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Fertilizer use on individually and jointly managed crop plots in Mozambique

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Abstract

Using plot level data, this study examines the differential fertilizer application rates on plots managed individually by men, women, or jointly in dual adult households in three districts in south-central Mozambique. The results suggest that—controlling for the demographics of the manager and plot characteristics—joint management of agricultural plots is associated with higher fertilizer application rates on maize plots but with lower fertilizer application on non-food cash plots. Absent equitable sharing of proceeds from jointly managed plots, efforts to increase access to inputs by women may need to be targeted at plots already managed by women themselves. In land-scarce environments where women are less likely to have parcels to cultivate autonomously, these results suggest that improving women's bargaining power under joint management of agricultural activities may be one way to improve gender equality in agriculture.

Key words: Mozambique, gender, plot management, fertilizer use

Introduction

A strong body of empirical evidence in development economics research (e.g. World Bank, 2001; Quisumbing *et al*., 2014) has shown that addressing gender inequalities can have profound positive effects on enhancing growth and poverty reduction in Africa. Gender inequalities in agriculture are well recognized, with consistent evidence suggesting that women tend to have more constrained access to agricultural inputs and technology (e.g. land, fertilizer, labor, and machinery) and to critical services (e.g. extension and credit) (Quisumbing, 1995; World Bank, 2001; Kassie, Ndiritu, and Stage, 2014).

Within households, differences in resource allocation among plots operated by different household members may be one of the factors that underpin gender gaps in agricultural productivity and welfare. Within the same household, aggregate agricultural productivity could be improved if everyone had equal access to inputs (Udry, 1996). It therefore stands to reason that one way to close these gaps is to ensure that all those engaged in agricultural activities have access to complementary inputs on the plots they own, control, or otherwise manage. In terms of gender gaps between male and female farmers, this access should happen both when women are part of dual- or multi-adult households and when they are the household heads themselves. One of the main ideas relevant for this study and that has recently been advanced to promote women's empowerment is joint land titling and ownership. The hypothesized empowering effect comes from the notion of "influence according to contribution" (Sen, 1990, as cited in Wiig, 2013), because women are enabled to contribute more to the household's common goods if they have greater and legally protected joint access to land.

A similar framework may be relevant for addressing gender disparities in access to and use of agricultural inputs at the intra-household level; not least because, in addition to joint farm activities (and perhaps in spite of joint ownership rights to land) individual members of a household often engage in separate agricultural production activities and often operate separate plots. The distribution and allocation of agricultural resources (land) or inputs (fertilizer) among economically active members of the household—and the allocation of the proceeds of farm production within the household—are usually determined by intra-household bargaining (Alderman *et al*., 1995; Udry *et al*., 1995).

While it may be argued that it is empowering when women autonomously manage and control separate plots, the continued observation of the existence of lower input use or lower yields (e.g. Gilbert, Sakala, and Benson, 2002; Peterman *et al*., 2011; FAO, 2011) on plots managed by women (controlling for plot quality) means that a more complex story may exist. In constructing the Women's Empowerment in Agriculture Index (WEAI), one of the domains used by Alkire *et al*. (2013) relates to decisions involving agricultural production and whether those decisions are made solely or jointly "with no judgment on whether sole or joint decision making better reflects greater empowerment". It is possible that increases in empowerment—suggested by individual control of agricultural plots—can be attenuated if there are no commensurate improvements in women's access to inputs. Such attenuation can occur if women are left to operate low quality and smaller plots on which only economically minor crops or those crops meant for household provisioning can be grown as the literature has previously suggested (Doss, 1999; DFID, 2007). On the other hand, joint management and control can be reflective of increased empowerment if it is motivated by improved access by women to productive resources (cash from wage income, for example), which can allow them to influence decisions in joint farm activities.

Using the example of fertilizer application rates on plots managed by different members of the household, this study asks whether there are systematic differences in the amount of fertilizer applied among plots operated individually by men or women and those operated jointly by both men and women. Our aim is to determine whether joint or individual management is associated with greater fertilizer use and what the observed differences may imply for gender equality in agriculture or future research.

This paper uses detailed datasets from a 2013 household survey in rural Mozambique, which identify the manager of each plot. Models of plot level fertilizer application rates were estimated using a number of covariates, such as individual characteristics (e.g. age and education), decision making on agricultural activities, plot preparation, inputs used, and plot characteristics. The models were fitted for three crop categories: maize, fruits and vegetables, and non-staple cash crops. We restrict our analysis of intra-household plot management to dual adult households because this sample lends itself to the analysis of intra-household gender differences. While women who are the sole heads of their households (especially *de jure* female heads) face the same common gender issues outlined in the literature, intra-household gender issues are frequently apparent in dual- or multi-adult households.

The rest of this paper is organized as follows. Section 2 provides an overview of agricultural gender gaps as found in the reviewed literature. Section 3 defines plot management, the analytical model, and variables used in the study. Section 4 presents the empirical results from the regression model. Section 5 provides a broader discussion of the results in the context of intra-household dynamics. Section 6 concludes by summarizing the key message, outlining the possible policy implications from the results and identifying issues that require further analysis.

Literature Review

Many studies examine differences in technology adoption between men and women by using a dummy variable identifying the sex of the household head as the gender indicator without further disaggregation into intra-household plot management (Quisumbing, 1996). Recent exceptions include: A study by Ndiritu, Kassie, and Shiferaw (2014) where the authors test for gender differences in the adoption of agricultural intensification practices in Kenya using plots managed by men, women, or both within a household; Slavchevska (2015), who applies the Oaxaca-Blinder decomposition method to study intra-household gender productivity differences in Tanzania; and de Brauw (2015), who examines the factors (such as a spouse's non-farm employment) that affect women's control of agricultural plots within the household.

There is empirical evidence in an earlier body of literature in agricultural and rural development showing that intra-household differences in access to incomes, inputs, and other resources are crucial and that analyzing questions of technology adoption at the intra-household level is paramount (see Kanbur and Haddad, 1994; Alderman *et al*., 1995; Quisumbing, 1996; Ghosh and Kanbur, 2008). In a study that tested whether agricultural inputs were used most efficiently across all plots within the household, Udry et al. (1995) found that by reallocating inputs from plots controlled by men to those controlled by women in Burkina Faso, the level of production in the household would have increased by 10 to 15 percent. According to Doss and McDonald (1999, p. 57) the inefficiencies reported in Udry et al. (1995) are consistent with the fact that household members "neither pool nor trade inputs with each other." Doss (2001) suggests that the reason why intra-household reallocation does not happen is because such exchanges can affect long-run bargaining power, even though in the short-run it could increase farm profits.

However, a considerable portion of the literature analyzes productivity differences at the *inter*-household level, with little discussion on the inequities in resource allocation that exist *within* the household. According to Quisumbing (1996), the biggest shortfall in much of this literature is that much of it implicitly assumes Pareto-efficient [i] *intra*-household input allocation. Yet allocative inefficiencies that arise from gender-determined agricultural division of labor *within* the household are more consequential for productivity differences than mere biological differences between men and women. In effect, there are few inherent differences between men and women that explain productivity differences better than unequal access to resources.

In fact, much of the evidence that women are less productive than men is largely attributable to lower input use among women. Consistent with this, Peterman et al. (2011) state that the literature has "not provided definitive conclusions" on whether there are productivity differences between male and female farmers. Quisumbing *et al*. (2001) find some evidence (albeit weak) of female-owned parcels having lower yields. Yet, after controlling for input use, Oladeepo and Fajuyigbe (2007) in a study in Osun State, Nigeria, found that female rice farmers were more technically efficient than their male counterparts. Similarly, studies in Gambia and Nepal by Chavas, Petrie, and Roth (2005) and Aly and Shields (2010) (respectively) find no productivity differences by sex of the household head for similar input levels. In Zimbabwe, Horell and

Krishnan (2007) found no productivity differences between male- and female-headed households. The thrust of this and related literature is not different from the argument put forward by Quisumbing (1996), which is that apparent productivity differences between men and women are a reflection of lower access to agricultural inputs, explaining why productivity differences between male and female farmers diminish or are eliminated once input use is taken into consideration.

However, the pre-production question of input use (specifically fertilizer) has not received the same treatment – in terms of empirical rigor—as gender gaps in productivity, despite the literature's admission that gender gaps in input access are behind observed differences in productivity. It is therefore important for future research to put more effort into analyzing gender differences in input use. Conceptually, the present study is based on the now-established fact that the household cannot be regarded as a monolithic unit that can be represented by one utility function for all individuals within the household (Alderman *et al*., 1995; Browning and Chiappori, 1998), although the relative analytical and empirical parsimony of the unitary household model has some advantage in econometric analysis (Browning *et al*., 1994). The existence of intra-household differences in access to agricultural inputs is one reason for considering alternative household models that go beyond the assumption of a homogenous household where members' preferences can be represented by one person. As argued by Vermueulen (2002), the paucity of intra-household analysis (with individuals rather than households being the unit of observation) wrongly implies that intra-household welfare is not important or that intra-household allocation is efficient (Alderman *et al*., 1995, Haddad *et al*., 1995).

Gender and agriculture in Mozambique

About 25 percent of agrarian households in Mozambique are headed by women (MINAG, 2005) suggesting that many rural women may be part of households headed by men, reaffirming the need for greater emphasis on intra-household analysis of gender issues in Mozambique. Encouragingly, an example at intra-household analysis in Mozambique was a study by Aalerud (2010), who demonstrate how the control of at least one plot improves the bargaining power of women; and another by de Brauw (2015), who analyzed the circumstances under which women have control and decision-making autonomy on plots they manage in multi-adult households. These studies are important because there is evidence of diversity in plot ownership and control within the household in Mozambique. For example, Woldemariam, Kassie, and Cachomba (2012) found that in areas of Mozambique similar to those we focus on in the present study, 46.7 percent of the total plots were managed both by men and women while 29.3 percent and 24 percent were managed individually by men and women, respectively. As shown by de Brauw (2015), in many cases men and women operate separate plots, with some plots being jointly controlled and subject to joint decision making.

The extent of women's contributions to agriculture in Mozambique is typical of many Sub-Saharan African countries. In the south-central regions (from where most of the data in this study was derived, i.e. Manica, Sussundega, and Angonia), women participate in nearly all agricultural activities, including land preparation, tending livestock (typically performed by men in other regions), planting, weeding, and harvesting. It is apparent that in this region, the division of labor in agricultural tasks is less clear than in other parts of Sub-Saharan Africa. While quantitative estimates for contributions to specific tasks are not readily available, by some estimates women contribute about 43 percent of all agricultural labor (Lidström, 2014; Aalerud, 2010). Generally, the coexistence of individual and joint plot management in the same household is not uncommon in Africa (see Udry, 1996; Goldstein and Udry, 2005 for examples from Ghana, Ndiritu Kassie and Shiferaw (2014) in reference to Kenya, Slavchevska (2015) for an example from Tanzania and de Braw (2015) and Woldemariam, Kassie, and Cachomba, 2012 in the context of Mozambique). Yet women continue to lack access to and control over key household resources, including cash, land, and livestock (Johnson *et al*., 2013; de Brauw, 2015). The farm structure in Mozambique is such that many households operate small, non-mechanized farms, with a typical farm averaging 1.2 ha. Many farms consist of contiguous and non-contiguous plots, with diversified crop plantings (sometimes as inter crops). There is little irrigation and farmers tend to grow traditional crop varieties, with limited use of fertilizer.

While many different crops are grown, maize is the main staple, grown by 80 percent of rural farming households. In Mozambique, maize provides 22 percent of calories (FAOSTAT, 2011). Given its status as the economic mainstay of many households, maize is one of the main crops studied in this paper. We also include fruits and vegetables, and other non-staple cash crops. Fruits and vegetables are often grown by women to supplement household income and feed families (Woldemariam, Kassie, and Cachomba, 2012). The data used in this study shows that 50.4 percent of the plots are planted with maize, 39.1 percent of plots are planted with fruits and vegetables, and 10.5 percent are planted with non-staple cash crops, including coffee, cotton, tobacco and sugar cane.

Methodology

In this section, we outline the basic models used in the analysis of fertilizer application rates at the plot level. Since this study is based on plot level observations, we first define what criteria were used to identify plots within the household's farm holdings. We then describe how plot ownership and management was defined. This is followed by a description of the regression models. Finally, we describe the variables used in these models and their hypothesized effects on fertilizer application rates are stated.

Definition of plots, plot ownership, and plot management

In order to collect data at the plot level, enumerators were trained to identify a plot as a unique patch of land with discernible boundaries contiguous or non-contiguous with other patches; recognizable as planted with a particular crop or crop association (such as inter-crops); and under a uniform, consistent form of crop management. These patches of land were regarded as plots if they were continuous and not split by a path more than thirty feet wide. Plot boundaries were therefore based on the crops grown, physical separation, and the identity of the operator within the household.

The person responsible for growing the crops and making day-to-day decisions on crop management (type of crop, when to plant, which inputs to use, etc.) was considered the plot manager, regardless of whether he or she was the plot owner. The survey instrument asked the respondent to indicate who made particular decisions on plots that were identified as managed by members of the household. A plot was considered "individually managed" if all decisions were made by one person or as "jointly managed" if at least two people were involved decision making regarding the plot (regardless of whether some of these decisions were jointly made or if different decisions were made exclusively by one individual among those involved in managing the plot). The household head was usually the primary respondent in the survey. In the absence of the household head, his or her spouse was the respondent. It was assumed that the household head or spouse could reasonably provide accurate answers regarding the various plots operated by members of the household during the most recent production season.

Regression models

We designed several regression models to explain how plot level rates of fertilizer application were correlated with individual characteristics of the plot operator (e.g. age) as well as plot management practices and plot characteristics. Each of these models used an ordinary least squares (OLS) estimator. Each regression model was then used to predict plot level fertilizer application in a counterfactual process akin to identifying treatment effects. In our case, indicator variables of whether the plot in question was individually or jointly managed and whether the operator was a man or a woman were construed as "treatments". Three different fertilizer application models were designed for three separate samples.

The first sample (sample 1) contains plots that were individually managed by male household members combined with all plots which were jointly managed. The second sample (sample 2) contains plots managed by female household members, also combined with all plots which were jointly managed. In both samples, a dummy variable indicating joint management was used to compare plots Individually Managed by Men (IMM) or plots Individually Managed by Women (IMW) with jointly managed plots.

The third sample (sample 3) is a pooled sample of only the plots IMM and IMW (excluding jointly managed plots) which was used to compare plots IMM and IMW. Each regression was done separately for three crop types (maize, fruits and vegetables, and non-staple cash crops). The regressions and the subsequent treatment effects analyses are formalized as follows:

$$F_p^1 = \alpha X_i^1 + \beta Z_p^1 + \gamma J_p + \varepsilon^1 \qquad (1)$$

$$F_p^2 = \alpha X_i^2 + \beta Z_p^2 + \gamma J_p + \varepsilon^2 \qquad (2)$$

$$F_p^3 = \alpha X_i^3 + \beta Z_p^3 + \gamma G_p + \varepsilon^3 \qquad (3)$$

Here F_p^1 indicates fertilizer application rate on plot p in sample 1 (denoted by superscript 1) containing plots IMM plus jointly managed plots and F_p^2 indicates those plots in sample 2 containing plots IMW plus jointly managed plots in the household. The variables denoted by X_i are the plot manager's demographic and household characteristics; those denoted as Z_p are plot level characteristics and J is a dummy which is equal to 1 if the plot p is managed jointly (J = 0 if plot p is individually managed). For jointly managed plots, the demographic characteristics of the person indicated as holding the most responsibilities in the jointly managed plot, usually the household head, were used in the regressions. In equation 3, F_p^3 predicts fertilizer application using *sample 3* (which was composed of plots IMM and IMW) without the jointly managed plots (maize, vegetable and fruits, and cash crop plots). The gender of the manager of plot p in sample

3 is denoted by G_p, which took the value 1 for plots IMM and 0 for plots IMW. The other variables remain as described for equations 1 and 2.

After fitting the fertilizer application model, the *estimated* equation (1) and equation (2) were used to produce counterfactual fertilizer application rates by using the coefficient for joint management. Somewhat akin to the impact evaluation literature [ii], the following conditional expectations for the various fertilizer application rates are computed from equations 1 and 2 above in the actual and counterfactual scenarios:

$$E\left(F_{ip}^1 \middle| J=0\right) = \alpha X_i^1 + \beta Z_p^1 \qquad \text{for plots IMM only} \tag{1(a)}$$
$$E\left(F_{ip}^1 \middle| J=1\right) = \alpha X_i^1 + \beta Z_p^1 + \gamma \qquad \text{for plots IMM only} \tag{1(b)}$$
$$E\left(F_{ip}^2\right) | J=0) = \alpha X_i^2 + \beta Z_p^2 \qquad \text{for plots IMW only} \tag{2(a)}$$
$$E\left(F_{ip}^2 \middle| J=1\right) = \alpha X_i^2 + \beta Z_p^2 + \gamma \qquad \text{for plots IMW only} \tag{2(b)}$$
$$E\left(F_p^3 | G=0\right) = \alpha X_i^3 + \beta Z_p^3 \qquad \text{for plots IMW only} \tag{3(a)}$$
$$E\left(F_p^3 | G=1\right) = \alpha X_i^3 + \beta Z_p^3 + \gamma \qquad \text{for plots IMW only} \tag{3(b)}$$

Equations 1(a) and 2(a) are the predicted fertilizer application rates derived from the fitted regression model, estimating fertilizer use in each sample based on the mean observed levels of the covariates. Equations 1(b) and 2(b) represent the “counterfactual” expected fertilizer application rates on plots IMM and plots IMW respectively by changing the management of these plots to joint. Using the fitted model, the counterfactual simulation is done by predicting fertilizer application rates on plots IMM or plots IMW by replacing all *J=0* with *J=1* for individually managed plots. [iii] Therefore, the counterfactual in equation 1(b) estimates what the fertilizer application on plots IMM would have been if these plots were managed jointly and all else were equal. The counterfactual in equation 2(b) estimates the fertilizer application on plots IMW would have been if these plots were managed jointly. A t-test of the difference between the fertilizer application rate recovered from 1(a) and that from 1(b) determined whether there was a significant difference in fertilizer use when these plots were IMM as compared to if they were to be jointly managed instead. A similar procedure is done using equations 2(a) and 2(b). Similarly, equation 3(a) predicts the fertilizer application rate derived from the fitted regression using only plots that are IMW, estimating fertilizer use based on the mean levels of the observed covariates. Equation 3(b) represents the “counterfactual” estimated fertilizer application rates on plots IMW if they were instead IMM. [iv] The section below explains the rationale for the covariates included in the regressions.

Demographics and household variables

“Education of plot operator” was measured as years of schooling and was hypothesized to be a predictor of greater cognitive ability to, for example, use extension information, thereby increasing fertilizer use. “Main occupation of plot operator” was measured as own farm activity, agricultural laborer, non-farm self-employment, and salaried employment. Three binary dummies were used, with agricultural laborer being the base comparison. The inclusion of these occupational categories was based on the hypothesis that having additional sources of cash income can increase the adoption of fertilizer. “Age of plot operator” was measured in years and used to control for farming experience. However, age could also have bidirectional effects on fertilizer adoption. Older farmers may have accumulated experience and be better placed to use fertilizer. Younger farmers may be more energetic and entrepreneurial, which can also improve fertilizer use. “Relationship of plot manager to household head” was measured as a dummy variable showing whether the decision maker was the household head, spouse, or another relation. The position of the plot manager in the household may affect their share of household resources. “District of residence” was captured by an indicator variable showing whether the household’s residence was in Manica, Sussundega, or Angonia (with Manica being the comparison district). The district of residence reflects (and is used to capture) the agro-ecology and other infrastructural conditions that may influence fertilizer availability, access, and returns.

Plot management and plot characteristics

The controls used here were meant to capture differences in plot management and characteristics that may influence the rate of fertilizer application independent of the gender of the manager or the management type on the plot. While it is true that fertilizer application affects the long-run soil fertility, other kinds of practices—such as manure application—can either complement or supplement fertilizer use, depending on the situation. Those able to access fertilizer easily may use manure as supplement to fertilizer and those with limited access may use manure instead of fertilizer. The implementation of soil and water conservation in the plot can affect the efficiency of fertilizer through soil loss mitigation and moisture conservation. Fertilizer efficiency may be lower on plots that are prone to erosion. The practice of maize-legume intercropping may complement fertilizer use if the legume species or variety planted can fix nitrogen and there is no serious competition (between the main crop and the legume) for other nutrients such as phosphorous that are applied through fertilizers. There is some agronomic evidence that maize-legume intercropping reduces the demand for fertilizer to achieve a specific level of yield (Kassie *et al*., 2015). The slope of the plot may indicate the soil erosion potential from water run-off. Plots that are less prone to erosion may receive more fertilizer than others that have higher erosion and soil nutrient loss potential. Similarly, the perceived soil fertility on plot (from the point of view of the plot manager) can influence the plot manager’s behavior in terms of input use. This may also have bidirectional impacts depending on how the farmer decides to manage perceived poor soil fertility (either reducing or increasing fertilizer use).

Data, data sources, and sampling

This paper uses household and agricultural production and marketing data gathered as part of a collaborative research program implemented in 2013 by the Eduardo Mondlane University in Mozambique and the International Centre for Maize and Wheat Improvement (CIMMYT). The research was designed to understand the social, economic, technological, and policy drivers for the sustainable intensification of maize and legume-based systems in the country. The data gathering was carried out in areas identified as the major maize and legume-based farming regions of Mozambique. Three districts (Angonia, Manica, and Sussundega) were selected for this purpose.

Multi-stage sampling methods were used to identify survey households. In the first stage, districts were selected purposively based on the importance of maize in the agro ecology. The distribution of sample households across the respective districts was proportional to the number of households per district according to the most recent government household census. Sub-district administrative units were used as further sampling clusters.

Table 1: Variables used in the fertilizer rate models[A]

Variable	*Sample 1* **Plots IMM+ jointly managed plots**	*Sample 2* **Plots IMW+ jointly managed plots**	*Sample 3* **Plots IMM + IMW (no jointly managed plots)**	**All plots**
Plot level fertilizer application per hectare (all crops)[B]	53.21 (309.21)	30.71 (68.5)	53.56 (265.3)	45.82 (214.34)
Education of plot manager (years)	4.19 (3.29)	4.27 (3.87)	4.21 (3.47)	4.22 (3.54)
Main occupation of plot operator				
Own farm production (crops and livestock)	0.83 (0.37)	0.84 (0.41)	0.82 (0.38)	0.83 (0.39)
Agricultural and non-agric. labourer	0.13 (0.08)	0.10 (0.11)	0.11 (0.05)	0.11 (0.08)
Non-farm self-employment	0.01 (0.11)	0.02 (0.14)	0.02 (0.12)	0.02 (0.12)
Salaried employment	0.03 (0.18)	0.04 (0.27)	0.05 (0.21)	0.04 (0.22)
Age of plot manager	38.4 (15.46)	41.32 (15.88)	39.28 (15.63)	39.67 (15.66)
Plot manager is household head	0.95 (0.18)	NA	0.44 (0.49)	0.70 (0.34)
Plot manager is spouse of household head	NA	0.82 (0.45)	0.34 (0.48)	0.58 (0.47)
Plot manager is another relation of household head	0.05 (.001)	0.18 (0.35)	0.21 (0.41)	0.15 (0.25)
Plot manager is male	NA	NA	0.70 (0.46)	0.70 (0.46)
District of residence is Angonia	0.33 (0.47)	0.33 (0.47)	0.31 (0.46)	0.30 (0.45)
District of residence is Manica	0.30 (0.46)	0.32 (0.45)	0.31 (0.46)	0.30 (0.46)
District of residence is Sussundega	0.37 (0.48)	0.35 (0.49)	0.38 (0.48)	0.40 (0.48)
Size of plot	1.09 (2.02)	0.97 (2.99)	1.03 (2.04)	1.04 (2.28)
Presence of intercrop on plot	0.17	0.25	0.19	0.20

	(0.37)	(0.44)	(0.39)	(0.40)
Manure applied on the plot	0.16	0.15	0.15	0.15
	(0.36)	(0.35)	(0.36)	(0.36)
Soil water conservation on the plot	0.55	0.56	0.56	0.56
	(0.50)	(0.49)	(0.49)	(0.39)
Plot slope				
Flat	0.66	0.67	0.50	0.61
	(0.47)	(0.46)	(0.40)	(0.44)
Medium slope	0.30	0.25	0.44	0.33
	(0.46)	(0.42)	(0.49)	(0.46)
Steep slope	0.04	0.08	0.06	0.06
	(0.18)	(0.27)	(0.21)	(0.22)
Soil fertility on plot				
Poor soil fertility	0.12	0.10	0.12	0.11
	(0.32)	(0.31)	(0.32)	(0.32)
Medium soil fertility	0.40	0.41	0.40	0.40
	(0.49)	(0.49)	(0.49)	(0.49)
Good soil fertility	0.48	0.49	0.48	0.48
	(0.50)	(0.50)	(0.50)	(0.50)
N	1079	499	1062	1578

[A] Standard errors in parentheses

[B] See Fig. 1 for breakdown by crop

Table 2: Type of plot management, by crop

	Maize				**Fruits and vegetables**				**Non-staple cash crops**			
	Managed by				**Managed by**				**Managed by**			
	Men only	**Women only**	**Both**	**Total**	**Men only**	**Women only**	**Both**	**Total**	**Men only**	**Women only**	**Both**	**Total**
Number of plots	402	94	158	654	188	68	83	339	231	79	17	327
(% of total)	(61.5)	(14.4)	(21.2)	(100)	(55.5)	(20.1)	(24.5)	(100)	(70.6)	(24.2)	(5.2)	(100)
Average plot size	1.55	1.56	1.38	1.49	0.33	0.7	0.27	0.43	1.0	1.0	0.95	

A total of 143 villages were randomly picked from government administrative records. Based on the selected villages, probability proportional to size sampling was used to identify the households that were interviewed. The data used here comprised a total of 381 households (14.7 % being female headed) and 1578 plots. Table 1 presents a summary of the variables used in this study.

The majority of plots were managed by men only: 62% of maize plots, 56% of fruit and vegetable plots and 71% of non-staple cash crops plots (see Table 2). In comparison, 14% of maize plots, 20% of fruit and vegetable plots and 25% of non-staple cash crops were managed by women only. Only 5% of non-staple cash crops were on plots that were managed jointly.

Table 3 compares the agricultural practices across plots with different types of management. Jointly managed maize plots were more likely to have maize-legume intercropping than plots managed by men. Compared to jointly managed plots, plots managed by men or women individually had a lower incidence of fertilizer use. Also, compared to plots managed by men, jointly managed plots tended to have higher incidences of soil and water conservation structures and manure use. Except in the case of improved seed, the jointly managed plots tended to have a higher incidence of adoption of the improved agricultural practices. Figure 1 compares fertilizer use across the management types: fertilizer application rates were highest on jointly managed plots and lowest on maize plots IMW and the average rate of fertilizer application on maize plots IMM was twice that of maize plots IMW.

Table 3: Adoption of improved practices on maize plots, by sex of manager

Variable	**A**	**B**	**C**	**D**	**E**	**F**
	Full sample	**Plot managed by**			**Diff D-B**	**Diff D-C**
		Men	**Women**	**Both (jointly)**		
Maize planted in association with legumes[A] - (1=Yes, 0=No)	0.208	0.162	0.169	0.309	-0.147***	-0.040
Maize-legume rotation (1=Yes, 0=No)	0.164	0.171	0.143	0.157	0.014	0.016
Improved seed (includes OPVs) (1=Yes, 0=No)	0.863	0.847	0.928	0.868	-0.022	0.060*
Chemical fertilizer (1=Yes, 0=No)	0.230	0.222	0.184	0.309	-0.087**	-0.125**
Soil and water conservation measures (1=Yes, 0=No)	0.556	0.533	0.520	0.600	-0.067*	-0.080
Manure use (1=Yes, 0=No)	0.161	0.136	0.224	0.205	-0.068**	0.019
Minimum tillage (maize and legumes)(1=Yes, 0=No)	0.090	0.090	0.072	0.111	-0.022	-0.039

[A] This is a practice involving the planting of maize and legumes in alternating rows. The benefits of this practice are the inclusion of protein-rich legumes in the harvest along with maize and the beneficial effects of legumes on soils.

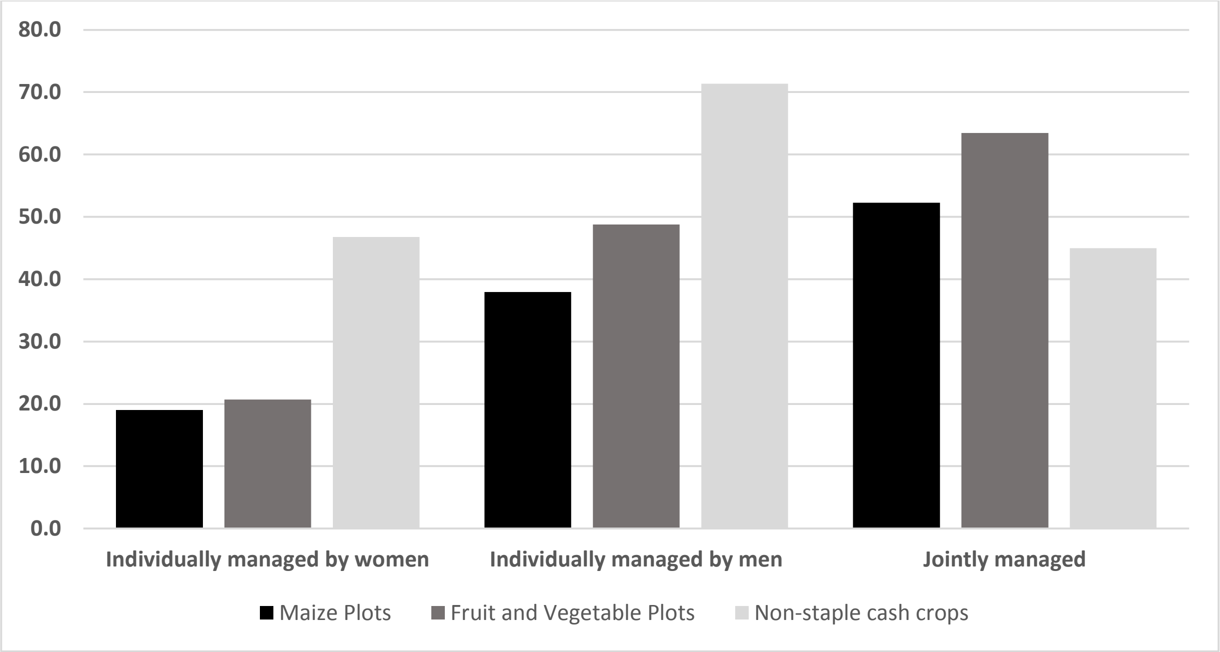

Figure 1: **Plot fertilizer application rates, by crop and manager**

Results from the regression models

Effect of demographic characteristics on fertilizer rate

The education of the plot manager was positively associated with fertilizer use (Table 4). Since we have controlled for occupation, the positive association between education and fertilizer application rates may be due to the ease with which more educated farmers are able to acquire and use information on best agricultural practices including fertilizer use. Being a laborer was positively associated with the rate of fertilizer application (in models where this was significant). Having salaried employment was only statistically significant for the sample of women growing fruits and vegetables. It may be that salaried employment increases the opportunity cost of spending time on the farm and thus reduces fertilizer use. A plot manager being the spouse of the household head is associated with greater fertilizer use for plots in the women's sample growing maize and fruits and vegetables and for cash crops in the pooled sample. Male plot managers used more fertilizer for fruits and vegetables and non-food cash crops, but not for maize.

Effect of plot characteristics and plot management on fertilizer application rate

The negative association between plot size and the fertilizer application rate suggests that the fertilizer application rate declines, consistent with limited fertilizer availability. The presence of intercrops on a plot was positively associated with the fertilizer application rate (on fruit and vegetable plots in the IMW sample and in the pooled IMW and IMM samples). Similar results were observed for IMW samples for cash crop plots. The use of manure was negatively associated with the fertilizer application rate. Compared to plots that the operator perceived as having poor soil quality, the perception of a plot being of medium or good quality was negatively associated with the fertilizer application rate. Similar results were observed for plots that were either medium sloping or steep sloping, compared to flat plots. Plots managed by farmers in

Sussundega and Angonia districts appear to be have more fertilizer applied than those in Manica. Comparing jointly managed with plots IMW shows that plots managed jointly were significantly associated with higher fertilizer application rates across the board.

Table 4: Factors influencing plot level fertilizer application rate (kg/ha), by management and crop type

	Plots IMM + Jointly managed plots ***Sample 1***			**Plots IMW + Jointly managed plots** ***Sample 2***			**Plots IMM and IMW (no jointly managed plots)** ***Sample 3***		
VARIABLES	Maize	Fruits and vegetables	Cash crops	Maize	Fruits and vegetables	Cash crops	Maize	Fruits and vegetables	Cash crops
Education of manager (years)	3.17*	5.27	9.89***	4.43*	2.25	1.53	1.24	2.62	8.22***
	(1.74)	(4.75)	(3.28)	(2.32)	(5.61)	(3.77)	(1.26)	(2.85)	(2.76)
Agric. or non agric. laborer	-6.23**	-16.64**	9.326	-4.37*	-24.30***	1.79	-2.56	2.39	3.16
	(2.48)	(6.46)	(5.83)	(2.46)	(9.03)	(3.89)	(1.96)	(4.94)	(5.23)
Non-farm self-employment	4.42	32.85***	22.72	-4.76	19.39***	-1.49	31.57	1.36	3.53***
	(70.03)	(82.29)	(7.67)	(9.18)	(7.05)	(5.58)	(56.06)	(7.89)	(8.13)
Salaried employment	-27.31	23.84	-14.38	-2.61	15.03**	1.48	-6.20	-38.98	2.48
	(39.52)	(10.32)	(26.49)	(3.13)	(6.02)	(3.64)	(35.85)	(109.08)	(9.99)
Age of manager	0.002	-0.22	0.86	0.19	0.20	1.39*	0.29	-0.47	0.16
	(0.35)	(0.98)	(0.760)	(0.64)	(1.826)	(0.83)	(0.33)	(0.680)	(0.65)
Manager is spouse of household head	NA	NA	NA	10.03**	31.75*	62.46	3.10	1.34	33.16*
	NA	NA	NA	(4.571	(17.06)	(56.94)	(9.58)	(2.39)	(18.69)
Manager is another relation of household head	-18.91**	-26.04	-13.74	-17.57**	-25.04	-7.48	-3.94	-8.14	-5.22
	(8.79)	(19.63)	(14.73)	(7.65)	(23.10)	(9.49)	(5.86)	(13.43)	(12.025)
Sex of household manager (male=1, 0 otherwise)	NA	NA	NA	NA	NA	NA	-0.88*	29.62*	35.41*
	NA	NA	NA	NA	NA	NA	(0.35)	(15.87)	(18.97)
Size of plot (ha)	-4.62**	22.11	2.96	-2.02	-31.70	-1.38	-3.28**	-6.59	-3.69
	(1.99)	(51.11)	(3.97)	(1.71)	(35.37)	(1.46)	(1.65)	(15.12)	(3.30)
Intercrop on plot	-6.37***	-85.57	33.75	-13.89	47.78	-34.84	-20.47**	-46.31	7.67
	(1.93)	(94.02)	(65.36)	(10.98)	(109.51)	(31.91)	(8.51)	(53.03)	(49.48)
Manure used on plot	9.42	6.39 **	39.48	1.15	37.31	1.82	11.04	6.50***	2.02
	(15.29)	(28.29)	(30.46)	(14.68)	(38.29)	(21.06)	(11.06)	(1.90)	(2.65)
Soil and water conservation on plot	0.78	26.91	1.87	2.49	5.33	35.47**	2.44	9.19	3.338
	(9.13)	(24.03)	(20.11)	(12.79)	(36.44)	(13.682)	(7.90)	(18.49)	(16.38)
Medium slope (c.f. flat)	-27.26**	7.860	31.50	-52.15**	7.18	3.20	0.209	14.19	7.16
	(13.73)	(33.46)	(23.06)	(22.84)	(39.69)	(18.54)	(8.65)	(19.10)	(18.36)
Steep slope (c.f. flat)	-10.79	-5.99	-5.15	-3.86*	-1.75	-5.69	-4.394**	-6.12*	-1.56
	(27.47)	(6.62)	(6.74)	(2.17)	(5.88)	(2.92)	(1.88)	(3.55)	(4.58)
Medium fertility (c.f. poor fertility)	-56.06***	-129.23***	-110.99***	-13.15	-30.76	-11.56	0.09	-90.42***	-112.73***
	(21.38)	(45.19)	(39.75)	(26.07)	(95.64)	(35.57)	(13.42)	(31.15)	(26.22)
Good fertility (c.f. poor fertility)	-68.13***	-103.719**	-91.99**	-28.63	-19.78	-2.79	-18.91	-90.28***	-118.42***
	(22.36)	(49.43)	(46.14)	(34.17)	(107.98)	(41.67)	(13.24)	(29.16)	(25.50)
Plot jointly managed (yes=1)	1.90*	28.70	-35.63	11.16*	47.28**	-30.37*	NA	NA	NA
	(1.27)	(45.84)	(45.30)	(6.73)	(16.53)	17.52)	NA	NA	NA
District of residence is Sussundega (c.f. Manica)	14.782***	26.04**	34.19***	10.88**	51.11**	9.72*	10.83***	14.84*	27.56***
	(3.52)	(10.84)	(8.85)	(4.63)	(23.15)	(5.56)	(3.45)	(8.38)	(7.23)
District of residence is Angonia (c.f. Manica)	4.43	85.49***	15.73***	3.83***	11.03**	31.85*	33.35***	3.82	1.47
	(10.89)	(21.79)	(4.76)	(1.46)	(4.73)	(17.26)	(10.81)	(2.57)	(1.96)
Inverse Mills ratio	216.45***	-19.35	-198.83	105.79*	-34.92	4.397	NA	NA	NA
	(79.97)	(97.07)	(132.33)	(61.31)	(63.66)	(49.53)	NA	NA	NA
Constant	89.21**	38.19	-156.34	67.47	-131.29	-100.74*	29.86	78.76	-8.98
	(40.60)	(100.23)	(122.70)	(45.47)	(154.43)	(53.29)	(33.95)	(71.09)	(69.81)

Results from simulations of fertilizer use if plots were managed jointly

In Table 5, the results of the counterfactual exercise are presented. These show how the predicted fertilizer use would change if individually managed plots were to be managed jointly. The regression model explaining the rate of plot level fertilizer application was fitted conditional on variables described earlier. The coefficients of the estimated model are then used to first estimate the predicted fertilizer application rates among plots IMW by setting $J = 1$. The counterfactual scenario was also done for plots IMM, by setting $J = 1$.

The results (Table 5, Panel A) show that in maize plots IMW, the predicted fertilizer application rates would be 34 kg/ha if they were jointly managed (compared to 22.7 kg/ha in the baseline scenario if they were individually managed). In contrast, if maize plots IMM were managed jointly, the fertilizer application would decrease modestly (albeit significantly) from 34.3 to 32.4 kg/ha.

Table 5: Plot level observed and counterfactual fertilizer application, by management type and crop (kg/ha)

	If managed individually as observed	**If managed jointly (from counterfactual simulation)**
	Panel A: Maize plots	
Plots IMW	22.65	33.83*[A]
	(6.48)	(7.77)
Plots IMM	34.32	32.44**
	(8.76)	(7.95)
	Panel B: Fruit and vegetable plots	
Plots IMW	20.71	67.91*[A]
	(18.8)	(20.3)
Plots IMM	48.8	77.5
	(12.01)	(17.7)
	Panel C: Non-food cash crop plots	
Plots IMW	46.78	16.43**[A]
	(26.8)	(52.4)
Plots IMM	71.35	35.72*
	(24.65)	(70.17)

[A] The asterisks *, ** and *** on the joint management figure denote that the difference between the joint and individual plot level fertilizer application rate application is significant at 10, 5 and 1% respectively.

The results estimated for fruit and vegetable plots are also presented (Table 5, Panel B). These are qualitatively similar to the maize plots in the sense that fruit and vegetable plots IMW have lower fertilizer application rates than those managed jointly or those IMM. Moreover, when fruit and vegetable plots IMW are simulated to be under joint management, their fertilizer application rates increase threefold (from 21 kg/ha to 68 kg/ha). Similarly, simulating fruit and vegetable plots that were IMM to be under joint management would increase fertilizer application from 49 kg/ha to 78 kg/ha.

The results are somewhat different when it comes to non-staple cash crop plots (Table 5, Panel C). While cash crop plots IMW are still reported as having lower fertilizer rates than cash crop plots IMM, joint management of cash crop plots IMW would lower fertilizer application on these plots. Similarly, joint management of IMM plots would lower fertilizer application on these plots as well. Two candidate explanations can be offered for this result: It is possible that there exists stronger division of labor in the type of cash crop managed by men and women, perhaps reducing the opportunities for joint management of cash crops. It may also be the case that the sharing of cash from these crops is harder, making joint management less likely than for maize and fruits and vegetable crops.

The literature suggests that women tend to specialize in staple crops, fruits, and vegetables (World Bank, 2009; DFID, 2007). In some cases, crops that were previously women's subsistence crops attracted the attention of men when these became commercialized and women lost control of them. The question raised by Doss (1999) however remains; as to whether these observed patterns are based on women's preferences (because they are primarily responsible for household provisioning) or because they lack the needed resources (including land, credit, and access to markets and information) to grow cash crops.

Results from simulations involving changing from female to male individual management (and vice versa)

A similar counterfactual exercise was done for the gender of the household manager by running a regression of both male and female managed plots (excluding jointly managed plots) and including a dummy variable for the gender of the manager (Table 6). If maize plots IMW were managed individually by men (treating maize plots IMW to be IMM), fertilizer application rates were only very marginally lower (23 to 22 kg/ha). Similarly, treating plots IMM as if they were IMW—has no statistically significant impact.

Table 6: Plot level observed and counterfactual fertilizer application, by sex of plot manager and crop (kg/ha)

	If managed as observed	**If manager is the opposite sex (counterfactual)**
Panel A: Maize Plots managed by men and women compared		
Plots IMW	22.65	21.77*
	(6.48)	(5.03)
Plots IMM	23.46	24.36
	(7.02)	(6.22)
Panel B: : Fruit and vegetable plots managed by men and women compared		
Plots IMW	20.71	50.32*
	(18.8)	(10.7)
Plots IMM	48.8	19.18*
	(12.01)	(15.87)
Panel C: Non-food cash crop plots managed by men and women compared		
Plots IMW	46.78	82.19
	(26.8)	(34.90)
Plots IMM	71.35	35.93
	(24.65)	(55.78)

[A]The asterisks *, ** and *** on the joint management figure denote that the difference between the joint and individual plot level fertilizer application rate application is significant at 10, 5 and 10% respectively.

In Panel B, the results suggest that simulating management by men on fruit and vegetable plots that were IMW increases fertilizer application rates on these plots from about 21 kg/ha to 50 kg/ha. The opposite approach, simulating management by women on plots that were IMM decreases fertilizer application from 49kg/ha to 18 kg/ha. In Panel C, there are no statistically significant differences when simulating the changes in the management from men to women.

Discussion: Will joint management lead to better technology adoption and yields?

In this section, we aim to situate our results within the broader context and offer suggestions for further research.

Will encouraging the change from individual management to joint management of plots and crops lead to increased fertilizer application on those particular plots?

The data presented in this paper reveal that there is some statistical association between joint management of plots and greater fertilizer use (except in the case of non-food cash crops where joint management is associated with lower fertilizer application rate). Although the association between joint management and greater fertilizer application rates is interesting, it reveals that, broadly, there is a need to do more research on intra-household input, land, and crop output and income allocation. It is still necessary to establish why joint management is related to higher fertilizer application rates.

Assuming that there are underlying reasons for why fertilizer use is higher under joint management, we are still left to wonder about sharing rules within the household. Whether the increase in fertilizer use is due to the pooling of resources remains an empirical issue that requires examination. Consequently and all else equal, greater fertilizer use should lead to higher yields. Whether the observed association between joint management means that household per capita consumption or crop incomes will also increase will depend on the sharing rules within particular households. These rules will determine whether the higher crop yields (or income therefrom) on jointly managed plots are available to all members of the household equally or not (Browning *et al*., 1994; Ghosh and Kanbur, 2008).

In the context of this study, we cannot say how the proceeds of jointly managed plots will be distributed. The results simply associate joint management of plots with higher fertilizer application. Tellingly, Udry *et al*. (1995) calculates that reallocating inputs from plots managed by men to those managed by women would increase crop output in the aggregate within the household. It is also not clear whether harvests from jointly managed plots are essentially communal resources under men's control. An example of this phenomenon is reported by Braun and Webb (1989), who describe an irrigation scheme in Gambia that was meant to increase rice yields, commercialize the crop, and increase women's incomes because rice was a "woman's crop". However, when rice yields and incomes increased, men took an interest in the rice crop and the crop subsequently became a "communal crop under the control of men" rather than a "private crop under the control of women" (see Alderman et al. 1995, p. 9).

If jointly managed plots receive more fertilizer, and if the goal is to increase input use, should that be done by encouraging joint plot management?

The caveats above suggest that if women have little control over the proceeds of jointly produced crops, then a more appropriate solution to improving women's access to and control of agricultural inputs is to target plots that are *ex ante* IMW within the households. The precondition for the success of this approach will be that women have access to land and plots on which they can exercise autonomy. Where land is limited and further intra-household subdivision and reallocation is not possible, the alternative would be to encourage joint management and the equitable sharing of crop yields and proceeds.

This raises the critical issue of bargaining power. In cooperative collective household models, household members can arrive at Pareto-efficient allocations via bargaining or engaging in strategic repeated games. The equilibrium allocation depends on various "threatpoints" or fall-back positions of the members concerned. If the social, legal, and economic environment provides the household members (especially women) with creditable fall-back positions, such as divorce and legal recourse or social sanctions, then it may be possible to achieve an equitable sharing of joint production. Without such bargaining power, unequal (inequitable) intra-household allocation is likely to be the outcome. The ubiquity of inequalities in intra household allocations—such as reported in Udry *et al*. (1995), Quisumbing (1996), Udry (1996), and Doss (2001)—lends weight to this particular concern about inefficient household sharing.

Summary, conclusions, and implications for policy and further research

In summary, the results reported in this paper suggest that joint management of agricultural plots (except for non-food cash crops) is associated with higher fertilizer application rates, controlling for the demographic characteristics of the main manager and other plot level controls. For maize plots, the simulated effect of joint management was modest for plots individually managed by men but substantial (a 49 percent increase) for plots individually managed by women. In fruit and vegetable plots, the simulated effect of joint management was large and significant for plots individually managed by women. The simulated effect of joint management for fruit and vegetable plots individually managed by men was insignificant (although nominally substantial, with a 59 percent increase under joint management). The effect of joint management on non-food cash crop plots individually managed by women was a 64 percent decrease in fertilizer application rates; likewise for non-food cash crop plots managed by men (a 49 percent decrease).

The effect of the gender of the plot manager was small for maize plots and only significant in the case of simulating plots IMW to be the counterfactual of those same plots being IMM (with male management being associated with marginally lower fertilizer application on maize plots). However, male management was substantially and significantly associated with higher fertilizer application on fruit and vegetable crops. The impact of male management for fruit and vegetable plots was similar to non-food cash crop plots, although the differences were not significant. Joint management would work well under the assumption that the benefits from additional production would be available to all household members on an equitable footing. That, however, remains an empirical assumption subject to further testing and confirmation or rejection. If evidence exists that there is no equitable sharing of proceeds from jointly managed plots (unfortunately this study provides no such evidence), then greater efforts for increasing access to inputs by women may need to be targeted at plots already being individually managed by women. Where land is scarce and access to extra plots that women can autonomously operate is limited, it may be possible to improve access by women to inputs and agricultural income by encouraging joint plot management and equitable sharing. As this study shows, analyzing input use at the sub-household level is important because it can generate data that can help inform programs/policies for increasing input use for both women and men, both at the aggregate level and within households.

The message from this study is not that joint management causes fertilizer use to increase (or decrease) if plot management changed from individual to joint. The choice of whether to manage a plot individually or jointly is certainly endogenous to all of the other agricultural decisions. Rather, these findings simply show that fertilizer use differs depending on who is managing the plot. Additional research is needed to understand whether programs that encourage joint management could actually increase fertilizer use. When designing such programs, it is important to remember that if participating women do not also have joint management of the outputs, they might not elect to participate in the first place.

Definitive policy recommendations will have to wait for further analyses of the underlying reasons for the apparent higher input use on jointly managed plots. More detailed studies of intra-household sharing rules among members of rural agrarian households is also warranted. This is especially true given the potential endogeneity in our model regarding unknown factors that may be correlated with joint management and also affect fertilizer use. These factors may ultimately be of interest for intra-household gender analysis and policy recommendations.

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[i] The concept of Pareto efficiency, as used in the economics of policy analysis, refers to a resource allocation between groups such that it is not possible to effect a reallocation of resources and improve one group's welfare without making another group worse off, suggesting that the present allocation is the most socially efficient. A Pareto inefficient allocation therefore refers to situations where it is possible to improve the welfare of one group through a reallocation without making another group worse off. An example of Pareto-inefficient fertilizer use would occur when it is possible to increase aggregate household crop output by reallocating some fertilizer from some plots to others (e.g. reallocating some fertilizer away from individually managed plot to jointly managed plots). However, the Pareto criterion does not tell us how to achieve these efficient allocations. Just finding out that intra-household allocations can be rearranged to increase household welfare does not tell one how that can be done.

[ii] Gender differences in agriculture can also be studied in a similar framework as that found in the wage decomposition literature in the manner of the Oaxaca-Blinder (OB) decomposition model. This is in recognition of the fact that both the amount of resources and the returns to those resources matter to gender differences in agricultural outcomes. This point was made by Quisumbing (1996). Recently, a number of studies that use the OB decomposition approach have appeared in the literature on gender differences in agriculture. Recently published papers such as Aguilar *et al*. (2015), Oseni *et al*. (2015) and Slavchevsca (2015) use the OB or related methods to study gender productivity differentials in Ethiopia, Malawi, Nigeria, and Tanzania. Although the approach we take may sound similar in concept to the OB method, the comparisons we make in this study do not really lend themselves to the decomposition approach in the OB method because some of the observed demographic covariates in the individual management are replicated in joint management.

[iii] In terms of econometric approaches, the decision on how to manage a plot is likely to be influenced by factors unobserved (unobservable) in the data but which also affect the amount of fertilizer applied, raising the issue of endogeneity. This requires the application of an instrumental variable related to joint management but unrelated to fertilizer use. We do not have such an instrument in our data. Instead, we used an inverse mills ratio based on the predicted probability of a plot being jointly or individually managed. This is meant to correct for endogeneity between fertilizer use and whether a plot is jointly managed or is individually managed.

[iv] Note that in equations 3(a) and 3(b) it is G (the gender indicator that is changed in the counterfactual simulation). Additionally, although not included in the equation list above, the equivalents of equations 3(a) and 3(b) were run for plots IMM.