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Evidence from Rural Households in the Amhara Region of Ethiopia

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Abstract

Soil nutrient depletion is a critical problem, contributing to low agricultural productivity and the limited domestic food supply in sub-Saharan Africa. Fertilizer use in Ethiopia is one of the lowest in sub-Saharan Africa. Particularly in the northern half of the Ethiopian highlands, use of dung as manure is also limited partly because of a significant level of dung consumption as a source of household fuel. Use of dung as fuel is also an important cause of health problems, mainly through indoor air pollution. Plantation interventions are carried out based on the expectation that fuelwood could substitute for dung, thus increasing agricultural productivity. This study examined (1) the determinants of rural households' decision to use dung as fuel and as manure, and (2) the determinants of consumption of woody biomass and dung as household fuel sources. We found that the decision to use dung as fuel and manure was influenced by household assets (such as livestock and land size), as well as household characteristics (such as family size and age-sex composition of members), suggesting the important role of asset, product, and labor market imperfections. The type of stove and distance to towns also influenced fuel use. We found no evidence that woody biomass and dung were substitutes as household fuel, and in fact there were indications that they are complements. These results suggest the need to focus on asset-poor households to address the limited use of manure. Moreover, energy issues should be considered simultaneously. Encouraging the use of more appropriate (or energy efficient) stoves and other sources of energy that can reduce the use of dung as fuel are important options because they can improve energy efficiency and agricultural productivity, as well as improved health from reduced indoor air pollution.

Key Words: Biomass fuel, dung use, manure, Ethiopia

JEL Classification Numbers: Q12, Q42, Q56

Contents

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1. Introduction

Countries in the low-income tropics face the challenge of increasing their food supply to fulfill demand. Overcoming this will be difficult because they have low agricultural yields associated with widespread failure to make investments that are sufficient to sustain the quality of farmland (Marenya and Barrett 2007). Soil nutrient depletion is a common problem in many parts of sub-Saharan Africa. In 37 sub-Saharan African countries, annual losses of nitrogen, phosphorus, and potassium have been estimated to be 4.4 million tons, 0.5 million tons, and 3 million tons respectively. These losses overwhelm the annual additions from fertilizer[1] applications (at rates of 0.8 million tons of nitrogen, 0.26 million tons of phosphorus, and 0.2 million tons of potassium, respectively). The countries with the highest levels of nutrient depletion are in eastern and southern Africa (Sanchez et al. 1997, cited in Waithaka et al. 2007).

Ethiopia has one of the lowest rates of fertilizer use (even within eastern and southern Africa), and a significant quantity of dung is also used by households as an important source of domestic fuel instead of manure, particularly in the northern half of the country's highlands. Virtually all household cooking fuel used in rural Ethiopia, where about 85 percent of the population lives, comes from solid fuels. Rural Ethiopian households have been dependent for centuries on two main solid fuels—woody biomass and dung. While kerosene (used for lighting), diesel, electricity, and liquefied petroleum gas are possible alternative energy sources, they are

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[1] The word 'fertilizer' in this paper refers to chemical or inorganic fertilizer.

hardly used at all in these rural areas for various reasons, but primarily prohibitively high prices and lack of access or availability. This pattern of biomass fuel use will continue for the near future, since there is no reason to believe that adequate availability of non-solid (cooking) fuels (which are affordable) will be expanded to rural areas any time soon.

Use of woody biomass and dung as energy sources has contributed to forest degradation, deforestation, and land degradation—all severe environmental problems in Ethiopia. In particular, burning dung as a fuel or heat source makes it unavailable as manure to increase agricultural productivity. Studies in Ethiopia have shown that dung as an energy source is the major contributor to reduced agricultural productivity from land degradation (Bojö and Cassells 1995). While manure is an important substitute when fertilizer is unobtainable, recent experiments in Ethiopia have also shown that using manure with fertilizer is optimal—which suggests a continuing need for manure (Erkossa and Teklewold 2007). Use of biomass fuels, including dung, also substantially contributes to health problems from indoor air pollution (Bruce et al. 2000; Ezzati and Kammen 2001).

A possible solution to the problem of limited use of dung as manure is to encourage households to substitute other fuels and use more efficient cooking stoves, so that dung can be used for manure. In Ethiopia, at least in the near future, these measures are likely to increase demand for woody biomass. On the supply side, this will require examining alternative energy sources, such as woody biomass, and particularly their supply.

This study focused on the demand side. In a country where there are imperfect markets and much risk, attempts to encourage dung use more as manure and less as fuel require knowledge of the determinants of these alternative uses of dung. Particularly in the northern half of the Ethiopian highlands, a significant quantity of dung is used by rural households as fuel and/or as manure with variations across households. Some households use it both as fuel and as manure, some only use it for one or the other, and still others do not use it for either fuel or manure.

In Ethiopia, it is not obvious from the literature whether dung and wood are substitutes for household energy sources. Some studies have suggested a need for different alternative fuels so that households can use more dung as manure (Erkossa and Teklewold 2007), and this has been one important justification for major afforestation programs in the country (Newcombe 1989). However, while such studies and actual interventions implicitly or explicitly assume that dung and fuelwood are substitutes, other studies have argued that cooking habits and related cultural practices indicate the need to use both wood and dung at the same time, suggesting a complementarity between the two fuel types. Previous studies have addressed some of these issues using cross-section data. Mekonnen (1999) found, for example, that dung and fuelwood may be complements in domestic energy consumption.

Our study used panel data collected over the years 2000, 2002, and 2005 to look at these issues and focused on two objectives. The first was to analyze the factors that determined farmers' adoption of dung as fuel and as manure. While addressing this objective, we attempted to focus on the issue of substitution or complementarity between use of wood as fuel, use of improved stoves and tree growing (on one hand), and use of dung as fuel and as manure (on the other). The second objective was to examine whether or not woody biomass and dung were substitutes as energy sources. To our knowledge, no study thus far has looked into the determinants of dung use as both fuel and manure using one data set. The focus of technology adoption studies on cross-section data has been identified as a problem by a recent survey of such studies (Doss 2006), and the use of panel data in this study is therefore another contribution to the literature. Our results suggested that household assets and household characteristics could be significant variables affecting the decision to use dung as fuel and/or manure, which in turn suggested the importance of market imperfections. We also found that woody biomass and dung are not substitutes and may even be complements—a result which points to the need to consider energy issues, such as alternative fuels and efficient cooking stoves, in attempts to encourage dung use as manure. This also implies that afforestation programs cannot be expected to solve the productivity problems in Ethiopian agriculture.

The next section presents the conceptual framework and empirical models used in this study. Section 3 presents the data, results, and discussions, while section 4 concludes.

2. Conceptual Framework and Empirical Models

The conceptual framework and empirical models used for the analyses of adoption of dung as fuel and manure, and determinants of biomass fuel consumption are presented below in that order.

2.1 Adoption of Dung as Fuel and Manure

Our conceptual framework to analyze the determinants of the decision to use dung as fuel and as manure was the one used in adoption studies (Feder et al. 1985; Doss 2006; Marenya and Barrett 2007). We used random utility theory to explain adoption in terms of a linear utility function which depended on a set of explanatory variables and a random component. In the absence of data on the net benefits of adoption of dung as fuel and as manure, we chose the interpretation that a household uses dung as fuel or as manure when the net benefit of doing so is greater than other alternatives. Since adoption of dung as fuel and as manure could be correlated within a household, we allowed for the possibility of correlation between the two practices. Thus, we used bivariate probit to allow for correlation between the errors between the two practices.

We also analyzed the determinants of household choice using a multinomial logit model, where the analysis is done for four groups: households that use dung only as fuel, those that use it only as manure, those that use it both as fuel and manure, and those that use it neither as fuel nor manure.

Following the literature, we used various explanatory variables, such as household labor-availability indicators in the presence of market imperfections; household assets/economic status indicators, such as being a lender, land size, number of trees farmed, and livestock owned (livestock also indicated the supply or availability of dung for the household—an important factor because dung is not typically traded, particularly in the rural areas); indicators of land tenure security; and market access. Location and time variables were also included to take into account the effects of temporal and spatial variation.

2.2 Biomass Fuel Consumption

For the analysis of fuel consumption, the fact that rural households in Ethiopia in general, and in our study areas in particular, consume and collect or produce dung and woody biomass necessitated the use of a non-separable household model. Such models have been developed and used in previous research (Amacher et al. 1993, 1996; Angelsen 1999; Cooke 1998; Köhlin 1998; Mekonnen 1999). The basic model used is one where utility is maximized with income, time, and household production functions as constraints. A major implication of such non-separable models is that since households both collect and consume fuels, market prices of these fuels either do not exist or they are not relevant for these households. The decision of the household is based on the relative scarcity of labor to collect these fuels; hence the prices of these fuels, which would be shadow prices, are household specific.

For the analysis of fuel consumption, we estimated fuel demand and consumption functions, where we explained quantities of woody biomass and dung consumed in terms of their determinants, including shadow prices of woody biomass and dung; availability of and shadow price of labor for collection; household size; and household assets, including trees and livestock, which may directly influence availability and also demand in this context. Following the literature, we also attempted to address the issue of endogeneity of shadow prices using instrumental variables.[2] The analysis was done only for those households that consumed a fuel type and the possible sample section bias this may introduce was addressed by using Heckman's two-step estimation procedure. Standard errors are bootstrapped.

3. Data Source, Results, and Discussion

In this section, we start by presenting the data source and descriptive statistics on the variables used for the study. This is followed by a presentation and discussion of regression results for adoption of dung as fuel and manure and the determinants of biomass fuel consumption in that order.

3.1 Data Source and Descriptive Statistics

We used panel data collected in the years 2000, 2002, and 2005 from a sample of rural households in the East Gojam and South Wollo zones of the Amhara region of Ethiopia. This data is part of a longitudinal survey conducted through a collaborative research project of the economics departments at Addis Ababa University and the University of Gothenburg and financed by Sida/SAREC. A total of 1520 households from 12 sites were interviewed in each of the three rounds. The selection of the 12 sites was deliberate to ensure variation in the characteristics of the sites, including agro-ecology and vegetative cover. Households from each site were then selected randomly.

3.2 Descriptive Statistics

Table 1 presents the descriptive statistics of the variables used in this paper for each of the survey years 2000, 2002, and 2005. The first seven variables are dependent variables used in the empirical analysis reported in this paper. The proportion of households that used dung as manure or as fuel (but not both) declined from 43 percent in the year 2000, to 37 percent in 2002, and then to 28 percent in 2005. On the other hand, the proportion of households that used dung

[2] The literature on non-separable household models in this context suggested the use of shadow prices, which are household specific (see, e.g., Cooke 1998; and Mekonnen 1999 for some details). Following the literature, the shadow price of labor was estimated as the marginal product of labor in fuel collection, while the shadow price of wood and dung was estimated as the marginal product of labor in the collection of the fuel type multiplied by the time spent to collect a unit of the fuel. We used time spent to collect a unit of a fuel type as identifying variables.

both as manure and fuel increased from 50 percent in 2000, to 56 percent in 2002, and then to 67 percent in 2005. Since the proportion of households using manure increased from 52 percent in 2000, to 59 percent in 2002, and then to 74 percent in 2005, while the proportion of those using dung as fuel declined only slightly from 91 percent in 2000 to 89 percent in 2005, this suggested that more and more households were using dung as manure over the survey periods in addition to using it as a fuel source.

The average quantity of dung used as manure by a household increased substantially in 2005 (769 kilograms—kgs), compared with 2000 (625 kgs) and 2002 (613 kgs). The average quantity of dung used as fuel declined from 1307 kgs in 2000 to 1157 kgs in 2005. This indicated that during the survey period more dung was used as manure and less as fuel over time. We also noted from table 1 that the quantity of wood consumed as fuel fluctuated between 2004 kgs (in 2002) and 2143 kgs (in 2005).

The rest of the variables in table 1 are mainly used as independent variables in the analyses. We saw in table 1 that those variables that increased consistently over the three survey years (between the years 2000 and 2005) included livestock owned (from 2.65 to 3.42 tropical livestock units—TLU), maximum education of a member of the household (from 3.07 years to 4.68 years), family size (from 5.03 to 5.35), and age of the head (from 46.43 to 50.39 years, as would generally be expected). We also noted a consistent decline in the number of trees grown (from 189 to 150) and in land size (from 1.11 to 1.01 hectares).

3.3 Determinants of the Decision to Use Dung as Fuel and/or as Manure

Estimation results of the bivariate probit model are presented in table 2 with the model diagnostics presented toward the end of the table. Robust standard errors were used. As can be seen in table 2, rho is statistically significant, suggesting the appropriateness of using the bivariate probit model. We found that the number of livestock owned (measured in TLU) statistically significantly increased the probability that a household used dung as fuel and also as manure, with the magnitude being slightly higher for the former. This was generally to be expected because livestock is the source of dung and manure and households will tend to rely more on dung and manure from their own livestock—although there is a practice of collecting dung from non-private sources.

Table 1 Descriptive Statistics

	Year 2000 (N=1329)			Year 2002 (N=1394)			Year 2005 (N=1309)		
Variable label	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Uses dung as manure or as fuel (yes=1, else=0)	0.43	0	1.00	0.37	0	1.00	0.28	0	1.00
Uses dung both as manure and fuel (yes=1, else=0)	0.50	0	1.00	0.56	0	1.00	0.67	0	1.00
Uses manure (yes=1, else=0)	0.52	0	1.00	0.59	0	1.00	0.74	0	1.00
Uses dung as fuel (yes=1, else 0)	0.91	0	1.00	0.90	0	1.00	0.89	0	1.00
Manure in kilograms (kg)	625.04	0	20535.86	612.83	0	28186.48	768.77	0	30000.00
Manure in kg per hectare	683.93	0	38792.43	768.79	0	20998.39	921.71	0	26440.21
Wood consumed as fuel (kg/yr)	2112.64	0	13635.34	2004.16	0	14850.00	2143.23	0	14949.48
Dung consumed as fuel (kg/yr)	1307.47	0	14665.00	1227.21	0	13800.00	1156.90	0	13546.64
Quantity of dung collected (kg/yr)	3146.12	0	43200.00	2574.30	0	47520.00	2588.10	0	46980.16
Quantity of wood collected (kg/yr)	4236.68	0	47245.26	3643.48	0	49680.00	4528.56	0	48510.06
Hours spent to collect wood per year	498.03	0	36500.00	340.97	0	10800.00	605.06	0	30102.50
Hours spent to collect dung per year	363.40	0	10271.43	262.79	0	10800.00	445.75	0	33480.00
Hours spent to collect a kg of wood	0.14	0	6.00	0.10	0	4.08	0.18	0	16.00
Hours spent to collect a kg of dung	0.18	0	14.86	0.12	0	1.63	0.23	0	15.59
Livestock owned (in TLU)	2.65	0	26.30	2.89	0	32.50	3.42	0	22.71
Uses chemical fertilizer (yes=1, else 0)	0.55	0	1.00	0.44	0	1.00	0.44	0	1.00
Expenditure on fertilizer	115.73	0	1369.30	90.29	0	1140.00	168.71	0	2621.00
Lent at least 50 ETB in last two years	0.04	0	1.00	0.04	0	1.00	0.08	0	1.00
Number of trees	189.29	0	3000.00	176.85	0	3000.00	149.84	0	3000.00

	Year 2000 (N=1329)			Year 2002 (N=1394)			Year 2005 (N=1309)		
Variable label	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Land size in hectares	1.11	0	10.50	1.10	0	8.80	1.01	0	8.75
Expected land size next five years (1 if decrease)	0.24	0	1.00	0.28	0	1.00	0.20	0	1.00
Sex of head (1 if male)	0.86	0	1.00	0.86	0	1.00	0.83	0	1.00
Age of head (in years)	46.43	17	100.00	48.15	15	102.00	50.39	13	100.00
Max. education of a member (in years)	3.07	0	12.00	3.63	0	15.00	4.68	0	19.00
Percentage of boys (5-14 years)	0.13	0	0.67	0.13	0	0.67	0.14	0	0.67
Percentage of girls (5-14 years)	0.11	0	0.67	0.12	0	0.67	0.13	0	0.75
Percentage of men (>14 years)	0.30	0	1.00	0.30	0	1.00	0.30	0	1.00
Percentage of women (>14 years)	0.30	0	1.00	0.31	0	1.00	0.31	0	1.00
Family size	5.03	1	16.00	5.07	1	13.00	5.35	1	14.00
Type of stove (1 if three stones)	0.84	0	1.00	0.73	0	1.00	0.81	0	1.00
Distance to town (in minutes)	59.07	0	240.00	61.02	0	240.00	62.46	0	240.00

TLU = tropical livestock units

ETB = Ethiopian birr; US$ 1 = ETB 8.5

We also found that households that consume more wood as fuel had a statistically significant and higher probability of using dung as fuel. This suggests some complementarity between use of dung as fuel and wood as fuel. The positive association of dung use as fuel with quantity of wood used as fuel could be related to the cultural practice of using the two fuel types together (discussed below).

Land size increased the likelihood of dung being used both as fuel and as manure. The positive and significant effect of land size on the decision to use dung as fuel might be due to the increased quantity of dung available when more grazing land for livestock was owned by the household. The results also suggested that households with more trees were more likely to use dung as manure, but there could be other interpretations of this. One possibility is that tree plantation was a household supply response to the demand for fuelwood, thus increasing the probability of also using dung as manure. Another possibility is that the number of trees might be interpreted as an indicator of economic status which would be positively correlated to manure application. It is also possible that manure was applied to the trees, suggesting complementarity between tree plantation and manure application (and thus also possible endogeneity).

Household characteristics were also associated with dung use as fuel and as manure. Households with male heads were more likely to use dung as fuel, while those with older heads were less likely to use dung as fuel. The result associated with the gender of the household head came perhaps from a greater fuel demand, particularly for heating in the presence of a male head. The negative association for older heads might be greater difficulty for older heads to collect dung. Households with a larger family size were more likely to use dung as fuel than as manure. (The estimates for dung as fuel were much less precise, making it statistically insignificant.) In the presence of labor market imperfections, this could be interpreted as the result when more labor is available to the household to apply manure, which is labor intensive. However, we also found that households with a higher percentage of men were less likely to use dung as fuel, while households with a higher percentage of women were less likely to use dung as manure. (Both were statistically significant.) This was perhaps because women more typically collect dung for fuel, while the result for dung use as manure could be because households with a higher percentage of women tend to be less involved in those agricultural activities that require applications of manure.

Households where the primary stove is the traditional three stones are more likely to use dung as fuel, indicating the energy inefficiency associated with such stove types. A cultural adaptation to fuelwood scarcity combined with three-stone stoves is that the wood is burned with dung, which makes it possible to cook longer with the same quantity.

Households that lived farther away from towns were more likely to use dung as manure. This was perhaps because there was a lower opportunity cost of dung when far away from the main market for dung. However, we should point out that the same variable had a positive but not statistically significant association with dung use as fuel.

Table 2 Bivariate Probit Estimates of the Decision to Use Dung as Fuel and as Manure

Variables	(1) Used dung as fuel (1=yes, 0=no)	(2) Used dung as manure (1=yes, 0=no)	Variables	(1) Used dung as fuel (1=yes, 0=no)	(2) Used dung as manure (1=yes, 0=no)
Livestock owned (ln TLU)	0.135 (5.59)***	0.104 (5.61)***	Percentage of boys (5–14 years)	0.314 (1.13)	0.229 (1.14)
Wood consumed as fuel (kg/year)	0.000 (2.09)**		Percentage of girls (5–14 years)	0.427 (1.49)	-0.027 (0.13)
Lent at least ETB 50 in last 2 years	-0.139 (0.92)	0.150 (1.28)	Percentage of men (> 14 years)	-0.674 (2.79)***	-0.176 (0.96)
Number of trees	0.000 (1.47)	0.000 (2.36)**	Percentage of women (>14 years)	0.211 (0.77)	-0.566 (2.80)***
Land size (in hectares)	0.156 (2.18)**	0.064 (1.82)*	Family size	0.024 (1.07)	0.062 (4.24)***
Sex of household head (1 if male)	0.183 (2.08)**	0.078 (1.11)	Expenditure on fertilizer		0.000 (0.50)
Age of household head (in years)	0.004 (2.02)**	-0.000 (0.32)	Expected land size next 5 years (1 if decrease)		0.015 (0.29)
Max. education of a household member	0.025 (2.59)***	0.008 (1.09)	Constant	0.485 (2.10)**	-0.590 (3.53)***
Observations	4032		Wald Chi2(74)	912***	
Rho	0.25***				

Robust z-statistics are in parentheses.
TLU = tropical livestock units. ETB = Ethiopian birr; US$ 1 = ETB 8.5
significant at 10%; ** significant at 5%; *** significant at 1%
Time-varying location dummies included, but not reported.

The probability of using dung as manure was not significantly associated with expenditure on fertilizer. This suggested that households were perhaps not systematically combining manure with fertilizer. Similarly, we did not find any statistically significant association between the expected land size of the household over the next five years (which we used as an indicator of tenure insecurity) and the probability of dung use as manure.

Although not reported, significant variation in the estimates was obtained across location and time by including time-varying location dummies. This suggested the importance of other site- and time-specific factors not included in the regression.

Multinomial logit estimates of the decision to use dung as manure and as fuel are presented in table 3. We used the following four groups of households for the multinomial logit analysis: households that used dung only as fuel; those that used it only as manure; those that used it as both fuel and manure; and those that used it as neither fuel nor manure. The group that used dung both as fuel and manure was the base category. Thus, the first column shows results for those households that used dung only as fuel; the second column, those households that used dung only as manure; and the third, for those that used dung neither as fuel nor manure.

Table 3 Multinomial Logit Estimates of Decision to Use Dung as Manure and Fuel

Variables	Dung used only as fuel	Dung used only as manure	Dung used as neither fuel nor manure
Livestock owned (in TLU)	-0.167 (6.22)***	-0.127 (2.21)**	-0.670 (7.39)***
Wood consumed as fuel (kg/year)	-0.000 (5.08)***	-0.000 (1.20)	-0.000 (3.21)***
Expenditure on fertilizer	-0.000 (0.06)	-0.001 (1.35)	-0.002 (1.52)
Lent at least ETB 50 in last 2 years	-0.400 (1.82)*	-0.145 (0.37)	0.307 (0.69)
Number of trees	-0.000 (2.02)**	-0.000 (0.50)	-0.001 (1.58)
Land size (in hectares)	-0.067 (1.19)	-0.353 (2.49)**	0.168 (0.75)
Expected land size in 5 years (1 if decrease)	-0.009 (0.10)	-0.083 (0.36)	-0.272 (1.33)
Sex of household head (1 if male)	-0.038 (0.30)	-0.271 (1.05)	-0.243 (1.10)
Age of household head (in years)	-0.002 (0.60)	-0.004 (0.64)	0.013 (2.82)***

Variables	Dung used only as fuel	Dung used only as manure	Dung used as neither fuel nor manure
Max. education of a household member (in years)	-0.031 (2.44)**	-0.013 (0.44)	0.081 (3.58)***
Percentage of boys (5-14 years)	-0.177 (0.33)	0.071 (0.08)	-0.896 (1.38)
Percentage of girls (5-14 years)	0.287 (0.80)	-0.351 (0.39)	-0.884 (.127)
Percentage of men (>14 years)	0.342 (1.05)	1.891 (2.55)**	1.132 (1.94)*
Percentage of women (>14 years)	1.332 (3.74)***	0.234 (0.24)	-0.058 (0.09)
Family size	-0.066 (2.56)**	0.060 (1.07)	-0.192 (2.85)***
Type of stove (1 if three stones)	0.013 (0.12)	-0.552 (2.62)***	-0816 (4.93)***
Distance to town (in minutes walking)	-0.005 (4.28)***	-0.002 (0.81)	-0.005 (2.12)**
Constant	0.748 (2.43)**	-1.701 (2.32)**	0.928 (1.62)
Observations	4032	4032	4032
Wald Chi2(117)		109869***	

Robust z-statistics are in parentheses.

significant at 10%; ** significant at 5%; *** significant at 1%

Time-varying dummies included, but not reported. The base outcome with which the results in the table were compared was households that used dung both as fuel and as manure.

The results showed that households with more livestock were less likely to be in any of the three groups and hence were more likely to use dung both as fuel and as manure. This was expected, since, in the absence of a (perfect) market for dung, those households with more livestock were more likely to have more dung and more likely to use it both as fuel and manure. We also noted from the magnitude of the coefficients that those that had more livestock were more unlikely to be in the group that did not use dung as fuel or manure, compared to those that used dung for just one of the two uses.

Households that consumed a greater amount of wood as fuel were more likely to be in the group that used dung both as fuel and as manure, compared to those that used dung only as fuel and those that used dung neither as fuel nor as manure. When the results for columns 1 and 3 were combined, it suggested that households that used more wood as fuel were more likely to use dung as well, suggesting complementarity between wood as fuel and dung as fuel.

Households that were lenders were less likely to be in the group that used dung only as fuel, compared to those that used dung both as fuel and manure. We used being a lender as an indicator of economic status of the household, which suggested that households that used dung only as fuel were poorer than those that used it both as fuel and manure.

Households with more trees were more likely to combine dung use as fuel and manure, compared with those who used dung only as fuel—perhaps suggesting that wealthier households were in the former group. Similar conclusions could apply to households that used dung neither as fuel nor manure, but the estimates were much less precise.

The estimates for land size in the groups that used dung only were negative, although they were much less precise for those that used dung only as fuel, and significant for user of dung as manure only. This suggested that households with more land were more likely to combine the use of dung as fuel and manure—perhaps their dung was better quality if they had better access to grazing land for their livestock. The estimates for our indicator of land tenure insecurity were, however, insignificant in this case as well.

Households with older heads were more likely to be in the group that used dung neither as fuel nor manure, perhaps suggesting the importance of the labor needed to collect dung for fuel and to apply it as manure. Households that had more educated members were more likely to be in the group that used dung neither as fuel nor as manure, but less likely to be in the group that used dung only as fuel, compared to those that used dung both as fuel and manure. This result suggested the importance of the opportunity cost of time for such households, compared to those households with fewer educated members. Moreover, the results for dung use only as fuel suggested the importance of awareness through better education about the negative health effects of dung as fuel.

Households with more members were more likely to combine the two uses of dung, compared to those that used dung only as fuel or those who used it neither as fuel nor manure, suggesting the role of labor availability for such activities. Households with a larger percentage of men were less likely to use dung both as fuel and as manure and more likely to be in one of the three other groups, although the results for those who used dung only as fuel were less precise. On the other hand, households with a larger percentage of women were more likely to use dung only as fuel, suggesting the important role of women in dung collection and use as fuel.

Households that mainly used three-stone stoves were less likely to be in the group that used dung only as manure or the group that did not use dung for fuel or manure. This suggested that, at least indirectly, such households were more likely to use dung only as fuel, which might be expected, given the fuel inefficiency associated with three-stone stoves. Households that lived further away from towns were more likely to use dung both as fuel and manure, compared to those that used it only as fuel or those that did not use it for either. This suggested a lower opportunity cost of dung for households located further away from towns, as the possibility (and hence, probability) of selling it to urban households was much less for such households.

As was the case for bivariate probit estimation results reported above, significant variation in the estimates was obtained across location and time through the time-varying location dummies included (but not reported), suggesting the importance of other factors not included in the regression that are site and time specific.

3.4 Determinants of Biomass Fuel Consumption

Estimates of the determinants of biomass fuel consumption are presented in tables 4 and 5. Table 4 reports the results for dung and table 5 for wood. In both tables 4 and 5, we reported random effects estimates because most of the coefficients were not significant in the fixed effects estimates, perhaps because of limited variation in the variables across rounds (Wooldridge 2002).

In both tables 4 and 5, the first column reports results when the shadow prices were not instrumented, while the second column shows instrumented shadow prices. As noted above, we used an inverse Mill's ratio to capture possible sample selection bias that could result from exclusion of households that did not use the particular fuel type considered. Our main variable of interest in this paper was the cross-price elasticity. We noted from both tables 4 and 5 that the cross-price elasticities were negative when we did not use instruments, suggesting that dung and wood are complements. However, when we used instruments, these cross-price effects became insignificant, perhaps reflecting the lack of good instruments.

We also noted from the results that household assets and family size were important determinants for biomass fuel consumption. Availability of labor from different age and gender groups were also important determinants of woody biomass consumption. For both dung and woody biomass consumption, we also found that households that used three-stone fires consumed more fuel—an expected result, given the inefficiency of such stoves.

Table 4 Estimates of Determinants of Level of Dung Consumption as Fuel

Variables	Random effects1	Random effects2	Variables	Random effects1	Random effects2
Log(shadow price of wood)	-0.065 (2.26)**	0.074 (1.20)	Family size	0.056 (4.48)***	0.053 (4.43)***
Log(shadow price of dung)	-0.200 (7.59)***	-0.062 (1.51)	Livestock owned (in TLU)	0.035 (4.60)***	0.041 (4.59)***
Log(shadow wage for wood collection)	-0.084 (3.16)***	-0.067 (0.74)	Land size (in hectares)	0.095 (3.43)***	0.133 (4.23)***
Log(shadow price for dung collection)	-0.112 (4.89)***	-0.083 (1.25)	Number of trees (log)	-0.005 (0.55)	-0.003 (0.30)
Sex of household head (1 if male)	0.008 (0.11)	0.033 (0.52)	Income (log)	0.0039 (3.06)***	0.039 (3.60)***
Age of household head (log)	-0.078 (1.12)	-0.094 (1.13)	Type of stove (1 if three stones)	0.115 (2.38)**	0.180 (3.67)***
Max. education of a household member (log)	-0.041 (1.54)	-0.045 (1.80)*	Distance to town (log)	-0.030 (1.41)	-0.011 (0.38)
Percentage of boys (5–14 years)	0.029 (0.18)	-0.022 (0.12)	Inverse Mills ratio	0.089 (0.45)	0.377 (1.94)*
Percentage of girls (5–14 years)	0.037 (0.20)	0.055 (0.32)	Constant	6.569 (22.02)***	6.481 (17.97)***
Percentage of men (>14 years)	0.083 (0.54)	0.008 (0.05)	Observations	2762	2898
Percentage of women (>14 years)	-0.055 (0.29)	-0.105 (0.55)	Number of hhid	1402	1429

Z statistics are in parentheses.
* significant at 10%; ** significant at 5 %; ***significant at 1%
Random effects1 is when endogenous variables were not instrumented, while Random effects2 is when they were.
Time-varying location dummies included in regressions, but not reported.

We should also note that similar to the results reported in tables 2 and 3, significant variation in the estimates was obtained across location and time through the time-varying location dummies included (but not reported) in the estimates for biomass fuel consumption (tables 4 and 5). This suggested the importance of other site- and time-specific factors that were not included in the regressions.

Table 5 Estimates of Determinants of Level of Wood Consumption as Fuel

Variables	Random effects1	Random effects2	Variables	Random effects1	Random effects2
Log(shadow price of wood)	-0.156 (6.38)***	-0.085 (0.98)	Family size	0.065 (7.01)***	0.061 (5.52)***
Log(shadow price of dung)	-0.041 (1.83)	-0.032 (0.53)	Livestock owned (in TLU)	0.007 (0.88)	0.011 (1.29)
Log(shadow wage for wood collection)	-0.155 (6.73)***	-0.294 (3.32)***	Land size (in hectares)	-0.044 (1.83)*	-0.037 (1.36)
Log(shadow price for dung collection)	0.059 (2.76)***	0.042 (0.66)	Number of trees (log)	0.021 (2.91)***	0.029 (2.99)***
Sex of household head (1 if male)	0.102 (2.01)**	0.078 (1.59)	Income (log)	0.043 (3.72)***	0.047 (4.14)***
Age of household head (log)	0.095 (1.42)	0.084 (1.21)	Type of stove (1 if three stones)	0.118 (2.34)**	0.126 (2.61)***
Max. education of a household member (log)	0.010 (0.42)	0.020 (0.89)	Distance to town (log)	0.005 (40.23)	-0.012 (0.47)
Percentage of boys (5–14 years)	0.343 (2.20)**	0.195 (1.29)	Inverse Mills ratio	-0.723 (4.91)***	-0.518 (3.74)***
Percentage of girls (5–14 years)	0.379 (2.59)***	0.250 (1.40)	Constant	6.131 (22.93)***	6.630 (26.37)***
Percentage of men (>14 years)	0.423 (2.88)***	0.323 (2.09)**	Observations	2470	2591
Percentage of women (>14 years)	0.375 (2.39)**	0.251 (1.37)	Number of hhid	1363	1392

Z statistics are in parentheses.

* significant at 10%; ** significant at 5%; *** significant at 1%

Random effects1 is when endogenous variables were not instrumented, while Random effects2 is when they were.

Time-varying dummies included in regressions, but not reported.

4. Conclusion

Soil nutrient depletion is a critical problem that contributes to low agricultural productivity and the very limited domestic food supply in sub-Saharan Africa. Fertilizer use in Ethiopia is one of the lowest in sub-Saharan Africa. Use of dung as manure, particularly in the northern half of the Ethiopian highlands, is also limited, partly because of a significant level of dung consumption as household fuel. In this study, we attempted to examine the determinants of rural households' decision to use dung as fuel and as manure. We also looked into the issue of whether dung and woody biomass were substitutes as household energy sources. We used panel data collected from 1520 households from 12 different sites over the years 2000, 2002, and 2005.

While there was no indication that woody biomass and dung were substitutes for household fuel sources, the results suggested that they might be complements. A possible explanation for this is that, when the two fuel types were used together, they burned longer. It is therefore not surprising that we found that the stove type is important both for the choice and level of fuel consumption. We also found that household assets and household characteristics, such as the gender-age composition of the household and family size, are important determinants of decisions to use dung as fuel and as manure.

Since scarcity of household assets, such as livestock and land size, leads to a lower probability of applying dung as manure, this could create a vicious cycle. There is a risk that asset-poor households could become increasingly poorer, partly because the productivity of their lands decreases due to limited use of manure. We also concluded that attempts to address the limited use of dung as manure should simultaneously address energy issues by encouraging use of more efficient stoves, identifying more appropriate stoves and energy sources, and influencing the behavior of households through awareness creation so that less dung is used as fuel and more used as manure. In this way, it will be possible not only to improve energy efficiency but also to increase agricultural productivity.

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