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The impact of conservation tillage on maize yield and input demand: the case of smallholder farmers in north-west Ethiopia*

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This study analyses the economics of conservation tillage (CT) with respect to its effect on maize yield and chemical fertiliser, herbicide, and female and male labour demand. We estimate production and input demand functions using seemingly unrelated regressions on plot-level cross-sectional farm household data collected in the north-west of Ethiopia. A two-step control function is applied to address potential endogeneity bias due to the inclusion of the CT adoption decision as an explanatory variable. Our results show that CT increases maize yield and chemical fertiliser demand. Additionally, the results show that the adoption of CT reduces female and male labour required for crop production. However, this is achieved through the increased use of herbicides, which might have an undesirable health and environmental effects.

Key words: conservation tillage, input demand, maize yield, seemingly unrelated regression.

1. Introduction

Agriculture is crucial for poverty reduction and sustainable development in sub-Saharan Africa (SSA). It is the mainstay of the economy of the region and employs the largest proportion of the population. Empirical evidence shows that the elasticity of poverty reduction to agricultural growth is significant (Pingali 2012). Meanwhile, the main driver for agricultural growth has been area expansion, but this may no longer serve as a sustainable option since the majority of land has already been brought under cultivation.

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Despite continuing efforts, agricultural productivity has been low in the region. For instance, the average annual yield of maize, which is a major staple crop in the region, was 1.5 tonnes/ha in 2010, while the world average in the same period was about 5 tonnes/ha (Shiferaw *et al.* 2011).

In order to unlock the potential of agriculture, the focus of increasing productivity sustainably should not be left to developing and disseminating improved varieties alone, but also to improving crop management and agronomic practices (Hobbs 2007). In the light of this, conservation tillage (CT) has been promoted to smallholder farmers in SSA. This method entails reduced tillage or zero tillage and covering the soil with mulch. Conservation tillage is the key component of what is called conservation agriculture, which also requires diversification of crop species and legume rotations (Kassam *et al.* 2009).[1] Smallholder farmers in Africa are often unable to practise the full range of practices related to sustainable agriculture (Teklewold *et al.* 2013) but incrementally adopt key components such CT and hence the policy interest on the potential gains from the uptake of such components. The objective of this study was to analyse the *ex post* impact of CT on smallholder farmers' maize yield and input demand, namely: chemical fertilisers; herbicides; and labour in Ethiopia.

Experimental studies in SSA indicate that CT could increase long-term crop yield and reduce yield variability through the abatement of soil erosion and conserving soil moisture (Ito *et al.* 2007; Kassam *et al.* 2009). CT might also shift input demand with further implication for smallholder farmers' welfare and environment. The adoption of CT might, for example, have a mixed effect on chemical fertiliser demand. It could crowd out the demand for chemical fertiliser by mitigating nutrient loss. Alternatively, it might stimulate the uptake of chemical fertiliser by increasing its productivity through raising soil organic matter content. Marenya and Barrett (2009) found that higher chemical fertiliser productivity is achieved on carbon-rich soils than on carbon-deficit soils. Despite environmental concerns, chemical fertiliser is considered as an important technology to increase crop yield of smallholder farmers in SSA. This is because the current level of chemical fertiliser use in the region falls short of the recommended rates, resulting in low crop yield and nutrient mining (Heisey and Norton 2007). Previous studies on the diffusion of chemical fertiliser have emphasised the role of remedying market imperfections, subsidies, learning and behavioural bias (see, e.g., Duflo *et al.* 2011; Ricker-Gilbert *et al.* 2011; Gurara and Larson 2013). However, it is also worthwhile to explore whether technologies such as CT could play a significant role in stimulating chemical fertiliser adoption.

[1] Conservation agriculture (CA) is an approach to managing agroecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment and includes the three CA principles: minimal soil disturbance, permanent soil cover and crop rotations.

CT has received wider attention from researchers and policymakers partly due to its ability to provide environmental benefits. It can sequester carbon and contribute to climate mitigation according to Lal (2004) and others. However, there are also concerns that it could be accompanied by increased use of herbicides to mitigate potential weed incidence, which could adversely affect the environment (Laukkanen and Nauges 2011) and health (Sheahana *et al.* 2017). This recent study in Ethiopia finds a negative effect on human health potentially because the types of herbicides used in Ethiopia could have toxicity levels harmful to humans; chemicals banned or replaced in high-income countries are often sold and used in Africa. For example, both dichlorophenoxyacetic acid (commonly known as 2,4-D) and trifluralin are used in Ethiopia (Sheahana *et al.* 2017).

Additionally, labour demand could change in response to CT adoption. CT may reduce labour required for tillage; however, it could demand more labour for weeding if herbicide use is limited (Giller *et al.* 2009). Assessing the impact of CT on labour demand is crucial from smallholder farmers' perspectives as imperfect labour market, and other input and output markets do not allow them to be guided merely by a profit maximisation objective. Specifically, such a study sheds light on whether the labour endowment of a farmer is likely to be a binding constraint for CT adoption. In a perfectly competitive market, a technology that increases profitability would be welfare enhancing irrespective of its effect on labour demand. However, in thin rural labour markets, production and consumption decisions are nonseparable (de Janvry *et al.* 1991). This implies that not only production affects consumption through its link with income but also leisure preference affects production decision since farmers tend to rely more on family labour than hired labour. The effect of CT on labour demand could thus influence its adoption and thereby smallholder farmers' welfare.

The empirical evidence on the economics of CT is mainly based on either experiments conducted in research stations or demonstration plots (see, e.g., Ito *et al.* 2000; Rockstrom *et al.* 2009). These studies are less likely to reflect the performance of the technology under heterogeneous farmers' socio-economic and biophysical conditions. Using large household survey data in Kenya, Suri (2011) found that the profitability of hybrid maize is uneven among smallholder farmers owing to heterogeneous socio-economic and biophysical conditions. This indicates that the promotion of improved technologies should not be based merely on results obtained from research stations. A few studies have investigated the impact of CT using survey data (Fuglie 1999; Laukkanen and Nauges 2011; Teklewold *et al.* 2013). With the exception of Teklewold *et al.* (2013), the studies were undertaken in developed countries and the results may not be extrapolated to smallholder farmers' context in sub-Saharan Africa. This points to an important research lacuna that needs to be addressed.

Unlike field experiments, measuring the impact of CT on yield and input demands using observed data poses a formidable challenge. Unobserved characteristics might affect both the adoption decision of CT, as well as yield and input demand. Teklewold *et al*. (2013) employed a switching endogenous regression model to assess the impact of CT on yield, agrochemicals and labour use. This estimation framework deals with the sample selection problem, but it fails to account for possible contemporaneous error correlation between the production and input demand equations. Production and input demand could be subjected to similar weather and market-related shocks, causing errors to be correlated across equations. In order to improve the efficiency of the estimates, we estimate production and input demand functions simultaneously using plot-level cross-sectional data collected in 2013 in north-west Ethiopia. We also address sample selection and corner solution problems associated with estimating censored input demand.

2. Empirical framework

We employ an econometric technique to analyse the *ex post* impact of CT on maize yield and input demand. As discussed earlier, the inputs considered are chemical fertiliser, herbicide and labour. Production and input demands could be exposed to similar shocks, causing contemporaneous error correlation across equations. For instance, weather shock could affect both production and input demand. Thus, we estimate production and input demand functions simultaneously using seemingly unrelated regression (SUR) framework. This would improve the efficiency of the estimates (Zellner 1962).

About 6 and 75 per cent of the surveyed plots did not receive chemical fertilisers and herbicides in 2012–2013, respectively. This implies that the demand for chemical fertilisers and herbicides is censored at zero. To estimate the systems of equations with censored dependent variables, we follow a two-step estimation procedure proposed by Shonkwiler and Yen (1999). This approach enables us to use the full set of observations to estimate the systems of equations. In the first stage, we estimate a probit model for both chemical fertilisers and herbicides adoption decisions, where cumulative distribution and probability density functions are generated:

$$\text{Prob}(d_{ihp} = 1/z_{ihp}) = \phi\,(z'_{ihp}\alpha) \qquad (1)$$

where Prob(.) is the likelihood that a farmer h uses input i (chemical fertilisers or herbicides) on plot p; d_{ihp} is input use decision that takes a value of one if a farmer applies input i on plot p and zero otherwise; $\Phi(.)$ is the cumulative distribution function for standard normal density function; z_{ihp} denotes household and plot characteristics that influence input use decisions; and α is a vector of parameters to be estimated.

In the second stage, the unconditional mean of the censored dependent variables is estimated as follows:

$$y_{ihp} = \phi(z'_{ip}\alpha)f(x'_{ihp}\beta) + \delta\phi(z'_{ihp}\alpha) + \varepsilon_{ihp} \quad (2)$$

where y_{ihp} is the amount of input i per hectare used by a farmer h on plot p; $\Phi(.)$ is the standard normal density function obtained from Equation (1); x_{ihp} are household and plot characteristics that affect the intensity of use of input i; and ε_{ihp} is idiosyncratic error term.

In estimating Equation (2), we face an endogeneity bias due to the inclusion of an endogenous explanatory variable, that is a dummy variable representing tillage type choice. Unobserved household and plot characteristics might dictate tillage type choice and adoption decisions on plots, with further influence on yield and input demand. These unobserved characteristics could lead estimates to be inconsistent. To circumvent this problem, we use a two-step control function approach (Wooldridge 2015). In the first step, a probit model for the choice of tillage type (at the plot level) is estimated and a generalised error term is generated. In the second step, production and input demand functions are estimated by including the generalised error term obtained in the first step as a right-hand side variable along with a dummy variable for tillage type choice. This procedure might result in inflated standard errors as it uses the estimated generalised residuals, and thus, bootstrapped standard errors are computed (Cameron and Trivedi 2005).

In a two-step control function approach, it is important to have covariates that directly affect the adoption of CT but not production and input demand functions. Access to herbicides could serve as a measure of the transaction costs incurred in the process of acquiring herbicides. This can be viewed as a fixed cost that does not vary with the intensity of herbicide purchase. The survey results show that herbicide use is common on maize plots with CT while it is rarely applied on conventional maize plots. It is thus reasonable to hypothesise that access to herbicide determines CT adoption but not maize yield directly, and thus, we use it for identification purpose.

3. Results and discussion

3.1 Data and descriptive statistics

Data for this study come from a survey conducted by the International Maize and Wheat Improvement Center (CIMMYT) in collaboration with the Amhara Agricultural Research Institute (ARRI) in South Achefer district, in the north-west of Ethiopia in 2013. The district was chosen for its potential for maize production, an important food security crop in the country. The district is predominantly characterised by a mixed crop–livestock production system. Conventional tillage, whereby oxen are used as a draft power and which involves repeated tilling using plough, is commonly practised in the area. On the other hand, CT in this paper refers to either no tillage or a single pass with minimal soil disturbance while keeping crop residues on a plot as mulch. Maize production in the area is rainfed, and it is expected that both rainfall distribution and amount could exert a considerable impact on maize yield. Kebeles[2] with good maize production potential were identified and 14 Kebeles were randomly selected in the district. Data were collected from a total of 278 farm households, which were drawn from Kebeles based on their population size. The farm households in each Kebele were randomly chosen. All plots operated by a farm household were surveyed. Face-to-face interviews were undertaken by experienced enumerators supervised by scientists from the CIMMYT and ARRI. It generated plot-level data on plot quality, plot size, chemical fertiliser, human labour, oxen labour, herbicide and crop yield. The data set also contains rich information pertaining to the socio-economic characteristics of farm households. A summary of the descriptive statistics for the key variables of interest for adopters and nonadopters of CT is provided in Table 1.

On average, maize covers about 0.61 ha of a farmer's land, representing about 49 per cent of the total amount of cultivated land. Other crops grown in the study area include *teff*, finger-millet, wheat, faba bean and field peas. However, the use of CT is limited to maize plots only. About 99 per cent of the surveyed farm households grow maize on one or more plots. On average, a farm household operates on about 2 maize plots, making the total number of surveyed maize plots 561. It was found that about 37 per cent of the sampled farm households implement CT on about 25 per cent of maize plots. About 61 per cent of farm households who apply CT on one or more maize plots also practise conventional tillage on other maize plots they operate. These farmers are treated as adopters for plots with CT and nonadopters for plots with conventional practices. This implies that a farm household can be both an adopter and a nonadopter at the same time. The survey results further show that farm household practise CT on about 4 per cent of the plots for the first time.

A statistical test (independent t-test or chi-square test depending on the nature of the variables) is undertaken to get some insight about key variables that differentiate adopters from nonadopters. CT adopters are found to be younger and better educated. They are also better connected to main markets including herbicide market. The survey results further show that the size of maize plots with CT is larger than with conventional tillage. However, CT adopters tend to own smaller farm size than nonadopters. Owning a smaller farm size may stimulate farm households to adopt yield-enhancing technologies such as CT in order to provide food to the household. They also appear to be less endowed with their own labour force than nonadopters.

The adoption of CT might cause change in resource allocation and farmers' welfare. One of the key resources which could be affected following the adoption of CT is the labour demand for crop production. The survey results indicate that the labour use on the conventional tillage plots is more

[2] Kebeles are the lowest administrative unit in Ethiopia.

Table 1 Characteristics of adopters and nonadopters of CT (plot level)

	Mean	
	Conventional tillage	Conservation tillage
Household characteristics		
Family size (man equivalent)	2.93* (1.17)	2.70 (1.12)
Sex of the head (1 = male, 0 = female)	0.96 (0.21)	0.94 (0.24)
Age of the head	43.80* (12.68)	40.83 (12.49)
Education of the head (years of schooling)	1.51* (2.20)	2.65 (2.82)
Resource endowment		
Total own farm size (ha)	1.32* (0.76)	1.14 (0.74)
Total livestock in tropical livestock unit (tlu)	5.68 (3.01)	6.18 (3.76)
Plot size (ha)	0.28* (0.13)	0.34 (0.19)
Fertility status (1 = poor, 2 = medium, 3 = good)	2.51 (0.68)	2.51 (0.63)
Rainfall index	0.67 (0.22)	0.65 (0.24)
Access to institutions		
Distance to main market (walking mins)	113.52* (63.82)	101.75 (51.86)
Distance to herbicide market (walking mins)	83.61* (55.72)	67.65 (41.17)
Distance to office of agricultural extension services (walking mins)	38.13 (25.75)	39.41 (28.32)
Resource allocation/input use		
Improved seed (1 = improved, 0 = local)	0.44 (0.50)	0.44 (0.50)
Herbicide use (litre/ha)	0.07* (0.36)	3.12 (2.22)
Draft power (oxen days/ha)	17.52* (8.12)	4.79 (6.29)
Female labour (man days/ha)	19.23* (13.92)	10.32 (9.88)
Male labour (man days/ha)	29.56* (18.38)	13.99 (10.85)
Hired labour cost (ETB/ha)	21.58* (109.23)	48.02 (141.60)
Chemical fertiliser use (kg/ha)	259.10* (155.39)	335.32 (112.30)
Outputs		
Maize yield (quintals/ha)	23.12* (12.00)	27.41 (14.75)
Gross margin (1,000 ETB/ha)	10.47* (5.96)	11.76 (7.42)
Number of observations	413	135

Note *Indicates that there is significant difference between adopters and nonadopters at 5% or less significance level. The standard deviations are in the brackets. One tlu is equivalent to 250 kg live animal weight. Fertility status of the plot is based on a farmer's subjective assessment of fertility status of his or her plot. The female and male labour refers to labour used for land preparation and planting.

than twofold of the CT plots. Similarly, the demand for oxen days declines with the CT plots. The average number of oxen days per hectare used on the conventional tillage plots is about fourfold of the CT plots. The reduction in labour and oxen days might facilitate the adoption of CT. CT might allow labour-constrained farmers expand their maize production. Alternatively, the released human labour can be utilised in other economic activities or a farmer would have increased leisure time, which eventually enhances the welfare of a farmer. On the other hand, the amount of paid-out labour cost is higher on plots with CT than conventional tillage. This means that CT adopters hire more labour than nonadopters. This is perhaps because CT adopters are more family labour-constrained than their conventional tillage user counterparts.

The reduced labour and oxen days with CT are accompanied by an increase in herbicide use.[3] About 92 per cent of CT plots are treated with herbicides, whereas it is applied to 5 per cent of conventional tillage plots only. One of the purposes of tillage is to lessen weed infestation, and its reduction might necessitate herbicide use. There are two types of herbicides that are commonly used along with CT. These are called roundup (glyphosate) and primagram (ultrazine).

We computed the gross margin for both conservation and conventional maize tillage plots. This is defined as the difference between maize revenue and production cost. Farmers grow maize for both home consumption and sales, and we use total maize produced for computing total maize revenue. Total maize revenue equals the product of maize volume produced and selling price. We used price data from a market survey conducted by the Central Statistical Authority of Ethiopia. The selling price for March was used for computing maize revenue since this is the time that most farmers sell a considerable portion of their produce. The costs include chemical fertilisers, herbicides, and hired labour and seed cost. However, this does not include labour, draft power and seed provided by a farm household. Thus, the computed gross margin here can be viewed as the return to unpaid inputs including land, seed, labour and oxen draft. On average, the gross margin reaped on CT plots is found to be greater than on conventional tillage maize plots. The gross margin gap would be wider if the value of reduced own labour and oxen days was considered in the calculation.

The adoption of CT might also affect yield distribution and income. The survey results demonstrate that average maize yield is about 2,741 kg/ha on CT plots while it is about 2,312 kg/ha on conventional tillage plots. Figure 1 depicts that the yield distribution for plots with CT apparently dominates the

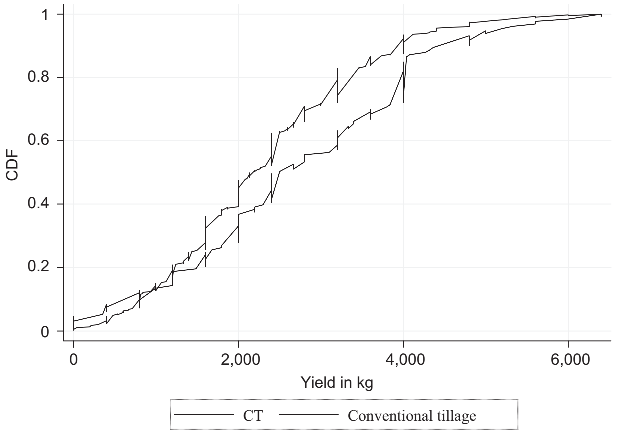

Figure 1 Maize yield distribution of conservation and conventional tillage plots.

[3] The correlation coefficient between labour and herbicide uses is negative and significant.

yield distribution for plots with conventional tillage. Thus, it is likely that a farm household prefers CT to conventional tillage since it could achieve higher yield with negligible effect on yield distribution with the former.

As mentioned at the outset, the adoption of CT could have an effect on chemical fertiliser use. Two types of chemical fertiliser, DAP (Diammonium phosphate) and urea, are widely used in the study area. The average total chemical fertiliser application on conventional and conservational tillage plots is about 259 and 335 kg/ha, respectively. There is also less variation in fertiliser use among maize plots with CT than conventional tillage.

It is important to mention here that the aforementioned discussion on the differences observed between CT and conventional tillage plots might not be necessarily due to the adoption of CT as confounding variables were not accounted for. The next section presents results based on rigorous econometric analysis.

3.2 Econometric results

In developing countries, where market imperfection is rampant, production inputs such as labour, oxen days, chemical fertilisers and herbicides are not the only drivers of crop yield. The socio-economic characteristics of farmers could also exert a significant impact on crop yield. Similarly, input and output prices, and available technologies are not the only factors driving the demand for chemical fertilisers, herbicides and labour. Due to market imperfection, input and output prices are endogenously determined and the socio-economic conditions of farmers could affect shadow input prices. We thus include the socio-economic characteristics of farmers in the determinants of input demand.

In order to improve the efficiency of the estimates, production and input demand functions are simultaneously estimated using SUR and bootstrapped standard errors are computed. Among the system of equations, the error terms of the male labour demand equation show a relatively strong and positive correlation with the error terms of the female labour and chemical fertiliser demand equations. This indicates that a decrease in male labour demand may be associated with a decrease in female labour and chemical fertiliser demand, *ceteris paribus*. This may be because, for example, if a male household member gets sick and is forced to curtail his agricultural labour supply, female household members may be also forced to do the same so that part of their time can be utilised to look after the sick household member. A health shock to a male household member may also result in reduction of chemical fertiliser use since chemical fertiliser application in Ethiopia depends on human labour.

However, the correlation coefficients of the error terms of the remaining equations are <0.1 in absolute terms. Nevertheless, the Breusch–Pagan Lagrange multiplier test rejects the null hypothesis – error independence across equations – at 1 per cent significance level. Thus, given the data, SUR

Table 2 Seemingly unrelated regression results (plot level)

	Estimated coefficients	Bootstrapped standard errors	*P*-value
Quantity produced kg/ha			
Fertiliser (kg/ha)	1.59***	0.41	0.000
Oxen days/ha	2.25	7.90	0.775
Human labour/ha	0.92**	0.43	0.033
Herbicide (litre/ha)	31.04	68.03	0.648
Improved seed	85.05	106.89	0.426
Fertility status of the plot	296.09***	72.59	0.000
Plot size (ha)	−874.22*	509.12	0.086
Man equivalent	70.62	46.4	0.128
Sex of the head	155.89	227.14	0.493
Age of the head	−5.24	4.70	0.265
Education of the head	13.84	29.24	0.636
Distance to main market	2.07**	0.86	0.016
Rainfall index	1,190.87***	229.59	0.000
Distance to agricultural extension services	−2.54	1.92	0.187
Livestock (tlu)	69.25***	17.09	0.000
Generalised residual	−286.83	266.35	0.282
CT adopter	936.01**	449.79	0.037
Constant	−464.94	455.30	0.307
R^2	0.24		
χ^2	157.58		
P-value	0.00		
Chemical fertiliser kg/ha			
CDF × Plot size	−336.55***	54.01	0.000
CDF × Man equivalent	12.32*	6.65	0.064
CDF × Sex of the head	−6.40	25.89	0.805
CDF × Age of the head	−1.29**	0.56	0.020
CDF × Education of the head	−4.33	3.09	0.161
CDF × Distance to main market	0.03	0.11	0.798
CDF × Rainfall index	43.90	27.22	0.107
CDF × Distance to agricultural extension services	−0.54**	0.22	0.015
CDF × Livestock	2.43	2.28	0.287
CDF × CT adopter	142.50***	43.38	0.001
CDF × Fertility status of the plot	16.49	11.53	0.153
CDF × Generalised residual	−60.98**	28.19	0.031
CDF	355.72***	56.00	0.000
PDF	−307.54***	85.23	0.000
R^2	0.82		
χ^2	2,315.69		
P-value	0.00		
Herbicide litre/ha			
CDF × plot size (ha)	−5.26***	1.61	0.001
CDF × Man equivalent	0.37	0.33	0.257
CDF × Sex of the head	0.19	0.91	0.836
CDF × Age of the head	0.02	0.02	0.466
CDF × Education of the head	−0.14	0.12	0.238
CDF × Distance to main market	0.00	0.01	0.685
CDF × Distance to herbicide market	−0.01	0.00	0.207
CDF × Rainfall index	1.30	1.30	0.318
CDF × Distance to agricultural extension services	0.00	0.01	0.719

Table 2 (*Continued*)

	Estimated coefficients	Bootstrapped standard errors	*P*-value
CDF × Livestock	−0.13*	0.08	0.084
CDF × CT adopter	6.87***	0.65	0.000
CDF × Fertility status of the plot	0.12	0.38	0.746
CDF	−0.63	1.66	0.703
PDF	1.15	0.82	0.162
R^2	0.61		
χ^2	799.72		
P-value	0.00		
Male farm labour in man days/ha			
Fertility status of the plot	1.12	1.09	0.303
Plot size (ha)	−29.94***	5.89	0.000
Man equivalent	2.75***	0.77	0.000
Sex of the head	6.51***	2.45	0.008
Age of the head	−0.01	0.06	0.836
Education of the head	−0.19	0.39	0.631
Distance to the main market	−0.01	0.01	0.596
Rainfall index	2.24	3.63	0.537
Distance to agricultural extension services	−0.01	0.03	0.834
Livestock	−0.18	0.2	0.357
Generalised residual	1.30	3.21	0.685
CT adopter	−14.47***	5.13	0.005
Constant	22.65***	5.9	0.000
R^2	0.22		
χ^2	141.31		
P-value	0.00		
Female farm labour in man days/ha			
Fertility status of the plot	1.58**	0.69	0.022
Plot size (ha)	−26.21***	4.53	0.000
Man equivalent	−0.31	0.48	0.525
Sex of the head	−5.70*	3.34	0.088
Age of the head	0.08*	0.04	0.054
Education of the head	−0.08	0.24	0.741
Distance to main market	−0.01	0.01	0.195
Rainfall index	5.45*	3.19	0.088
Distance to agricultural extension services	0.01	0.02	0.789
Livestock	0.07	0.23	0.75
Generalised residual	3.78	3.06	0.217
CT adopter	−12.08**	5.12	0.018
Constant	24.18***	5.24	0.000
R^2	0.21		
χ^2	134.66		
P-value	0.00		
Number of observations	513		

Note ***, ** and * are 1%, 5% and 10% significance level, respectively. CDF and PDF are cumulative and probability density functions estimated from a probit model for chemical fertiliser and herbicide use decisions.

yields more efficient estimates than single-equation OLS (ordinary least square) estimator. The overall fit of each of the equations is found to be statistically significant. Table 2 presents econometric estimation results for the production and input demand functions. It is important to note that a plot is used as the unit of analysis for econometric estimation.

3.3 Determinants of maize yield

As the interest of this study is to assess the effect of CT on land productivity, we use yield instead of output as the dependent variable in estimating the production function. In estimating the production function, both maize output and inputs are thus converted into per hectare basis. The Cobb–Douglas, quadratic and linear functional forms are used to estimate the production function. The estimated Cobb–Douglas production function has the smallest adjusted R-squared value. Its coefficients for some of the inputs did not also have the expected sign. Furthermore, the coefficients for the squared terms in the quadratic production function turn out to be insignificant. Its adjusted R-squared is also smaller than the linear function. In order to check whether CT adoption has a strong slope effect, we generated interaction terms – by interacting CT adoption with the other explanatory variables – and included them as additional explanatory variables. However, our findings show that the interaction terms have no significant effect on the dependent variables. The results imply that there is no gain in running separate regressions for CT adopters and nonadopters. Thus, we present the results of the estimated linear production function that includes the CT adoption decision as an explanatory variable.

Our estimation strategy deals with endogeneity bias that could emanate due to the inclusion of tillage type choice as an explanatory variable. As discussed in the methodology section, a two-step control function is applied, and access to herbicides is used as exclusion restriction. This variable is found to be a strong determinant of the CT adoption decision, but it does not have a statistically significant impact on maize yield by its own right. This warrants the appropriateness of using it for identification purpose. The generalised residual predicted from the probit model of CT adoption decision is statistically insignificant in the yield function. This implies that there are no common unobserved factors that affect both CT adoption and yield.

In the estimated production function, the coefficient for CT is positive and statistically significant. Keeping other factors constant, a switch to CT from conventional tillage increases maize yield by about 9 quintals/ha, on average. As expected, the intensity of chemical fertiliser also affects maize yield positively. The median chemical fertiliser elasticity of maize yield is approximately 0.18. This implies that a 1 per cent increase in chemical fertiliser use around the median raises maize yield by about 0.18 per cent. Similarly, the intensity of labour use is positively associated with maize yield. On the other hand, our results reveal that the intensity of herbicide application does not have a statistically significant effect on maize yield. This is not consistent with our *a priori* expectation. Indeed, herbicides do not inherently possess a yield-enhancing property like fertilisers. Rather, it is used to reduce yield loss due to weed infestation.

Moreover, the results show that the intensity of oxen draft use does not have a statistically significant effect on maize yield, whereas the size of own livestock positively and significantly influences maize yield. This could be due to the reason that the size of own livestock could better approximate oxen draft use than the reported by a farmer due to recalling problem. The size of own livestock could also reflect the amount of manure utilised as organic fertiliser to enhance maize yield.

Plot characteristics are also found to be the important drivers of crop yield. Consistent with our *a priori* expectation, higher yield is obtained on good fertile soil than poor fertile soil, keeping other factors constant. Our results further show that plot size is inversely related to yield, supporting previous empirical evidence in SSA (Larson *et al.* 2014). On the other hand, farmers closer to main markets achieve lower maize yield than their counterparts with poor market access. This is contrary with our prior expectation and warrants further investigation.

Although the surveyed farmers are located in one district, there might be still microclimate differences. During the survey, farmers were asked about their assessment of the rainfall distribution and amount for the last 3 years and an aggregated rainfall index is computed based on their responses. This index takes a value that ranges from zero to one. The rainfall condition is better as the rainfall index gets closer to one. Consistent with our *a priori* expectation, the coefficient for rainfall index is positive and statistically significant.

3.4 Determinants of input demand

We have discussed that CT adoption affects maize yield positively. In this section, we examine whether the adoption of CT could also bring a shift in input demands, which might have further implication for household's welfare and the environment. The coefficient for generalised residual is statistically significant in the chemical fertiliser demand function. This indicates that there are common unobserved characteristics that affect both CT and chemical fertiliser adoption decisions, and estimates would be inconsistent if chemical fertiliser function was not augmented with the generalised residual. However, the generalised residual becomes statistically insignificant in labour and herbicide demand functions.

Our results indicate that CT positively and significantly affects chemical fertiliser and herbicide use. On the other hand, CT adoption is associated with reduced female and male labour demand for crop production. Reducing tillage might cause increased weed incidence with the consequent yield loss. In order to mitigate potential yield loss, CT adopters could respond either by increasing herbicide use or labour. Our findings suggest that adopters have responded by increasing herbicide use.[4] Similarly, Laukkanen and Nauges (2011) found that CT adoption increases both chemical fertiliser and

[4] The remark on the relationship between labour and herbicide use is based on a simple correlation test and thus does not imply causation.

herbicide use. On the other hand, Teklewold *et al.* (2013) found that CT adoption increases herbicide uptake but dampens chemical fertiliser demand. This might suggest that the impact of CT on chemical fertiliser demand is context-specific. In our study area, it the positive effect of CT on chemical fertiliser demand outweighs its negative effect. As discussed in the introduction, the positive effect of CT adoption on chemical fertiliser demand may be due to improvement in organic carbon content of the soil that improves chemical fertiliser productivity. On the other hand, the negative effect of CT on chemical fertiliser demand may emanate from the ability of CT to mitigate nutrient loss and thereby chemical fertiliser demand.

Additionally, the results show that plot size is negatively related to chemical fertiliser, herbicide and labour use. This shows that smaller plots receive higher amounts of inputs, *ceteris paribus*. This could be due to the fact that farm households who operate on smaller plots need to increase the productivity of their farms in order to provide food for the household. This might support the induced innovation theory, which asserts that increased population pressure necessitates intensification of the production system by employing yield-enhancing technologies. This result is also consistent with the existing empirical evidence conducted in similar settings (Alene *et al.* 2008; Gurara and Larson 2013).

Furthermore, our findings indicate that farm household characteristics affect chemical fertiliser demand. The size of a farm household in terms of male adult equivalent is found to positively contribute to the adoption of chemical fertiliser. This could be due to the need to increase crop yield in order to support large family size. It could be also associated with the fact that labour-rich households have the labour force needed for fertiliser application. On the other hand, the age of a household head is inversely related to the intensity of chemical fertiliser use. This could be because older farmers might have better experience and social networks, which might help them to find other lucrative livelihood activities such as nonfarm activities. As a result, the opportunity cost of investing their resources into crop production could be higher. It might also be due to the reason that farmers could be more risk averse as they get older and this might discourage adoption of chemical fertiliser, assuming that chemical fertiliser is risk increasing. The results also show that farmers located closer to agricultural extension offices are likely to use higher levels of chemical fertiliser.

On the other hand, the results show that higher female labour force is used on more fertile maize plots than less fertile maize plots. This could be because the marginal productivity of labour is higher on fertile plots and this might stimulate the increased deployment of labour. The labour force of a farm household is also positively associated with increased use of male labour for maize production. This could perhaps reflect the existing labour market imperfections. With perfect labour market, a farm household's labour endowment would have marginal effect on labour use. Similarly, male-headed households employ more labour for maize production than female-headed households. Most of the variables included in herbicide and labour demand functions are insignificant. This could be due to the fact that the data for this study are drawn from one district, and consequently, the variation in the explanatory variables might not be strong enough to bring about a significant change in the demand for these inputs.

4. Summary and conclusions

Conservation tillage (CT) has been promoted for smallholder farmers as a means to improve agricultural productivity and sustainably. Such endeavours have primarily been informed by evidence coming from research stations and demonstration plots. However, these results might not be replicated under diverse biophysical and socio-economic conditions of smallholder farmers. This study bridges the knowledge gap by analysing the effect of CT on maize yield, chemical fertiliser, herbicide, and female and male labour demand using plot-level cross-sectional farm household data in north-west Ethiopia. In order to improve the efficiency of the estimates, we estimate production and input demand functions using seemingly unrelated regression (SUR). We employ a two-step control function to minimise the potential bias that arises due to the inclusion of CT adoption decision as an explanatory variable, which is an endogenous variable.

Our econometric results reveal that CT increases maize yield and stimulates chemical fertiliser adoption. The results further show that the adoption of CT reduces female and male labour required for crop production. This also adds value to the economics of CT since the rural labour market is thin. This makes CT attractive in maize production both in terms of increased farm productivity and labour savings, which also implies a reduction in the demand for animal traction commonly used in crop production in Ethiopia. The released labour can be used to engage in other livelihood activities, especially important when the production season is short and labour markets are imperfect or reduce the pressure on the scarce female labour time. However, this is achieved with increased use of herbicides, which might have undesirable effects on human health and the environment, but this effect can be minimised by using recommended low-impact herbicides. Crop yield and input demand are further influenced by some farm household characteristics, resource endowment, and distance to market and agricultural extension services. Thus, remedying market imperfections, including access to information is vital to address low crop yield and input demand conditions among smallholder farmers.

There are some caveats in the current study that ought to be addressed in future research. This study is based on data collected during a single production season. Thus, climate variability remains unaccounted for. Moreover, the effect of CT on maize yield might not be limited to the current period and may also affect future yield through its long-term effect on increasing soil organic matter and soil nutrients when practised continuously. From the results of this study, it is unclear whether the observed results are due to the immediate or cumulative effect of CT. It is therefore worthwhile to utilise panel data in future to examine the performance of CT across different seasons and over time. The experimental data suggest that the dynamic effect of CT is likely to be positive. There is also a need to replicate similar studies in other parts of the country as these findings may differ in other relevant socio-economic and agro-ecological settings. Furthermore, future studies need to analyse the effect of CT on farm household income and food security since CT involves the application of at least some of the crop residues as mulch, which otherwise could be used as animal feed. This is particularly important given the fact that mixed crop–livestock production is the predominant livelihood strategy in the study area. Thus, the promotion of CT to smallholder farmers should be informed not only by its effect on crop production but also by its effect on livestock production as well as the effect of selected herbicides on health and the environment. In this study, we have rather focussed on crop yield since farmers in the study area mainly rely on their own inputs, which poses a difficulty in accurately computing household income.

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Appendix

As mentioned in the methods section, we apply a two-step control function approach to address endogeneity problem associated with the inclusion of conservation tillage (CT) adoption decision as explanatory variable in both production and input demand functions. In the first step, the approach involves estimating a probit model for CT adoption decision. The results of the probit model estimation are presented in Table A1. In the study area, farm households manage multiple plots and CT adoption decision is made at plot level. The estimation is thus made using a plot rather than a farm household as a unit of analysis.

The overall fitness of the model is significant. Farmers are more likely to adopt CT on larger plots than smaller once. This could be perhaps associated with the economics of scale in applying CT. The results also show that the likelihood of adoption of CT is higher on plots located farther away from homestead. Applying conventional tillage on far away plots could be both human and oxen labour demanding. This could raise the incentive to adopt CT on plots located farther away from homestead. The results further reveal that better education and access to agricultural extension could facilitate the adoption of CT. This might suggest the role of information on CT adoption. Furthermore, the size of own livestock appears to increase the odds of CT adoption. Better livestock endowed farm households could afford to buy herbicide, which is often applied along with CT. The results also show that CT adoption is constrained by limited access to herbicide market.

Table A1 Probit model estimates for CT adoption

	Estimated coefficients	Standard errors	*P*-value
Plot size in ha	1.884***	0.441	0.000
Total farm size in ha	−0.152	0.125	0.224
Man equivalent	−0.014	0.073	0.849
Sex of the head	−0.358	0.306	0.242
Age of the head	0.001	0.007	0.863
Education of the head	0.093***	0.028	0.001
Market access ($\times 10^2$)	−0.097	0.127	0.441
Rainfall index	−0.227	0.301	0.451
Agricultural extension access	0.004*	0.003	0.091
Plot distance	0.032***	0.005	0.000
The size of oxen in tlu	−0.095	0.072	0.191
The size of non–oxen livestock in tlu	0.047*	0.026	0.066
Herbicide access	−0.005***	0.002	0.002
Constant	−0.821*	0.473	0.082
Pseudo R^2	0.181		
LR χ^2	106.59		
Prob > χ^2	0.00		
Number of observations	526		

Note ***, ** and * represent significance level at 1, 5 and 10% significance level.