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Combined Agronomic and Economic Modeling in Farmers' Determinants of Soil Fertility Management Practices: Case Study from the Semi-Arid Ethiopian Rift Valley

Shiro Mukai

Independent Researcher, Kakinokizaka, Meguro-ku, Tokyo 152-0022, Japan; shiro_mukai@yahoo.co.jp

Abstract: Studies on smallholders' determinants of soil fertility management practices have become increasingly important for boosting agricultural productivity, particularly in cereal-based farming systems in sub-Saharan Africa. In these parts of Africa, farmers preferentially apply organic and inorganic fertilizers to the fields close to their housing compounds (infields). In addition, they prefer to use more fertilizers to grow cash crops rather than food crops. Many researchers suggested that farmers use limited nutrient resources in their hot-spot fields, e.g., infields and/or cash-crop fields. Recent econometric case studies have suggested using a model that considers a complementarity or substitutability between organic and inorganic fertilizers use. This study employed bivariate probit models to analyze 524 plot data collected from the northern semi-arid Ethiopian Rift Valley. A K-means cluster analysis divided the sample data into two subdatasets, representing food-crop-based cropping system (FCCS) and cash-crop-based cropping system (CCCS). Based on narrative inquiry interviews and the cluster analysis, this study considered reflecting the structure of the local farming system in modeling: a data segmentation approach and dummy variable method. Bivariate and univariate probit analyses showed that, first, the farmers' determinants differed between the FCCS and CCCS. Second, the correlation between organic and inorganic fertilizers use was independent. Farmers' determinants were primarily governed by the biophysical features of the plots (commuting distance to the plot, plot size, type of the plot, etc.), which narrowed down the feasible soil fertility management options in the plot to one or two; farmers' more specific decisions on soil fertility management practices depend on individual farmers' socioeconomic endowments (farm holding, livestock ownership, etc.).

Keywords: sub-Saharan Africa; organic fertilizer; inorganic fertilizer; reciprocal relationship; bivariate probit; food-crop-based cropping system; cash-crop-based cropping system; mixed approach

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1. Introduction

In the areas of (i) highland temperate mixed farming systems that include Ethiopia, (ii) maize mixed (or agro-pastoral maize mixed) farming systems that extensively spread over East and Southern Africa, (iii) agro-pastoral millet/sorghum farming systems that include the semi-arid zone of West Africa, and (iv) cereal–root crop mixed farming systems that include the mid-belt states of Nigeria, crops and livestock are of equal importance, and cattle are kept for plowing, milk, manure, bridewealth, savings, and emergency sale in case of crop failure [1]. These areas are almost equivalent to mixed farming systems under rainfed (37% of the sub-Saharan Africa (SSA) land area [2]), and livestock densities (cattle, sheep, and goats) are higher than in other parts of SSA [2]. These areas, also known as cereal-based farming systems, have a comparative advantage for cereal production compared to the root-and-tree-crops-based farming systems in other parts of SSA [3]. In addition to a higher organic fertilizer (OF) application there, inorganic fertilizer (IF) use levels are higher, with a mean of 22 kg ha^{-1} in Malawi, Kenya, and Ethiopia, compared with the root-and-tree-crops-based farming systems of less than 4 kg ha^{-1} in Rwanda, Burundi, Uganda, and Nigeria [3].

Partly because farm-level IF prices in SSA are among the highest globally [4], most farmers are constrained by a shortage of cash to use IFs [5]. Many medium-term (over five years and more) soil fertility management experiments conducted in SSA invariably showed that the best results (in terms of medium-term sustained yield response) were from those treatments that combined organic and inorganic inputs [6]. Given these contexts, the combined use of OFs and IFs (i.e., integrated soil fertility management) has been advocated in SSA since the 1990s [7].

It is widely perceived that African farmers are underutilizing IFs. However, recent analyses of national-level household surveys found that a significant portion of farmers in Kenya [8,9], Nigeria [10], and Zambia [11,12] apply IFs at the economically optimal level, given the crop yield response rate to IF (i.e., agronomic efficiency) and prevailing prices. However, even in these areas where IFs are used at optimal application rates, adopting complementary inputs (e.g., OFs) will be required to raise maize response rates to IF applications [9,12,13].

Many researchers report that farmers in the cereal-based farming systems in SSA preferentially allocate OFs, IFs, labor, and sometimes even land tenure security to the fields close to their housing compounds (infields), as opposed to the fields far from their compounds (outfields). It results in strong gradients of soil fertility decline with increasing distance from compounds. The resulting within-farm differences in soil fertility are as wide as those found between agroecological zones, e.g., west Kenya [14] and southwestern Niger [15], and between soil types, e.g., Zimbabwe [16].

In SSA, where mixed food (or subsistence)- and cash-crops economies prevail, farmers' decisions on soil fertility management depend on the farmers' production choices (food or cash crop) in the field [17]. Smallholders in Nakuru [17] and Vihiga [18] districts, Kenya, use significantly more IFs for cash crops than for food crops ($p < 0.05$). De Jager et al. [19] concluded that food-crop fields (mainly maize) tended to have more negative nutrient balances than cash-crop fields (mainly coffee and tea) because farmers used more manure and IFs for cash crops than for food crops in three districts in Kenya. Thus, agronomists and some economists acknowledged that farmers tend to prioritize their scarce nutrient resources (OFs and IFs), limited labor, and crop management (plant density, planting time, weed infestation, etc.) in their hot spots (infields and/or cash-crop fields), which they perceive to be fertile [20]. Farmers may realize it is an efficient way to boost crop yield response to nutrient inputs.

The analyses of factors that condition farmers' adoption of soil fertility management practices are essential for the technology generation and dissemination because they would answer several questions, such as what categories of farmers adopt/do not adopt and what factors drive the adoption of the technologies [21]. Thus, the studies on smallholders' determinants of OF and IF use have been increasingly crucial for boosting agricultural productivity, particularly in the cereal-based farming systems in SSA.

Studies on soil fertility management practices have been conducted in the cereal-based farming systems since the early 2000s [22]. Ten studies have recently collected plot-level data from the field to address the determinants of sustainable land management practices, including OF and IF use (Table 1). Three studies used instrumental variable analysis [23–25]. Seven studies used multivariate probit (MVP) analysis [26–32]. Eight examined a reciprocal relationship (complementarity or substitutability) between OF and IF use (Table 1). A complementary relationship between two practices implies that adopting one is associated with adopting the other. A substitute relationship suggests that the two practices can compete for the same scarce resources [30].

Table 1. Signs and statistically significant levels of independent variables used in previous technology adoption studies.

	Benin [23]			Pender and Gebremedhin [24]		Marenya and Barrett [26]		Kassie et al. [27]		Ketema and Bauer [25]		Teklewold et al. [28]	
	OF	IF											
		LP [a]	HP [a]	OF	IF	OF	IF	OF	IF	OF	IF	OF	IF
Household-Level Factors													
gender	+	+	+	+ ***	–	+ **	+ *	–	+	–	+	– *	+
age	–	– **	+ ***	–	+	– **	–	– **	–	+ *	–	+	+
education	+	–	+ *	+	–	+ * [b]	+ [c]	+	+	+	+	nu	nu
off-farm	–	+	–	–	–	+ ***	+ *	nu	nu	nu	–	+	–
farm	–	–	+ ***	–	– **	+ **	+ *	+	+	– ***	–	nu	nu
livestock	+ **	+	– ***	+ [d]	+ ** [e]	+ *	+ **	+ **	+ ***	+	+ ***	+ ***	+
labor	– **	+	+	–	–	+ ***	+ **	+	–	+ *	nu	nu	nu
asset	nu	nu	nu	nu	nu	nu	nu	nu	nu	nu	nu	–	+ ***
Plot-Level Factors													
ownership	– ** [f]	+ * [g]	+ [h]	nu	nu	nu	nu	+ ***	+ **	+	+	+ ***	–
slope[i]	+	+ ***	+ ***	nu	nu	nu	nu	– ***	– ***	+ **	+	– **	+ ***
plotsize	–	+	+ ***	nu	nu	nu	nu	nu	nu.	+ ***	+ ***	nu	nu
distance	– ***	–	– **	– ***	– **	nu	nu	+	+ **	– *	+	+	– ***
Access to Markets or Services													
market	+ *** [j]	– [j]	+ [j]	+ [k]	+ [k]	nu	nu	+	–	nu	+	–	–
credit	–	– *	+ ***	+ [m]	+ *** [n]	nu	nu	nu	nu	–	+ *	–	+ **
extension	+	– ***	– ***	–	–	nu	nu	+ ***	+ ***	nu	nu	nu	nu

	Ahmed [29]		Hassen [30]		Kassie et al. [31]								Ahmed [32]	
					Kenya		Malawi		Ethiopia		Tanzania			
	OF	IF	OF	IF	OF	IF	OF	IF	OF	IF	OF	IF	OF	IF
Household-Level Factors														
gender	nu	nu	+	–	+	–	+	+ ***	+	–	–	–	–	+ *
age	–	+	–	+	+ **	–	+	–	+	– **	+	+	+ *	+ **
education	+	+ *	+	+ *	+ **	+ ***	+	–	–	+	–	+ **	+	+ *
off-farm	–	+	–	+ ***	nu	nu	nu	nu	nu	nu	nu	nu	nu	nu
farm	–	–	nu	nu	+	+	+	– **	+ **	– **	+	– *	–	+ **
livestock	+ **	–	+ ***	nu	+ ***	–	+ **	+	+	+	+ ***	+ ***	+ ***	– ***
labor	+	– *	+ ***	+	–	–	+ *	–	–	–	+ ***	–	nu	nu
asset	nu	nu	+	+ ***	+ **	+	–	+	–	+ ***	+	+ ***	nu	nu
Plot-Level Factors														
ownership	+	+	+	+ ***	+ *	–	+ *	+ ***	+ ***	+	+ ***	+	+ **	–
slope[i]	– ***	+	+ **	+ ***	–	+	–	–	+	+ **	+	– *	nu	nu
plotsize	+	+ *	–	+	– *	+	–	+ ***	– ***	+ ***	+ **	– ***	nu	nu
distance	–	– **	– ***	–	+ **	–	–	–	– ***	+ ***	+ ***	+ ***	–	–

Table 1. *Cont.*

	Benin [23]			Pender and Gebremedhin [24]		Marenya and Barrett [26]		Kassie et al. [27]		Ketema and Bauer [25]			Teklewold et al. [28]	
	OF	IF												
		LP [a]	HP [a]	OF	IF	OF	IF	OF	IF	OF	IF		OF	IF
Access to Markets or Services														
market	−	+	+	−	−	+ **	+	−	− *	+	+	+ ***	+ [l]	− ** [l]
credit	+	+	nu	nu	+	−	+	−	− **	−	+	+	−	+ **
extension	+ ***	+	− ***	−	−	−	+	+	+	+	+	+	− *	+ ***

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. nu; not used. OF; organic fertilizer, IF; inorganic fertilizer. The definition of variables *gender*, *off-farm*, *farm*, *livestock*, *labor*, *market*, *plotsize*, *distance* were the same as those in Table 2. *Age*; HH (household head) age. *Education*; HH education years. *Asset*; total value of HH asset. *Ownership*; the plot is owned by HH; 1, otherwise; 0. *Slope*; slope gradient of the plot. *Credit*; credit is used; 1, otherwise; 0. *Extension*; if there is extension contact; 1, otherwise; 0. [a] LP; low potential areas, HP; high potential areas. [b] + * for primary school education, + ** for secondary school education. [c] + for primary school education, + ** for secondary school education. [d] + *** for oxen (number), + for other cattle (number). [e] + for oxen (number), + ** for other cattle (number). [f] However, + ** if plot is expected to be operated within the next 5 years; 1, otherwise; 0. [g] However,—if plot is expected to be operated within the next 5 years; 1, otherwise; 0. [h] However, −** if plot is expected to be operated within the next 5 years; 1, otherwise; 0. [i] a steep slope; 1, otherwise; 0. [j] Distance to the nearest input supply shop. [k] Distance to the nearest district (*woreda*) town. [l] Distance to the farmer training centre. [m] + for formal credit, —for informal credit. [n] + *** for formal credit, + for informal credit.

Table 2. Descriptive statistics of the soil fertility management practices (n = 524).

Dependent Variables *Man* (1 = OFs Were Applied, 0 = Otherwise) *Fer* (1 = IFs Were Used, 0 = Otherwise)	Expected Sign	Mean	Std. Dev.	Min.	Max.	FCCS Plots (n = 266)			CCCS Plots (n = 258)	
						[1] Only OF (n = 218)	[2] Only IF (n = 5)	[3] No Amend (n = 43)	[4] Only IF (n = 153)	[5] OF + IF (n = 105)
Independent Variables **Socioeconomic Characteristics of the Sample Households**										
zone (sub-area; 1 = MM, 0 = MD)	+	0.50	0.50	0	1	0.56 [a]	0.20 [ab]	0.21 [b]	0.54 [a]	0.46 [a]
gender (HH head gender; 1 = male, 0 = female)	±	0.88	0.33	0	1	0.88 [ab]	0.80 [ab]	0.86 [ab]	0.84 [a]	0.93 [b]
training (1 = received, 0 = otherwise) [a]	+	0.58	0.49	0	1	0.56 [ab]	0.60 [ab]	0.67 [ab]	0.52 [a]	0.66 [b]
off-farm (1 = engaged, 0 = otherwise) [b]	±	0.29	0.45	0	1	0.30 [ns]	0.40 [ns]	0.35 [ns]	0.29 [ns]	0.26 [ns]
crop (1 = FCCS, 0 = CCCS) [c]	±	0.51	0.50	0	1	1.00 [a]	1.00 [a]	1.00 [a]	0.00 [b]	0.00 [b]
farm (total farmland holding; ha)	±	2.06	1.73	0.1	14.5	2.08 [ab]	1.77 [ab]	1.76 [ab]	1.82 [a]	2.48 [b]
livestock (livestock ownership level; TLU) [d]	+	3.30	2.60	0	13.4	3.43 [a]	1.35 [ab]	2.47 [b]	2.71 [b]	4.32 [c]
labor (family and permanent labor force; persons) [e]	±	3.56	1.80	0	12.0	3.57 [ns]	2.80 [ns]	3.45 [ns]	3.44 [ns]	3.80 [ns]
market (distance from the nearest market; km)	±	2.12	2.11	0.5	9.0	2.43 [ad]	0.90 [b]	0.97 [b]	1.76 [c]	2.41 [d]
Biophysical Characteristics of the Sample Plots										
plotsize (size of the plot; ha)	+	0.33	0.26	0.01	2.00	0.22 [a]	0.55 [b]	0.51 [b]	0.39 [b]	0.39 [b]
distance (commuting distance to the plot; m)	±	734	1193	0	10000	82 [a]	3221 [abc]	1453 [b]	1321 [b]	790 [c]
0 m ≤ 100 m [f]		246 plots (47%)				187 (86%)	0 (0%)	5 (12%)	30 (20%)	24 (16%)
100 m ≤ 1000 m		170 plots (32%)				28 (13%)	1 (20%)	22 (51%)	67 (44%)	52 (34%)
1000 m <		108 plots (21%)				3 (1%)	4 (80%)	16 (37%)	56 (37%)	29 (19%)
Types of the sample plot [g]	*Arada*	230 plots (44%)				218 (100%)	0 (0%)	12 (28%)	0 (0%)	0 (0%)

Table 2. *Cont.*

Dependent Variables *Man* (1 = OFs Were Applied, 0 = Otherwise) *Fer* (1 = IFs Were Used, 0 = Otherwise)	Expected Sign	Mean	Std. Dev.	Min.	Max.	FCCS Plots (n = 266)			CCCS Plots (n = 258)	
						[1] Only OF (n = 218)	[2] Only IF (n = 5)	[3] No Amend (n = 43)	[4] Only IF (n = 153)	[5] OF + IF (n = 105)
Masa		258 plots (49%)				0 (0%)	0 (0%)	0 (0%)	153 (100%)	105 (100%)
Golba		36 plots (7%)				0 (0%)	5 (100%)	31 (72%)	0 (0%)	0 (0%)

Soil fertility management practices, [1–5] correspond to those in Table 3. Different superscript letters indicate statistically significant differences between [1] and [5] ($p < 0.05$). *ns*: not significant. [a] Variable *training* refers to whether the household head received compost training from the district agricultural office. [b] Variable *off-farm* refers to whether the household member has an off-farm job. [c] FCCS; food-crop-based cropping system, CCCS; cash-crop-based cropping system. [d] TLU, Tropical livestock unit; *livestock* (TLU) = cattle ownership level (TLU) × (1 − fuel use rate (%)/100) + other livestock ownership level (TLU). The fuel use rate indicates what percentage of dung produced by the cattle was consumed for fuel. [e] Converted to adult (from 16 to 65 years old) labor force equivalent. [f] Segments of *distance* (m). [g] Types of the sample plot: *arada*, *masa*, and *golba* (Oromo) are farmers' field classifications in the study area (Figure 1).

Table 3. Cropping systems, field types, soil fertility management practices, and the cluster number assigned by the K-means cluster analysis (n = 524).

Cropping Systems [a]		Plot No.	Main Crops	Field Types [b]	Soil Fertility Management Practices [c]	Cluster No. (Subdataset, n)
FCCS (n = 266)	Continuous food crop cultivation	218	Maize, barley	Infield (*arada*)	[1] Continuous OF application (n = 218)	1 (FCCS, 218)
		44	Maize	Outfield (*golba*)	[3] No soil amendment on fertile *golbas* or *onas* (n = 39)	1 (FCCS, 27) and 2 (CCCS, 17)
					[2] IF use on unfertile *golbas* (n = 5)	2 (CCCS, 5)
		4	Sorghum	Outfield (*golba*)	[3] No soil amendment (n = 4)	1 (FCCS, 4)
CCCS (n = 258)	Food crops and cash crops are rotationally cultivated	258	Food crops (sorghum, barley, beans, and peas) and cash crops (tef, wheat, haricot bean, rainfed vegetables)	Outfield (*masa*)	[4] Only IF use (n = 153) [5] IF and compost application (n = 105)	2 (CCCS, 258)

[a] FCCS; food-crop-based cropping system, CCCS; cash-crop-based cropping system. [b] Flat and low-lying cropland and *golbas* can be seen only in the mid-altitude dry sub-area. [c] OF; organic fertilizer, IF; inorganic fertilizer. [1–5] correspond to the soil fertility management practices in Table 2.

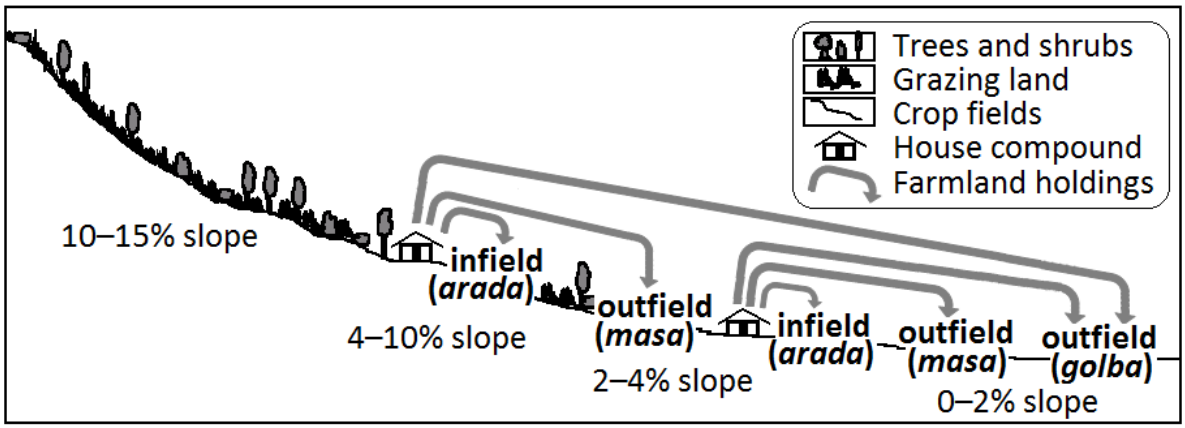


Figure 1. Micro-topography, land use, and field types in the northern semi-arid Ethiopian Rift Valley. Arrows in the figure indicate farmland holdings.

These ten studies were conducted in mixed food- and cash-crops economies in the cereal-based farming systems (Table 4). All the studies selected sample plots randomly

from the study area; the samples were a mixture of food- and cash-crop plots. Thus, farmers' soil fertility management strategy in a sample plot may differ between two distinctive cropping systems (i.e., food-crop-based and cash-crop-based cropping systems). However, no study addressed the issue of whether the variations of cropping systems in a sample plot affect the farmers' determinants of soil fertility management strategy.

Table 4. Mixed food- and cash-crop data collected for the previous technology adoption studies.

	Benin [23]		**Pender and Gebremedhin [24]**		**Marenya and Barrett [26]**		**Kassie et al. [27]**		**Ketema and Bauer [25]**		**Teklewold et al. [28]**		**Ahmed [29]**		**Hassen [30]**		**Ahmed [32]**	
Farming systems	Highland temperate mixed		Highland temperate mixed		Maize mixed		Highland temperate mixed		Maize mixed		Highland temperate mixed		Agro-pastoral maize mixed		Highland temperate mixed		Maize mixed	
	FC	CC	FC	CC	FC	CC	FC	CC	FC	CC	FC	CC	FC	CC	FC	CC	FC	CC
Crops	Ba, Ma, Wh, Be	Tef, Wh, Ma, Be	Ba, Wh, Be	Wh, Be	Ma, Be	Tea, Cof	Ba, Wh	Wh, Be	Ma, So	Cha, Cof	Ba, So, Ma, Wh, Be	Tef, Wh, Ma, Be	Ma (71%)	Ma (21%)	Ba, So, Wh, Be	Tef, Wh, Be	Ma (77–83%)	Ma (5–10%)

FC; food crops, CC; cash crops, Ba; barley, Be; beans, Ca; cassava, Ma; maize, Mi; millet, So; sorghum, Wh; wheat, Chat; catha edulis, Cow; cowpea, Cof; coffee, Cot; cotton, Gr; groundnuts, On; onion, Po; potato, Py; pyrethrum, Sug; sugarcane, Ve; vegetables. Teklewold et al. [28], Ahmed [29], and Ahmed [32] targeted only maize plots. The percentages of the harvested maize utilized for house consumption, seed, sale, wages in kind, animal feed, and others in the sample districts in 2002 are available from CSA [33,34]. The percentages of house consumption and sale were shown for food-crop maize and cash-crop maize in brackets, respectively. The sample districts were Arsi-Negele district, Oromia region for Ahmed [29] and Haramaya and Girawa districts, Oromia region for Ahmed [32]. Teklewold et al. [28] selected nine districts from Oromia, Amhara, and SNNPR regions but did not specify the sample districts. Thus, the average figures for these three regions were shown. Kassie et al. [31] collected field data from Kenya, Malawi, Ethiopia, and Tanzania; however, the sampling areas were not specified. Farming systems are from Dixon et al. [1].

Of the eight studies, two found complementary and six found substitute relationships between OF and IF use (Table 1). Kassie et al. [27] found a complementary relationship. They further suggested the causes of it: (i) all of the stochastic dominance analyses for the grain productions of tef (Eragrostis tef), wheat, and barley, showing grain yields were significantly higher in the plots where compost and/or IF were used. Thus, farmers perceived their yield advantage, and (ii) wealthier households with higher livestock ownership and farm size levels were more likely to adopt innovations, such as compost and IF use. The latter point, suggesting that more affluent households tended to own a larger livestock herd and generate cash for purchasing IFs, was also suggested by Marenya and Barrett [26], which also found a complementarity. Interestingly, Teklewold et al. [28] also found that: (i) the stochastic dominance analyses showed farmers perceived manure and IF use as more profitable; and (ii) households with higher livestock ownership levels and wealth levels were more likely to use manure and IF. These factors that positively influenced both manure/compost and IFs appeared to be almost identical between Kassie et al. [27] and Teklewold et al. [28]; however, Teklewold et al. [28] found a substitute relationship between manure and IF use for maize. These contradictory findings obtained from different environments in SSA have not been cleared in these three econometric studies.

Some economists have claimed there is a substitute relationship between OF and IF, discussing how (i) Fertilizer is expensive in price and inadequate in supply but less demanding of labor in its application. Manure is mostly freely available but labor-intensive in transportation and application. As a result, the choice between the two is mainly based on labor endowments and the farmers' income levels [25,30]. (ii) Farmers lack knowledge about these inputs' complementary nature or optimum combinations [25,30]. (iii) IF use were less likely on plots with good soil quality, whereas manure use was more likely on good soil quality plots [28]. Econometric analysis effectively determines a potential endogeneity bias of adoption decisions. However, either the instrumental variable or MVP analyses cannot distinguish the sources of the endogeneity [33]. This made it difficult to

compare the econometric analyses conducted in different environments and to understand the sources of the complementary or substitute relationships. The econometric analyses in the cereal-based farming systems in SSA appear to highlight the difference between agronomist and economist viewpoints.

We need to consider the background of an econometric analysis because a reciprocal relationship between OF and IF use can be highly affected by environmental conditions, such as the historical roles of OF application in the site and the climate and soil conditions. Long-term experiments are usually needed when analyzing the effects of OF applications on soil organic carbon content. This is because most soil organic carbon changes require many years (10 to 100 years) to be detectable by present analytical methods [34]. A long-term (22-year) maize yield experiment in the sub-humid Kenyan highlands (mean annual rainfall; 980 mm) with treatments of different combinations and rates between farmyard manure and IF application showed that maize yield dynamics involved temporal changes [35]. They found that applying IF alone initially outyielded other treatments, including manure alone and manure + IF combination. This trend changed after the 6th year, and manure + IF gave higher yields than all other treatments. After that, the difference between IF alone and manure + IF increased by 15–50% in the 12th to 22nd years [35]. Thus, increasing soil organic matter through manure application influences maize yields over the longer term, while inorganic nutrient application controls shorter-term yields. In fields with a short history of OF application, OF and IF use may be independent or substituted. Conversely, the relationship may be complementary in fields with a long history of OF application. These temporal soil properties and yield changes in the survey site can influence a reciprocal relationship between OF and IF use.

Sorghum yield trial with goat manure and IF applications, another long-term (13-year) experiment in SSA, was conducted in semi-arid Kenya (mean annual rainfall; 790 mm) [36]. Soil organic carbon and available phosphorus (P) increased for the first seven years of manure application and then remained constant, with similar results in terms of the temporal soil property change with the aforementioned maize experiment in the Kenyan highlands. However, trends in sorghum grain yield were not identifiable because of season-to-season variations. Because semi-arid SSA has a great variability of rainfall, which raises the risk and uncertainty of IF use [37], early and widespread adoption of IFs has not occurred [36]. Even in semi-arid SSA, Hassen [30] found that the farmers tended to adopt IFs for the soils that were less acidic, fertile, and had a relatively higher water-holding capacity. Conversely, the farmers tended to not adopt IFs for soils of acidic, less fertile, and lower water-holding capacity because they feared the fertilizer burn of seeds, increasing the risk of low harvests in dry years [30,37]. Instead, a semi-arid area with high population density, such as Kano in northern Nigeria, has a long history of arable farming with manure application [36]. Manure application increases the water-holding capacity of droughty soils and neutralizes soil acidity [38]. However, OFs have their problems, such as limited supplies and the work of handling bulky materials. The effects and costs of OF and IF differ but may be complementary in general [36] or in less-acidic soil areas [30]. However, it is likely to be a substitute in acidic soil areas in dry land SSA [30]. Thus, additional explanations are needed to analyze the background of the resultant relationship between OF and IF. It helps understand their sources and compare them with those from different environments.

This study aimed, firstly, to examine the relevance of the combined economic and agronomic aspects in econometric modeling to assess farmers' adoption of soil fertility management practices in the northern part of semi-arid Ethiopian Rift Valley (Figure 2). This study hypothesized that a pooled dataset collected from the study area is categorized into two subdatasets: food-crop-based cropping system (FCCS) and cash-crop-based cropping system (CCCS), and farmers' decision-making processes may differ between the two. Specifically, this study employed a data segmentation approach and a dummy variable method to reflect these two datasets, i.e., the structure of a local farming system, into modeling strategies. A K-means cluster analysis (K = 2) was conducted for all the sample plot data (n = 524) to validate the hypothesis. Based on the K-means cluster analysis,

bivariate probit (BVP) models with the pooled dataset and subdatasets were formulated, and the models were tested.

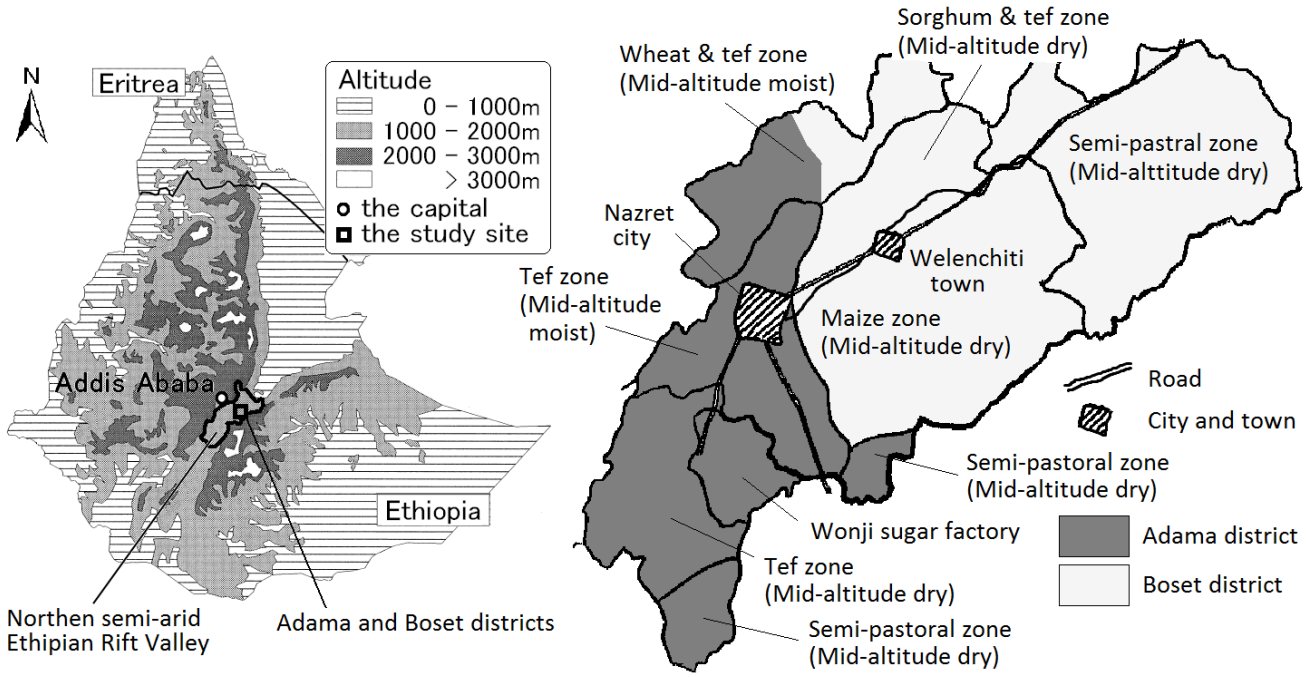


Figure 2. Study area. The study area contains five agroecological sub-zones (right figure was adapted from ICRA, 1999 [39]).

This study aimed, secondly, to use qualitative research methods (i.e., field observations and careful interviews with farmers [40] to supplement the econometric analyses. If an attempted combined approach of economic and agronomic aspects has proved to be the true model, the conventional models had probably omitted a variable that belonged in the true model. This problem generally causes the OLS (ordinary least squares) estimators to be biased, called omitted variable bias [41]. Some goodness-of-fit tests were conducted to assess the various BVP models, representing the combined and conventional approaches. In addition to these quantitative tests, some findings from qualitative research methods helped explain the rationale of farmers' decisions. Mixed methods (quantitative and qualitative) used in this study may have a more persuasive power to compare the differences in the farmers' determinants in different environments and, therefore, more policy implications.

2. Materials and Methods

2.1. Study Area and Narrative Inquiry Interviews

Adama and Boset districts (*woredas*) are situated in the northern semi-arid Ethiopian Rift Valley (Figure 2). They contain a mid-altitude dry sub-area (1000–1600 m above sea level) and mid-altitude moist sub-area (similarly, 1600–1800 m) in terms of maize growing areas in Ethiopia [42]. The mean annual rainfall at Welenchiti (1992–2013) and Ejere (1976–2013), closest to mid-altitude dry and mid-altitude moist sub-areas, respectively, are 874 and 881 mm (Figure 3). Most crops are cultivated from May to December over the short (March and April) and long (July to September) rainy seasons. Farmers in both districts grow food crops (maize, sorghum, wheat, barley, and beans and peas, except haricot bean) and cash crops (tef, haricot bean, and rainfed vegetables [39].

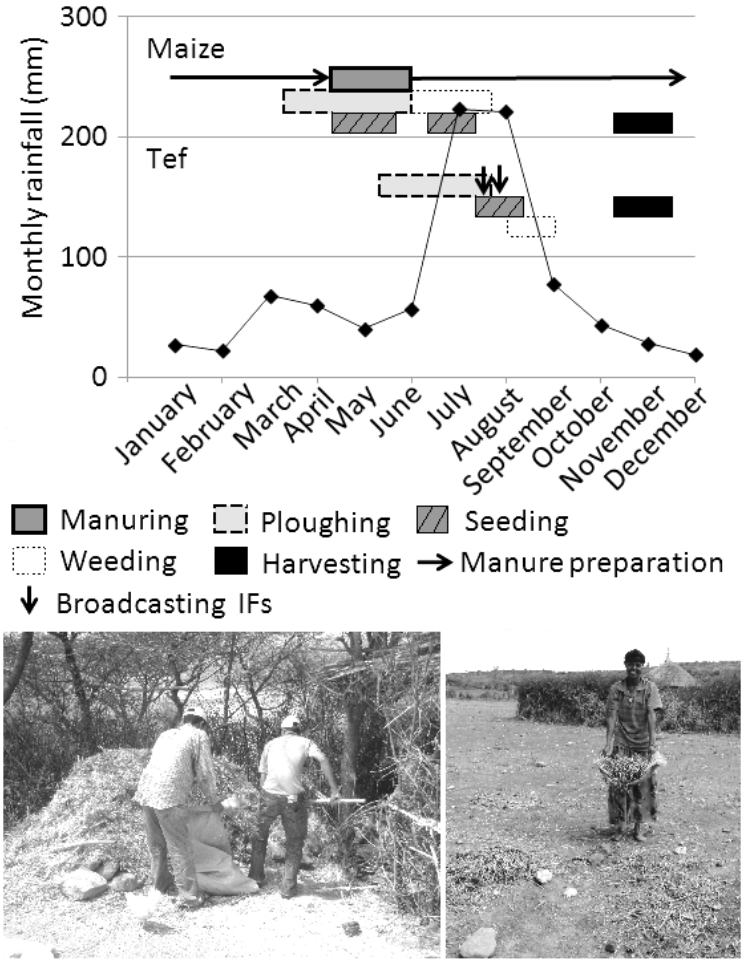


Figure 3. Cropping calendar and rainfall (**upper** figures) and farmer's organic fertilizer application practices (**lower** photos). Farmers were going to carry compost (*kosi*) from a pile to an *arada* field (**left** photo), and a housewife was going to dump household wastes onto an *arada* field (**right** photo). Source: monthly mean rainfall data were from Welenchiti rainfall gauge (1992–2013).

Of the nine major crops of the Adama and Boset districts, maize, sorghum, wheat, barley, lentils, horse beans, and field peas are used mainly for house consumption (55–74% of the total usage; Table 5). In contrast, tef and haricot beans are primarily used for income sources (54–75%). The major crops in the mid-altitude moist sub-area are wheat, tef, and maize, whereas those in the mid-altitude dry sub-area are sorghum, tef, and maize [39]. The nine major crops and rainfed vegetable fields are mixed in both sub-areas.

Table 5. Crop utilization of the major crops in Adama and Boset districts, Oromia region, in 2002.

Crop	Cultivated Area (ha)	Percent Utilized for (%)		
		House Consumption	Sale	Others
Tef	23,752	31	54	16
Maize	21,915	74	14	12
Haricot beans	8431	14	75	11
Sorghum	6334	73	16	11
Wheat	3422	58	16	26
Field peas	3789	55	23	21
Barley	2775	56	16	28
Horse beans	442	73	11	16
Lentils	408	71	21	8

Others include seed, wages in kind, and animal feed. Source: The author's calculation based on CSA [43].

The study area contains five agroecological sub-zones (tef, maize, semi-pastoral, sorghum and tef, and wheat and tef [39]; Figure 2). Tef, maize, semi-pastoral, and sorghum and tef sub-zones comprise mid-altitude dry sub-area, while tef and wheat and tef sub-zones comprise mid-altitude moist sub-area.

In 2011, narrative inquiry interviews [44] were conducted in two villages, each from the mid-altitude dry and mid-altitude moist sub-areas. The objectives of the interviews were to ascertain the research subjects: (i) history of village formation; (ii) land use/cover changes; (iii) changes in farming practices and cropping system; and (iv) changes in soil fertility management practices. A snowballing sampling strategy [45] was used to identify and select information-rich cases. The seven recorded interviews were transcribed into written English. Initial codes were created based on the emerging patterns in the transcribed texts [46]. To dig deeper into the processes, secondary codes were generated based on the frequency of appearances in the texts.

The narrative inquiry interviews showed that farmers categorize crop fields into *arada*, *masa*, and *golba* (Oromo; Figure 1). *Aradas* are located adjacent to the housing compounds. Most households hold continuously cropped maize fields in *aradas* (Table 3). Farmers harvest the upper half of maize stalk early for animal feeds and sometimes harvest it in October, not waiting for its maturing stage from November to December to eat raw (Figure 3). For poor farmers, maize is significant as an emergency food to weather a food shortage in the slack season. Farmers apply OFs (compost and household wastes) to *aradas* (Figure 3). Maize yields are significantly affected by soil fertility levels, particularly N and P [47].

Masas are far from their compounds (Figure 1). Farmers dichotomize *aradas* and *masas* regarding their relative soil fertility levels. OF application to *aradas* improves soil chemical properties (significantly increasing SOC, total N, P, CEC, K, Na, Mg, EC, and NO_3-N while significantly lowering pH) and soil physical properties (significantly lowered soil compaction and bulk density and significantly increased porosity) compared to those of *masas* [48]. In relatively unfertile *masas*, food crops other than maize (sorghum, wheat, barley, beans, and peas) and cash crops (tef, haricot beans, and rainfed vegetables) are rotationally cultivated (Table 3).

In addition to IFs, many farmers apply compost to *masas*; however, they do not prefer to apply compost frequently or in large quantities. First, immature cattle manure often contains weed seeds [49], which causes a weed problem. Tef, the most popular cash crop in the study area (Table 5), suffers weed damage easily. Weed competition causes 52% of crop losses [50]. Second, the tef is also vulnerable to lodging. Nitrogen applications beyond the optimum rate often aggravate tef lodging [51]. Lodging is a major factor, limiting tef yield and quality [52].

Masa soils in the mid-altitude moist and mid-altitude dry sub-areas have the mean available P contents of 1.9–2.6 mg kg^{-1} [48]. That is categorized as a very low Olsen P level for crop cultivation [48,53]. Parent materials in the Ethiopian Rift Valley are volcanic rocks, alkaline lava, ashes, and ignimbrites, mainly of Tertiary and Quaternary deposits of a rift system [54]. The very low available P may be attributed to the high degree of P fixation and its precipitation as calcium phosphate in calcareous alkali soils [55], which is very common in the northern and central Ethiopian Rift Valley [56]. Thus, the P amendment of the *masa* soil is very crucial in Adama and Boset districts [56] even for low-P-requiring crops, such as haricot beans [53,57], the second most popular cash crop in the study area (Table 5).

Crop fields situated in flat and low-lying lands are called *golbas* (Figure 1). The soil fertility of *golbas* is maintained by the inflow of fertile soil from their upper-reach fields in the rainy season. Farmers cultivate maize and sorghum in a fertile *golba*. However, when soil fertility in a *golba* has declined for a certain reason, farmers use IF for the continuous maize cultivated in the *golba*. *Golbas* can be seen only in the mid-altitude dry sub-area. The mid-altitude moist sub-area comprises only *aradas* (fields close to the compounds and fertile) and *masas* (fields far from the compounds and unfertile).

Thus, the infield-outfield system observed in other parts of SSA can be typically seen in the northern Ethiopian Rift Valley. It associates strong gradients of soil fertility decline with increasing distance from compounds. This within-farm soil fertility gradient is also favorable for crop nutrient requirements of the locally representative high-nutrient-requiring food crop (maize) and low-nutrient-requiring cash (tef and haricot beans) crops.

Compost (*kosi*; Oromo) is made from various locally available organic materials, such as animal dung, kitchen ash, crop residues, and feed refusals. These compost materials are piled up in the corners of the yards of houses for several months to a few years for decomposition [58] (Figure 3). In most cases, farmers carry compost from compost piles to the field from May to June immediately before crop seeding and scatter it on the ground (Figure 3). The compost is incorporated into the soil by subsequent plowings. Household wastes are composed of the same organic materials as compost [49], which is collected through sweeping the yard of the house and dumped on an *arada* every few days, mainly by a housewife (Figure 3).

Mukai [59] surveyed the relationships between compost application, soil nutrients, and maize yield in the northern semi-arid Ethiopia Rift Valley (n = 30 plots; sorghum-tef zone; mid-altitude dry sub-area; Boset district; Figure 2). Long-term compost application patterns (i.e., years of continuous use, application dose, and frequency of application) to the sample *arada* plots were investigated through interviews and field measurements from 2011 to 2016. These data were averaged over the farmer's continuous manure application years to obtain the estimated manure application rate (Mg ha^{-1} yr^{-1} DM) for the sample *aradas*. This research found that the farmers applied the mean 6.0 Mg ha^{-1} yr^{-1} of compost over 17 years to maize. Significant linear or curve-linear correlations were found (i) between the annual nutrient supply (N, P, and K) and soil nutrient levels and (ii) between the soil nutrient levels and maize productivity with minor exceptions. Thus, farmers in the study area perceive OF use as more profitable for maize.

A simple survey conducted in 2012 interviewed 40 farmers in Merko Odalega village, Boset district (sorghum-tef zone; mid-altitude dry sub-area; Figure 2). IF application rates, urea (46% N) and DAP (diammonium phosphate; 18% N and 46% P), for tef cultivation in 40 *masa* plots and tef yields were ascertained from the farmers. The survey found that the mean IF application rates to tef were 15.7 kg N ha^{-1} and 39.2 kg P ha^{-1}. All tef plots received IFs (100% received DAP, and only 1 plot received urea). The tef yield was 1.1 $\pm$ 0.3 Mg ha^{-1} (mean $\pm$ S.D.). Regression analyses found that the tef yield was significantly positively predicted by the N application rate ($ß$ = 0.021; p = 0.03; r = 0.34). In contrast, the P application rate did not significantly predict the tef yield ($ß$ = 0.003; p = 0.50; r = 0.11). Reviewing tef research in Ethiopia, Mamo et al. [51] stated that researchers had proven the significance of N and P amendment for tef nationwide; however, P application was of secondary importance and was recommended at minimum levels, except for P-fixation

soils. The optimum rate of N application is 60 kg ha^{-1}. Applications beyond this rate aggravate lodging [51]. The national average of tef yield was ~1.0 Mg ha^{-1} [51]. Due to declined soil available P and P-fixation, DAP application has recently become the minimum requirement for farmers in the northern and central Rift Valley [56]. The 40 sample farmers applied below the optimum rate of N application, 60 kg N ha^{-1}. Thus, this simple survey agreed with the nationwide findings. Farmers in the study area perceive IF use as a more profitable option for tef cultivation.

2.2. Variable Selection

In this study, a binary dependent variable (used or not used) was employed to assess OF and IF use (rather than the intensity of use; Table 2). This was because, first, compost application for continuous maize cultivation in *aradas* (Table 3) is a continuous event for several to a dozen years. It was not easy to assess the precise amount of compost application in a single-shot survey [25,60]. Second, a household waste input onto an *arada* took place every few to several days, and the amount was variable.

Many farmers apply compost to *masas* where food and cash crops are rotationally cultivated (Table 3). Farmers' choice of soil fertility management practices in a *masa* plot differs yearly. They usually take a compost rotational application method; compost is applied to a plot once every several years. Farmers use IFs whenever they grow cash crops; however, they use no IFs when they grow food crops. In addition, IF intensity and composition, e.g., urea and DAP, vary according to what cash crops are cultivated. Thus, an interview about the soil fertility management option in a *masa* plot targeting a single year may not capture the reality of the soil fertility management practice in the plot. Therefore, when we interviewed a farmer, whether they applied any OFs and/or IFs to the sample plot during the last two to three years was first asked, and if they replied yes, then that plot was designated as an OF and/or IF application plot.

Limited studies conducted comparative experiments to investigate which scenario was more advantageous, an annual low-dose or high-dose application every other year [61]. Grimes and Clark [62], who conducted a study in the Coast Province, Kenya, concluded that an annual 3 Mg ha^{-1} application and 9 Mg ha^{-1} application once every three years had the same effects. Kihanda et al. [61] suggested that the residual manure that plants did not use during the growth periods in the current season would be stabilized in soil organic matter. Therefore, it does not matter whether OFs are applied every season or in some seasons only. All ten studies (Table 1) used binary dependent variables for OF and IF use.

2.3. Sampling Procedure for a Semi-Structured Questionnaire Survey

A semi-structured questionnaire survey was conducted in 2012. This questionnaire contained questions to collect quantitative data for the econometric analysis and supplementary qualitative data on compost making and application. In Ethiopia, population censuses were conducted in 1984, 1994, and 2007, from which district (*woreda*)-level population data are available over the three years, and village (*kebele*)-level population and household numbers are available from the 1994 and 2007 censuses [63–65]. Using the rural population in 1984, 1994, 2005, 2007, and 2014 (the government projected those in 2005 and 2014 [66,67]), the total household numbers in the rural part of the study area (Adama and Boset districts) in 2012 were estimated to be 50,117. The mean plot number per household in the study area was 5.7 (the 319 total sample households held 1820 plots); thus, the total plot number in the study area was estimated to be 285,667.

The survey team targeted the collection of the sample plots and households, with a 5% confidence interval in size under a 95% confidence level corresponding to a z-score [68]. The numbers of sample plots and households were allocated to the five agroecological sub-zones in proportion to the total household number of each sub-zone. The survey team visited every sub-zone and selected sample plots randomly; subsequent interviews were conducted with the plot owner. After eliminating questionnaires with invalid data, 524 plot data (4.3% confidence interval) were collected from 319 households (5.5% confidence interval).

2.4. Econometric Analysis

Farmers may consider two soil fertility management practices, OF and IF use, as being complementary or substitutes, and unobserved disturbances may correlate with the adoption equations. If a correlation exists, the estimates of separate (probit) equations of the soil fertility management decisions will lead to bias and inconsistent estimates [33]. This study adopted a bivariate probit (BVP) model to overcome this econometric problem.

A variable *man* represents household heads' binary choices of OF adoption (*man* = 1) or no adoption (*man* = 0) in the plot, while variable *fer* denotes IF adoption (*fer* = 1) or no adoption (*fer* = 0). The observed adoption choice can be modeled following a random utility formulation. The assumption is that if the net benefits of OF application (man_p^*) and IF use (fer_p^*) are higher than non-adoptions in plot p, the household head decides to adopt those practices. Both the man_p^* and fer_p^* are continuous latent variables determined by observed socioeconomic characteristics of the sample household heads and biophysical features of the sample plots (χ'_{mp} and χ'_{fp}, respectively) and the error terms (ε_{mp} and ε_{fp}, respectively):

$$fer_p^* = \beta_f \chi'_{fp} + \varepsilon_{fp}\ man_p^* = \beta_m \chi'_{mp} + \varepsilon_{mp}\ p = 1, \ldots, n \tag{1}$$

Given the latent nature of fer_p^* and man_p^*, the estimations are based on observable binary discrete variables of fer_p and man_p:

$$fer_p = \begin{matrix} 1\ if\ fer_p^* > 0 \\ 0\ otherwise \end{matrix} \quad man_p = \begin{matrix} 1\ if\ man_p^* > 0 \\ 0\ otherwise \end{matrix} \tag{2}$$

The error terms (ε_{fp} and ε_{mp}) are assumed to be independently and identically distributed as bivariate normal:

$$E(\varepsilon_{fp}) = E(\varepsilon_{mp}) = 0,\ Var(\varepsilon_{fp}) = Var(\varepsilon_{mp}) = 1,\ Cov(\varepsilon_{fp}, \varepsilon_{mp}) = \rho \tag{3}$$

where ρ is a correlation coefficient. The parameter vector $\beta = \left(\beta'_f, \beta'_m, \rho'\right)$ can be estimated by maximum likelihood. The likelihood function to be maximized is:

$$L(\beta) = \sum_{p=1}^{n} \left[d_{11} \ln P_p^{11} + d_{10} \ln P_p^{10} + d_{01} \ln P_p^{01} + d_{00} \ln P_p^{00} \right] \tag{4}$$

where: $d_{11} = fer_p man_p$, $d_{10} = fer_p(1 - man_p)$, $d_{01} = (1 - fer_p) man_p$, $d_{00} = (1 - fer_p)(1 - man_p)$, $P_p^{11} = prob\left(fer_p = 1, man_p = 1 \middle| \chi_{fp}, \chi_{mp}\right) = \Phi_{p2}(\beta'_{fer}\chi_{fp} + \beta'_{man}\chi_{mp}, \rho)$, $P_p^{10} = \Phi_{p2}(\beta'_{fer}\chi_{fp}, -\beta'_m\chi_{mp}, -\rho)$, $P_p^{01} = \Phi_{p2}(-\beta'_{fer}\chi_{fp}, \beta'_m\chi_{mp}, -\rho)$, $P_p^{00} = \Phi_{p2}(-\beta'_{fer}\chi_{fp}, -\beta'_m\chi_{mp}, \rho)$, and $\Phi_{p2}(_, _, \rho)$ are the bivariate normal distribution functions of the model error terms. If ε_{fp} and ε_{mp} are independent, maximizing the likelihood function (4) is equivalent to maximizing the likelihood functions for Equations (1) and (2) separately, i.e., two univariate probit (UVP [69]). The likelihood-ratio test was used for the hypothesis of independence ($p < 0.05$). Stata 13.0 (StataCorp LP) was used to perform this estimation [70].

A K-means cluster analysis was conducted to validate the hypothesis that the pooled dataset is categorized into FCCS and CCCS subdatasets. All the variables of the plot data were standardized and used for the analysis. Based on the study hypothesis, K = 2 was assigned.

This study employed a data segmentation approach and a dummy variable method to incorporate the structure of a local farming system into econometric models. Data segmentation is advantageous when a potential endogeneity (i.e., complementary or substitute relationships) bias exists between two variables. This problem can be handled with causal chains in econometrics. However, segmentation offers the simpler alternative of splitting the data first on the variables that come earliest in the causal chain. The benefits of segmentation can be achieved by using dummy variable regressions, representing the segments [71].

The following four BVP models were created: (i) BVP model for the pooled dataset with independent variable *crop* (main cropping systems to which the sample plot belonged; 1 = FCCS, 0 = CCCS; model 1), (ii) BVP model for the pooled dataset without *crop* (model 2), (iii) BVP model for Cluster 1 subdataset (model 3), and (iv) BVP model for Cluster 2 subdataset (model 4). Models 3 and 4 are based on the data segmentation approach, while model 1 represents the dummy variable method. Model 2 does not consider the structure of the pooled dataset; therefore, it is a conventional model.

Four goodness-of-fit tests were conducted to test the validity of the data segmentation approach and a dummy variable method. (i) The squared residuals obtained from the pooled dataset (SSR_1 for model 1 and SSR_2 for model 2) and the sum of the squared residuals obtained from the two subdatasets ($SSR_{3+4} = SSR_3 + SSR_4$) were compared to test the equality of coefficients between the model 3 and model 4 [43]. (ii) The percentage of correctly estimated values, (iii) Bayesian information criterion (BIC), and (iv) log-likelihood were also examined. The univariate probit (UVP) analyses were shown by the average marginal effects [72].

2.5. Supplementary Qualitative Data on Compost Making and Application

The semi-structured questionnaire survey collected two types of supplementary data on compost making and application from the sample households. The first question was asked to the household heads who had made compost: "from whom did you acquire compost-making and application techniques?". The second question was asked for each sample plot if any OFs were not applied to the plot within the recent three years: "why did you not apply OFs to the plot?".

Based on the content analysis completed after the narrative inquiry interviews, four answers, such as the household heads learned the compost techniques from (i) administration, (ii) family and relatives, and (iii) neighbors, were prepared for the first question. Similarly, for the second question, the household heads did not apply OFs because: (i) the plot is a fertile *golba* or *ona* (previous *aradas* where soil fertility remained after the homestead move); (ii) shortage of OF materials (livestock dung); (iii) shortage of labor force to make or carry compost; (iv) the plot is too far from the homestead; and (v) use of IFs is a sufficient soil amendment. The sample household heads answered no other answers out of these categories in the semi-structured questionnaire survey.

3. Results

3.1. Model Comparison

The K-means cluster analysis showed that the data categorized in each cluster was 249 for Cluster 1 and 275 for Cluster 2. Cluster 1 contained all the continuous maize cultivation plots in *aradas* (FCCS plot data; $n = 218$) and part of the continuous maize cultivation plots in *golbas* (FCCS plot data; $n = 27$), as well as all the continuous sorghum cultivation plots in *golbas* (FCCS plot data; $n = 4$; Table 3). Cluster 2 comprised all the food- and cash-crop rotational cultivation plots in *masas* (CCCS plot data; $n = 258$) and the remaining continuous maize cultivation plots in *golbas* (FCCS plot data; $n = 22$). Valuables *man* (OFs were applied or not), *fer* (IFs were used or not), *crop* (cropping systems of the plot; FCCS or CCCS), *plotsize* (the plot size), and *distance* (commuting distance to the plot; Table 2) showed statistically significant differences ($p < 0.05$) between Cluster 1 and Cluster 2 (Figure 4). Standardized means of these variables demonstrated that Cluster 1 had characteristics similar to the FCCS plot data, and Cluster 2 had those to the CCCS plot data (Figure 4). Thus, the 249 plot data categorized into Cluster 1 were referred to as the FCCS subdataset, and the 275 plot data categorized into Cluster 2 were referred to as the CCCS subdataset (Table 3).

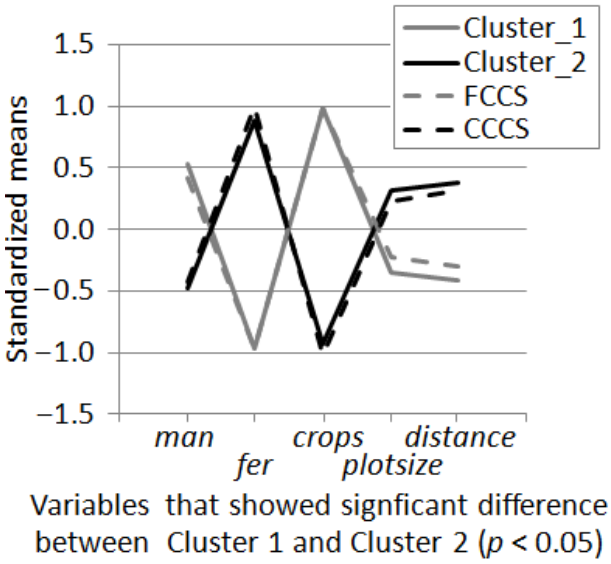


Figure 4. Standardized means of variables used for the K-means cluster analysis.

The narrative inquiry interviews and K-means cluster analysis illustrated that the biophysical features of the fields, e.g., commuting distance, plot size, and field types (*arada*, *masa*, and *golba*), represent the distance from the compound, soil types, soil fertility level, and slope of the plot. These biophysical features first determine the cropping system of the plot. Then, the varieties of feasible soil fertility management practices are narrowed down to one or two, as categorized in Table 3, in the northern semi-arid Ethiopian Rift Valley.

The four BVP analyses (Table 6) showed that the coefficients of dependent variables for the models with the pooled dataset (models 1 and 2) were similar regarding signs and significant levels and were blends between those for the FCCS subdataset (model 3) and CCCS subdataset (model 4). In contrast, the likelihood-ratio test of $\rho = 0$ (the correlation coefficient of the error terms of the two BVP models; Equation (3)), i.e., the hypothesis of independence, showed contrasting results between the models. Model 1 (the pooled dataset with *crop*), model 3, and model 4 commonly indicated the household heads considered their choices of OF and IF use independent (ρ was not significant, and the likelihood-ratio test also showed H_0: $\rho = 0$ were not rejected). Conversely, model 2 (the pooled dataset without *crop*) significantly indicated that the two soil fertility management options were substitutes ($\rho < 0$).

Table 6. Variable coefficients of the bivariate probit models (models 1, 2, 3, and 4).

	Model 1 (Pooled Dataset, *n* = 524)		**Model 2 (Pooled Dataset, *n* = 524)**		**Model 3 (FCCS Subdataset, *n* = 250)**		**Model 4 (CCCS Subdataset, *n* = 274)**	
	OFs (*Man*)	**IFs (*Fer*)**	**OFs (*Man*)**	**IFs (*Fer*)**	**OFs (*Man*)**	**IFs (*Fer*)**	**OFs (*Man*)**	**IFs (*Fer*)**
zone	0.01 (0.15)	0.10 (0.34)	−0.06 (0.14)	0.19 (0.13)	0.52 (0.36)	−0.37 (2.30)	−0.33 * (0.18)	0.39 (0.56)
gender	0.21 (0.21)	0.36 (0.47)	0.21 (0.20)	−0.05 (0.18)	−0.56 (0.47)	2.03 (2.66)	0.41 (0.29)	0.91 (0.72)
training	0.03 (0.14)	0.23 (0.32)	0.02 (0.13)	0.03 (0.12)	−0.37 (0.34)	−0.30 (0.96)	0.23 (0.17)	0.28 (0.51)
off-farm	−0.07 (0.16)	0.20 (0.36)	−0.03 (0.15)	−0.07 (0.13)	0.10 (0.32)	0.50 (0.82)	−0.09 (0.20)	−0.46 (0.69)
crop	1.06 *** (0.15)	−4.52 *** (0.37)	not used	not used	not used [a]	not used [a]	−7.18 (37,036.70)	−13.01 (910,950.00)
farm	0.13 *** (0.05)	0.03 (0.10)	0.12 *** (0.05)	0.03 (0.03)	0.22 (0.18)	−0.16 (0.52)	0.13 ** (0.06)	0.24 (0.33)
livestock	0.12 *** (0.03)	−0.11 (0.07)	0.09 *** (0.03)	−0.05 (0.04)	0.26 *** (0.10)	−0.19 (0.19)	0.12 *** (0.04)	−0.26 * (0.15)

Table 6. *Cont.*

	Model 1 (Pooled Dataset, *n* = 524)		Model 2 (Pooled Dataset, *n* = 524)		Model 3 (FCCS Subdataset, *n* = 250)		Model 4 (CCCS Subdataset, *n* = 274)	
	OFs (*Man*)	**IFs (*Fer*)**	**OFs (*Man*)**	**IFs (*Fer*)**	**OFs (*Man*)**	**IFs (*Fer*)**	**OFs (*Man*)**	**IFs (*Fer*)**
labor	−0.03 (0.05)	0.04 (0.10)	0.00 (0.04)	0.01 (0.03)	0.00 (0.13)	0.08 (0.34)	−0.05 (0.05)	0.31 (0.21)
market	0.12 *** (0.04)	0.03 (0.09)	0.11 *** (0.04)	0.03 (0.09)	0.23 * (0.12)	−0.03 (0.36)	0.09 * (0.05)	0.11 (0.22)
plotsize	−1.03 *** (0.30)	0.57 (0.56)	−1.22 *** (0.28)	0.81 (0.24)	−1.26 ** (0.62)	1.50 (1.91)	0.23 (0.49)	0.55 (4.50)
distance	−0.00 *** (0.00)	0.00 *** (0.00)	−0.00 *** (0.00)	0.00 *** (0.00)	−0.00 *** (0.00)	0.00 ** (0.00)	−0.00 *** (0.00)	−0.00 (0.00)
Log-likelihood		−261.52		−540.89		−50.85		−163.96
ρ [b]	0.00 (0.22)		−0.56 (0.07) ***		−0.72 (1.32)		0.90 (0.75)	
BIC		679.57		1225.80		228.69		473.86
LR test [c]	χ^2 (1) = 0.004, $p > \chi^2$ = 0.985		χ^2 (1) = 46.292, $p > \chi^2$ = 0.000		χ^2 (1) = 0.109, $p > \chi^2$ = 0.741		χ^2 (1) = 0.358, $p > \chi^2$ = 0.358	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Numbers in parentheses are standard error. a Because the FCCS subdataset contained only FCCS plot data, the variable *crop* was not used for model 3. In contrast, the CCCS subdataset contained 12 FCCS plot data (all the continuous sorghum plots in *golbas* and part of the continuous maize plots in *golbas*) and 262 CCCS plot data. b ρ (Equation (3)) indicates a correlation coefficient of the error terms of the two bivariate probit models (ε_{fp} and ε_{mp}; Equation (1)). c Likelihood-ratio test of $\rho = 0$.

The BVP analyses showed that the squared residuals obtained from model 1 (SSR_1) was 83.1 and that from model 2 (SSR_2) was 194.8, while the sum of the squared residuals (SSR_{3+4}) obtained from model 3 (SSR_3 = 55.7) and model 4 (SSR_4 = 15.8) was 71.5. Calculating the chi-square statistic for the difference between SSR_1 and SSR_{3+4} with the degree of freedom (t statistics), 500, resulted in 81.4. Similarly, SSR_2 and SSR_{3+4} resulted in 862.0, both of which were greater than $\chi^2_{0.05}$ (12), 21.0. Thus, the null hypothesis that the BVP analyses (i.e., the regression coefficients) of models 3 and 4 were equal for was rejected for both cases. The percentage of correctly estimated values was 77% for model 1, 57% for model 2, and 80% for models 3 (91%) and 4 (71%). BICs were 679.57 for model 1, 1225.80 for model 2, 228.69 for model 3, and 473.86 for model 4.

These analyses demonstrated that farmers' decision-making processes differed between the FCCSs and CCCSs, and it is better to analyze each subdataset separately rather than the pooled dataset. Thus, further parameter estimations were conducted with two univariate probit (UVP) models (Table 7).

The four goodness-of-fit tests showed that omitting the variable *crop*: (i) increased the squared residuals obtained from model 2 (SSR_2); (ii) lowered the percentage of correctly estimated values of model 2; (iii) increased the BIC of model 2; and (iv) lowered the log-likelihood of model 2 than that of from model 1 (with *crop*). All these indicated that model 1 fitted the dataset better than model 2.

3.2. Determinants of Soil Fertility Management Practices

The BVP and UVP analyses for the FCCS subdataset (model 3 in Tables 6 and 7) commonly showed that the household heads who had (i) a larger quantity of livestock (*livestock*), (ii) the plots that were smaller in size (*plotsize*), and (iii) the plots that were closer to their compounds (*distance*) tended to apply OFs to their plots. Commuting distance was the only significant variable that affected the farmers' choices of IF use for the FCCS subdataset.

Table 7. Mean marginal effects of the univariate probit models (models 3 and 4).

	Model 3 (FCCS Subdataset)		Model 4 (CCCS Subdataset)	
	OFs (*man*)	**IFs (*fer*)**	**OFs (*man*)**	**IFs (*fer*)**
zone	0.04 (0.03)	−0.00 (0.00)	−0.09 (0.06)	0.03 (0.02)
gender	−0.03 (0.02)	0.00 (0.00)	0.13 (0.09)	0.01 (0.04)
training	−0.03 (0.02)	−0.00 (0.00)	0.09 (0.06)	−0.00 (0.00)
off-farm	0.01 (0.02)	0.00 (0.00)	−0.04 (0.07)	−0.01 (0.02)
farm	0.02 (0.01)	−0.00 (0.00)	0.05 ** (0.02)	0.00 (0.00)
livestock	0.02 *** (0.01)	−0.00 (0.00)	0.04 *** (0.01)	−0.00 (0.00)
labor	0.00 (0.01)	0.00 (0.00)	−0.02 (0.02)	−0.00 (0.00)
market	0.02 * (0.01)	−0.00 (0.00)	0.03 * (0.02)	0.01 (0.01)
plotsize	−0.09 ** (0.05)	0.00 (0.00)	−0.13 (0.15)	−0.08 (0.04)
distance	−0.00 *** (0.00)	0.00 ** (0.00)	−0.00 *** (0.00)	−0.00 (0.00)

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Numbers in parentheses are standard error. Variable *crop* was omitted from model 4 because of collinearity between *crop* and *fer*.

The BVP and UVP analyses for the CCCS subdataset (model 4 in Tables 6 and 7) showed that the household heads who had (i) a larger quantity of livestock (*livestock*), (ii) a larger farmland area (*farm*), and (iii) the plots that were closer to their houses (*distance*),which tended to apply OFs to their plots. The BVP or UVP analyses for the CCCS subdataset demonstrated no significant determinant for IF use.

The BVP analysis for the pooled dataset with the variable representing the cropping system of the plot (*crop*; model 1 in Table 6) was a blend of those for the FCCS subdataset (model 3) and CCCS subdataset (model 4). The variables *crop*, *farm*, *livestock*, and *market* significantly and positively affected farmers' OF choices, and *plotsize* and *distance* significantly and negatively affected farmers' OF choices. The *distance* significantly and positively affected farmers' IF choices, and the *crop* significantly and negatively affected farmers' IF choices. Variable *crop* significantly influenced both the OF and IF use, i.e., a confounding variable (*crop* is a common cause of both OF and IF use) for the pooled dataset [73].

3.3. Food-Crop-Based Cropping Systems (FCCSs)

The FCCS plots (n = 266) contained two sub-cropping systems (Table 3), (i) continuous maize (sometimes barley) cultivation in *aradas* (n = 218) and *golbas* (n = 44) and (ii) continuous sorghum cultivation in *golbas* (n = 4). Farmers have three soil fertility management options for the FCCS plot: (i) continuous OF application (compost or household wastes) to continuous maize plots (n = 218), (ii) no soil amendment (no OF or IF application) for continuous maize (n = 39) and sorghum (n = 4), and (iii) IF use for maize in *golbas* (n = 5). The no-soil-amendment option was used only when the FCCS plots were in fertile *golbas* (n = 27 for maize and n = 4 for sorghum) or *onas* (n = 12 for maize). For FCCSs, IFs were used only for unfertile *golbas* (only in five maize *golba* plots). Of the 218 continuous maize plots where OFs were applied, household wastes were input to 112 plots (51%), while compost was applied to 106 plots (49%).

The mean size (*plotsize*) and commuting distance (*distance*) of the compost application FCCS plots (continuous maize cultivation plots) were 0.22 ha and 82 m, respectively. Those were significantly lower than the mean values of the sample plots (0.33 ha and 734 m; Table 2) and the FCCS plots with the no-soil-amendment or IF use options (0.51–0.55 ha and 1453–3221 m). This evidence agrees with the BVP and UVP analyses for the FCCS subdataset (model 3 in Tables 6 and 7).

Approximately 87% of the household waste input FCCS continuous maize plots reported no commuting distance. Of those plots, the ones smaller than 0.1 ha in size accounted for 51%, the reality of which is backyard maize plots. Thus, the OF application

FCCS plots were grouped into two categories regarding distance from the compound. The first category corresponds to both backyard maize plots and the *arada* plots ≤ 0.25 ha in size located adjacent to the farmers' houses where household wastes were the main input. These plots have a short distance from the compound and a small enough space so that a housewife can afford to dump household wastes after sweeping the yard of the house.

The second category contained long-term compost application plots, approximately 75% of which were over 10 m from the compound and approximately 75% more than 0.25 ha in size. Farmers prefer applying compost to household wastes when the commuting distance is longer and the plot is larger. There are two options: (i) piling up household waste materials in the corner of their house's yard and making compost, carrying it a few times a year by donkeys, and (ii) repeatedly carrying household wastes once every few to several days. They likely assessed the former option as an advantage in labor productivity.

All the five FCCS plots where IF was used were in unfertile *golbas* and had commuting distances of 1000, 1500, 1825, 5000 and 10,000 m, most of which were greater than the mean commuting distance of the *golba* plots, 1105 m (Table 2). The five household heads of these five *golba* FCCS plots had common attributes of relatively low livestock ownership levels and low family labor force (not significant for both *livestock* and *labor*). Thus, they selected low-weight IFs as a soil fertility management option for long-distance maize plots. This agrees with the BVP and UVP analyses for the FCCS subdataset (model 3 in Tables 6 and 7). All 36 sample *golbas* were located in the mid-altitude dry sub-area, lower than the mid-altitude moist sub-area in altitude and closer to the Welenchiti town. The specificity in the location of the *golbas* is likely to be the cause that variables *zone* and *market*, which showed significant differences between the continuous OF application FCCS *arada* plots and the no-soil-amendment or IF-use FCCS *golba* plots (Table 2).

Of the 218 continuous maize plots where OFs were applied, compost was applied to 106 plots (for the other 112 continuous maize plots, household wastes were input). Of the 106 continuous maize plots, compost was applied every year to 96 plots (91%), while it was applied once every few years to 10 plots (9%). Compost has been applied to these maize FCCS plots for 14 years on average (Table 8).

Table 8. Compost application to the food-crop-based cropping system (FCCS) plots and the cash-crop-based cropping system (CCCS) plots.

	FCCS Compost-Application Plots (*n* = 106)	**CCCS Compost-Application Plots (*n* = 105)**
Frequency of compost application	1.1 ± 0.5	1.3 ± 0.7
Every year	96 (91)	86 (82)
Once every two years or more	10 (9)	19 (18)
Continuous compost application years	14 ± 12	11 ± 10
from whom the sample household heads acquired compost application techniques [a]		
Administration	29 (27)	35 (33)
Relatives	65 (61)	57 (54)
Neighbors	11 (10)	16 (15)
Others	3 (3)	2 (2)
Total compost application area (ha)	0.28 ± 0.25	0.66 ± 0.47
Compost application area in a year (ha)	0.24 ± 0.23	0.40 ± 0.25

The household heads who applied compost were interviewed. Mean ± standard deviation. Numbers are frequencies, and numbers in parentheses are %. [a] Multiple answers were allowed.

3.4. Cash-Crop-Based Cropping Systems (CCCSs)

The CCCS plots (*n* = 258) contained the *masas* where food crops, except maize (sorghum, barley, beans, and peas) and cash crops, were rotationally grown (Table 3). Those food crops are usually cultivated without IF use. In contrast, regardless of the attributes of each household, virtually all sample households used IF for the CCCS plots

whenever they grew cash crops, where compost was also partially applied. Farmers have two soil fertility management options for the CCCS plot: (i) only IF use (n = 153) and (ii) IF and compost application (n = 105).

The mean *plotsize* and *distance* of the compost-application CCCS plots were 0.39 ha and 790 m, while those for the no-compost-application CCCS plots (i.e., only IFs were used) were 0.39 ha and 1321 m (Table 2). No difference in the plot size was observed, whereas the commuting distance of the compost-application CCCS plots was significantly shorter than that of the no-compost-application CCCS plots. This agrees with the BVP and UVP analyses for the CCCS subdataset (model 4 in Tables 6 and 7).

Compost was applied to the CCCS plots held by the 105 sample household heads. These 105 sample household heads held the mean 0.66 ha of compost-application CCCS plot, of which they annually applied compost to the mean 0.40 ha (Table 8). The household heads were not necessarily applying compost every year to these CCCS plots; 37% of the 105 compost-application household heads divided the compost-application CCCS plots into blocks and rotated the application to each block every few years.

The farmers used IFs in the CCCS plots across every distance range (Table 2). IF use in the CCCS plots was not significantly governed by commuting distance. Relatively low-weight IFs are convenient for farmers to carry, even to long-distance fields by donkeys and camels.

For both the FCCS and CCCS plots, the household heads who applied OFs to their plots had significantly more livestock heads than those with no OF application plots (Table 2). The household heads who held larger total farmland area (*farm*) tended to apply compost to their CCCS plots; however, this was not the case for the FCCS plots (Table 2). These agree with the BVP and UVP analyses (models 3 and 4 in Tables 6 and 7).

The highest proportion of the household heads who applied compost to the FCCS and CCCS plots acquired compost application techniques from their relatives (Table 8). Together with the household heads who acquired the techniques from their neighbors, 71% (FCCSs) and 69% (CCCSs) of the compost household heads acquired the techniques through the farmer-to-farmer (or farmer-led) transfer method. Meanwhile, 27% (FCCSs) and 33% (CCCSs) of the household heads replied either "acquired it by fast compost training" or "I knew it previously, but the training facilitated its use." The household heads who received compost training (*training*) from the district agricultural office tended to prepare and apply compost to their CCCS plots (Table 2). However, neither the BVP nor the UVP analyses reflected these effects (Tables 6 and 7).

4. Discussion

4.1. Determinants of the Soil Fertility Management Options

In this study, commuting distance (*distance*) to the plot significantly affected the farmers' decision on soil fertility management, except for IF use in the CCCS plot. Not many previous studies used the biophysical features of the sample plots for independent variables, such as commuting distance (*distance*) and plot size (*plotsize*). Among those employed variables, *distance* and the relationship between *distance* and soil fertility management practices appears to be environment-specific (Table 1). In this study, farmers tended to use OFs for the plots closer to the housing compounds for both the FCCS and CCCS. This agreed with Benin, 2006 [23], Pender and Gebremedhin, 2006 [24], Ketema and Bauer, 2011 [25], Ahmed, 2015, 2017 [29,32], the cases for Malawi and Ethiopia in Kassie et al., 2015 [31], and Hassen, 2015 [30]; however, this disagreed with Kassie et al., 2009 [27], Teklewold et al., 2013 [28], and the cases for Kenya and Tanzania in Kassie et al., 2015 [31]. Of these studies, Pender and Gebremedhin, 2006 [24], Ketema and Bauer, 2011 [25], and Hassen, 2015 [30] discussed the econometric analysis. All of them noted the labor costs required to carry bulky OFs (manure or compost), which agree with this study.

In contrast, the impacts of commuting distance on IF use differed between the FCCS and CCCS in this study. Farmers use IFs only for the FCCS plots in unfertile *golbas*, far from their compounds. Conversely, farmers use IFs for all the CCCS plots regardless of the commuting distances. Of the ten studies in Table 1, Kassie et al., 2009 [27] and the

cases for Ethiopia and Tanzania in Kassie et al., 2015 [31] found that the farmers used IFs for the plot, distant from the compound significantly, whereas Benin, 2006 [23], Pender and Gebremedhin, 2006 [24], Teklewold et al., 2013 [28], and Ahmed, 2015 [29] found that the farmers used IFs for the plot closer to the compound significantly. Of these studies, Kassie et al., 2009 [27] discussed whether plots close to the homestead could be relatively fertile compared to distant plots because homestead plots may benefit from the addition of household wastes and other soil-fertility-enhancing materials (e.g., ash). In contrast, Pender and Gebremedhin, 2006 [24] and Ahmed, 2015 [29] discussed whether farmers are more likely to use IFs on plots closer to their residence, probably because more intensive land management is used on plots closer to the residence. In this study, plot size (*plotsize*) impacts on farmers' decision making were ambiguous for both the OF and IF use. Among the previous studies that used variable *plotsize*, Ketema and Bauer, 2011 [25] and the case for Tanzania in Kassie et al., 2015 [31] found that farmers significantly applied OFs to the larger plots in size. In contrast, the cases for Kenya and Ethiopia in Kassie et al., 2015 [31] found that farmers significantly applied OFs to the smaller plots (Table 1).

Thus, the relationships between the biophysical features of the sample plots, such as commuting distance and plot size, and soil fertility management practices are generally environment-specific. It can be better for the quantitative analysis to be supported by qualitative evidence to suggest policy implications and compare the research findings conducted in different environments.

The livestock ownership level (*livestock*) significantly positively affected the farmers' decision on OF application to the FCCS and CCCS plots, which agreed with all previous studies in Table 1. Many previous studies suggested that farmers' wealth levels indicated by the variables, such as total farmland holding (*farm*), livestock ownership level (*livestock*), and the total value of assets (*asset*), positively influenced OF and IF use (Table 1). This was generally in line with the BVP and UVP analyses with minor exceptions, especially fitting in the combined use of compost and IFs on the CCCS plots. This suggests that, first, the biophysical features of the fields have narrowed down the feasible soil fertility management options in the plot to one or two. Then, individual farmers' socioeconomic conditions, including cash liquidity and various resource constraints, represented by *farm* and *livestock*, govern specific soil fertility management practices in the plot, such as combinations of OFs and IFs, varieties of OFs (compost or household wastes) and IFs (DAP and/or urea), the intensity of OF and/or IF use, application frequency, etc.

The impact of public support on soil fertility management practices (e.g., *credit*, *extension* in Table 1) was generally positive. In the study area, approximately one-third of compost-application farmers of CCCS plots acquired the technique from administrative training (Table 8). This could help more farmers practice combining compost and IFs on their CCCS plots. Compost training provided by the district agricultural office effectively encouraged integrated soil fertility management practices, mainly on CCCS plots.

4.2. Reciprocal Relationship between Organic and Inorganic Fertilizers Use

In the study area, IF use in the FCCS plot was rare and was limited only to a special case (only when the plot in *golbas* had lost its soil fertility). Thus, it can be natural to consider that the household heads' decisions on OF and/or IF use in the FCCS plots are mutually independent and consistent with the BVP analysis.

Any factors did not significantly govern IF use in the CCCS plots ($p < 0.05$). This agreed with the field observations that virtually all the farmers used IFs to grow cash crops in all the *masas*, where compost was also partially applied. No "only IF-application" option was observed for the CCCS. In these circumstances, compost application to the CCCS plots can be considered a supplementary means to boost soil fertility. Compost is not a rival type of IFs, consistent with the BVP analysis (signs of ρ were positive for model 4), although the hypothesis of independence was proved. Thus, farmers' soil fertility management practices for the CCCS plots in the study area appear to be an example of the integrated soil fertility management, which agronomists have recommended.

This study implemented two approaches to reflect the structure of a local farming system in modeling: a data segmentation approach and a dummy variable method. The four goodness-of-fit tests for the four BVP models showed that the models with a data segmentation approach (models 3 and 4) were best-fits, followed by those with a dummy variable method (model 1). Model 1 proved that the variable *crop* was a confounding variable affecting the adoption of OFs and IFs simultaneously. Model 2 (the conventional model) that omitted *crop* did not differ much in model estimation (i.e., signs and significant levels of coefficients) from model 1; however, it showed an incorrect correlation between OF and IF use (i.e., ρ). The model that omits a confounding variable causes an omitted variable bias, and a causal relationship cannot be correctly inferred [73]. Thus, the efforts to reflect the structure of the local farming system in modeling are essential to analyze farmers' determinants of soil fertility management choices in the study area.

As discussed in the Introduction, many environmental factors determine the reciprocal relationships between OF and IF use. This study employed only a single variable representing the structure of a local farming system. However, examining the reciprocal relationships between the two soil fertility options can be refined by introducing additional relevant biophysical variables in the econometric process. For instance, this study did not rigorously analyze the implications of spatial differences in OF application history, the nature of the soil that affects water-holding capacity, etc., on our understanding of the complementarity/substitutability question. Those are the limitations of this study.

5. Conclusions

In cereal-based farming systems in SSA, mixed food-crop and cash-crop economies prevail. Many researchers suggested that farmers prioritize their scarce nutrient resource (OFs and IFs) use in their hot-spot fields, e.g., infields and/or cash-crop fields. Narrative inquiry interviews found that the infield-outfield system and within-farm soil fertility gradients were typically observed in the study area. Within-farm soil fertility gradients are also favorable for crop nutrient requirements in the study area: high-nutrient-requiring food crop (maize) grown in the infields (*aradas*) and low-nutrient-requiring cash crops (tef and haricot beans) grown in the outfields (*masas*). Previous studies found that farmers in the study area perceived the yield advantage of OF use for maize (food crop) and IF use for tef (cash crop).

The cluster analysis showed that the plot data could be categorized into clusters representing the FCCS and CCCS. The BVP analyses found that farmers' decision-making processes between the FCCS and CCCS subdatasets differed, and it was better to analyze the two subdatasets separately using two UVP models. The model comparison showed that the model with the data segmentation approach fitted best to the dataset, followed by the model with a dummy variable, *crop* (the plot belongs to FCCS or CCCS). These models commonly showed that the farmers' determinants of OF and IF use were independent. In contrast, the BVP model that did not consider the structure of the farming system (a conventional model; the pooled dataset without *crop*) led to a wrong conclusion on the reciprocal relationship between OF and IF use. The conventional BVP model may have caused an omitted variable bias in this study.

In the northern semi-arid Ethiopian Rift Valley, farmers' decisions on soil fertility management practices in a plot are primarily governed by the biophysical features of the fields, such as commuting distance (*distance*), mid-altitude dry or mid-altitude moist sub-areas (*zone*), and distance from the market (*market*). They determine the cropping system there (*crop*), and feasible soil fertility management options in the plot are narrowed down to one or two. More specific decision on the soil management practices, especially in the CCCS plot, depends on individual farmers' socioeconomic endowments, such as total farmland holdings (*farm*) and livestock ownership level (*livestock*). Compost training provided by the administration helps disseminate compost preparation and application techniques, encouraging integrated soil fertility management in the area.

An adoption study of innovative technologies with a mixed approach has some advantages, such as quantitative analyses being able to be supported by qualitative evidence and the research findings conducted in different environments being able to be compared, which, therefore, provides more policy implications.

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