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Gender Differences in the Adoption of Cereal Intensification Strategy Sets in Burkina Faso

by

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GENDER DIFFERENCES IN THE ADOPTION OF CEREAL INTENSIFICATION STRATEGY SETS IN BURKINA FASO

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EXECUTIVE SUMMARY

In the West African Sahel, current issues of land fragmentation resulting from high rates of population growth and climate change exacerbate conditions of chronic food insecurity. In this context, agricultural intensification is necessary in order to increase food supply and better understanding gender differences in the adoption of intensification strategies is crucial for designing effective policies to enhance farm productivity sustainably.

So far, much of the empirical research on gender differences in Sub-Saharan Africa has focused on assessing relative productivity rather than examining gender-differentiated determinants of adoption. In conducting gender research, the selection of the appropriate unit of analysis matters. In none of the previous analyses, including those conducted in Burkina Faso, were researchers able to control for whether individual plots were managed by the household head.

In addition to the unit of analysis, the attributes of technology, techniques or practices affect the incentives for their use. The vast majority of adoption studies conducted in the West African Sahel have focused on soil and water conservation (SWC) practices. In this region, as compared to Eastern and Southern Africa, use of modern inputs appears to have received relatively less attention from researchers, with the exception of some work on maize.

In this study, we draw on these two strands of literature to address the adoption of intensification strategies in cereals production in Burkina Faso. We define intensification strategy sets (enhancing, protecting, conserving inputs), considering that the economic attributes of inputs affect adoption incentives. Our approach departs from earlier gender studies by selecting the individual plot as unit of analysis rather than the household.

We apply multivariate probit models with the Chamberlain-Mundlak device to examine whether 1) female managers adopt intensification strategy sets at lower rates than their male counterparts on cereals plots; 2) gender differences in the likelihood of adoption depend on the strategy set; and 3), determinants of adoption differ between male and female managers of individual plots.

Descriptive statistics show lower rates of adoption for women compared to men for all intensification strategy sets. For instance, women plot managers are only slightly more than half as likely to use yield-enhancing inputs as men plot managers (8 vs. 15%, respectively). However, more nuanced results emerge from the econometric analysis, once we controlled for other covariates.

The gender of the plot manager remains statistically significant for one out of three intensification strategy sets, after controlling for other covariates. No gender differential is found in the probability of adopting the yield-enhancement and yield-protection sets, whereas gender of the plot manager significantly influences the probability of adopting the soil and water conservation set. This finding reflects how both the socio-cultural farming context and economic attribute of the technology affect incentives to adopt. Having more limited access to resources and less intrahousehold negotiation power, women are less likely to adopt SWC strategies, which entail bulkier inputs, more intensive labor, and generate impacts over a longer time horizon.

The underlying process that explains adoption differs between male and female plot managers. Plot size and distance from residence influence the probability of adoption of men

and women alike, whereas plot topography affects the adoption decision differently across gender. Household resources and market and institutional factors do influence the probability of adoption but in different ways. Women's adoption decisions are influenced by variables capturing labor availability, whereas other household resources affect mostly men's decisions, especially in regards to the SWC set.

The interrelatedness of adoption strategy sets (yield-enhancing, yield-protecting, and soil-and-water-conserving) confirms the policy importance of designing mechanisms to encourage the use of combinations of strategies. An intensification strategy set cannot be promoted in isolation, without considering incentives for other sets. At the same time, the variation in input use within strategy sets confirms that farmers in these environments are not best approached with a fixed package in mind.

Gender differentials in adoption rates for the SWC set and among determinants of adoption, confirm the need to collect data disaggregated at the plot level and design and promote policies that, while respecting socio-cultural norms, also respect opportunities and incentives for individuals within multigenerational, multi-family farms. Some changes are needed to redress the male bias in extension services, by including women as beneficiaries and covering topics on sustainable intensification, which takes into account women's constraints to technology adoption. Credit access also remains crucial for inputs purchased with cash (yield-enhancing and yield-protecting sets), especially for women who have limited economic control within the household. Improving access to education, income, and equipment to women could contribute to increase their bargaining power and thereby, adoption of sustainable intensification strategies.

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ACRONYMS

CRE	correlated random effects
DGESS	General Research and Sectoral Statistics Department (*Direction Générale des Études et des Statistiques Sectorielles*
DGPER	*Direction Générale pour la Promotion De Économie Rurale*
EPA	Continuous Farm Household Survey (*Enquête Permanente Agricole)*
FAO	Food and Agriculture Organization of the United Nations
IFAD	International Fund for Agricultural Development
INERA	Institut de l'Environnement et de Recherches Agricoles
MASA	Ministry of Agriculture and Food Security (*Ministère de l'Agriculture et de la Sécurité Alimentaire*
MVP	multivariate probit
SWC	soil and water conservation
UNDP	United Nations Development Program

1. INTRODUCTION

Uncertain rainfall and degraded soils have long characterized farming systems in much of the West African Sahel. To harvest enough to feed their families, farmers themselves have devised various techniques for managing land and water intensively (e.g., Reij, Tappan, and Smale 2009). Since the great droughts of the 1970s and 1980s, national and international research organizations have also developed and introduced high-yielding varieties of sorghum, millet, and maize, along with fertilizer and recommended agronomic practices (Matlon 1990; Sanders, Nagy, and Ramaswamy 1990). Still, farmers in the West African Sahel are among the most disadvantaged on a global scale and remain highly vulnerable to chronic food insecurity. In this adverse farming environment, sustainable agricultural intensification is necessary in order to increase food supply by smallholder farmers.

Current issues of land fragmentation resulting from high rates of population growth and climate change exacerbate the situation. Socio-cultural norms guiding land use and crop cultivation are evolving in response to food insecurity (Guirkinger and Platteau 2014; Kazianga and Wahhaj 2013), with incentives for more individualized decision-making. For instance, more women are planting sorghum—a crop traditionally cultivated by men—on their individual plots, in order to contribute to food security, and also because sorghum prices have risen relative to other crops they grew before (Dabiré et al. forthcoming). Understanding gender differences in the adoption of intensification strategies is crucial for designing effective policies to enhance farm productivity sustainably.

So far, much of the empirical research on gender differences in Sub-Saharan Africa has focused on assessing relative productivity rather than examining gender-differentiated determinants of adoption. In her critical review of the literature on gender differentials in farm productivity, Quisumbing (1996) concluded that lower yields on farms managed by women resulted from lower amounts of inputs and resources used. Estimating a restricted profit function to test the relative efficiency of men and women maize farmers in Western Kenya, Alene et al. (2008) found no evidence of gender-related differentials in either technical or allocative efficiency once they had controlled for resource access. In Ghana, Goldstein and Udry (2008) found than women achieved lower outputs and profits on their cassava/maize plots than did their husbands because of less secure tenure rights. Udry et al. (1995) estimated that food production in Burkina Faso could increase by as much as 10-15% if productive resources were allocated more efficiently across men and women of a same household. Using data from 1993/1994 in the Yatenga Plateau of Burkina Faso, Kazianga and Wahhaj (2013) found that no gender differential in productivity persisted when individual plots managed by female household members were compared with male household members, but they were unable to identify individual fields managed by heads.

In conducting gender research, the selection of the appropriate unit of analysis matters. Peterman et al. (2011) demonstrated the sensitivity of productivity differentials to whether comparisons were made by household versus plot. In none of the previous analyses, including those conducted in Burkina Faso, were researchers able to control for whether individual plots were managed by the household head. In addition to the unit of analysis, the attributes of technology, techniques or practices affect the incentives for their use.

The literature on technology adoption is voluminous—in part due to myriad, context-specific strategies farmers deploy to enhance or protect yields, and manage water and soils. The vast majority of adoption studies conducted in the West African Sahel have focused on soil and water conservation practices (see Sidibe 2005; Kazianga and Masters 2002; Somda et al. 2002; Maiga 2005; Ouédraogo 2005; Slingerland and Stork 2000 for Burkina Faso only). In this region, as compared to Eastern and Southern Africa, use of modern inputs appears to have received relatively less attention from researchers, with the exception of some work on maize (Smith et al. 1997; Alene et al. 2008), and recent impact overviews funded under DIIVA (Alene and Mwalughali 2012). In other regions, several recent studies have examined the determinants of adoption of multiple yield enhancing, protective, and/or conserving strategies (Kassie et al. 2013; Teklewold et al. 2013; Kamau, Smale and Mutua 2014). To our knowledge, research by Ndiritu, Kasie and Shiferaw (2014) is unique in addressing the gender dimensions of adopting a combination of intensification strategies in Kenya; however, the data-generating context did not permit plot-wise gender comparisons.

In this study, we draw on these two strands of literature to address the adoption of intensification strategies in cereals production in Burkina Faso. Evidence have shown that women tend to be more constrained in terms of access to and use of productive resources and services (FAO 2011; World Bank 2014; UNDP 2014). We define intensification strategy sets (enhancing, protecting, conserving inputs), considering that the economic attributes of inputs affect adoption incentives. We hypothesize that 1) female managers adopt intensification strategy sets at lower rates than their male counterparts on cereals plots; 2) gender differences in the likelihood of adoption depend on the strategy set; and 3) determinants of adoption differ between male and female managers of individual plots.

We apply multivariate probit models to test our hypotheses. Our approach departs from earlier gender studies by selecting the individual plot as unit of analysis rather than the household, controlling for headship and other plot manager characteristics in addition to gender and other covariates. By applying the models to data collected in a nationally representative, statistical sample of farmers over a three-year period (2009/10-2011/12), we test our hypotheses while controlling for both time-varying and unobservable heterogeneity with the Chamberlain-Mundlak device. Our aim is to contribute to the design of policies to support the sustainable intensification of cereal production in Burkina Faso.

2. GENDER, FARM STRUCTURE, AND CEREAL PRODUCTION IN BURKINA FASO

Production of rainfed cereals by smallholder farmers dominates agriculture in Burkina Faso, where sorghum, millet, and maize account for over 70% of total cultivated land. Needing less moisture, millet, and sorghum are well adapted to drylands and are cultivated throughout the country. Both cereals play an important role in achieving food security, since they constitute the basis of the diet for a vast majority of Burkinabe (DGPER 2012). In contrast, maize is grown only in the wetter zones of the country.

It is also in the wetter zones that cotton, the main country's export, is produced by smallholder farmers. Traditionally, farmers have grown cotton in rotation with maize and millet/sorghum. Compared with households who did not grow cotton, cotton producers have benefited for years from a vertically integrated, highly institutionalized cotton sector. Inputs are provided on credit to cotton-growing households, and cotton gin companies also offer them extension services for cultivation practices and natural resource management (Theriault and Tschirley 2014; Theriault and Serra 2014). Such services have important spillovers for cereal production; it is estimated that 60% of fertilizer obtained through cotton cultivation are diverted toward cereal fields, including maize (Holtzman et al. 2013).

Most smallholders in drylands areas continue to be oriented toward meeting subsistence food needs. Drawing from historical, ethnographic research (e.g., Hammond 1966; Lallemand 1977); Kazianga and Wahhaj (2013) note some defining features of Burkinabe farm households, which were also depicted by Udry (1996). Farm work is conducted across numerous plots with well-defined boundaries, for which the management has been assigned to a specific adult member, under the titular authority of the household head who is often an elder patriarch. Some plots are worked collectively by household members, while others are individually managed. According to existing social norms, collective plots are managed by the head of the household and all proceeds from collective plots are used to meet the household's needs. In contrast, proceeds from production on individual plots can be retained by the manager or contributed to the common welfare of the household.

Individual plots are managed by different household members, male or female, with substantive control over decisions related to input (e.g., choice of crops) and output (e.g., share of revenues). For example, married sons of the patriarch, and some unmarried sons, are often allocated their own fields. Upon marriage to sons of the patriarch, wives are allocated small plots to meet the specific needs of their own children and to contribute ingredients used in preparation of meals consumed in common with the larger family group. In some instances, widows of a male family member may be allocated fields to ensure their subsistence.

Even when land has been allocated, the extent to which major factors of production such as labor and draught power are shared is the outcome of a complex intrahousehold negotiation. Ethnographic studies report that often, as a reflection of the priority placed on overall household welfare, household labor is allocated first to the collective fields. Household members can only work on their individual fields after completing all their tasks on the collective fields.

Another important feature of the Burkinabe farming structure is the interplay between customary norms and formal tenure rights. Konaté (2006) explains that in patrilineal systems such as that of Burkina Faso, land rights are transmitted via male family members. Because of the principle of exogamy (marriage outside the family), women are generally awarded no more than usufruct rights at marriage. The possibility of divorce, and thus alienation of lineage lands outside the family, poses an inherent threat. Thus, despite that all Burkinabe are equal in the rights according to the Constitution, and that the Agrarian Reform of 1996 declares no discrimination, customary norms, which are inherently unequal, prevail in practice. For instance, in some regions of Burkina Faso, women have no access to plots except for the off-season (Konaté 2006). Another example of gender inequality is the allocation of irrigated plots to male farmers only in Dakiri, eastern Burkina Faso (Zwarteveen 1997).

3. METHODS

3.1. Data Source

The data for this analysis are drawn from the Continuous Farm Household Survey (*Enquête Permanente Agricole* (EPA)) collected by the General Research and Sectoral Statistics Department (*Direction Générale des Études et des Statistiques Sectorielles* (DGESS)) of the Ministry of Agriculture and Food Security (*Ministère de l'Agriculture et de la Sécurité Alimentaire* (MASA)) in Burkina Faso. The sampling frame for the EPA is based on the 2006 Population Census. The EPA generates production, area, and yield data for rainfed crops, serves as an early warning system for food insecurity, and furnishes general information about livestock holdings, income and expenditures of rural households, and farm input use, using a nationally representative sample of 4,130 household farms in 826 villages across all 45 provinces. In this article, we utilize data covering the 3-year period from 2009/10 through 2011/12. These are the last years for which fully cleaned data are available. After dropping households that were not continuously surveyed throughout the three year period and missing observations for variables of interest, we are left with over 2,700 households cultivating about 40,000 cereal plots, including roughly 9,000 cereal plots that are individually managed and where maize, sorghum or millet were the primary crops.

The format of the EPA data reflects the socio-demographic structure of farm family decision-making in Burkina Faso, as described in section 2. Rainfall estimates from the National Oceanic and Atmospheric Administration's Climate Prediction Center at the commune level are used to control for rainfall variability.

3.2. Empirical Strategy

The objective of our analysis is to test gender differentials in rates of adoption and determinants of adoption across an array of inputs on rainfed cereals. For tractability, we utilize a straightforward latent variable framework to model the decision of individuals (male and female plot managers) to adopt as a binary outcome. We group input use outcomes in terms of strategy sets (yield enhancing, yield protecting, and soil and water conserving), each of which plays a different role in the intensification of cereal production (sorghum, maize and millet).

Consistent with the overall perspective of decision-making within a complex household in the face of imperfect or missing markets, we consider that individual choices are conditioned on household, market, and institutional characteristics. Recognizing that even if markets were perfect and complete, differentiation in input use could result from plot-specific variable features of land and microclimate, we also model choices as conditional on plot and agro-climatic characteristics. As in the case of productivity differentials, gender specialists have demonstrated that controlling for education or marital status along with access to productive resources may eliminate gender differences in adoption rates (Doss 1999). As such, plot manager characteristics constitute key covariates for hypothesis testing.

It is expected that individual family members will adopt intensification strategies that maximize their perceived benefits. Let the perceived benefits derived from adopting an intensification strategy by farmer i at time t, be:

$$y_{it}^{*} = X_{it}\beta + u_{it} + c_i \qquad i=1,\dots,n, \text{ and } \quad t=1,\dots,T \qquad 1$$

where, X_{it} is a set of observable covariates, β is a vector of parameter estimates, u_{it} is the normally distributed error term independent of X_{it}, and c_i are the time-invariant unobserved effects (Greene 2003; Hsiao 2003). Although, perceived benefits derived from a strategy are unobservable (y_{it}^*), the decision to adopt is observable (y_{it}) and is expressed as:

$$y_{it} = 1 \text{ if } y_{it}^* > 0 \qquad 2$$

$$= 0 \; \textit{otherwise}$$

Here, y_{it} is a limited dependent variable, which takes a value of 1 if the farmer *i* makes the observable decision of adopting any intensification strategy within a set at time *t* and zero otherwise. As specified, both c_i and β are unknown parameters to be estimated by the probability model (Greene 2010; Hsiao 2003):

$$\text{Prob}\,(y_{it} = 1 \mid X_{it}, c_i) = \text{F}(X_{it}\beta + c_i) \qquad 3$$

Given the binary nature of the dependent variable (to adopt or not), the possible interdependence across a set of intensification strategies, a multivariate probit model is used to examine the gender differentials in the determinants of adoption.

The multivariate probit model can be seen as an extension of the probit model, since it allows estimating several probit models simultaneously, while allowing the error terms in those models to be correlated (Greene 2003). Correlation occurs when unobservable characteristics (e.g., intrinsic management skills) captured by the error terms, influence the adoption decision of a set of strategies. A positive correlation in the error terms of probit models suggests that the adoption of different strategies may be complementary whereas a negative correlation suggests that they may be substitutable (Ndiritu, Kasie, and Shiferaw 2014; Khanna 2001; Dorfman 1996). Ignoring the possible correlation across the set of probit models could lead to bias and inconsistent estimates (Greene 2003).

In nonlinear models estimated with panel data, such as we employ here, the use of a fixed-effect approach to control for unobserved, time-invariant effects is problematic, since it leads to inconsistent parameter estimates (Greene 2010; Hsiao 2003). This is known as the incidental parameter problem, which also occurs with the inclusion of household-level dummy variables (Wooldridge 2015). A commonly used approach to address this problem in panel data estimation is Correlated Random Effects (CRE), also known as the Chamberlain-Mundlak device (Chamberlain 1984; Mundlak 1978; Cameron and Trivedi 2005; Wooldridge 2010). The CRE approach allows for unobserved time-invariant effects or unobserved heterogeneity (c_i) to be correlated with observed covariates in nonlinear models, through the projection of those effects on the time average ($\overline{X_i}$) of covariates:

$$c_i = \overline{X}_i\delta + \alpha_i + \omega, \qquad \alpha_i \mid X_i \sim N(0, \sigma_\alpha^2) \qquad 4$$

Following this approach, we estimate the reduced form

$$\text{Prob}\,(y_{it} = 1 \mid X_{it}) = \text{F}(X_{it}\beta + \overline{X}_i\delta + \alpha_i + \omega)\,, \qquad 5$$

Where $\overline{X}_i$ are the means of covariates that vary over time for household *i*, α_i is the normally distributed error term, and other parameters are as defined above. Wooldridge (2015) refers to the class of models we estimate as the "unobserved effects" nonlinear (probit) model, in which the empirical interest is to estimate a response probability in a microeconomic setting, while also addressing the problem of heterogeneity (c_i). According to Wooldridge (2015), the focus of the nonlinear unobserved effects model is on "parametric approximations that are logically consistent" with the binary nature of the dependent variable rather than on estimation of parameters per se. Though a linear model is a useful starting point for estimating average partial effects, the model imposes the restriction that $0 \leq X_{it}\beta + c_i \leq 1$ for all X_{it} . The linear functional form for equation 5 cannot hold over a wide range of values of X_{it} and c_i , and may thus may provide a poor approximation (Wooldridge 2015).

Equation 5 is the basis of the econometric estimation. As indicated above, to implement the CRE approach, household means of time-varying, observed covariates are included as additional regressors. All regressions are estimated with time (year dummy) effects and the variance option of clustering by household identifier, which generates the robust standard errors. The use of clustered standard errors allows for correlation among the unobservable characteristics of plot managers belonging to the same household.

3.3. Defining Adoption Operationally

Ideally, adoption would be defined and measured as the achievement of a longer-term outcome that represents a supply-demand equilibrium (e.g., Griliches 1957). Nonetheless, when measured on a national scale and over a 3-year period as presented here, annual use provides a valuable indication of cumulative adoption over a large population of smallholder farmers. In this study, we explore the use (short-term adoption) of several intensification strategy sets.

Table 1 provides a definition of the strategies used, as measured in the underlying data. Improved seed includes use of any farmer-recognized variety of purchased seed for a given crop. Inorganic fertilizer use includes using NPK and/or urea. Herbicides, fungicides, and pesticides can be of solid or liquid form. Organic manure includes application of manure, compost pit, household refuse, animal and/or other penning. Anti-erosion structures include stone contour bunds, planting pits (*zaï*) and/or half-moons (*demi-lunes*), porous and nonporous dikes, living fences and grass bands (*bandes enherbées*). In the survey, the adoption of improved seeds, manure and anti-erosion practices were qualitatively measured. The use of inorganic fertilizer, herbicide, pesticide, and fungicide were quantitatively measured. Any quantity greater than zero has been considered to reflect the adoption of the practice/technology. By doing so, we may have lost information about intensity—which is not the focus of this study—but have gained the possibility of examining the determinants of adoption of a broad range of strategy sets.

Table 1. Definition and Summary Statistics for Dependent Variables

Strategy Sets	**Definition**	All individually-managed N=9050	Male-managed N=3078	Female-managed N=5972	p-value
Yield-enhancement	Improved seeds and/or inorganic fertilizer	10.7	15.2	8.2	0.000
Yield-Protection	Herbicide, fungicide, and/or pesticide	16.7	18.6	15.7	0.000
Soil and water conservation	Manure and/or anti-erosion structures	25.0	29.6	22.6	0.000

Source: As prepared by authors.

To gain tractability in our multivariate probit analysis when the adoption of any one of multiple inputs is feasible, we have grouped them into *strategy sets* according to the way they influence crop yields and their economic attributes (Table 1). The dependent variable of strategy sets 1, 2, or 3 is equal to 1 when any of the inputs grouped in that set is used. Yield-enhancing inputs (set 1) include improved seed and inorganic fertilizer, which are often used together since improved seed is bred with the goal of attaining a higher response rate to fertilizer, when planted with adequate moisture, than local seed. Yield-enhancing inputs are depicted as shifting the supply curve outward. Yield-protecting inputs (set 2) are used with the aim of maintaining or saving yield when the crop is beset by plant pests or disease. These counteract an inward shift of the supply curve. These include pesticides, fungicides, and herbicides. Soil and water conservation (SWC) techniques (set 3) are composed of soil amendments such as manure, as well as anti-erosion or water-harvesting structures. We envisage SWC techniques as reducing the decline in soil fertility, but also as having the potential to shift the supply curve outward, over time.

The sets can also be viewed from the perspective of their economic attributes, which affect adoption/use incentives. Set 1 inputs are often considered to be annual inputs that would be neutral to scale if not for the lumpiness of fertilizer (related to its weight and the costs of inland transport, in particular). Theory predicts that farmers consider input-output ratios, marginal rates of yield response to the inputs, and annual expenditure constraints when deciding whether to use them (see, for example, Feder and Slade 1984). Since the path-breaking work of Lichtenberg and Zilberman (1986), the productivity effects of set 2 inputs are typically modelled in the framework of production functions with damage abatement, in order to include yield reduction from pest damage as a proportional transformation of the yield response. Set 3 strategies are often thought to be labor-intensive and not to justify the costs of labor investment in a single year of production (e.g., Ruben, Pender, and Kuyvenhoven 2007; Lee 2005). In some cases, such as dikes and contour bunds, these require collective labor efforts within and among farms because of soil erosion and water flow externalities. Thus, intensification strategies included in set 3 may exhibit some attributes of public goods.

3.4. Factors Affecting Adoption of Strategy Sets

The choice of explanatory variables draws from the concepts we outline above and a vast theoretical and empirical literature on the adoption of agricultural innovations in developing country agriculture, including reviews by Feder, Just, and Zilberman (1985); Feder and Umali (1993); and more recently by Foster and Rosenzweig (2010). A principle in this literature is that costs, and access to information about a new technology, are related to capital endowments, such as farm size. In their overview, Sunding and Zilberman (2001) emphasize that adoption of technology often occurs in response to constraints and/or to seize economic opportunities. There is a wide consensus in the literature regarding the factors that influence agricultural technology adoption. These factors can be grouped under socio-demographic, plot, household, market, and institutional and agro-climatic characteristics. Among these factors, financial and labor constraints along with land tenure have often been found to influence farmers' adoption decision in regard to intensification strategies (examples of recent studies include Kassie et al. 2015; Arslan et al. 2014; Ndiritu, Kassie, and Shiferaw 2014; Kamau, Smale and Mutua 2014; Kassie et al. 2013; Teklewold et al. 2013). After reviewing many empirical studies on soil conserving practices, Knowler and Bradshaw (2007) were unable to identify factors that uniformly explain adoption across crops, regions, and technology. These and other authors (e.g., Tittonell et al. 2005) highlight the context-specificity of the combinations of practices farmers find optimal under their conditions.

Table 2 provides definitions of the explanatory variables used in our econometric models and summary statistics. Departing from earlier gender studies, a dummy variable capturing the gender of the plot manager rather than the gender of the household head is used along with a household headship dummy variable. This allows us to compare whether technology adoption on individual plots differs by gender, while controlling for headship. Age, education, and marital status of the plot managers are also included as plot manager characteristics. Other covariates include physical characteristics of the individual plots, such as size, distance to the household residence, and topography (i.e., low land, slope).

Table 2. Definitions and Summary Statistics for Explanatory Variables

		All	**Male-managed**	**Female-managed**	**p-value**
Independent Variables	**Definitions**	**Mean (S.D)**	**Mean (S.D)**	**Mean (S.D)**	
Plot Manager Characteristics					
Woman	If the plot manager is a woman=1; Otherwise=0	0.65 (0.48)			
Age	Age of the plot manager (years)	39.0 (15.4)	37.5 (17.1)	39.8 (14.5)	0.000
Education	If the plot manager has a primary education=1; Otherwise=0	0.11 (0.31)	0.23 (0.42)	0.046 (0.21)	0.000
Head	If the plot manager is the household head=1; Otherwise=0	0.15 (0.36)	0.38 (0.48))	0.03 (0.17)	0.000
Married	If the plot manager is married=1; Otherwise=0	0.78 (0.41)	0.68 (0.46	0.83 (0.37)	0.000
Plot Characteristics					
Distance	If the plot is far from the house=1; Otherwise=0	0.60 (0.49)	0.58 (0.49)	0.61 (0.49)	0.003
Lowland	If it is a lowland plot=1 Otherwise=0	0.072 (0.26)	0.083 (0.28)	0.067 (0.25)	0.006
Slope	If it is a plot with a steep slope=1; Otherwise=0	0.065 (0.25)	0.070 (0.26)	0.063 (0.24)	0.145
Size	Size of the plot (hectares)	0.35 (0.46)	0.46 (0.61)	0.29 (0.30)	0.000
Household Characteristics					
Children/women ratio*	Ratio of children to woman at the household level (persons)	2.43 (1.28)	2.40 (1.32)	2.45 (1.26)	0.047
Adults*	Number of adults in the household (persons)	5.55 (3.17)	5.73 (3.38)	5.45 (3.05)	0.000
Landholding*	Total land cultivated by the household (hectares)	3.90 (3.21)	3.85 (3.38)	3.93 (3.11)	0.109
Livestock	Number of livestock owned by the household- measured in tropical livestock units (ln TLU)	1.69 (0.85)	1.71 (0.91)	1.68 (0.82)	0.053
Non-farm income*	Value of non-farm income at the household level (ln CFA)	7.40 (5.68)	7.45 (5.70)	7.37 (5.67)	0.248
Cotton hectares*	Number of cotton hectares cultivated at the household level (hectares)	0.25 (1.05)	0.24 (1.13)	0.25 (1.01)	0.328

Table 2 cont.

		All	**Male-managed**	**Female-managed**	**p-value**
Independent Variables	**Definitions**	**Mean (S.D)**	**Mean (S.D)**	**Mean (S.D)**	
Credit	If the plot manager has had access to credit over the last 12 months=1; Otherwise=0	0.022 (0.15)	0.03 (0.17)	0.018 (0.13)	0.000
Extension	Number of years since the plot manager has received any extension services (years). Top-coded at 5 years.	4.92 (0.48)	4.89 (0.55)	4.94 (0.44)	0.000
Density of agro-dealers	Number of agro-dealers per 100 km^2 in each province (units)	0.54 (0.65)	0.54 (0.65)	0.54 (0.64)	0.299
Agro-climatic characteristics					
Rainfall	Coefficient of variation of rainfall in each commune over the last three years (mm)	854.9 (180.3)	868.5 (190.5)	847.7 (174.1)	0.000
Millet	If millet is cultivated on the plot=1; Otherwise=0	0.31 (0.46)	0.24 (0.43)	0.35 (0.48)	0.000
Maize	If maize is cultivated on the plot=1; Otherwise=0	0.13 (0.33)	0.25 (0.43)	0.07 (0.25)	0.000

Source: As prepared by authors. * denotes time-variant household variables.

Next we include the covariates known to explain differences in input adoption among households, including wealth and the availability of labor, which is a complementary input for all three strategy sets. In the complex household structure of Burkina Faso, these provide the context for individual negotiation and decision-making. Total landholding, livestock, non-farm income, and number of cotton hectares are used as proxies for wealth. The number of livestock owned also provides information regarding the availability of manure. Households growing cotton benefit not only from the cash it generates, but from better access to inputs on credit and extension services provided through the cotton ginneries. We expect decisions regarding the scale of cotton production to precede or predetermine the choice of technology on cereal plots. Labor availability is measured as the total number of adults in the household and as the overall ratio of children to women. With the exception of the livestock variable, which does not vary much across survey years, the time-averages of all other household variables are included in the models to control for correlated random effects.

In the household framework with imperfect markets, market and institutional factors affect adoption incentives via transactions costs and endogenous prices. The tenure variable measures whether or not the plot manager has secure rights over the plot (i.e., land certificate, lease agreement, farming permit). The number of years since plot managers received any extension services is expected to be negatively correlated with technology adoption. Credit access is defined as whether or not the plot manager reported access to credit in the preceding year, regardless of whether credit was used in the survey season. A variable capturing the density of agro-dealers at the province level is included as a proxy for market access.

To account for potential interannual fluctuation in moisture availability for cereal crops, the coefficients of variation in total annual rainfall at the commune level over the last three years are included. Cereal dummy variables are also included to control for crop differences.

4. RESULTS

4.1. Hypothesis I

Table 1 reports adoption rates on individually managed plots for each of the intensification strategy sets, including all plots and differentiating by gender of the plot manager. Out of 9050 individual cereal plots, about 2/3 are managed by women and 1/3 by men. Among all individually managed plots, the SWC set is the most widely adopted (25%), followed by the yield-protecting set (17%) and the yield-enhancing set (11%). The higher adoption rate of the SWC set relative to other strategy sets shows that farmers recognize the importance of managing soil and water resources effectively in this challenging production environment, despite the costs in terms of tools, equipment, and labor.

The first hypothesis is tested with a simple comparison of means, without controlling for other covariates. Differences in adoption rates between men and women are statistically significant for all intensification strategy sets, as shown by the Pearson Chi-squared tests. Women plot managers are only slightly more than half as likely to use yield-enhancing inputs as men plot managers (8 vs. 15%, respectively). The differential in simple adoption rates is less meaningful for yield-protecting inputs (16 v. 19%).

Adoption rates for components of each set are shown in Appendix Table A1. Fertilizer use is the dominant input in the yield-enhancing set, while manure is the most widely adopted in the SWC set. Rates of adoption herbicides, pesticides, and fungicides are under 10% on average, and differences between men and women plot managers, although statistically significant, are not likely to be meaningful.

4.2. Hypothesis II

Table 3 shows the results from the pooled multivariate probit (MVP) regression for all cereal individual plots. The likelihood ratio tests lead us to reject the null hypothesis of independent error terms overall and across intensification strategy sets. Multivariate probit is preferred statistically to separate probit regressions, indicating that the probability of adopting one set is interdependent on the decision of whether to adopt another set. Ignoring the correlation across error terms would otherwise lead to inefficient coefficient estimates and thereby, to false prediction of the outcome (Hsiao 2003).

The gender of the plot manager remains statistically significant for one out of three intensification strategy sets, after controlling for other covariates. No gender differential is found in the probability of adopting the yield-enhancement and yield-protection sets, whereas gender of the plot manager significantly influences the probability of adopting the soil and water conservation set. After controlling for a wide range of covariates, female farmers are as likely as male farmers to adopt modern inputs (e.g., fertilizer/improved seeds and herbicide/fungicide/pesticide) on their individual plots. However, female plot managers are less likely to adopt the soil and water conservation set on their individual cereal plots.

Regression coefficients can be interpreted in terms of sign but not as marginal effects. Compared with univariate probit models, estimating marginal effects and standard errors for multivariate probit models is “extremely messy” (Greene 2010) and can be computationally infeasible (Hsiao 2014). Our attempt to compute them failed after a week of iterations. However, for illustrative purpose, marginal effects derived from univariate probit models, which present some efficiency losses compared to the multivariate probit model, are presented in appendix (see Table A2).

Table 3. Pooled Multivariate Probit Model Results-Full Sample

Independent Variables	**Yield-Enhancing (Set 1)**	**Yield Protecting (Set 2)**	**SWC (Set 3)**
Plot Manager Characteristics			
Woman	-0.094	-0.060	-0.129**
	(0.073)	(0.064)	(0.057)
Age	-0.002	-0.003**	0.007***
	(0.001)	(0.002)	(0.002)
Education	0.127	0.040	-0.044
	(0.088)	(0.078)	(0.067)
Head	-0.208**	-0.120	0.019
	(0.095)	(0.090)	(0.070)
Married	0.264***	0.103	0.125**
	(0.067)	(0.063)	(0.055)
Plot Characteristics			
Distance	0.106*	0.169***	-0.216***
	(0.061)	(0.055)	(0.048)
Lowland (bas-fond)	-0.018	-0.085	-0.054
	(0.096)	(0.082)	(0.079)
Slope (versant)	0.178**	-0.0779	0.245***
	(0.0830)	(0.0849)	(0.073)
Size	0.237***	0.213***	0.046
	(0.053)	(0.050)	(0.046)
Household Characteristics			
Children/woman ratio	0.024	0.032	0.048**
	(0.026)	(0.024)	(0.019)
Adults	0.049***	0.004	0.024**
	(0.017)	(0.013)	(0.012)
Landholding	-0.026	0.003	-0.053***
	(0.020)	(0.020)	(0.020)
Livestock	0.003	0.147***	0.123***
	(0.043)	(0.044)	(0.036)
Non-farm income	0.006	-0.003	-0.011**
	(0.007)	(0.007)	(0.006)
Cotton hectares	0.141**	-0.037	0.208**
	(0.059)	(0.050)	(0.084)
Market and Institutional Characteristics			
Tenure	0.122**	-0.009	0.189***
	(0.060)	(0.059)	(0.047)
Credit	0.464***	0.387***	-0.185
	(0.144)	(0.133)	(0.133)
Extension	-0.072[1]	-0.118**	0.006
	(0.045)	(0.049)	(0.041)
Density of agro-dealers	-0.288***	-0.284***	-0.099**
	(0.083)	(0.070)	(0.044)
Agro-climatic Characteristics			
Rainfall	5.435***	-0.624	4.316***
	(0.729)	(0.768)	(0.659)
Millet	-0.086	-0.310***	-0.123***
	(0.065)	(0.059)	(0.047)
Maize	1.176***	0.097	0.308***
	(0.074)	(0.071)	(0.066)
	Coefficient	Std.error	p-value
rho21	0.281	0.0349	0.000
rho31	0.213	0.0300	0.000
rho32	0.0935	0.0287	0.001

Likelihood ratio test rho21=rho31=rho32: chi2(3)=251.6, Prob>chi2=0.0000

Number of observations: 9050

***,** and * denote significance at 1%, 5% and 10%. All regressions include time dummy and household time-average variables. 1. P-value=0.12. Robust clustered standard errors at the household level.

The results from the univariate probit models suggest that being a woman reduces the probability of adopting the SWC set by 4 percentage points. This effect is large in magnitude, given that the average rate of adoption of the SWC set is 25%.

In addition to the univariate probit models (Table A2), a multivariate probit model with seven intensification strategies (rather than three intensification strategy sets) was run to ensure the validity of our findings (Table A3). Overall, the results remain robust to different specifications of the dependent variables and models. Our findings are also consistent with previous studies that found no gender difference in the probability of adopting fertilizer and improved seed (Ndiritu, Kasie, and Shiferaw 2014; Doss and Morris 2001), but gender differences in the adoption of some sustainable intensification practices, such as manure and minimum tillage (Ndiritu, Kasie, and Shiferaw 2014). This last finding, and ours, does not mean that the gender of the farmer influences adoption decision per se, but rather reflects how the socio-cultural farming context combined with the economic attributes of technology affect adoption.

The economic attributes of the yield-enhancing and yield-protecting sets, both made of modern inputs, are quite different than those of the soil and water conservation set. Seed, pesticides, fungicides, and herbicides are relatively light, divisible, and relatively easy to adopt (i.e., do not require extra labor and/or access to heavy equipment). Fertilizer, though lumpy, is often purchased by the household and distributed among members. Plot managers can reap the benefits of any of these during the same year of their adoption. In contrast, the SWC set are made of bulky inputs (e.g., stones and manure), and require more labor and equipment to transport and apply. The full benefits of the SWC generally cannot be reaped in the short-run.

Intrahousehold negotiation plays a key role in plot manager access to household assets, including land, equipment, and labor. In a patrilineal society, such as in Burkina Faso, we can expect women (e.g., daughters-in-law) to have less bargaining power than men (e.g., sons of the patriarch). With lower bargaining power, female plot managers have limited access to household resources and less incentive to make long-run investments on their plots, since they face greater uncertainty about their usufruct rights on that specific plot. For instance, in absence of access to transport equipment, Burkinabe women have had to carry stones on their heads to implement soil and water conservation strategies, aggravating their labor burden (CDCS 1992). The limited labor availability, especially of young men, has also been found to be a major barrier to the adoption of SWC strategies in Burkina Faso (CDCS 1992). In our analysis, we are able to control for some household resources, but not for the intrahousehold negotiation that influences their allocation. Thus, the result—that SWC set is less likely to be adopted by women than men—is more likely to reflect that difference in intrahousehold negotiation than the gender of the plot manager per se.

4.3. Hypothesis III

To test whether the determinants of adoption differ by plot managers, we compare the pooled (restricted) regression to separate (unrestricted) regressions for men and women plot managers with a modified Chow test that is appropriate for nonlinear regressions (Greene 2003). Comparing the pooled to the separate regressions, we reject the hypothesis that regression parameters are the same for male and female plot managers (the log-likelihood ratio of 393 vs. Chi-squared critical value of 112 with 75 degree of freedom at 1% significance). In other words, the underlying process that explains adoption differs between male and female plot managers. The statistical results are supported by observable differences in statistically significant determinants between the two sets of regressions (Tables 4 and 5). While some factors are common, several are specific to either men or women plot managers.

Table 4. Multivariate Probit Model Results-Male Managed Plots

Independent Variables	**Yield-Enhancing (Set 1)**	**Yield Protecting (Set 2)**	**SWC (Set 3)**
Plot Manager Characteristics			
Age	-0.001	-0.002	0.006***
	(0.002)	(0.002)	(0.002)
Education	0.006	0.139	-0.032
	(0.187)	(0.129)	(0.103)
Head	-0.144	0.007	-0.186
	(0.248)	(0.234)	(0.178)
Married	0.265**	0.106	0.071
	(0.103)	(0.084)	(0.077)
Plot Characteristics			
Distance	-0.001	0.133**	-0.176***
	(0.076)	(0.063)	(0.057)
Lowland (bas-fond)	0.212*	-0.043	-0.028
	(0.112)	(0.107)	(0.100)
Slope (versant)	0.212**	-0.121	0.322***
	(0.108)	(0.102)	(0.091)
Size	0.175*	0.229***	-0.087
	(0.095)	(0.087)	(0.096)
Household Characteristics			
Children/woman ratio	-0.026	0.033	0.033
	(0.031)	(0.030)	(0.025)
Adults	0.052**	0.001	0.014
	(0.024)	(0.016)	(0.015)
Landholding	-0.009	0.043	-0.058**
	(0.025)	(0.026)	(0.026)
Livestock	-0.008	0.135***	0.215***
	(0.051)	(0.048)	(0.047)
Non-farm income	0.011	-0.003	-0.018**
	(0.010)	(0.010)	(0.008)
Cotton hectares	0.159*	-0.083	0.237**
	(0.085)	(0.085)	(0.106)
Market and Institutional Characteristics			
Tenure	-0.025	-0.137*	0.145**
	(0.082)	(0.076)	(0.065)
Credit	0.356*	0.295	-0.481***
	(0.185)	(0.200)	(0.174)
Extension	-0.102*	-0.196***	-0.018
	(0.056)	(0.064)	(0.061)
Density of agro-dealers	-0.035	-0.215***	0.013
	(0.074)	(0.070)	(0.062)
Agro-climatic Characteristics			
Rainfall	2.560**	-0.537	1.769**
	(1.024)	(1.008)	(0.861)
Millet	-0.052	-0.368***	-0.071
	(0.105)	(0.092)	(0.076)
Maize	1.262***	0.191**	0.335***
	(0.098)	(0.089)	(0.076)
	Coefficient	Std.error	p-value
rho21	0.293	0.0432	0.000
rho31	0.129	0.0417	0.002
rho32	-0.035	0.0395	0.379

Likelihood ratio test rho21=rho31=rho32: chi2(3)=77.7, Prob>chi2=0.0000
Number of observations: 3078. ***,** and * denote significance at 1%, 5% and 10%. All regressions include time dummy and household time-average variables. Robust clustered standard errors at the household level.

Table 5. Multivariate Probit Model Results-Female Managed Plots

Independent Variables	Yield-Enhancing (Set 1)	Yield Protecting (Set 2)	SWC (Set 3)
Plot Manager Characteristics			
Age	-0.001	-0.002	0.006***
	(0.002)	(0.002)	(0.002)
Education	0.006	0.139	-0.032
	(0.187)	(0.129)	(0.103)
Head	-0.144	0.007	-0.186
	(0.248)	(0.234)	(0.178)
Married	0.265**	0.106	0.071
	(0.103)	(0.084)	(0.077)
Plot Characteristics			
Distance	-0.001	0.133**	-0.176***
	(0.076)	(0.063)	(0.057)
Lowland (bas-fond)	0.212*	-0.043	-0.028
	(0.112)	(0.107)	(0.100)
Slope (versant)	0.212**	-0.121	0.322***
	(0.108)	(0.102)	(0.091)
Size	0.175*	0.229***	-0.087
	(0.095)	(0.087)	(0.096)
Household Characteristics			
Children/woman ratio	0.047	0.030	0.057**
	(0.033)	(0.029)	(0.025)
Adults	0.042**	0.001	0.038***
	(0.021)	(0.017)	(0.014)
Landholding	-0.030	-0.024	-0.052*
	(0.031)	(0.023)	(0.027)
Livestock	0.043	0.163***	0.057
	(0.055)	(0.058)	(0.044)
Non-farm income	0.001	-0.004	-0.007
	(0.009)	(0.008)	(0.007)
Cotton hectares	0.085	0.018	0.029
	(0.059)	(0.055)	(0.136)
Market and Institutional Characteristics			
Tenure	0.178**	0.077	0.219***
	(0.073)	(0.075)	(0.061)
Credit	0.484***	0.519***	0.119
	(0.179)	(0.170)	(0.169)
Extension	-0.050	-0.035	0.034
	(0.061)	(0.060)	(0.065)
Density of agro-dealers	-0.616***	-0.338***	-0.158***
	(0.142)	(0.096)	(0.051)
Agro-climatic Characteristics			
Rainfall	6.88***	-0.942	5.708***
	(0.875)	(0.914)	(0.813)
Millet	-0.091	-0.289***	-0.168***
	(0.076)	(0.067)	(0.054)
Maize	1.138***	-0.056	0.295***
	(0.110)	(0.106)	(0.111)
	Coefficient	Std.error	p-value
rho21	0.254	0.0436	0.000
rho31	0.224	0.0345	0.000
rho32	0.154	0.0343	0.000

Likelihood ratio test rho21=rho31=rho32: chi2(3)=153.1, Prob>chi2=0.0000. Number of observations: 5972. ***,** and * denote significance at 1%, 5% and 10%. All regressions include time dummy and household time-average variables. Robust clustered standard errors at the household level.

Among the socio-demographic characteristics, age of the plot manager positively influences the probability of adopting SWC strategies for both men and women. In this society, where elderly people are highly regarded, older women's status and power within the household nearly approach those of men (Udvardy and Cattell 1992). Both older male and female plot managers can use their authority to gain access to the household resources needed to adopt SWC strategies.

Being the head of the household does not statistically influence adoption of intensification strategy sets on individual plots, regardless of the gender. In contrast, primary education influences the likelihood that male plot managers adopt fertilizer and improved seed on their plots but not that of female plot manager, who are largely without formal education. The marital status of the plot managers influence the probability of adopting the yield-enhancing set for both gender but only the SWC sets for men. These findings reflect that the input subsidy program has been targeting households (not individuals) and by the same token, married farmers. Married men can more easily adopt labor-intensive intensification strategies, such as SWC, since they "have greater rights to the labor of their wives than married women have to the labor of their husbands or sons." (Udvardy and Cattell 1992).

Plot characteristics, such as topography, size, and distance from residence influence the adoption of intensification strategies. The furthest the plot is from the residence, the lower is the probability of adopting SWC strategies for both female and male farmers, since a distant plot requires more time, labor, and energy in transport. The larger is the plot size, the higher is the probability of adopting modern inputs (yield-enhancing and yield-protecting sets) for both men and women. In contrast, the plot's topography affects adoption of intensification strategies differently for male and female plot managers. Although men are as likely as women to manage plots on land with slopes, the probability of adopting yield-enhancing and SWC sets on these plots is statistically significant for women only. On lowland farm plots, the yield-enhancing set is more likely to be adopted by women but less likely to be adopted by men.

The probability of adopting intensification strategy sets on individual cereal plots is influenced by household characteristics, but the influence of these factors depends on the gender of the plot manager. Household landholding size, non-farm income earned, and total hectares cultivated in cotton statistically affect the decision to adopt SWC for male plot mangers only. In contrast, factors related to labor availability significantly affect the decision to adopt SWC strategies for female plot manager only. The number of household adult members also influences women's probability to adopt the yield enhancing set. These results reinforce the idea that women's access to labor plays a crucial role in technology adoption (Meinzen-Dick et al. 2011).

Gender differences are apparent in the ways market and institutional factors affect the probability of adopting intensification strategy sets. Both female and male plot managers with secure rights over their plots are more likely to adopt the SWC strategy set. With tenure security, farmers have more incentives to adopt SWC strategies, which have medium- to longer-term impacts, since they are more likely to reap the benefits from their investment. Those results are consistent with previous studies (Kassie et al. 2015; Kassie et al. 2013; Ouédraogo, Mando, and Zombre 2001). Extension services, which mostly target male farmers, statistically influence their decision to adopt modern inputs. The longer it has been since male farmers received any extension services, the less likely they are to adopt the yield-enhancing and yield-protecting sets. This finding adds to the evidence that receiving advice from extension agents positively influences adoption of fertilizer and improved seed, as well as herbicide/pesticide/fungicide use (Ragasa et al. 2013). Whether farmers have had access to credit over the last twelve months influences their probability to adopt intensification strategy sets. Being credit-unconstrained positively affects the probability of adoption of both modern input sets by women. In comparison, male plot managers, who are more often credit-unconstrained, are more likely to adopt the yield-enhancing strategy set but less likely to adopt the SWC set. This may suggest a trade-off between manure and chemical fertilizer on individual cereal plots managed by male plot managers who do not face credit constraints.

The density of agro-dealers in each province significantly influences the intensification decision, especially for women. A priori, the negative sign is puzzling. However, it may reflect the weaknesses of the Burkinabe private input supply sector. Many agro-dealers are located in urban areas, far from villages where farmers grow cereals and most of the time, they do not sell inputs on credit. But more importantly, the cotton parastatal remains an important player in the input market by providing fertilizer and improved seeds on credit for both maize and cotton crops (Theriault and Serra 2014). These inputs are provided directly to cotton farmer groups, mostly composed of men, bypassing agro-dealers. Consequently, more agro-dealers are moving their focus from fertilizer to horticultural inputs, such as seeds (Holtzman et al. 2013).

The coefficient of variation of annual rainfall at the commune level is positive and significant for two out of three intensification sets, regardless of gender. This suggests that all farmers respond to increased variability in water supply in their commune by adopting yield enhancing and SWC sets. Our results are consistent with Arslan et al. (2014) who found that longer delays on the onset of the rainy season and higher rainfall variability lead to higher level of adoption of conservation farming and minimum soil disturbance in Zambia.

The choice of crops also influences the decision of adoption. Compared to sorghum, maize plots are more likely to benefit from the adoption of yield enhancement and soil and water conservation strategy sets by both male and female managers and from the yield-protecting set by male managers only. In contrast, the adoption of yield-protection strategies are less likely to occur on millet plots managed by men and women, whereas the decision to adopt SWC is less on millet plots managed by women. These reflect the economic importance of maize as a cash crop and partially explain why maize is the most studied crop in the technology adoption literature. but only the SWC sets for men. These findings reflect that the input subsidy program has been targeting households (not individuals) and by the same token, married farmers. Married men can more easily adopt labor-intensive intensification strategies, such as SWC, since they "have greater rights to the labor of their wives than married women have to the labor of their husbands or sons." (Udvardy and Cattell 1992).

Plot characteristics, such as topography, size, and distance from residence influence the adoption of intensification strategies. The furthest the plot is from the residence, the lower is the probability of adopting SWC strategies for both female and male farmers, since a distant plot requires more time, labor, and energy in transport. The larger is the plot size, the higher is the probability of adopting modern inputs (yield-enhancing and yield-protecting sets) for both men and women. In contrast, the plot's topography affects adoption of intensification strategies differently for male and female plot managers. Although men are as likely as women to manage plots on land with slopes, the probability of adopting yield-enhancing and SWC sets on these plots is statistically significant for women only. On lowland farm plots, the yield-enhancing set is more likely to be adopted by women but less likely to be adopted by men.

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Gender differences are apparent in the ways market and institutional factors affect the probability of adopting intensification strategy sets. Both female and male plot managers with secure rights over their plots are more likely to adopt the SWC strategy set. With tenure security, farmers have more incentives to adopt SWC strategies, which have medium to longer term impacts, since they are more likely to reap the benefits from their investment. Those results are consistent with previous studies (Kassie et al. 2015; Kassie et al. 2013; Ouédraogo, Mando and Zombre 2001). Extension services, who mostly target male farmers, statistically influence their decision to adopt modern inputs. The longer it has been since male farmers received any extension services, the less likely they are to adopt the yield-enhancing and yield-protecting sets. This finding adds to the evidence that receiving advice from extension agents positively influences adoption of fertilizer/ improved seed (Ragasa et al. 2013). Whether farmers have had access to credit over the last twelve months influences their probability to adopt intensification strategy sets. Being credit-unconstrained positively affects the probability of adoption of both modern input sets by women. In comparison, male plot managers, who are more often credit-unconstrained, are more likely to adopt the yield-enhancing strategy set but less likely to adopt the SWC set. This may suggest a trade-off between manure and chemical fertilizer on individual cereal plots managed by male plot managers who do not face credit constraints.

The density of agrodealers in each province significantly influences the intensification decision, especially for women. A priori, the negative sign is puzzling. However, it may reflect the weaknesses of the Burkinabe private input supply sector. Many agro-dealers are located in urban areas, far from villages where farmers grow cereals and most of the time, they do not sell inputs on credit. But more importantly, the cotton parastatal remains an important player in the input market by providing fertilizer and improved seeds on credit for both maize and cotton crops (Theriault and Serra 2014). These inputs are provided directly to cotton farmer groups, mostly composed of men, by-passing agro-dealers. As a consequence, more agro-dealers are moving their focus from fertilizer to horticultural inputs, such as seeds (Holtzman et al. 2013).

The coefficient of variation of annual rainfall at the commune level is positive and significant for two out of three intensification sets, regardless of gender. This suggests that all farmers respond to increased variability in water supply in their commune by adopting yield-enhancing and SWC sets. Our results are consistent with Arslan et al. (2014) who found that longer delays on the onset of the rainy season and higher rainfall variability lead to higher level of adoption of conservation farming and minimum soil disturbance in Zambia.

The choice of crops also influences the decision of adoption. Compared to sorghum, maize plots are more likely to benefit from the adoption of yield-enhancement and soil and water conservation strategy sets by both male and female managers and from the yield-protecting set by male managers only. In contrast, the adoption of yield-protection strategies are less likely to occur on millet plots managed by men and women, whereas the decision to adopt SWC is less on millet plots managed by women. These reflect the economic importance of maize as a cash crop and partially explains why maize is the most studied crop in the technology adoption literature.

5. CONCLUSIONS

In this article, we have tested gender differences in the likelihood and determinants of adoption of sustainable intensification strategies in cereals production in Burkina Faso. We contribute to the literature on the role of African women in agricultural development by controlling not only for the gender of the plot manager but also the social status of the plot manager in the household (headship, age, marriage). This perspective reflects the underlying socio-demography of farm organization and decision-making in much of the West African Sahel—a structure which is also in a process of increasing individualization due to land-population dynamics. We also contribute to the literature on adoption of sustainable farming practices by exploring the use of numerous inputs grouped in terms of strategies (yield-enhancing, yield-protecting, soil-and-water-conserving), and their interrelationships, while controlling for major cereal crop (sorghum, maize, millet).

Descriptive statistics show that 66% of the individual cereal plots are managed by women, but that only 3% of them are the household heads. In contrast, about 40% of the male plot managers of individual cereal plots are heads of household. This highlights the importance of unit of analysis in examining gender differentials in adoption of intensification strategies (household vs plot; collective vs individual plots), especially in a context characterized by complex farming household structure, such as in Burkina Faso.

Overall, the SWC strategy set is the most frequently adopted, followed by the yield protecting and the yield enhancing, regardless of gender. Findings from the descriptive statistics also suggest that women are adopting at lower rates any of the three intensification strategy sets. However, more nuanced results emerge from the econometric analysis, once we controlled for other covariates.

The likelihood ratio test confirms the interrelatedness of intensification strategy sets and the appropriateness of the multivariate probit model. Results from the pooled regression show no difference in the probability of adopting the yield-enhancing and yield-protecting sets between men and women on their individual cereal plots, after controlling for other covariates. In contrast, gender of the plot manager statistically influences the probability of adoption of the SWC strategy set, with female plot managers being less likely to adopt. This finding reflects how both the socio-cultural farming context and economic attribute of the technology affect incentives to adopt. Having more limited access to resources and less intrahousehold negotiation power, women are less likely to adopt SWC strategies, which entail bulkier inputs, more intensive labor, and generate impacts over a longer time horizon.

Results lead us also to reject the hypothesis that regression parameters are the same for men and women plot managers. Running separate regressions per gender, we compare the determinants of adoption of intensification strategy sets. We find that socio-demographic characteristics, such as education and marital status influence the probability of adoption of intensification strategy sets for men. Distance of the plot from the residence, and size of the plot influence the probability of adoption of men and women alike. In contrast, plot topography affects the adoption decision differently across gender, which probably reflects differences in initial land type allocations and crops produced. Household resources and market and institutional factors do influence the probability of adoption but in different ways. Women's adoption decisions are influenced by variables capturing labor availability, whereas other household resources affect mostly men's decisions, especially in regards to the SWC set. Extension services, which are mainly targeted to men, are found to influence their adoption decision of modern inputs (yield-enhancing and yield-protecting sets). In comparison, having access to credit influence women decision to adopt modern inputs, which may reflect their limited access to household resources, such as non-farm income or cash-income from cotton. Secure tenure rights positively influence the decision to adopt intensification strategy sets that have medium to long terms benefit, such as SWC.

6. POLICY IMPLICATIONS

Our results provide insights on the influence of gender and economic attributes of technology on adoption decision that are relevant to the design and implementation of effective policies to sustainably increase production by both male and female farmers in Burkina Faso and some other areas of the West African Sahel. The interrelatedness of adoption strategy sets (yield enhancing, yield protecting, and soil-and-water-conserving) confirms the policy importance of designing mechanisms to encourage the use of combinations of strategies. An intensification strategy set cannot be promoted in isolation, without considering incentives for other sets.

At the same time, the variation in input use within strategy sets confirms that it is best if farmers in these environments are not approached with a fixed package in mind, but instead, with a recognition that due to constraints related to microclimate, labor, and cash, they will need the option of selecting from menus of practices to suit their own conditions. Although plant breeders and agronomist must work to achieve complementarity by designing optimal packages of inputs, farmers' optima will be as heterogeneous as the farm population and agroecology. The significance of plot characteristics in our models also supports this notion. Future research might explore the relative costs and benefits of research and extension designs that support this heterogeneity rather than blanket, uniform recommendations.

Gender differentials in adoption rates for the SWC set and among determinants of adoption, confirm the need to collect data disaggregated at the plot level and design and promote policies that, while respecting socio-cultural norms, also respect opportunities and incentives for individuals within multigenerational, multifamily farms.

The role of public extension services, for which funding support has declined in recent decades in favor of other types of information provision, nonetheless appears to be important in adoption decisions, especially in regards to modern inputs. Some changes are needed to redress the male bias in extension services, by including women as beneficiaries and covering topics on sustainable intensification, which takes into account women's constraints to technology adoption. Credit access also remains crucial for inputs purchased with cash (yield-enhancing and yield-protecting sets), especially for women who have limited economic control within the household. Improving access to education, income, and equipment to women could contribute to increase their bargaining power and thereby, adoption of sustainable intensification strategies.

Other institutional (in Burkina Faso, these would be largely customary norms) factors (marriage, tenure) also appear to play key roles in adoption of strategies for sustainable intensification of agriculture. Marriage, in particular, appears as significant for young men, as compared to women plot managers, most of whom obtained usufruct rights upon marriage. Among men, major differences in social status are related to headship and marriage. Only a tiny minority of women in the sample are heads. Looking toward the next generation of farmers and the transfer of rights and responsibilities, inter-generational differences among men within households may be as important to take into consideration as differences between men and women.

APPENDICES

Table A1. Definition and Summary Statistics for Each Intensification Strategy

Strategies	Definition	All individually managed	Male managed	Female managed	p-value
Improved seed	Improved variety of seed of the crop is used on the plot	1.68	2.85	1.05	0.000
Inorganic fertilizer	Urea and/or NPK is applied to the plot on which the crop is grown	9.57	13.8	7.33	0.000
Herbicide	Herbicide (solid or liquid) is applied to plot on which the crop is grown	6.34	9.32	4.75	0.000
Fungicide	Fungicide (solid or liquid) is applied to plot on which the crop is grown	8.29	8.25	8.31	0.915
Pesticide	Pesticide (solid or liquid) is applied to plot on which the crop is grown	3.08	2.61	3.34	0.049
Organic manure	Manure, compost pit, household refuse, animal and/or other penning is applied to the plot on which the crop is grown	17.5	22.1	15.0	0.000
Anti-erosion structures	Plot on which crop is grown contains stone contour bunds, porous and nonporous dikes, living fences and grass bands, planting pits (zai) or half-moons (demi-lunes)	12.0	13.0	11.4	0.026

Source: As prepared by authors.

Table A2. Univariate Probit Models by Intensification Strategy Sets

Independent Variables	**Productivity-Enhancing (Set 1)**	**Marginal Effects**	**Yield-Protecting (Set 2)**	**Marginal Effects**	**SWC (Set 3)**	**Marginal Effects**
Plot Manager Characteristics						
Woman	-0.0882	-0.0135	-0.0636	-0.0149	-0.125**	-0.0375**
	(0.0736)	(0.0115)	(0.0641)	(0.0151)	(0.0568)	(0.0173)
Age	-0.00165	-0.000249	-0.00312*	-0.000724*	0.00742***	0.00220***
	(0.00194)	(0.000293)	(0.00165)	(0.000383)	(0.00151)	(0.000446)
Education	0.144	0.0231	0.0375	0.00882	-0.0448	-0.0131
	(0.0881)	(0.0151)	(0.0781)	(0.0186)	(0.0666)	(0.0193)
Head	-0.215**	-0.0300**	-0.133	-0.0295	0.0182	0.00541
	(0.0954)	(0.0123)	(0.0897)	(0.0190)	(0.0706)	(0.0211)
Married	0.272***	0.0375***	0.103	0.0232*	0.124**	0.0359**
	(0.0705)	(0.00889)	(0.0633)	(0.0138)	(0.0545)	(0.0153)
Plot Characteristics						
Distance	0.0990	0.0148	0.164***	0.0374***	-0.220***	-0.0663***
	(0.0617)	(0.00905)	(0.0554)	(0.0123)	(0.0476)	(0.0145)
Lowland (bas-fond)	-0.0363	-0.00539	-0.0880	-0.0197	-0.0573	-0.0167
	(0.0981)	(0.0143)	(0.0829)	(0.0180)	(0.0787)	(0.0226)
Slope (versant)	0.178**	0.0292**	-0.0839	-0.0188	0.246***	0.0774***
	(0.0834)	(0.0147)	(0.0860)	(0.0187)	(0.0723)	(0.0238)
Size	0.233***	0.0351***	0.214***	0.0496***	0.0494	0.0146
	(0.0523)	(0.00784)	(0.0499)	(0.0115)	(0.0460)	(0.0136)
Household Characteristics						
Children/woman ratio	0.0258	0.00390	0.0330	0.00764	0.0476**	0.0141**
	(0.0262)	(0.00396)	(0.0234)	(0.00541)	(0.0190)	(0.00561)
Adults	0.0509***	0.00769***	0.00355	0.000824	0.0252**	0.00746**
	(0.0169)	(0.00259)	(0.0132)	(0.00305)	(0.0117)	(0.00349)
Landholding	-0.0262	-0.00396	0.00120	0.000278	-0.0553***	-0.0164***
	(0.0200)	(0.00302)	(0.0197)	(0.00457)	(0.0198)	(0.00582)
Livestock	-0.00520	-0.000785	0.145***	0.0337***	0.122***	0.0362***
	(0.0434)	(0.00656)	(0.0436)	(0.0102)	(0.0355)	(0.0104)
Non-farm income	0.00601	0.000908	-0.00384	-0.000890	-0.0112*	-0.00331*
	(0.00694)	(0.00105)	(0.00672)	(0.00156)	(0.00573)	(0.00170)
Cotton hectares	0.138**	0.0208**	-0.0348	-0.00808	0.210**	0.0622**
	(0.0592)	(0.00896)	(0.0502)	(0.0116)	(0.0846)	(0.0251)

Table A2 cont.

Independent Variables	**Productivity-Enhancing (Set 1)**	**Marginal Effects**	**Yield-Protecting (Set 2)**	**Marginal Effects**	**SWC (Set 3)**	**Marginal Effects**
Market and Institutional Characteristics						
Tenure	0.126**	0.0193**	-0.00978	-0.00226	0.191***	0.0576***
	(0.0608)	(0.00958)	(0.0596)	(0.0138)	(0.0467)	(0.0143)
Credit	0.478***	0.0910***	0.384***	0.104**	-0.175	-0.0491
	(0.145)	(0.0338)	(0.133)	(0.0406)	(0.133)	(0.0352)
Extension	-0.0655	-0.00989	-0.118**	-0.0275**	0.00582	0.00172
	(0.0451)	(0.00681)	(0.0492)	(0.0115)	(0.0413)	(0.0122)
Density of agro-dealers	-0.306***	-0.0462***	-0.297***	-0.0688***	-0.102**	-0.0302**
	(0.0861)	(0.0133)	(0.0739)	(0.0171)	(0.0437)	(0.0129)
Agro-climatic Characteristics						
Rainfall	5.620***	0.849***	-0.578	-0.134	4.336***	1.283***
	(0.729)	(0.120)	(0.762)	(0.177)	(0.659)	(0.194)
Millet	-0.0858	-0.0127	-0.312***	-0.0684***	-0.128***	-0.0374***
	(0.0661)	(0.00967)	(0.0586)	(0.0124)	(0.0465)	(0.0135)
Maize	1.176***	0.277***	0.111	0.0268	0.296***	0.0939***
	(0.0743)	(0.0223)	(0.0707)	(0.0175)	(0.0669)	(0.0223)
Number of Observations	9050		9050		9050	

***,** and * denote significance at 1%, 5% and 10%. All regressions include time dummy and household time-average variables. Robust clustered standard errors at the household level.

Table A3. Multivariate Probit Model by Intensification Strategies

Independent Variables	Inorganic Fertilizer	Improved Seed	Fungicide	Herbicide	Pesticide	Anti-erosion Structure	Organic Fertilizer
Plot Manager Characteristics							
Woman	-0.078	-0.125	-0.069	-0.200**	0.106	-0.072	-0.150**
	(0.077)	(0.097)	(0.079)	(0.079)	(0.102)	(0.066)	(0.065)
Age	-0.002	-0.003	-0.002	-0.004*	-0.000	0.005***	0.008***
	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)
Education	0.198**	-0.065	-0.068	0.118	0.102	-0.010	-0.088
	(0.089)	(0.136)	(0.104)	(0.098)	(0.109)	(0.075)	(0.079)
Head	-0.237**	-0.001	-0.133	-0.164	-0.012	-0.011	0.002
	(0.101)	(0.127)	(0.107)	(0.115)	(0.142)	(0.086)	(0.078)
Married	0.258***	0.125	0.059	0.177**	0.101	0.020	0.173***
	(0.072)	(0.113)	(0.074)	(0.085)	(0.098)	(0.061)	(0.061)
Plot Characteristics							
Distance	0.093	0.133	0.056	0.385***	0.147*	-0.079	-0.281***
	(0.064)	(0.093)	(0.068)	(0.074)	(0.083)	(0.058)	(0.051)
Lowland (bas-fond)	-0.012	-0.157	0.027	-0.135	-0.153	0.077	-0.202**
	(0.098)	(0.214)	(0.098)	(0.112)	(0.129)	(0.086)	(0.083)
Slope (versant)	0.183**	0.108	-0.068	-0.070	-0.164	0.313***	0.164**
	(0.088)	(0.132)	(0.100)	(0.107)	(0.147)	(0.083)	(0.078)
Size	0.259***	0.083	0.031	0.297***	0.076	0.020	0.067
	(0.053)	(0.088)	(0.057)	(0.066)	(0.054)	(0.053)	(0.051)
Household Characteristics							
Children/woman ratio	0.0232	-0.012	0.046	0.015	0.010	0.036	0.051**
	(0.027)	(0.034)	(0.031)	(0.026)	(0.034)	(0.024)	(0.021)
Adults	0.050***	0.025	0.007	0.003	0.0120	0.012	0.032**
	(0.017)	(0.020)	(0.018)	(0.015)	(0.018)	(0.014)	(0.013)
Landholding	-0.022	-0.053	-0.048**	0.059*	0.049	-0.030	-0.049**
	(0.021)	(0.035)	(0.022)	(0.031)	(0.047)	(0.022)	(0.023)
Livestock	0.029	-0.035	0.227***	0.004	0.058	-0.0013	-0.015
	(0.044)	(0.059)	(0.056)	(0.052)	(0.111)	(0.077)	(0.070)
Non-farm income	0.0031	0.008	-0.006	-0.005	0.019*	-0.002	-0.017***
	(0.007)	(0.012)	(0.008)	(0.010)	(0.010)	(0.006)	(0.006)
Cotton hectares	0.167***	-0.034	0.146*	-0.051	-0.158	0.194**	0.127
	(0.065)	(0.066)	(0.088)	(0.082)	(0.112)	(0.089)	(0.079)
Market and Institutional Characteristics							
Tenure	0.123*	0.041	-0.052	0.006	0.075	0.188***	0.131**
	(0.063)	(0.088)	(0.071)	(0.074)	(0.084)	(0.055)	(0.052)

Table A3 cont.

Independent Variables	Inorganic Fertilizer	Improved Seed	Fungicide	Herbicide	Pesticide	Anti-erosion Structure	Organic Fertilizer
Credit	0.457***	0.375*	0.391**	0.382**	-0.020	0.020	-0.173
	(0.152)	(0.198)	(0.157)	(0.176)	(0.213)	(0.175)	(0.143)
Extension	-0.064	-0.107*	-0.075	-0.118**	-0.027	-0.022	0.061
	(0.045)	(0.064)	(0.058)	(0.051)	(0.063)	(0.054)	(0.044)
Density of agro-dealers	-0.290***	-0.102**	-0.368***	-0.149**	-0.191	-0.033	-0.204***
	(0.092)	(0.050)	(0.087)	(0.061)	(0.123)	(0.053)	(0.044)
Rainfall	5.604***	1.626*	-0.640	0.093	0.283	4.879***	3.189***
	(0.769)	(0.958)	(0.934)	(0.894)	(1.197)	(0.801)	(0.654)
Millet	-0.119*	0.089	-0.153**	-0.525***	-0.242***	-0.142***	-0.124**
	(0.069)	(0.109)	(0.069)	(0.093)	(0.080)	(0.054)	(0.054)
Maize	1.163***	0.953***	-0.423***	0.674***	-0.228**	-0.272***	0.572***
	(0.078)	(0.106)	(0.132)	(0.072)	(0.098)	(0.084)	(0.067)
	Coefficient	Std.error	p-value				
rho21	0.128	0.0567	0.024				
rho31	0.237	0.0471	0.000				
rho41	0.174	0.0406	0.000				
rho51	0.208	0.0568	0.000				
rho61	0.218	0.0363	0.000				
rho71	0.223	0.0347	0.000				
rho32	0.022	0.0413	0.588				
rho42	0.087	0.0439	0.048				
rho52	0.065	0.0445	0.141				
rho62	0.044	0.0360	0.217				
rho72	0.058	0.0343	0.092				
rho43	-0.014	0.0403	0.730				
rho53	-0.072	0.0399	0.072				
rho63	0.143	0.0396	0.000				
rho73	0.139	0.0345	0.000				
rho54	0.179	0.0490	0.000				
rho64	-0.069	0.0300	0.021				
rho74	-0.154	0.0328	0.000				
rho65	0.107	0.0377	0.005				
rho75	0.079	0.0378	0.037				
rho76	0.260	0.0319	0.000				

Likelihood ratio test
rho21=rho31=rho41=rho51=rho61=rho71=rho32=rho42=rho52=rho62=rho72=rho43=rho53=rho63=rho73=rho54=rho64=rho74=rho65=rho75=rho76=0
:chi2(21)=532.6, Prob>chi2=0.0000
***,** and * denote significance at 1%, 5% and 10%. All regressions include time dummy and household time-average variables.
Robust clustered standard errors at the household level.

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