_0 + \bar{S}_{i0}\theta_0 + \hat{\lambda}_{i0}\gamma_0 + \in_{i0} = 1,2,3,4....j = 1,2,3,4..RegimeJ: W_{iJ} = S_{iJ}\alpha_J + \bar{S}_{iJ}\theta_J + \hat{\lambda}_{iJ}\gamma_J + \varepsilon_{iJ}, ifJ = 5 \quad (2)$$

Here, $\in_{ij}$ is an error term with a mean of 0 and $\gamma_j$is the coefficient of covariance between $v_{ij}$and ε_{ik} in each equation. Moreover,$\hat{\lambda}_{ij}$is the inverse mill's ratio estimated from the estimated probabilities of the MNL model. The formula for the IMR is computed as $\lambda_{ij} = \sum_{k\neq j}^{J} \rho\left[\frac{\hat{P}_{ik} ln(\hat{P}_{ik})}{1-\hat{P}_{ik}} + \ln(\hat{P}_{ij})\right]$, where ρ denotes the correlation between the equations and $\hat{P}$ is the estimated probability of adopting any of the MATs.

2.1. Survey design and data collection

The data used in this study came from a survey of farmers in areas where a research for development project was implemented for several years. Coordinated by the International Maize and Wheat Improvement Center, in collaboration with local research partners, the project focused on testing and scaling conservation farming methods to promote sustainable intensification among smallholder farmers in multiple regions of Ethiopia.

The data were collected from a random sample of 873 households and 1624 maize plots. The sampling procedure involved a continuous random sampling approach for the evaluation of the impacts. This was a two-stage approach. The first stage was the selection of primary sampling units (PSUs). Below the districts (*woredas*), the villages (*kebeles*) were deemed to be the lowest administrative units. Within these PSUs *(kebeles*), households were randomly selected as units of analysis. The study, therefore, limited itself to PSUs that were found to be within a 25-km radius of project demonstration plots (as the region of project influence). Prior to data collection, the research protocols were reviewed by the lead authors' research ethics committee (Institutional Research Ethics Committee) – IREC. The study was deemed low risk with appropriate protections for personal identifying information. The IREC was approved under file number IREC 2018.014

The actual data collection was conducted through recall techniques for the farmers to provide responses based on a structured questionnaire. The questionnaire was administered by teams of graduate-level field enumerators (who spoke the local language). The data generated included household composition as well as demographic information related to sex, age and education. Other farm- and household-related information included land holdings, access to agricultural and market information and distance to output and input markets, among others. At the level of plots, the data included information related to the plot characteristics, inputs used on the plots, the distance of the plots from homestead. Table 1 provides summary statistics of the outcome and control variables used in the empirical model (see the following for similar variables: Kassie et al., 2018; Manda, Alene, Gardebroek, Kassie, & Tembo, 2016; Teklewold et al., 2013).

In addition to the survey data and in order to control for weather-induced impact heterogeneity, we extracted historical rainfall data from CHIRPS. The CHIRPS repository is a 30-year global rainfall dataset with 0.05° resolution satellite imagery with *in situ* station that creates gridded time series rainfall information (Michler, Baylis, Arends-Kuenning, & Mazvimavi, 2019). During the survey, the households

Table 1. Adoption of MAT categories.

Package Code	D1 (ML diversification)	D0 No ML diversification	F1 Fertilizer	F0 No fertilizer	S1 SWC	S0 No SWC	N	Percent
D0F0S0		✓		✓		✓	77	4.6
D1F0S0	✓			✓		✓	60	3.58
D0F1S0[3]		✓	✓			✓	407	24.31
D0F0S1A		✓		✓	✓		21	1.25
D1F1S0	✓		✓			✓	636	37.99
D1F0S1	✓			✓	✓		29	1.73
D0F1S1		✓	✓		✓		153	9.14
D1F1S1	✓		✓		✓		291	17.38

D, F and S refer to maize-legume diversification, chemical fertilisers and soil and water conservation measures. Subscript "1" denotes the adoption of the MATs, while "0" denotes non-adoption. The number of maize plots is 1624.

were geo-referenced using the global positioning system (GPS), and, therefore, each household had a GPS coordinate associated with its main location. We made use of the household GPS information from the survey to download the historical rainfall-related information from CHIRPS. The dataset provided monthly rainfall information from 2001 to 2017.

2.2. Descriptive statistics

Of the 1624 maize plots enumerated, there were no MAT packages on 77 (4.6%) of them. Plot managers implemented maize-legumes diversification as the only MAT in about 3.6% of the plots. The adoption rate of maize-legume diversification is comparable with the findings of the study conducted by Kassie et al. (2018), which reported an adoption rate of 3.8% in Ethiopia. Fertilisers alone were applied in about 24.3% of the plots. The adoption rate of soil and water conservation measures alone was implemented on only 1.25% of the maize-legume plots. However, soil and water conservation (SWC) was found in 17.38% of the maize-legume plots, where it was implemented with maize-legume diversification and fertilisers. The two-package combination of maize-legume diversification and fertilisers was implemented on 38% of the plots. The adoption rates of maize-legume diversification with soil and water conservation measures as well as the combination of the full package was estimated at 1.73% and 9.14%, respectively.[3]

Table 2 below presents the descriptive statistics of demographic, rainfall and plot characteristics of the households that adopted the different combinations of MATs as well as pairwise comparison with the non-adopters. The selection of the explanatory variables included in the empirical analysis (Kassie et al., 2018; Khonje et al., 2018; Teklewold et al., 2017). The summaries suggest that the users of the MATs operate larger plots, own more livestock, and used more maize seed than the non-adopters.

[3]Owing to low numbers of observations, we dropped the MAT categories of soil and water conservation measures (N = 21), maize-legume diversification and soil and water conservation measures (N = 29) from the analysis because including them in the analysis would make the model face difficulties in converging. However, we produced the impact estimates (Table S11 in the online appendix) by combining these two dropped categories with the others as a robustness check and to minimize self-selection bias. The results were almost similar with those obtained by dropping the two categories (see Table 5 and Table S11 in the supplementary material).

Table 2. Descriptive statistics of the variables used in the model based on MAT adoption status.

Variables	$D_0F_0S_0$	D_1 F_0S_0	D_0 F_1S_0	D_1 F_1S_0	D_0 F_1S_1	D_1 F_1S_1
Outcome Variables						
Maize yield per ha	2280	2684**	3897***	3608***	3801***	3847***
Maize marginal returns	16,713	19,775**	26,106***	23,674***	25,678***	25,332***
Explanatory Variables						
Gender head	0.857	0.883	0.845	0.923**	0.869	0.856
Age head	44.78	45.82	44.74	43.57	44.77	43.49
Education head	3.987	3.733	3.518	4.041	3.85	4.271
Household size	6.286	6.65	6.032	6.256	6.209	6.134
Farm size	1.348	1.447	1.367	1.437	1.57	1.699**
TLU	3.403	4.632**	4.255	4.532***	5.546***	5.097**
Maize seed per ha	27.96	22.29***	24.55**	21.83***	24.23***	21.38***
Access to credit (yes = = 1)	0.61	0.65	0.855***	0.635	0.752**	0.797***
Government support (yes = 1)	0.636	0.683	0.597	0.514**	0.353***	0.632
Plot Size	0.447	0.342**	0.394	0.415	0.570**	0.540*
Plot distance from home (min)	13.42	10.97	18.05	15.75	30.38***	17.29
Women managed plot (yes = 1)	0.117	0.083	0.12	0.058**	0.111	0.096
Jointly managed plot	0.792	0.883	0.803	0.890**	0.621***	0.777
Men managed plot (yes = 1)	0.091	0.017*	0.076	0.052	0.268***	0.127
Good fertile soil (yes = 1)	0.351	0.45	0.452	0.604***	0.464	0.375
Medium fertile soil (yes = 1)	0.584	0.483	0.491	0.374***	0.497	0.601
Low fertile soil (yes = 1)	0.065	0.05	0.057	0.022**	0.039	0.024*
Region (Oromia = 1)	0.805	0.650**	0.575***	0.321***	0.621***	0.488***
Region (SNNP = 1)	0.195	0.35	0.425***	0.679***	0.379***	0.512***
Rainfall Shock						
Total rainfall of the growing season	773.2	879.1***	1011***	1006***	954.7***	942.8***
Rainfall shock index	0.62	0.647	0.619	0.595	0.512***	0.552**
Instrumental Variables						
Total Rainfall 2016 (ln)	802.78	883.55***	991.94***	986.36***	925.05***	926.21***
Distance to input market	1.57	1.67	1.51	1.48	1.5	1.302***
Distance to nearest market	8.221	7.267	6.369***	6.972*	5.948***	6.916**
Awareness of project activities (yes = 1)	0.026	0.067	0.133***	0.230***	0.242***	0.392***
Group membership	0.065	0.183**	0.317***	0.219***	0.333***	0.399***
N	77	60	407	636	153	291

1.
(1) D0F0S0 is the reference category. Every group is tested against the reference category. *** P < 0.01, ** P < 0.05, * P < 0.1.
(1) D0F0S0 is the reference category. Every group is tested against the reference category. *** P < 0.01, ** P < 0.05, * P < 0.1.

2.3. Descriptive statistics by the gender of the plot manager

The descriptive statistics of plot-level characteristics based on the gender of the plot manager have been presented in Table 3 below. Each gendered MAT category was tested against the base category of non-adoption. For example, the maize yields from WMP, MMP and JMP ranged from 1765–3665 kg/ha, 1915–3788 kg/ha and 2398–3915 kg/ha, respectively. The descriptive results further showed that the average maize yield per hectare for WMP, MMP and JMP is estimated as 3493 kg/ha, 3504 kg/ha, and 3676 kg/ha, respectively. The average plot size of WMP, MMP, and JMP is estimated at 0.447 ha, 0.542 ha, and 0.435 ha, respectively. Women tended to manage a nearby plot with an average walking time of 13 minutes (roughly a quarter an hour which was similar to the average walking time of JMP of about 17 minutes). On the other hand, men tended to manage plots that are relatively distanced from home, with an average walking distance of about 32 minutes (roughly half an hour, which was twice the walking time to WMP or JMP).[4]

3. Results and discussion

3.1. Adoption determinants of MATs

We present the marginal effects in Table 4 and discuss some of the statistically significant correlates of adoption. Among the socio-economic characteristics, being a male household head was significantly and positively associated with the use of the combination of maize-legume diversification and fertiliser while it was significantly and negatively associated with the use of the D1F1S1 combination (which contains all the three MATs). Farm size was negatively associated with maize-legume diversification, and larger farms were associated with the likelihood of adopting the D1F1S1 combination. Access to credit appeared to positively correlate with the fertiliser-only category (i.e., fertiliser applied without any other MAT combinations). The access to credit was negatively associated with combining the fertiliser with maize/legume combination. The compensatory effects of legumes on soil nutrients may make it less likely that plot managers will use their limited liquidity on fertilisers. Moreover, the receipt of government-support appeared significantly and negatively correlated with fertiliser use in combination with SWC. Government support could also proxy for being in a vulnerable economic situation, which may explain the reduced adoption of better agricultural practices. The WMPs were likely to be planted to maize-legume diversification while MMPs were likely to have maize-legume diversification only. The propensity of WMP to have D1F0S0 is consistent with the common observation that legumes are mostly grown by women . The correlates of adoption also showed that JMP were less likely to have fertilisers, which is consistent with the findings of Marenya, Kassie, and Tostao (2015) whose overall conclusion is not that joint management of plots cause less fertiliser use but that it reflects the dynamics of intra-household input allocation that are yet to be fully understood. It is conceivable that JMPs are not the main priority plots compared to MMPs, which are often considered to be the main food and income plots for the households (Doss et al., 2015).

[4]Consider that the average walking speed for a human is typically thought of as 3–4 miles/hour.

Table 3. Some descriptive statistics of gendered plot level characteristics.

Variable	D0F0S0	D1F0S0	D0F1S0	D1F1S0	D0F1S1	D1F1S1	Total
Women-managed plots							
Maize yield	1765	2843	3830***	3307**	3748***	3665***	3493
Maize returns	12,679	21,061	25,597***	21,200**	26,400***	24,438**	23,387
Plot size	0.439	0.262**	0.398**	0.355***	0.735	0.449	0.447
Plot distance from home (min)	6.44	5	12.65	9.92	8.24	24.64	13.1
Women managed plot (yes = 1)	0.117	0.083	0.12	0.058**	0.111	0.096	0.089
Good fertile soil (yes = 1)	0.333	0.6	0.429	0.622	0.412	0.393	0.47
Medium fertile soil (yes = 1)	0.556	0.4	0.469	0.324	0.588	0.571	0.469
Pesticide use(yes = 1)	0.00	0.00	0.408**	0.378**	0.412**	0.357**	0.352
Manure use (yes = 1)	0.778	0.8	0.345***	0.243***	0.353**	0.393**	0.345
Men-managed plots							
Maize yield	1915	2800	3595***	3353**	3788**	3569**	3504
Maize returns	13,804	21,620	23,761*	21,488*	25,088*	20,258	22,281
Plot size	0.536	0.25	0.569	0.561	0.516	0.538	0.542
Plot distance from home (min)	43.57	10	25.61	17.18	48.17	30.78	31.93
Men managed plot (yes = 1)	0.091	0.017*	0.076	0.052	0.268***	0.127	0.092
Good fertile soil (yes = 1)	0.429	0.00	0.387	0.667	0.659	0.568	0.567
Medium fertile soil (yes = 1)	0.571	0.00	0.548	0.303	0.268	0.405	0.387
Pesticide use(yes = 1)	0.00	0.00	0.387**	0.091	0.073	0.135	0.152
Manure use (yes = 1)	0.286	0.00	0.00	0.121	0.219	0.189	0.147
Jointly-managed plots							
Maize yield	2398	2642	3936***	3642***	3816***	3915***	3676
Maize returns	17,642	19,421	26,405***	23,963***	25,804***	26,274***	24,618
Plot size	0.408	0.355	0.377	0.41	0.564**	0.552**	0.435
Plot distance from home (min)	10.98	11.47	18.14	16.04	26.66**	14.17	16.58
Jointly managed plot	0.792	0.883	0.803	0.890**	0.621***	0.777	0.818
Good fertile soil (yes = 1)	0.344	0.453	0.462*	0.599***	0.389	0.341	0.489
Medium fertile soil (yes = 1)	0.59	0.491	0.489	0.382***	0.579	0.637	0.48
Pesticide use(yes = 1)	0.016	0.057	0.199***	0.175***	0.337***	0.319***	0.205
Manure use (yes = 1)	0.492	0.453	0.171***	0.133***	0.358*	0.199***	0.199

Table 4. Marginal effects of the determinants of combinations of MATs.

Explanatory variables	(1) D1F0S0	(2) D0F1S0	(3) D1F1S0	(4) D0F1S1	(5) D1F1S1
Gender head	−0.011	−0.000	0.131*	0.002	−0.113**
	(0.025)	(0.060)	(0.070)	(0.043)	(0.047)
Age head	0.000	0.000	−0.000	0.000	−0.001
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Education head	0.000	−0.003	0.002	−0.002	0.003
	(0.002)	(0.003)	(0.004)	(0.002)	(0.003)
Household size (ln)	0.020	−0.015	−0.003	−0.025	0.011
	(0.018)	(0.036)	(0.039)	(0.023)	(0.031)
Farm size (ln)	−0.032*	−0.058	0.070	−0.035	0.087***
	(0.018)	(0.041)	(0.043)	(0.025)	(0.033)
TLU (ln)	0.005	−0.017	0.026	0.031**	−0.026
	(0.009)	(0.021)	(0.022)	(0.013)	(0.017)
Maize seed (kg/ha) (ln)	−0.029***	0.050*	−0.057**	0.030	−0.046**
	(0.008)	(0.026)	(0.025)	(0.020)	(0.021)
Access to credit (yes = 1)	−0.010	0.176***	−0.167***	0.008	0.013
	(0.011)	(0.028)	(0.027)	(0.016)	(0.023)
Government support (yes = 1)	0.019*	0.036	−0.020	−0.074***	0.019
	(0.011)	(0.023)	(0.025)	(0.015)	(0.020)
Plot distance from home (min) (ln)	−0.009	0.008	−0.028**	0.025***	0.005
	(0.006)	(0.013)	(0.013)	(0.008)	(0.010)
Women managed plot (yes = 1)	0.285***	−0.659	0.224	0.241	0.014
	(0.109)	(0.457)	(0.479)	(0.233)	(0.355)
Jointly managed plot (yes = 1)	−0.009	−0.154**	0.165*	−0.020	0.062
	(0.037)	(0.078)	(0.091)	(0.038)	(0.058)
Good fertile soil (yes = 1)	−0.028	−0.017	0.112	−0.046	−0.019
	(0.029)	(0.077)	(0.089)	(0.052)	(0.073)
Medium fertile soil (yes = 1)	−0.017	−0.012	0.087	−0.004	−0.060
	(0.027)	(0.074)	(0.086)	(0.050)	(0.072)
Pesticide use (yes = 1)	−0.047**	−0.047	0.000	0.015	0.153***
	(0.023)	(0.035)	(0.039)	(0.022)	(0.030)
Manure use (yes = 1)	0.029***	−0.068**	−0.103***	0.060***	0.048**
	(0.010)	(0.028)	(0.031)	(0.017)	(0.024)
Mean plot distance from home	0.008	0.006	0.012	−0.006	−0.016
	(0.008)	(0.019)	(0.020)	(0.012)	(0.016)
Mean women managed plot	−0.291**	0.726	0.025	−0.363	−0.183
	(0.114)	(0.462)	(0.486)	(0.241)	(0.359)
Mean jointly managed plot	0.049	0.189**	0.031	−0.119***	−0.196***
	(0.041)	(0.090)	(0.098)	(0.042)	(0.064)
Mean good fertile plot	0.008	−0.052	−0.074	0.059	0.077
	(0.039)	(0.098)	(0.111)	(0.067)	(0.100)
Mean medium fertile plot	−0.004	−0.089	−0.188*	0.036	0.251**
	(0.037)	(0.096)	(0.109)	(0.066)	(0.099)
Total rainfall growing season	−0.030	0.151**	0.308***	−0.040	−0.270***
	(0.029)	(0.063)	(0.073)	(0.039)	(0.059)
Rainfall shock index	0.038*	0.029	0.084*	−0.112***	−0.051
	(0.022)	(0.044)	(0.044)	(0.033)	(0.036)
Oromia (yes = 1)	0.032**	0.168***	−0.247***	0.074***	−0.067**
	(0.013)	(0.029)	(0.032)	(0.023)	(0.028)
Distance to input market	0.012*	0.035**	0.005	0.014	−0.067***
	(0.007)	(0.016)	(0.018)	(0.012)	(0.016)
Distance to nearest market	0.015*	−0.036*	0.011	−0.042***	0.026
	(0.009)	(0.019)	(0.020)	(0.013)	(0.016)
Participated in project extension activities (yes = 1)	−0.027	−0.085***	0.023	0.029	0.115***
	(0.018)	(0.031)	(0.030)	(0.019)	(0.021)
Group membership	−0.007	−0.026	−0.004	0.017	0.056***
	(0.013)	(0.027)	(0.028)	(0.017)	(0.021)
Observations	1624	1624	1624	1624	1624

Standard errors in parentheses. D0F0S0 is the reference category. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5. Impacts of multiple agricultural technologies (MATs) on maize yield (the full sample).

Outcome	MATs		Adoption Status		ATT
Variable	Choice	N	A	C	(A-C)
Maize yield (kg/ha)	D1F0S0	60	2569(114)	2352(134)	217(176)
	D0F1S0	407	3625(47)	2802(74)	833(87)***
	D1F1S0	636	3321(41)	2372(54)	949(68)***
	D0F1S1	153	3595(110)	2544(115)	1051(159)***
	D1F1S1	291	3618(77)	1999(61)	1619(98)***
	D1F0S0	60	18,753(9129)	18,142(1280)	611(1572)
Maize	D0F1S0	407	23,957(328)	22,574(713)	1383(785)*
income	D1F1S0	636	21,153(276)	18,670(513)	2483(582)***
Birr/ha	D0F1S1	153	23,742(778)	19,474(1071)	4268(1324)***
	D1F1S1	291	23,182(482)	14,848(523)	8334(711)***

We report actual outcome (A) with the adoption of the different combinations of MATs and counterfactual outcome (C) without the MATs and difference between actual and counterfactual outcomes as impact (ATT). The standard errors in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Legumes equivalent were added to the maize yield.

3.2. The impacts of MATs on maize yield and maize income

Table 5 demonstrates the impacts of the different combinations of MAT bundles on maize yield and maize returns. To estimate the true average effects, plots that were under specific MAT combinations were compared with these same plots had they not been under any of the MATs. Moreover, to determine the average adoption effects of the bundles of MATs, we compared columns A and C of Table 5. The full sample average treatment effect on the treated (ATT) results in Table 5 shows the impacts of adoption of MATs on maize net incomes, which are computed as the difference between columns A and C. In general, we found that plots with MATs had significantly higher maize yields and net incomes, both of which increase with the intensity of adoption.

The results show that the average impact of the adopting fertilisers is estimated at 833 kg/ha and 1383 birr/ha,[5] after controlling for observed and unobserved determinants. Moreover, the impacts of the combination of fertiliser and maize-legume diversification (D1F1S0) is estimated at 949 kg/ha and 2483 birr/ha. These are in accordance with the findings of Kassie et al. (2018) who found a positive impact of D1F1S0 in the Ethiopian context. The impact of fertilisers and soil and water conservation packages (D0F1S1) on maize yield and maize marginal returns is estimated at 1051 kg/ha and 4268 birr/ha, respectively. Expectedly, we found that the largest effects of MATs were realised with the adoption of all the three MATs (1619 kg/ha and Birr 8334/ha). These findings are consistent with the extant literature (Kassie et al., 2018; Teklewold et al., 2013) in Ethiopia (Khonje et al., 2018; Manda et al., 2016) and Zambia.

3.3. Heterogeneity effects of MATs by gender

We now turn to the effects of the MATs packages as disaggregated by the gender of the plot manager (Table 6). Overall, we find positive and significant impacts of the combination of MATs on maize yield and maize marginal returns across all the MATs groups when disaggregated by the gender of the plot manager, except for the maize-legume diversification only package. The results in Table 6 showed that WMPs had higher yield returns than those managed jointly. However, we did not find significant differences

[5]At the time of the study, the Birr (official currency in Ethiopia) was exchanging at $1 = 22 Birr .

Table 6. Gendered impacts of multiple agricultural technologies on maize yield.

Outcome Variable	MATs Category	Women-managed plots			Men-managed plots			Jointly-managed plots				
		A	C	ATTa (A-C)	A	C	ATTb (A-C)	A	C	ATTc (A-C)	ATTa-ATTb	ATTa-ATTc
Maize	D1F0S0	2743	2214	529	NA	NA	NA	2523	2399	124	NA	405
Yield		(558)	(631)	(843)				(117)	(139)	(182)		(676)
(kg/ha)	D0F1S0	3667	2316	1351***	3444	2154	1290***	3635	2936	699***	61	652***
		(143)	(172)	(131)	(189)	(217)	(287)	(51)	(84)	(98)	(232)	(194)
	D1F1S0	3026	1802	1224***	3313	1899	1414***	3341	2437	904***	-190	320*
		(130)	(169)	(213)	(250)	(239)	(345)	(43)	(57)	(72)	(258)	(192)
	D0F1S1	3769	2199	1560***	3455	2257	1198***	3624	2729	895***	371	675
		(315)	(299)	(435)	(249)	(166)	(299)	(131)	(160)	(207)	(496)	(431)
	D1F1S1	3532	1540	1992***	3348	1613	1735***	3673	2119	1554***	257	438*
		(314)	(120)	(336)	(242)	(119)	(270)	(82)	(73)	(109)	(378)	(265)
Maize net income	D1F0S0	19771	16214	3557	NA	NA	NA	18395	18609	(-)214		3770
(Birr/ha)		(3920)	(4595)	(6040)				(956)	(1373)	(1673)		(6050)
	D0F1S0	23506	18450	5056**	22359	16864	5495**	24176	23733	443	-439	4613**
		(997)	(1714)	(1983)	(1270)	(1991)	(2362)	(361)	(817)	(893)	(2042)	(1889)
	D1F1S0	18832	13420	5412***	20919	14664	6255**	21318	19247	2071***	-843	3341*
		(850)	(1554)	(1771)	(1656)	(2169)	(2729)	(288)	(549)	(620)	(2153)	(1819)
	D0F1S1	26627	16992	9635***	22140	16364	5776***	23917	21259	2658	3859	6977**
		(2307)	(2539)	(3431)	(1609)	(1292)	(2064)	(954)	(1547)	(1818)	(3481)	(3809)
	D1F1S1	21959	11303	10656***	19429	11269	8160***	23948	15873	8075***	2496	2581
		(1915)	(1027)	(2173)	(1234)	(952)	(1558)	(527)	(628)	(820)	(2260)	(1979)
	N		136			143			1267			

Note. We report actual outcome with MATs (A), counterfactual outcome without MATs scenario (C) and difference between the actual and counterfactual scenarios as average treatment effect on the treated (ATT). Standard errors in parenthesis . NA refers to non-applicable because of too few observations. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

between WMPs and MMPs, but we did find that the adoption of fertiliser alone increased maize yield by 1351 kg/ha for WMP, by 1290 kg/ha for MMP and 699 kg/ha for JMP (Table 6). Similarly, the average treatment effect of the adoption of fertilisers and maize-legume diversification was estimated to be 1224 kg/ha, 1414 kg/ha and 904 kg/ha for WMP, MMP and JMP, respectively. Similarly, the average treatment effect of D1F1S0 on maize marginal returns was estimated to be 5412 birr/ha, 6255 birr/ha and 2071 birr/ha for WMP, MMP and JMP, respectively. The average treatment effects of the adoption of fertilisers and soil and water conservation measures is estimated to be 1560 kg/ha and 9635 birr/ ha for WMP, 1198 kg/ha and 5776 birr/ha for MMP and 895 kg/ha for JMP. Similar to the results resented in Table 5, the higher impact of MATs was realised with the adoption of the full package (D1F1S1) in all the gender groups.

Notably, the results in Table 6 showed that there was no statistical difference regarding the impact of fertilisers on the maize yield or financial returns between WMP and MMP. Nominally, the ATTs of the MAT packages were higher for WMPs (except in the case of D1F1S0, although it was still not statistically significant). On the other hand, some differences between WMPs and JMPs were found to be statistically significant. The average maize yields on WMPs was found to be statistically higher at 652 kg/ha and 4613 birr/ha than JMPs under D0F1S0. Similarly, the ATTs for WMPs were statistically higher under D1F1S0 and D1F1S1 by 320 kg/ha and 438 kg/ha, respectively. In relative terms, WMPs had ATTs that were 93% higher for D0F1S0 and 35% and 28% higher for D1F1S0 and D1F1S1, respectively. In brief, the yield and marginal return performance of the MATs of WMPs were either equal to those of MMPs or, in some cases, higher than those of JMPs.

3.4. Heterogeneity effects by gender and rainfall endowment

Table 7 presents the estimates for the impacts of MATs on maize yield and maize marginal returns disaggregated by gender and rainfall endowments. Analysing the differential impacts of MATs on plots that are managed by different genders and are exposed to different rainfall exposure (rainfall stress and rainfall surplus) can help in further understanding how the patterns observed in Table 6 hold when the weather variables are included, given that these impacts are likely to be context specific (Tomich et al., 2019;). In general, we find positive results of the different combinations of MATs disaggregated by gender and rainfall endowments. However, plots with rainfall surplus have better performances than plots with rainfall shortage. Moreover, similar to the results in Table 6, the plots managed solely by women have nominally higher outcomes than the ones managed jointly and by men in both the rainfall endowment scenarios.

3.5. Brief Discussion: gender intentional agricultural development

Which is the best way to achieve gender intentional agricultural development: promoting individual or joint control of agricultural resources? The implications of the results presented in Table 6 and Table 7 are twofold. First, after controlling for demographic factors, improved agronomy, input use and other covariates such as market access and locational and rainfall differences, the productivity in plots controlled by women is at

Table 7. Gendered impacts of MATs on maize yield by rainfall endowment.

		Rainfall-deficit plots								
Outcome	MAT		WMPs			MMPs			JMPs	
Variable	Category	A	C	ATT(A-C)	A	C	ATT(A-C)	A	C	ATT(A-C)
	D1F0S0	2433	2608	(-)175	NA	NA	NA	2521	2328	193
		(443)	(922)	(480)				(119)	(135)	(183)
Maize	D0F1S0	3107	1937	1170***	2706	1639	1067***	3253	2475	778***
		(165)	(183)	(116)	(114)	(201)	(193)	(54)	(83)	(75)
Yield	D1F1S0	3043	1471	1572***	3179	1774	1405***	3219	2162	1057***
		(169)	(185)	(162)	(289)	(230)	(215)	(49)	(58)	(56)
(kg/ha)	D0F1S1	2993	1449	1544***	3407	2185	1222***	3151	2255	896***
		(205)	(297)	(415)	(289)	(183)	(337)	(139)	(139)	(173)
	D1F1S1	3039	1342	1698***	3423	1592	1831***	3530	1993	1537***
		(389)	(111)	(380)	(262)	(123)	(251)	(88)	(76)	(94)
	D1F0S0	16,876	17,796	(-)920	NA	NA	NA	18224	17,267	957
		(3025)	(6578)	(3554)				(956)	(1111)	(1541)
Maize	D0F1S0	19,738	13,687	6051***	17,884	11,479	6405***	21,678	18,560	3118***
		(1129)	(1416)	(948)	(874)	(1568)	(1461)	(397)	(697)	(633)
Income	D1F1S0	18,871	10,230	8641***	19,761	13,170	6591***	20,497	16,174	4323***
		(1066)	(1476)	(1294)	(1864)	(1890)	(1526)	(328)	(486)	(446)
(Birr/ha)	D0F1S1	21,261	10,224	11,037***	21,714	15,330	6384***	20,779	16,595	4184***
		(1560)	(2275)	(3077)	(1862)	(1321)	(2254)	(1065)	(1152)	(1408)
	D1F1S1	17,568	9490	8078***	19,761	11,056	8705***	22,820	14,772	8048***
		(1914)	(943)	(2025)	(1310)	(978)	(1467)	(538)	(648)	(698)
	N		72			110			889	
	Rainfall surplus plots									
Outcome	MATs		WMPs			MMPs			JMPs	
Variable	Category	A	C	ATT(A-C)	A	C	ATT(A-C)	A	C	ATT(A-C)
	D1F0S0	3207	1623	1584				2529	2670	(-)141
		(1473)	(923)	(2395)				(353)	(436)	(612)
Maize	D0F1S0	4021	2555	1466***	4232	2704	1528***	4261	3691	570***
		(182)	(248)	(251)	(239)	(346)	(204)	(71)	(152)	(142)
Yield	D1F1S0	3000	2286	714**	3734	2293	1441**	3614	3052	562***
		(210)	(277)	(274)	(497)	(692)	(549)	(81)	(120)	(88)
(kg/ha)	D0F1S1	4642	3044	1598***	3732	2676	1056*	4513	3621	892**
		(473)	(360)	(445)	(234)	(357)	(489)*	(198)	(331)	(388)
	D1F1S1	4573	1958	2615***	2727	1781	946	4454	2806	1648***
		(337)	(244)	(490)	(564)	(487)	(433)	(168)	(183)	(198)
	D1F0S0	24,113	13,841	10,272	NA	NA	NA	19047	23,730	(-)4683

(*Continued*)

Table 7. (Continued).

		Rainfall-deficit plots								
		(9737)	(8483)	(18,219)				(2924)	(4959)	(6113)
Maize	D0F1S0	25,892	21,466	4426*	27,132	22,608	4524**	28,264	32,201	(-)3937***
		(1297)	(2519)	(2284)	(1766)	(3191)	(1899)	(516)	(1554)	(1442)***
Income	D1F1S0	18,776	18,099	677	24,539	19,335	5204	23,153	26,112	(-)2960***
		(1442)	(2811)	(2400)	(3465)	(6810)	(5246)	(555)	(1261)	(989)
(Birr/ha)	D0F1S1	32,664	24,607	8057*	24,623	22,395	2228	29,812	30,022	(-)210
		(3591)	(3003)	(3575)	(1611)	(3696)	(4408)	(1402)	(3437)	(3597)
	D1F1S1	31,229	15,130	16,099**	16,688	13,017	3671	30,105	21,880	8225***
		(2299)	(2037)	(3387)	(3918)	(3876)	(3439)	(1312)	(1664)	(1893)
			64		33			378		

We report actual outcome with multiple MATs (A), counterfactual outcome without MATs scenario (C) and difference between the actual and counterfactual scenarios as average treatment effect on the treated (ATT). Standard errors are in parenthesis. NA refers to non-applicable because of data limitations. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

least equal to (or potentially higher) than those managed jointly or by men. The significantly higher yields on WMPs compared to JMPs is noteworthy. In some cases, the joint management of resources (i.e., inputs and agricultural plots) may appear as one way to achieve better redistribution and control for men and women (Haider et al., 2018). For example, Ethiopian law now requires that both the husband and wife be jointly listed in land lease certificates (Holden & Bezu, 2014) in order to improve women's access to land. The impacts of this policy shift remain to be analysed. Our findings suggest that this may not be straightforward.

Autonomous management of agricultural plots will require fundamental changes not only in the legal regimes but, more importantly, in social norms and women's bargaining power. For example, in many rural areas, a larger piece of land (constituting the farm) is often sub-divided into separate tiny plots among family members, to be operated individually or jointly. In situations where further sub-division of land and individual titling is not feasible (and only small pieces of land can be shared) among household members, the issue of intra-household bargaining power becomes paramount (Marenya et al., 2015).

4. Conclusions

There are well-documented disparities among men and women in rural areas with regards to access to and control agricultural resources. Therefore, a more targeted approach to improve women's access to agricultural innovations can increase the overall agricultural productivity. This study uses gender-disaggregated household and plot-level survey data from Ethiopia to explore the impacts of multiple agronomic practices disaggregated by the sex of the plot manager. Using a multinomial endogenous switching regression methodology and controlling for observed and unobserved heterogeneity as well as endogeneity, the study found that MATs have a positive and significant effect on maize yields and maize marginal returns. Moreover, when we controlled for demographics, plot quality and agronomic practices (among others), we found that women managed plots had treatment effects (yields) that were statistically the same as those of male managed plots (and nominally higher in a number of cases). The study confirms that once access to inputs, agronomy, market and extension are controlled for, women farmers' productivity is commensurate with that of male farmers. Implicitly, our results point to the need for more studies on strengthening women's bargaining power (through education and inclusive financial services) and modernising legal regimes to safeguard women's property rights as part of the toolkit for reducing gender-mediated gaps in access to agricultural inputs or resources more broadly.

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