JAE Journal of Agricultural Economics

Journal of Agricultural Economics, Vol. 69, No. 3, 2018, 756–776
doi: 10.1111/1477-9552.12262

Does Intensive Tillage Enhance Productivity and Reduce Risk Exposure? Panel Data Evidence from Smallholders' Agriculture in Ethiopia

Zewdu Ayalew Abro, Moti Jaleta and Hailemariam Teklewold[1]

(Original submitted August 2017, revision received October 2017, accepted November 2017.)

Abstract

We analyse the impact of intensity of tillage on wheat productivity and risk exposure using panel household-plot level data from Ethiopia. In order to control for selection bias, we estimate a flexible moment-based production function using an endogenous switching regression treatment effects model. We find that tillage has a complementary impact on productivity and risk exposure. As the intensity of tillage increases, productivity increases and farmers' exposure to risk declines. Our results suggest that smallholder farmers use tillage as an ex-ante risk management strategy. The main policy implication of this study is that the opportunity cost of switching to reduced tillage in wheat production seem rather high unless farmers are supported by appropriate incentive schemes.

Keywords: *Agricultural productivity*; *Ethiopia*; *risk exposure*; *tillage*; *wheat*.

JEL classifications: *D81, O12, Q12, Q16, Q18.*

[1]Zewdu Ayalew Abro is with the Department of Agricultural Economics and Rural Development, University of Goettingen, Germany. Email: zabro@uni-goettingen.de for correspondence. Moti Jaleta is in the Socio-Economics Program, CIMMYT, Addis Ababa, Ethiopia. Hailemariam Teklewold is in the Environment and Climate Research Center, Ethiopian Development Research Institute, Addis Ababa, Ethiopia. The authors acknowledge two projects that collected the panel data used in this study; namely, Diffusion and Impacts of Improved Varieties in Africa (DIIVA) and Tracking Varietal Change and Adoption of Rust Resistant Wheat Varieties in Ethiopia funded by the Standing Panel for Impact Assessment (SPIA) and Durable Rust Resistance in Wheat (DRRW) project through Cornell University and the Bill & Melinda Gates Foundation, respectively. Zewdu Ayalew Abro was financially supported through a stipend from the German Academic Exchange Service (DAAD). We thank Bethelhem Legesse Debela, Esther Gehrke and Matin Qaim for their comments on an earlier draft of the paper. The authors would also like to thank two anonymous referees for their critical comments and the Editor of this journal for his valuable comments and editing the manuscript.

1. Introduction

Tillage is one of the most important innovations in our history to offset deteriorating natural soil fertility (Boserup, 2007; Hobbs *et al*., 2008). Agronomic studies show that intensive tillage practices have four main benefits. First, tillage suppresses already germinated weeds, and it initiates new weed germination. Suppressing weeds helps crops to use the available soil nutrients without competition (Boomsma *et al*., 2010; Guan *et al*., 2015; Sime *et al*., 2015). Low density of weeds saves additional labour spent in weeding activities. Second, as plant debris is mixed with the soil through tillage, the incidence of foliar diseases that may survive from previous infections could decline (Bailey, 1996; Bockus and Shroyer, 1998; Krupinsky *et al*., 2007). Third, intensive tillage could increase soil moisture by increasing water infiltration rate (Guan *et al*., 2015; Sime *et al*., 2015; Temesgen *et al*., 2008). Last but not least, by softening the soil and allowing the preparation of fine seedbed, tillage facilitates uniform seed germination. Uniform seed germination in turn increases the density of the plant and suppresses weeds (Hobbs *et al*., 2008; Mouazen *et al*., 2007; Weiner *et al*., 2001). Consequently, intensive tillage serves as an *ex-ante* risk management strategy in order to reduce potential production risks induced by various stresses such as diseases and weeds.

However, the conservation agriculture (CA)[2] literature shows that intensive tillage practices disturb the biological functions of soil microorganisms and its diversity leading to loss of soil organic matter (Hobbs *et al*., 2008; Kassam *et al*., 2009; Lal, 2001). Soil organic matter provides not only the necessary nutrients for crop growth but also stabilises soil structure. Tillage-induced loss of soil organic matter thus leads to lower soil fertility (Kassam *et al*., 2009). Furthermore, in drought prone areas, intensive tillage practices may lead to soil moisture evaporation, increasing the chance of crop failure (Kassam *et al*., 2009; Piggin *et al*., 2015; Shiferaw *et al*., 2014). Despite such negative effects, intensive tillage is widely practiced in many developing countries (Giller *et al*., 2009; Grabowski *et al*., 2016; Lalani *et al*., 2016; Stevenson *et al*., 2014).

In this paper, our goal is to analyse the impact of intensive tillage practices on productivity and risk exposure of wheat farmers. We use two rounds of panel data collected in Ethiopia. Ethiopia is an interesting case study because intensive tillage practices remain the dominant method of seedbed preparation, and reduced tillage is rarely practiced (Jaleta *et al*., 2016). Furthermore, the majority of farmers have a deep historical connection with the plough (Aune *et al*., 2001; McCann, 1995). It is thus important to understand farmers' motivation behind their strong attachment with the millennia-old intensive ox-plough tillage system. This tillage system is under pressure because of its implications for soil degradation (Aune *et al*., 2001). Introduction of sustainable tillage practices is a challenge to policy-makers. By shedding light on the opportunity costs of switching to reduced tillage, our study should help identify policy instruments that consider the trade-offs between the biophysical, economic and risk effects as well as the needs and preferences of smallholder farmers in Ethiopia and elsewhere with similar tillage systems.

---

[2]CA has three main components: minimum soil disturbance, crop rotation & intercropping, and crop residue management (Hobbs *et al*., 2008). In order to draw sound conclusions about the impact of tillage on yield and production risk, these factors need to be controlled for. The findings we present in this paper are robust to differences in practicing crop rotation and residue management.

Many studies find that the introduction of reduced tillage has brought significant productivity and income gains in maize production (Jaleta *et al*., 2016; Kassie *et al*., 2015b; Teklewold *et al*., 2013). Similar findings were also reported for wheat (El-Shater *et al*., 2016; Erenstein *et al*., 2008; Krishna *et al*., 2016; Krishna and Veettil, 2014). In South Asia, for example, a review of the literature by Krishna *et al*. (2016) reveals that farm-level benefits (yield and low costs of production) of reduced tillage in wheat production are higher than for conventional tillage. In addition to the reported yield gains and reduced costs of production, other studies on both crops show that adoption of reduced tillage has lower downside risk exposure than conventional tillage (Aryal *et al*., 2016; Kassie *et al*., 2015a; Magnan *et al*., 2011; Ngwira *et al*., 2013; Sommer *et al*., 2011). Regardless of agronomic differences (e.g. grain size and weed management) in maize and wheat, findings of studies in both crops underscore that reduced tillage is important for the protection of farmers from livelihood failures.

Despite the documented positive impacts, studies from developed countries show that farmers may not adopt reduced tillage because they are averse to risk (Gandorfer *et al*., 2011; Meyer-Aurich *et al*., 2009; Tew *et al*., 1986; Williams *et al*., 1990). In developing countries, particularly in Sub-Saharan Africa, there is skepticism about the effectiveness of reduced tillage (Giller *et al*., 2009, 2011; Halbrendt *et al*., 2014; Tessema *et al*., 2015). As a policy response, various payment schemes are used to encourage farmers' adoption of reduced tillage in the USA and European Union (Claassen *et al*., 2008; Kertész and Madarász, 2014; Power, 2010; Ribaudo *et al*., 2010). In developing countries, there seems to be an implicit assumption that the documented benefits of reduced tillage are sufficient incentive for its widespread adoption. But dis-adoption of donor-supported CA interventions, including reduced tillage, has been reported (Andersson and D'Souza, 2014; Brown *et al*., 2017; Lalani *et al*., 2016; Pedzisa *et al*., 2015). Low or non-adoption of reduced tillage is also associated with lack or absence of locally adapted reduced tillage technologies (e.g. zero tillage seeders) and service providers, lack of farmers' exposure to the technologies, and high initial investment costs (El-Shater *et al*., 2016; Loss *et al*., 2015). As a result, most farmers continue practicing intensive tillage (Andersson and D'Souza, 2014; Teklewold and Mekonnen, 2017).

Thus far, most studies focus on reduced tillage, and there is a lack of evidence on the risk and productivity implications of intensive tillage practices in smallholder family farms in developing countries. In moisture stressed areas of the Nile Basin of Ethiopia, Teklewold and Mekonnen (2017) find that reduced tillage has the potential to increase farm income from major cereals. On the other hand, they show that higher tillage intensities increase farm income in higher rainfall areas. Our study is a contribution to this literature by studying the productivity impact of intensive tillage practices using a different dataset for a single crop. Given that various crops may respond differently to tillage practices, analysing the crop level impact of various intensities of tillage is important. Furthermore, to the best of our knowledge, this research is the first that documents the impact of intensive tillage practices on farmers' risk exposure in developing countries. Finally, previous studies of reduced tillage treat non-adopters as an homogeneous group. Nevertheless, farmers who practice some form of tillage (either oxen or tractor based) are more likely to be heterogeneous (Teklewold and Mekonnen, 2017). Our data provide us with an opportunity to understand the heterogeneous effects of various intensities of tillage. Heterogeneous effects of tillage practices may imply that farmers' tillage decisions are influenced by unobserved factors (e.g. managerial skills). In order to handle selection bias stemming from unobserved heterogeneity, we estimate a flexible moment-based production function using an endogenous switching regression treatment effects model.

The rest of this paper is structured as follows. In section 2, we briefly discuss the study areas, the data and sampling procedure. Section 3 describes the econometric methods and we present the results in section 4. Section 5 concludes.

2. Study Areas, Data and Sampling Procedure

We use household survey data collected by the International Maize and Wheat Improvement Center (CIMMYT) and the Ethiopian Institute of Agricultural Research (EIAR). Wheat production is rain-fed in Ethiopia. Rainfall in the survey areas were 1200 mm and 1207 mm in 2009/10 and 2013/14, respectively (Fick and Hijmans, 2017). The majority of the survey areas (more than 90%) are at least 2,000 meters above sea level. The survey is representative of the main wheat producing zones of Ethiopia, and was collected in two rounds (Tolemariam *et al.*, 2016). The survey covers the 2009/10 and 2013/14 harvesting seasons. In the first step, 148 major wheat-growing districts that passed the minimum 2,000 ha wheat area per district threshold were purposely selected. In these districts, after taking account of differences in agro-ecologies, 120 peasant associations (PA), the smallest administrative unit, were then randomly selected. Finally, well-trained teams of enumerators interviewed 15 to 18 households in each PA, leading to 2,096 households in the sample. Most of these households were also interviewed in the second round of the survey.

The survey instrument was a structured questionnaire. Detailed plot and household characteristics were collected. Among these, the key variables of interest include plot characteristics such as slope, colour and fertility of the soil, the presence of production stresses (e.g. drought), and plot size. Besides, data were collected on detailed farm management practices such as crop rotation, residue management, use of improved varieties and manure application. Farmers provided information on quantity of production, expenses on fertilisers and other agrochemicals, number of labour days and oxen days spent for each plot. Also collected were characteristics of the head of the household such as education, age, sex, number of (non) relatives he/she relies on within and outside the village, and his/her confidence in government officials and extension workers. Other household-level variables include number of extension contacts per year, and whether the household received food relief from the government.

The dataset has close to 6,000 wheat plots in both rounds. We drop extreme observations below the 1st or above the 99th percentile of the yield distribution (Abdul-Salam and Phimister, 2016). We use 5,891 plots from 1,928 households in our regressions. Among the 1,928 households, 1,420 exist in both rounds while 508 households were only in either the 2009/10 or 2013/14 round. The unbalanced data show that some households did not produce wheat in one of the two survey years.

3. Econometric Strategy

Our objective is to estimate the impact of intensity of tillage on both productivity and risk exposure. In this paper, productivity is measured by the quantity of production per hectare (yield). Risk exposure is measured by the second central moment (variance) and third central moment (skewness) of the error distribution of yield after controlling for differences in inputs, household and plot characteristics. We proxy our main variable of interest, the intensity of tillage, by the frequency of tillage for each plot. This proxy may not reflect differences in the strength of the oxen draft power and the quality of other farming equipment (particularly the traditional plough). However, these quality differences are more likely to be time invariant since farmers are less likely to change these factors over a short period so that our econometric method should handle such potential heterogeneities. In what follows, we first discuss the procedures we follow for the estimation of the mean yield function, variance, and the skewness of the error distributions. Next, we discuss the econometric methods and how the results are interpreted.

3.1. Moment-based flexible production function

We disentangle the impact of intensity of tillage on mean yield, variance and skewness using a flexible moment-based production function proposed by Antle (1983). The flexible moment-based production function divides the variation in yield into two parts. First, differences in inputs and other observable characteristics explain part of the variation in yield, which is the mean effect of the explanatory variables on yield. Second, the unexplained variation of yield (the error distribution) is modelled as an economic structure reflecting the riskiness of agricultural production (Antle, 1983; Asche and Tveterås, 1999; Just and Pope, 1978). The error distribution of the yield function provides relevant information to analyse farmers' risk exposure. Skewness measures the extent of farmers' downside risk exposure (e.g. crop failure) by distinguishing unexpected bad and good events, but the variance does not (Di Falco and Chavas, 2009; Di Falco and Veronesi, 2014). Despite this disadvantage of the variance, we use both variance and skewness as a measures of risk exposure. Using both measures helps to understand the total cost of risk.

Following Di Falco and Veronesi (2014), we assume a continuous and twice differentiable production function $y = g(\boldsymbol{x}, \upsilon)$ where y is yield, $\boldsymbol{x}$ is a vector of explanatory variables and υ is a random variable representing risks associated with random shocks (e.g. rainfall and temperature). The probability distribution of $g(\boldsymbol{x}, \upsilon)$ is given by:

$$g(\boldsymbol{x}, \upsilon) = f_1(\boldsymbol{x}, \beta_1) + u, \tag{1}$$

where $f_1(\boldsymbol{x}, \beta_1) = E[g(\boldsymbol{x}, \upsilon)]$ is the mean of $g(\boldsymbol{x}, \upsilon)$ and $\boldsymbol{u} = g(\boldsymbol{x}, \upsilon) - f_1(\boldsymbol{x}, \beta_1)$ is a heteroskedastic and non-symmetric random variable. The variance and the skewness is given by:

$$E\{[g(\boldsymbol{x}, \upsilon) - f_1(\boldsymbol{x}, \beta_1)]^m | \boldsymbol{x}\} = \boldsymbol{f_m}(\boldsymbol{x}, \boldsymbol{\beta_1}), \tag{2}$$

where $m = 2, 3$ is the second and the third central moments of the error distribution representing variance and skewness, respectively. We first test whether the distribution of u is heteroskedastic and non-symmetric, which is a precondition for the variance and skewness analysis. The null hypotheses of constant variance and symmetric distribution are rejected at the 10% level of significant or below for most of the models (see Table S3 in the online Appendix). We then estimate the mean function $f_1(\boldsymbol{x}, \beta_1)$, the variance $f_2(\boldsymbol{x}, \beta_1)$ and the skewness $f_3(\boldsymbol{x}, \beta_1)$.

3.2. The endogenous switching regression model

Farmers' choice of tillage may be dependent on the benefit they get from a specific intensity of tillage, given the information they have about their plots and their resource endowments. But all the factors that motivate the farmers to choose a specific intensity of tillage may not be observed, which creates a sample selection problem. For example, farmers may have unobserved private information about the quality of the land, and failing to account for such unobserved factors may introduce estimation bias (Kassie *et al.*, 2015b). Endogeneity may also arise because some of the explanatory variables (e.g. plot characteristics such as slope) may influence both the choice of the intensity of tillage and the outcome variables, yield and risk exposure (Alene and Manyong, 2007).

The other important issue to consider in our estimation is that intensive tillage practices may affect the productivity of inputs. For instance, a well-prepared seedbed through intensive tillage may supress weeds. Low weed density in turn may increase the productivity of labour because higher yield could be achieved with a reduced amount of weeding labour. In order to take this in to account, we could introduce non-linearity to the intensity of tillage by estimating a linear model and introducing quadratic and interaction terms with inputs. This approach is not convenient in the sense that we need to instrument not only the intensity of tillage and the quadratic term of the intensity of tillage but also the interaction terms between inputs and intensity of tillage. Furthermore, we are not interested in the coefficients of the explanatory variables *per se*. Rather, we want to establish a counterfactual framework in order to compare the impact of each intensity of tillage with a counterfactual outcome had the plots that were ploughed at higher intensities of tillage been ploughed at a lower intensity of tillage. For these reasons, we use the endogenous switching regression model (ESR) which is a convenient econometric method of obtaining counterfactual outcomes by estimating separate production functions for each intensity of tillage. The ESR helps us to control for the sample selection and endogeneity problems while allowing complete interaction between the explanatory variables (including inputs) and intensity of tillage (Alene and Manyong, 2007; Kabunga *et al.*, 2012; Kassie *et al.*, 2010).

We estimate the ESR in six[3] regimes as follows (Di Falco and Veronesi, 2014; Kassie *et al.*, 2010):[4]

$$Y_{IT} = \beta_{IT}\boldsymbol{X}_{IT} + \rho_{IT}\boldsymbol{P}_{IT} + \vartheta_{IT}\boldsymbol{H} + \tau_{IT}T + \pi_{IT}\boldsymbol{D} + \theta_{IT}\bar{\boldsymbol{M}}_{IT} + \sigma_{IT}\hat{\lambda}_{IT} + \varepsilon_{IT} \tag{3}$$

where IT = 2,3,4,5,6 and 7 or more and indicates the intensity of tillage. Y is logarithm of yield and $\boldsymbol{X}$ represents expenses on fertilisers and agrochemicals, labour days, and oxen days, all in logarithms. Since several farmers used no fertilisers or other agrochemicals, we follow Battese (1997): after taking logarithms, undefined values are replaced by zero, and additional dummy variables are added to indicate zero quantities of particular inputs. $\boldsymbol{P}$ is a vector of plot characteristics, farm management practices (e.g. crop residue retention), and production stresses (e.g. drought). $\boldsymbol{H}$ is a vector of household-level variables (e.g. education, age and sex of the head), whether the household receives food relief from the government, social status (measured by the number of people that the farmers know inside and outside the village) and whether the farmers are confident in the skills of the extension workers and government

[3]The few plots that were ploughed <2 times and more than seven times are clubbed to intensities of tillage 2 and 7 times, respectively.

[4]We avoid notational cluttering by suppressing the subscripts referring to plot i, household j and time t.

officials. T is a time dummy that takes a value of 1 for 2013/14 and 0 for 2009/10. $\boldsymbol{D}$ is a vector of dummies of agro-ecology that controls for differences in weather patterns and other unobserved characteristics of each agro-ecology. $\varepsilon_{IT} = u_j + e_{ij}$ represents composed error terms of unobserved heterogeneity (u_j) for household j and the usual error terms of plot i in household j . The β, ρ, ϑ, τ, π, θ and σ are parameters to be estimated.

Equation (3) could be estimated using either a fixed or random effects estimator. We choose to estimate all of the terms in (3) using random effects for two reasons. First, our data show that the cross-sectional variation is consistently higher than the within variation for both the dependent and independent variables. In such situations, the random effects estimator is more efficient than the fixed effects because it uses both the cross-sectional and the variation of the variables over time. Second, if we use the fixed effects estimator, we would lose a sizeable 508 observations that produced wheat only either in 2009/10 or 2013/14. Unlike the fixed effects estimator, however, the random effects model hinges on a strong assumption that unobserved heterogeneity (e.g. innate ability and unobserved quality differences in oxen power) are independent of the explanatory variables. In order to avoid incorrect inference from biased estimated coefficients because of endogeneity (correlations between the explanatory variables and time invariant unobserved heterogeneity), we use the Mundlak's fixed effects, which is represented by $\bar{\boldsymbol{M}}$ in equation (3). In the Mundlak's fixed effects, we assume that the time invariant unobserved heterogeneity (u_j) is a linear function of the averages of the time and plot varying explanatory variables ($\bar{\boldsymbol{M}}$), $u_j = \boldsymbol{\theta}\bar{\boldsymbol{M}} + \gamma_j$ with $\gamma_j \sim IID(0, \sigma^2)$, where $E(\gamma_j \bar{M}) = 0$ and $\boldsymbol{\theta}$ is the corresponding vector of coefficients, and γ_j is a normally distributed error term uncorrelated with $\bar{\boldsymbol{M}}$ (Di Falco and Veronesi, 2014; Mundlak, 1978).

In equation (3), the $\hat{\boldsymbol{\lambda}}$ s are selection correction terms, and they are defined as:

$$\hat{\lambda}_{IT} = \sum_{IT \neq r}^{M} \delta_{IT} \left[\frac{\hat{P}_{IT} \ln \hat{P}_{IT}}{1 - \hat{P}_{IT}} + \ln \hat{P}_r \right].$$

$\hat{P}_r$ is the probability of choosing the rth intensity of tillage (Bourguignon *et al.*, 2006; Dubin and McFadden, 1984). The probabilities are estimated using a random effects ordered logit model (REOLM). δ_{IT} is the correlation coefficient between the error terms of the REOLM and the regime switching equations (3), ε_{IT}.

For model identification, in addition to the non-linear selection terms, $\hat{\lambda}$, we use an exclusion restriction that correlates with intensity of tillage but not with yield or risk exposure (Di Falco *et al.*, 2011). We use the peasants' association (PA), the smallest administrative unit, median frequency of tillage as an exclusion restriction. Since individuals belonging to the same group tend to be similar in behaviour (Angrist, 2014; Manski, 1993), we hypothesise that the PA's tillage practices may tend to shape a farmer's practice in a particular plot. Thus, the PA's median frequency of tillage is more likely to be correlated with the frequency of tillage for a given plot, but should not affect a given plot's yield directly. Covariate shocks such as changes in weather patterns could affect both the intensity of tillage, and yield and risk exposure.[5] We control for the various shocks and fixed effects of agro-ecology in both the REOLM and second stage regressions. Therefore, the median frequency of tillage could pick up

[5]We regressed the median frequency of tillage against various shocks, and we confirm the two are correlated.

inherent differences in production potentials and profitability of tillage choice stemming from unobserved factors. A falsification test, following Di Falco *et al.* (2011), shows that the exclusion restriction is statistically valid for 15 of the 18 equations (see the online Appendix, Tables S3–S5).

3.3. Counterfactual analysis

Our main objective is to estimate the treatment effects of increasing the intensity of tillage on yield and risk exposure (variance and skewness). Selection-corrected predictions of the counterfactual yield and risk exposure are obtained from equation (3) (Bourguignon *et al.*, 2006). The counterfactual outcome is defined as the expected wheat yield and risk exposure of higher tillage intensities (3,4,5,6,7 or more) that would have been obtained if the returns (coefficients) on their characteristics ($\boldsymbol{X}_{IT}$) had been the same as the returns (coefficients) on the characteristics ($\boldsymbol{X}_{IT}$) of the reduced tillage intensities ($IT = 2$). We obtain the actual conditional expectations in the sample and the conditional expectations for the counterfactual outcome using equations (4a) and (4b), respectively, as follows:

$$E(Y_{IT}|IT = i) = \beta_{IT}\boldsymbol{X}_{IT} + \sigma_{IT}\hat{\lambda}_{IT}, i = 3, 4, 5, 6, 7 \text{ or more} \quad (4a)$$

$$E(Y_2|IT = i) = \beta_2\boldsymbol{X}_{IT} + \sigma_2\hat{\lambda}_{IT}, i = 3, 4, 5, 6, 7 \text{ or more} \quad (4b)$$

All the right-hand side variables in equations (3) are subsumed in $\boldsymbol{X}$ in equations (4a–4b). The average treatment effects on the treated (ATTs) for both yield and risk exposure (variance and skewness) are calculated using equation (5) (Di Falco and Veronesi, 2014):

$$\text{ATTs} = E(Y_{IT}|IT = i) - E(\text{Y}_2|IT = i) = (\beta_{IT} - \beta_2)\boldsymbol{X}_{IT} + (\sigma_{IT} - \sigma_2)\hat{\lambda}_{IT}, \quad (5)$$

where IT = 3,4,5,6,7 or more. Positive ATTs for yield show that the chosen intensity of tillage increases farmers' yield relative to the counterfactual outcome. Similarly, when the ATTs of the skewness are positive, higher intensities of tillage reduces downside risk exposure. On the contrary, when the ATTs of the variance are positive, it indicates that higher intensities of tillage tend to increase variance of yield and vice versa.

3.4. The impact of intensity of tillage on the cost of risk

Tillage is an *ex-ante* risk management strategy used by farmers in order to minimise production risks that may arise due to high incidence of diseases and weeds, among other benefits. We estimate the cost of risk to each intensity of tillage and the counterfactual outcome using a quantile-based approach developed by Kim *et al.* (2014) and used in empirical applications by Kassie *et al.* (2015b). The quantile-based approach represents the risk-preference of the decision-maker by the Constant Relative Risk-Aversion (CRRA) utility function: $U(Q) = (Q^{1-b})/(1 - b)$, where $Q > 0$ is yield and $b > 0$ is the relative risk aversion coefficient. The cost of risk is measured by the risk premium (R) using equation (6) (Kassie *et al.*, 2015b; Kim *et al.*, 2014):

$$R \approx 0.5 \times [F(b_k) - F(b_{k-1})] \times \left\{ \frac{b(m_{k1})^{-b-1}}{\sum_{i=1}^{k} \left\{ [F(b_k) - F(b_{k-1})] \times (m_{i1})^{-b} \right\}} \times m_{k2} + \left[b(M_1)^{-1} \right] \times [m_{k1} - M_1]^2 \right\} + \left(\frac{1}{6}\right) \times [F(b_k) - F(b_{k-1})] \times \left\{ -\frac{b(1+b)(m_{k1})^{-b-2}}{\sum_{i=1}^{k} \left\{ [F(b_k) - F(b_{k-1})] \times (m_{i1})^{-b} \right\}} \times m_{k3} - \left[b(1+b)(M_1)^{-2} \right] \times [m_{k1} - M_1]^3 \right\} \tag{6}$$

where m_{k1}, m_{k2} and m_{k3} are the partial mean, variance and skewness of yield distributions in quantile k, respectively; $F(b_k)-F(b_{k-1})$ is the probability of each partial central moment in quantile k; M_1 is the overall all central moment of the distribution of yield in quantile k. The cost of risk is computed for each quantile by using the predicted values of yield, variance and skewness for both the actual and counterfactual conditions in equation (4a) and equation (4b), respectively.

4. Results

4.1. *Intensity of tillage, input use and yield*

In this subsection, we present the intensity of tillage practices, input use and its correlation with yield. The summary statistics, definitions and measurements for all the explanatory variables used in our regressions are presented in our online Appendix, Table S1. In Table 1, we show that 83% of the plots were ploughed between 3 to 5 times, which is within the recommended frequency of tillage by the Ethiopian extension system (MOA, 2014). For the remaining 17% of the plots, farmers ploughed below or above the recommended intensity of tillage. 5% of the plots were ploughed 2 or fewer times, and the majority of these (4%) were ploughed twice. Plots that were ploughed 6 times were approximately 8%. For another 5% of the plots, farmers ploughed 7 or more times. Since the

Table 1
Frequency of tillage (2009/10–2013/14) (%)

Frequency of tillage	Number of plots	%
2	307	5.1
3	1,648	27.6
4	2,083	34.8
5	1,205	20.2
6	455	7.6
7 or more	283	4.7
Total	5981	100

number of no-till[6] plots (28) and plots that were ploughed once (19) were very small, they were categorised with plots that were ploughed twice.[7] Similarly, the number of plots that was ploughed more than 7 times were only 75, and they were categorised with plots that were ploughed 7 times.[8]

The households' tillage practices may vary from time to time. This is shown in Table 2 using a transition matrix. We calculate the household-level transition matrix by using the plot level frequencies of tillage for each round. The diagonal cells of Table 2 show the percentage of households who do not change the frequency of tillage across rounds. At the frequency of tillage equal to 4 or below, the majority of the households choice of the frequency of tillage remains identical over the 2 years. But when the frequency of tillage is 5 or above, the percentage of households who chose identical frequency of tillage over the 2 years is below 40%.

Table 2

Transition matrix: Change in frequency of tillage between 2009/10 and 2013/14 (%)

		2013/14						
Frequency of tillage		2	3	4	5	6	7 or more	Total
2009/10	2	49.1	37.7	11.3	0.0	0.0	1.9	100
	3	7.4	58.6	28.6	3.4	1.4	0.6	100
	4	1.9	25.0	55.3	15.4	1.9	0.6	100
	5	0.7	8.8	41.2	38.5	9.5	1.4	100
	6	0.7	3.4	19.7	43.5	19.1	13.6	100
	7 or more	0.0	4.3	10.8	25.8	31.2	28.0	100

[6]The no-till plots are not strictly zero tillage plots as defined in the conservation agriculture literature. Farmers reported that 17 of the 28 no-till plots have a steep slope while they reported that the fertility of the soil is poor in 20 of the 28 no-till plots. These plots are no-till plots perhaps because the topography of the plot is not convenient for ploughing. They also do not use any mechanised form of farming methods (e.g. zero-tillage seeders). Farmers may use hoes for sowing and ploughing is not needed.

[7]Having a separate category for no-till plots remains important if there are enough observations. When we group the no-till plots and plots that were ploughed once with those plots that were ploughed twice, the grouping may hide potential differences in yield and risk exposure. We used a joint F test for this case. First, we created two dummy variables. *NOTILL* equals 1 if the plots are no-till plots and 0 otherwise, and *ONETILL* equals 1 if the plots were ploughed once and 0 otherwise. Next, we run a regression by taking yield as a dependent variable, and *NOTILL*, *ONETILL* and other factors in equation (3) as explanatory variables. After controlling for confounding factors, the coefficients of *NOTILL* and *ONETILL* are not jointly significant (F test: Chi squared= 2.81 and p-value= 0.25) showing that there is no yield difference between the no-till plots, plots that were ploughed once, and the plots that were ploughed twice. We conclude that we do not face a serious problem of hiding potential heterogeneities by grouping these plots. However, the coefficient of *NOTILL* is negative and significant at 10% indicating that the yield of no-till plots tends to be lower than plots that were ploughed twice. We also undertook the same regression taking our measures of risk exposure (skewness and variance) as dependent variables. The results show that *NOTILL* and *ONETILL* are not statistically significant, individually and jointly.

[8]Following the approach in footnote 7, yield and downside risk are not significant (F test: Chi squared = 0.34 and P-value = 0.84) between plots that were ploughed 7 times and 8 or more times.

In Table 2, the cells to the right of the diagonal indicate that the households increase tillage frequency between 2009/10 and 2013/14. The values to the left of the diagonal show that households' frequency of tillage declines across rounds. Most of the changes in households' choice of tillage frequency is to the left of the diagonal showing a reduction in the frequency of tillage across years. A small proportion of the households increased their frequency of tillage. Irrespective of increasing or decreasing the frequency of tillage, we do not observe a significant jump in the choice of the frequency of tillage to an extremely high or low intensity of tillage. Rather the majority of the households tend to increase or decrease the intensity of tillage to the next higher or lower tillage intensity. Even though the transition matrix hides potential heterogeneities across plots within a household, it gives an insight that most households have changed the frequency of tillage over the survey period.

In Figure 1, we present a scatter plot depicting the correlation between the frequency of tillage and yield. As Figure 1 shows, we observe that yield and frequency of tillage are positively correlated indicating that yield tends to increase with frequency of tillage. However, the relationship shown in Figure 1 does not control for differences in inputs and other confounding factors that may explain part of the variation in yield.

In Table 3, we show average input use by the frequency of tillage. As expected, the use of oxen increases with the frequency of tillage. However, the labour requirement declines as the frequency of tillage increases, reflecting the decline in the need to control for weeds. The quantity of labour for weeding is low at higher frequencies of tillage suggesting that farmers might be able to control weeds by increasing tillage or by increasing use of herbicides. We are unable to identify if the cost of agrochemicals at a

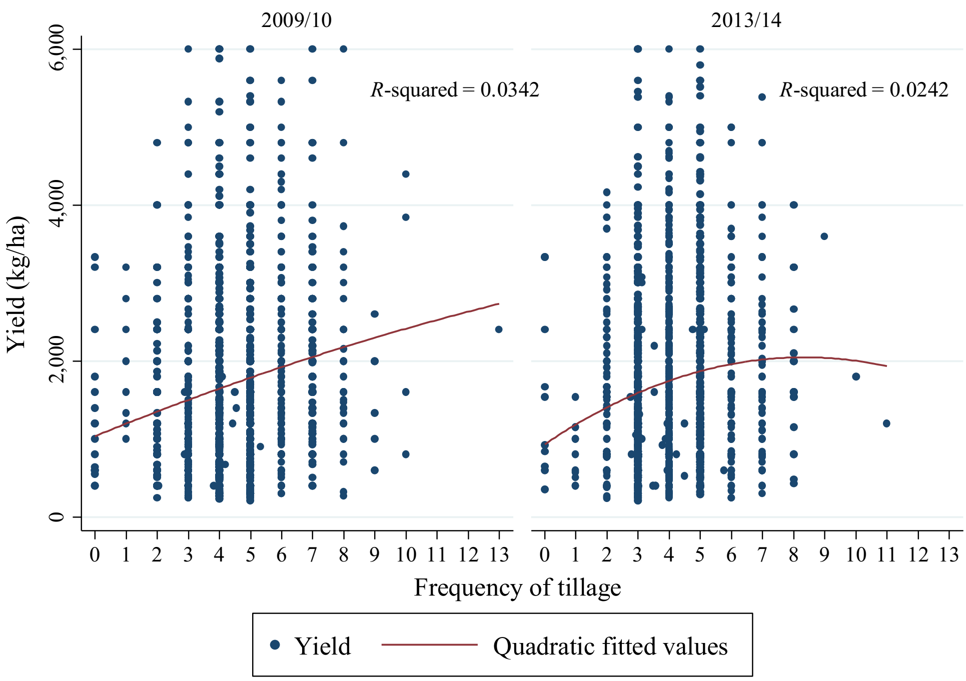

Figure 1. Wheat yield distributions by frequency of tillage and survey year [Colour figure can be viewed at wileyonlinelibrary.com]

Table 3
Inputs use and intensity of tillage (2009/10–2013/14)

Inputs	Frequency of tillage						
	2	3	4	5	6	7 or more	Total
Oxen power (days/ha)	14.4	19.0***	23.7***	28.1***	33.3***	37.6***	24.2
	(7.4)	(9.1)	(9.9)	(11.6)	(14.8)	(14.9)	(12.0)
Labour (days/ha)	103.4	111.2*	92.4**	78.5***	82.8***	89.2**	94.5
	(87.1)	(85.0)	(79.1)	(59.3)	(47.5)	(65.1)	(76.0)
Labour for land preparation (days/ha)	15.4	15.4***	18.3***	21.4***	26.3***	28.2***	19.1
	(19.2)	(11.1)	(10.0)	(14.0)	(18.5)	(16.5)	(13.4)
No rotation in the plot	16.4	14.7	17.1	19.7	27.2***	28.7**	17.6
	(23.7)	(9.0)	(8.2)	(17.3)	(32.3)	(13.4)	(14.5)
Legume rotation in the plot	10.4	15.1***	18.9***	22.9***	26.7***	26.3***	17.6
	(6.1)	(11.7)	(11.0)	(15.5)	(18.8)	(21.3)	(12.6)
Other cereals rotation in the plot	20.7	15.9***	18.4*	21.5	26.0***	28.5***	20.1
	(25.0)	(11.4)	(10.1)	(12.6)	(15.0)	(16.5)	(13.3)
Labour for weed control (days/ha)	34.2	37.2	24.8***	16.1***	15.0***	14.6***	25.7
	(37.7)	(44.0)	(39.6)	(24.7)	(21.2)	(19.8)	(37.4)
No rotation in the plot	28.6	40.3**	25.5	12.3***	8.7***	10.8*	26.6
	(35.1)	(41.1)	(38.0)	(26.4)	(10.8)	(14.7)	(37.5)
Legume rotation in the plot	35.3	43.1*	32.0	20.7***	19.4**	19.9	34.2
	(34.5)	(47.4)	(51.1)	(30.9)	(23.9)	(35.8)	(45.9)
Other cereals rotation in the plot	35.1	32.2	21.3***	15.9***	15.6***	15.6***	22.0
	(42.0)	(42.0)	(32.9)	(22.3)	(22.0)	(18.8)	(32.6)
Expenses on fertilisers (Birr/ha)[a]	578.2	697.8***	829.0***	830.8***	931.1***	995.9***	796.0
	(691.8)	(687.1)	(724.6)	(621.5)	(649.9)	(711.4)	(692.9)
Expenses on other agrochemicals (Birr/ha)[a]	9.5	25.6***	39.2***	55.6***	50.7***	57.5***	39.0
	(24.2)	(59.9)	(60.8)	(70.1)	(51.4)	(61.3)	(62.0)

Notes: (i) Standard deviations are in parentheses, (ii) the comparison group for the statistical test is ≤2, (iii) ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, (iv) [a]the expenses are in real terms, deflated by zone level price index.

higher frequency of tillage is driven by uses of herbicides, fungicides or pesticides because we do not have accurate data for each. Using information about the previous season's crop for each of the wheat plots, we show that higher intensities of tillage are associated with a lower number of labour days spent on weed control regardless of the status of crop rotation. Despite the fact that strategic choice of crop rotations may help to control for weeds, our data show that the mean number of labour days spent on weeding tends to be low in plots that did not use crop rotation.

Table 3 further shows that higher frequency of tillage is associated with high expenses on fertilisers and agrochemicals. This may reflect that those who plough at a higher frequency are wealthier with a better command of important inputs to invest in their plots. However, the standard deviation reveals that the variability of fertilisers and agrochemicals expenses are high showing the existence of strong heterogeneity in input use. The heterogeneity in input use may indicate that the responsiveness of inputs to yield may differ depending on the choice of tillage frequency. In the next subsection, we present our empirical results after controlling for these potential heterogeneities by allowing the inputs and other explanatory variables to have a differential effect on yield for each intensity of tillage.

4.2. Econometric results

Our primary interest is to quantify the impact of intensity of tillage on yield and risk exposure. As a result, we do not discuss the coefficients of each of the models in detail. The estimation results are provided in the online Appendix, Tables S2–S5. In the rest of this subsection, we present the average treatment effects on the treated (ATTs) and the cost of risk measured by the risk premium.

4.2.1. Impact of intensities of tillage on yield and risk exposure

In Table 4, we present the ATTs of yield and measures of risk exposure (variance and skewness). The rows indicate the intensity of tillage that are used as a treatment. We report the actual expected yield, variance and skewness of the error distribution of yield observed in the sample in columns (A), (D) and (G), respectively. The counterfactual expected yield, variance, and skewness are reported in columns (B), (E) and (H) of Table 4, respectively. The ATTs are estimated using the formula in equation (5). Column (C) of Table 4 shows the ATTs on yield while columns (F) and (I) show the ATTs on risk exposure.

The ATTs for yield measure the average yield a farmer could obtain by increasing the intensity of tillage in comparison to the counterfactual outcome. As column (C) of Table 4 shows, all but one of the tillage intensities show an increase in yield in comparison to the counterfactual outcome. On average, ploughing 4 times increases yield by 83 kg. The increase in yield is even higher if the farmers plough their plots 5 times leading to an average yield gain of 279 kg. Ploughing 6 times increases yield by 229 kg. The results show farmers obtain the highest yield when the intensity of tillage is 7 or more (419 kg). Since ploughing 3 times reduces yield by 45 kg, farmers may be able to increase yield by increasing the intensity of tillage. This result is consistent with Teklewold and Mekonnen (2017) who show that increasing the intensity of tillage increases net farm income in the Nile Basin of Ethiopia. Even though the method of ploughing is different, similar high expected returns from conventional tillage are

Table 4
Average treatment effects on the treated (ATTs) on yield and risk exposure (variance and skewness)

	Yield			Risk exposure					
Intensity of tillage (IT)	Actual expected yield (A)	Counterfactual expected yield (B)	ATTs = A-B (C)	Actual expected variance (D)	Counterfactual expected variance (E)	ATTs = D-E (F)	Actual expected skewness (G)	Counterfactual expected skewness (H)	ATTs = G-H (I)
3	1,296.7	1,341.3	–44.6**	0.263	0.294	–0.031***	–0.028	–0.049	0.021***
	(11.3)	(16.8)	(20.3)	(0.002)	(0.004)	(0.005)	(0.002)	(0.004)	(0.009)
4	1,521.4	1,438.3	83.1***	0.241	0.294	–0.054***	–0.028	–0.068	0.040***
	(12.0)	(16.2)	(20.1)	(0.002)	(0.004)	(0.005)	(0.001)	(0.004)	(0.004)
5	1,686.8	1,408.1	278.7***	0.224	0.299	–0.075***	–0.055	–0.092	0.037***
	(17.1)	(21.1)	(27.1)	(0.003)	(0.006)	(0.007)	(0.003)	(0.005)	(0.005)
6	1,703.2	1,473.8	229.4***	0.277	0.261	0.016	–0.065	–0.096	0.031**
	(26.3)	(32.8)	(42.1)	(0.009)	(0.009)	(0.013)	(0.010)	(0.008)	(0.012)
7 or more	1,852.0	1,433.5	418.6***	0.188	0.258	–0.069***	–0.026	–0.119	0.094***
	(40.8)	(43.2)	(59.4)	(0.008)	(0.011)	(0.014)	(0.005)	(0.010)	(0.011)

Notes: (i) ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, (ii) standard errors are in parentheses, (ii) negative (positive) values of the skewness indicate downside (upside) risk.

reported in the USA and Germany (Gandorfer *et al.*, 2011; Meyer-Aurich *et al.*, 2009; Williams *et al.*, 1990).

Our measures of risk exposure are the variance and skewness of the error distribution of yield. In column (F) of Table 4, almost all of the ATTs are negative showing that higher intensities of tillage are variance reducing. Negative values of the skewness is evidence of downside risk exposure whereas positive values indicate evidence of upside risk. Columns (G) and (H) of Table 4 show that both the actual and the counterfactual skewness values are negative indicating that farmers are likely to face downside risk. The positive ATTs for the skewness reveals that farmers' downside risk exposure tends to decline as the intensity of tillage increases (Column (I), Table 4).

Studies show that reducing the intensity of tillage is beneficial in moisture stress areas because minimum soil disturbance helps to preserve soil moisture (Kassie *et al.*, 2010, 2015b; Teklewold and Mekonnen, 2017). We check the sensitivity of our results presented in Table 4 to differences in rainfall patterns by splitting the data into three: low, medium and high rainfall areas.[9] The results are presented in our online Appendix, Table S6. Regardless of rainfall patterns, our results consistently show higher yield and lower risk exposure at higher intensities of tillage.

Finally, it is also worth noting that reducing tillage may reduce the costs of production, which may lead to a net income benefit to the farmers (Giller *et al.*, 2009; Jaleta *et al.*, 2016; Krishna *et al.*, 2016). We have analysed the impact of increasing intensities of tillage on farmers' returns to land net of variable costs of production. The ATTs for net return to land (Birr/ha), variance and skewness of its error distribution are reported in the online Appendix, Table S7. At higher intensities of tillage, the results reveal that farmers' net return to land is higher and downside risk exposure is lower, consistent with the results presented above. However, the variance of net return to land tends to increase when the intensity of tillage is five and more.

4.2.2. Impact of intensity of tillage on the cost of risk

We estimate the cost of risk using a quantile-based approach using equation (6) above. We divide the distributions of yield, variance and skewness obtained from equations (4a) and (4b) into two quantiles.[10] We use the lowest quantile in order to estimate the cost of risk because unfavourable risks are located at the lower tail of the distributions. Following Kassie *et al.* (2015b) and Kim *et al.* (2014), we give various estimated cost of risk at different levels of Constant Relative Risk-Aversion (CRRA) preferences (0.5 to 3) for both the counterfactual outcome and each intensities of tillage. The results are reported in Figure 2.

Figure 2 shows that the cost of risk is the lowest at higher intensities of tillage. As the relative risk aversion coefficient increases, the cost of risk tends to rise reflecting the fact that risk averse farmers are willing to avoid risk at a higher cost. Figure 2 further reveals that the vertical distance between the counterfactual outcome and each intensity of tillage is greatest at intensities of tillage 3 and 4, suggesting that farmers obtain the greatest reduction in the cost of risk for plots that were ploughed 3 and 4

---

[9]The source for the rainfall data is Fick and Hijmans (2017).

[10]In order to understand the sensitivity of our results to a different quantile, we divided the distributions of the yield, variance and skewness in equations (4a and 4b) into 4 equal parts and estimated the cost of risk. Even though the number of observations in each quantile drops, the conclusion we draw about the cost of risk remain the same.

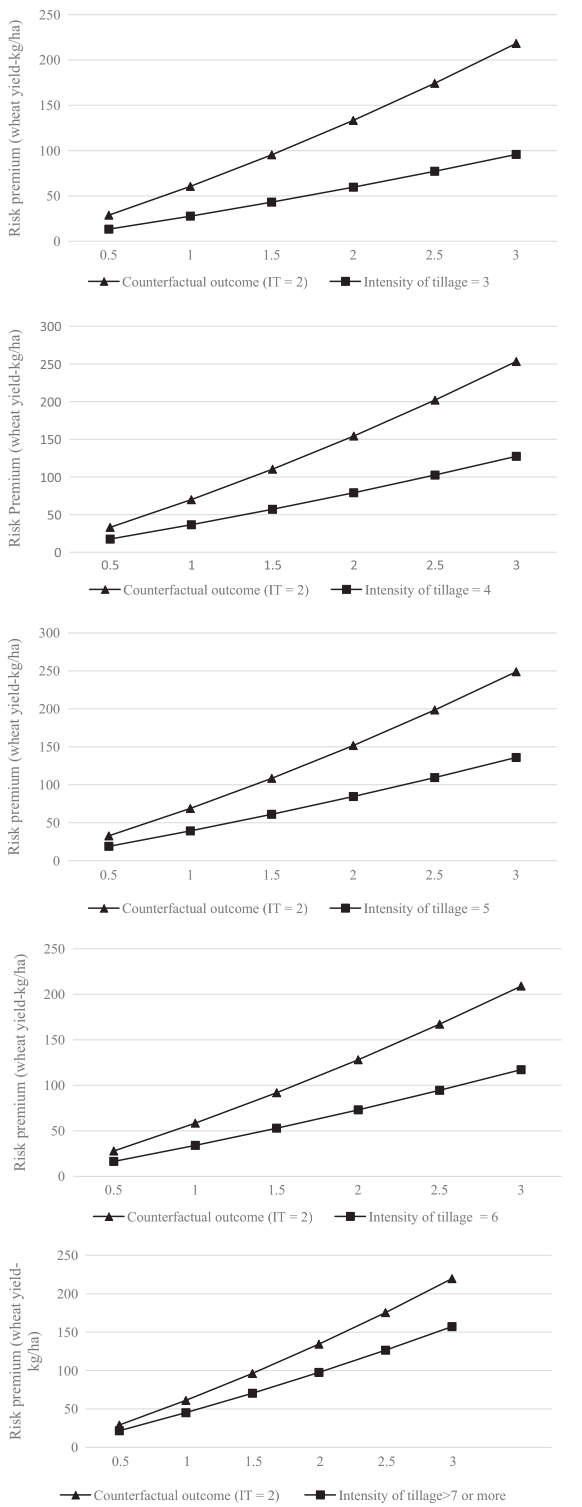

Figure 2. The impact intensity of tillage on the cost of risk

times. After the 4th intensity of tillage, in comparison to the counterfactual outcome, the contribution of an additional round of tillage to a reduction in the cost of risk tends to decline. We also find qualitatively similar results when net return to land (Birr/ha) and its variance and skewness are used as outcome variables (see online Appendix, Figure S1).

5. Concluding Remarks

In many developing countries, tilling the land is the most common practice. Tillage provides various services to the famers such as facilitating uniform and easy seed germination, suppressing weeds, increasing the soils' water infiltration rate, and reducing the incidence of various diseases. However, intensive tillage practices may lead to soil degradation by increasing soil erosion and disturbing soil microorganisms beneficial to the soil ecosystem. Agricultural scientists, international organisations and national governments promote reduced tillage as a solution to mitigate the negative impact of soil degradation. The farm-level impacts of reduced tillage have been widely studied. However, there is limited research on the productivity and risk implications of intensive tillage practices in developing countries where many farmers practice intensive tillage.

We study the impact of intensity of tillage practices on productivity and risk exposure in major wheat producing zones of Ethiopia. Understanding the potential gains and losses from intensive tillage practices in the farmers' fields is crucial in order to promote sustainable intensification practices that considers the needs of smallholder farmers. We estimate a flexible moment-based production function using an endogenous switching regression treatment effects model. Our results show that high intensities of tillage are generally associated not only with higher yields but also with lower risk exposure. Our findings strongly suggest that farmers use tillage as a strategy to increase productivity and minimise production risks. Our results further show that the cost of risk is the lowest at the higher intensities of tillage.

Under the current circumstances of wheat farmers in Ethiopia, high intensity tillage seems to be important. Even though intensive tillage exacerbates soil erosion, the net effect tends to be positive, high expected yield and low risk exposure. Findings of impact assessments on reduced tillage interventions in many countries show that reduced tillage has the potential to improve productivity and livelihood of rural households. The findings of the studies on reduced tillage differ from our findings perhaps because the potential nonlinear effects of various intensities of tillage for non-adopters of reduced tillage were not controlled in these studies.

In the literature, there is a consensus that the full benefits of reduced tillage are realised only after many years. As our results show, there is a short-term opportunity cost of switching to reduced tillage. Promoting reduced tillage should be accompanied with incentive schemes that could potentially compensate yield losses and production risks. However, detailed crop and agro-ecological specific studies are required because the impact of intensive tillage practices might be crop and context specific. In situations where an adequate number of observations with no-till is in the sample, future studies which use similar approaches to ours will need to make a distinction between no-till and reduced tillage. Further research might be also required to identify the impact of intensive tillage on yield and risk under varying rainfall conditions, and controlling for the effects of sowing date and the history of tillage in specific plots.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Summary statistics, descriptions and measurements for the variables used in the regressions (2009/10–2013/14).

Table S2. The selection equation, random effects ordered logit model (REOLM).

Table S3. Results of the endogenous switching regressions: the dependent variables are logarithms of yield (kg/ha).

Table S4. Results of the endogenous switching regressions: the dependent variables are risk exposure (variances).

Table S5. Results of the endogenous switching regressions: the dependent variables are risk exposure (skewness).

Table S6. Average treatment effects on the treated (ATTs) on yield and risk exposure variance and skewness) by three rainfall regimes.

Table S7. Average treatment effects on the treated (ATTs): net return to land (Birr/ha) and risk exposure (variance and skewness).

Figure S1. The impact intensity of tillage on costs of risk: net return to land and risk exposure (variance and skewness).

References

Abdul-Salam, Y. and Phimister, E. 'Efficiency effects of access to information on small-scale agriculture: Empirical evidence from Uganda using stochastic frontier and IRT models', *Journal of Agricultural Economics*, Vol. 68, (2016) pp. 494–517.

Alene, A. D. and Manyong, V. M. 'The effects of education on agricultural productivity under traditional and improved technology in northern Nigeria: An endogenous switching regression analysis', *Empirical Economics*, Vol. 32, (2007) pp. 141–159.

Andersson, J. A. and D'Souza, S. 'From adoption claims to understanding farmers and contexts: A literature review of conservation agriculture (CA) adoption among smallholder farmers in southern Africa', *Agriculture, Ecosystems and Environment*, Vol. 187, (2014) pp. 116–132.

Angrist, J. D. 'The perils of peer effects', *Labour Economics*, Vol. 30, (2014) pp. 98–108.

Antle, J. M. 'Testing the stochastic structure of poduction: A flexible moment-based approach', *Journal of Business & Economic Statistics*, Vol. 1, (1983) pp. 192–201.

Aryal, J. P., Sapkota, T. B., Stirling, C. M., Jat, M. L., Jat, S. H., Rai, M., Mittal, S. and Sutaliya, J. M. 'Conservation agriculture-based wheat production better copes with extreme climate events than conventional tillage-based systems: A case of untimely excess rainfall in Haryana, India', *Agriculture, Ecosystems and Environment*, Vol. 233, (2016) pp. 325–335.

Asche, F. and Tveterås, R. 'Modeling production risk with a two-step procedure', *Journal of Agricultural and Resource Economics*, Vol. 24, (1999) pp. 424–439.

Aune, J. B., Bussa, M. T., Asfaw, F. G. and Ayele, A. A. 'The ox ploughing system in Ethiopia: Can it be sustained?', *Outlook on Agriculture*, Vol. 30, (2001) pp. 275–280.

Bailey, K. L. 'Diseases under conservation tillage systems', *Canadian Journal of Plant Science*, Vol. 76, (1996) pp. 635–639.

Battese, G. E. 'A note on the estimation of Cobb-Douglas production functions when some explanatory variables have zero values', *Journal of Agricultural Economics*, Vol. 48, (1997) pp. 250–252.

Bockus, W. W. and Shroyer, J. P. 'The impact of reduced tillage on soilborne plant pathogens', *Annual Review of Phytopathology*, Vol. 36, (1998) pp. 485–500.

Boomsma, C. R., Santini, J. B., West, T. D., Brewer, J. C., McIntyre, L. M. and Vyn, T. J. 'Maize grain yield responses to plant height variability resulting from crop rotation and tillage system in a long-term experiment', *Soil and Tillage Research*, Vol. 106, (2010) pp. 227–240.

Boserup, E. *Woman's Role in Economic Development. New Introduction by Nazneen Kanji, Su Fei Tan and Camilla Toulmin* (London: Earthscan, 2007).

Bourguignon, F., Fournier, M. and Gurgand, M. 'Selection bias corrections based on the multinomial logit model: Monte Carlo comparisons', *Journal of Economic Surveys*, Vol. 21, (2006) pp. 174–205.

Brown, B., Nuberg, I. and Llewellyn, R. 'Negative evaluation of conservation agriculture: Perspectives from African smallholder farmers', *International Journal of Agricultural Sustainability*, Vol. 15, (2017) pp. 467–481.

Claassen, R., Cattaneo, A. and Johansson, R. 'Cost-effective design of agri-environmental payment programs: U.S. experience in theory and practice', *Ecological Economics*, Vol. 65, (2008) pp. 737–752.

Di Falco, S. and Chavas, J.-P. 'On crop biodiversity, risk exposure, and food security in the highlands of Ethiopia', *American Journal of Agricultural Economics*, Vol. 91, (2009) pp. 599–611.

Di Falco, S. and Veronesi, M. 'Managing environmental risk in presence of climate change: The role of adaptation in the Nile Basin of Ethiopia', *Environmental & Resource Economics*, Vol. 57, (2014) pp. 553–577.

Di Falco, S., Veronesi, M. and Yesuf, M. 'Does adaptation to climate change provide food security? A micro-perspective from Ethiopia', *American Journal of Agricultural Economics*, Vol. 93, (2011) pp. 825–842.

Dubin, J. A. and McFadden, D. L. 'An econometric analysis of residential electric appliance holdings and consumption', *Econometrica*, Vol. 52, (1984) pp. 345–362.

El-Shater, T., Yigezu, Y. A., Mugera, A., Piggin, C., Haddad, A., Khalil, Y., Loss, S. and Aw-Hassan, A. 'Does zero tillage improve the livelihoods of smallholder cropping farmers?', *Journal of Agricultural Economics*, Vol. 67, (2016) pp. 154–172.

Erenstein, O., Farooq, U., Malik, R. K. and Sharif, M. 'On-farm impacts of zero tillage wheat in South Asia's rice–wheat systems', *Field Crops Research*, Vol. 105, (2008) pp. 240–252.

Fick, S. E. and Hijmans, R. J. 'Worldclim 2: New 1-km spatial resolution climate surfaces for global land areas', *International Journal of Climatology*, (2017).

Gandorfer, M., Pannell, D. and Meyer-aurich, A. 'Analyzing the effects of risk and uncertainty on optimal tillage and nitrogen fertilizer intensity for field crops in Germany', *Agricultural Systems*, Vol. 104, (2011) pp. 615–622.

Giller, K. E., Witter, E., Corbeels, M. and Tittonell, P. 'Field crops research conservation agriculture and smallholder farming in Africa: The heretics' view', *Field Crops Research*, Vol. 114, (2009) pp. 23–34.

Giller, K. E., Corbeels, M., Nyamangara, J., Triomphe, B., Affholder, F., Scopel, E. and Tittonell, P. 'A research agenda to explore the role of conservation agriculture in African smallholder farming systems', *Field Crops Research*, Vol. 124, (2011) pp. 468–472.

Grabowski, P. P., Kerr, J. M., Haggblade, S. and Kabwe, S. 'Determinants of adoption and disadoption of minimum tillage by cotton farmers in eastern Zambia', *Agriculture, Ecosystems and Environment*, Vol. 231, (2016) pp. 54–67.

Guan, D., Zhang, Y., Al-kaisi, M. M., Wang, Q. and Zhang, M. 'Tillage practices effect on root distribution and water use efficiency of winter wheat under rain-fed condition in the North China Plain', *Soil & Tillage Research*, Vol. 146, (2015) pp. 286–295.

Halbrendt, J., Gray, S. A., Crow, S., Radovich, T., Kimura, A. H. and Tamang, B. B. 'Differences in farmer and expert beliefs and the perceived impacts of conservation agriculture', *Global Environmental Change*, Vol. 28, (2014) pp. 50–62.

Hobbs, P. R., Sayre, K. and Gupta, R. 'The role of conservation agriculture in sustainable agriculture', *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, Vol. 363, (2008) pp. 543–555.

Jaleta, M., Kassie, M., Tesfaye, K., Teklewold, T., Jena, P. R., Marenya, P. and Ernstein, O. 'Resource saving and productivity enhancing impacts of crop management innovation packages in Ethiopia', *Agricultural Economics*, Vol. 47, (2016) pp. 513–522.

Just, R. E. and Pope, R. D. 'Stochastic specification of production functions and economic implications', *Journal of Econometrics*, Vol. 7, (1978) pp. 67–86.

Kabunga, N. S., Dubois, T. and Qaim, M. 'Yield effects of tissue culture bananas in Kenya: Accounting for selection bias and the role of complementary inputs', *Journal of Agricultural Economics*, Vol. 63, (2012) pp. 444–464.

Kassam, A., Friedrich, T., Shaxson, F. and Pretty, J. 'The spread of conservation agriculture: Justification, sustainability and uptake', *International Journal of Agricultural Sustainability*, Vol. 7, (2009) pp. 292–320.

Kassie, M., Zikhali, P., Pender, J. and Köhlin, G. 'The economics of sustainable land management practices in the Ethiopian highlands', *Journal of Agricultural Economics*, Vol. 61, (2010) pp. 605–627.

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P. and Ernstein, O. 'Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa', *Land Use Policy*, Vol. 42, (2015a) pp. 400–411.

Kassie, M., Teklewold, H., Marenya, P., Jaleta, M. and Erenstein, O. 'Production risks and food security under alternative technology choices in Malawi: Application of a multinomial endogenous switching regression', *Journal of Agricultural Economics*, Vol. 66, (2015b) pp. 640–659.

Kertész, Á. and Madarász, B. 'Conservation agriculture in Europe', *International Soil and Water Conservation Research*, Vol. 2, (2014) pp. 91–96.

Kim, K., Chavas, J. P., Barham, B. and Foltz, J. 'Rice, irrigation and downsiderisk: A quantile analysis of risk exposure and mitigation on Korean farms', *European Review of Agricultural Economics*, Vol. 41, (2014) pp. 775–815.

Krishna, V. V. and Veettil, P. C. 'Productivity and efficiency impacts of conservation tillage in northwest Indo-Gangetic Plains', *Agricultural Systems*, Vol. 127, (2014) pp. 126–138.

Krishna, V., Keil, A. and Aravindakshan, S. 'Conservation tillage for sustainable wheat intensification in South Asia', in: P. Langridge (ed.), *Achieving Sustainable Cultivation of Wheat. Volume 2. Cultivation Techniques* (Cambridge, UK: Burleigh Dodds Science Publishing Limited, 2016, pp. 1–22).

Krupinsky, J. M., Halvorson, A. D., Tanaka, D. L. and Merrill, S. D. 'Nitrogen and tillage effects on wheat leaf spot diseases in the northern Great Plains', *Agronomy Journal*, Vol. 99, (2007) pp. 562–569.

Lal, R. 'Managing world soils for food security and environmental quality', *Advances in Agronomy*, Vol. 74, (2001) pp. 155–192.

Lalani, B., Dorward, P., Holloway, G. and Wauters, E. 'Smallholder farmers' motivations for using conservation agriculture and the roles of yield, labour and soil fertility in decision making', *Agricultural Systems*, Vol. 146, (2016) pp. 80–90.

Loss, S., Haddad, A., Khalil, Y., Alrijabo, A., Feindel, D. and Piggin, C. 'Evolution and adoption of conservation agriculture in the Middle East', in: M. Farooq and K. H. M. Siddique (eds.), *Conservation Agriculture* (Cham, Switzerland: Springer, 2015,pp. 197–224).

Magnan, N., Lybbert, T. J., Mrabet, R. and Fadlaoui, A. 'The quasi-option value of delayed input use under catastrophic drought risk: The case of no-till in Morocco', *American Journal of Agricultural Economics*, Vol. 93, (2011) pp. 498–504.

Manski, C. F. 'Identification of endogenous social effects: The reflection problem', *The Review of Economic Studies*, Vol. 60, (1993) pp. 531–542.

McCann, J. C. *People of the Plough. An Agricultural History of Ethiopia, 1800–1990* (Madison: The University of Wisconsin Press, 1995).

Meyer-Aurich, A., Gandorferb, M., Gerld, G. and Kainz, M. 'Tillage and fertilizer effects on yield, profitability, and risk in a corn-wheat-potato-wheat rotation', *Agronomy Journal*, Vol. 101, (2009) pp. 1538–1547.

MOA. *Wheat Production Extension Manual (in Amharic)* (Ethiopia's Ministry of Agriculture (MOA), Ethiopian Institute of Agricultural Research and Agricultural Transformation Agency (ATA): Addis Ababa, 2014).

Mouazen, A. M., Smalders, S., Gebregziabher, M. S., Nyssen, J., Verplancke, H., Deckers, J., Romon, H. and Baerdemaeker, J. D. 'Improving the animal drawn tillage system in Ethiopian highlands', *Soil and Tillage Research*, Vol. 95, (2007) pp. 218–230.

Mundlak, Y. 'On the pooling of time series and cross section data', *Econometrica*, Vol. 46, (1978) pp. 69–85.

Ngwira, A. R., Thierfelder, C., Eash, N. and Lambert, D. M. 'Risk and maize-based cropping systems for smallholder Malawi farmers using conservation agriculture technologies', *Experimental Agriculture*, Vol. 49, (2013) pp. 483–503.

Pedzisa, T., Rugube, L., Winter-Nelson, A., Baylis, K. and Mazvimavi, K. 'Abandonment of conservation agriculture by smallholder farmers in Zimbabwe', *Journal of Sustainable Development*, Vol. 8, (2015) pp. 69–82.

Piggin, C., Haddad, A., Khalil, Y., Loss, S. and Pala, M. 'Effects of tillage and time of sowing on bread wheat, chickpea, barley and lentil grown in rotation in rainfed systems in Syria', *Field Crops Research*, Vol. 173, (2015) pp. 57–67.

Power, A. G. 'Ecosystem services and agriculture: Tradeoffs and synergies', *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, Vol. 365, (2010) pp. 2959–2971.

Ribaudo, M., Greene, C., Hansen, L. and Hellerstein, D. 'Ecosystem services from agriculture: Steps for expanding markets', *Ecological Economics*, Vol. 69, (2010) pp. 2085–2092.

Shiferaw, B., Tesfaye, K., Kassie, M., Abate, T., Prasanna, B. M. and Mekir, A. 'Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options', *Weather and Climate Extremes*, Vol. 3, (2014) pp. 67–79.

Sime, G., Aune, J. B. and Mohammed, H. 'Agronomic and economic response of tillage and water conservation management in maize, central rift valley in Ethiopia', *Soil and Tillage Research*, Vol. 148, (2015) pp. 20–30.

Sommer, R., Ryan, J., Masri, S., Singh, M. and Diekmann, J. 'Effect of shallow tillage, moldboard plowing, straw management and compost addition on soil organic matter and nitrogen in a dryland barley/wheat-vetch rotation', *Soil and Tillage Research*, Vol. 115–116, (2011) pp. 39–46.

Stevenson, J. R., Serraj, R. and Cassman, K. G. 'Evaluating conservation agriculture for small-scale farmers in Sub-Saharan Africa and South Asia', *Agriculture, Ecosystems and Environment*, Vol. 187, (2014) pp. 1–10.

Teklewold, H. and Mekonnen, A. 'The tilling of land in a changing climate: Panel data evidence from the Nile Basin of Ethiopia', *Land Use Policy*, Vol. 67, (2017) pp. 449–459.

Teklewold, H., Kassie, M. and Shiferaw, B. 'Adoption of multiple sustainable agricultural practices in rural Ethiopia', *Journal of Agricultural Economics*, Vol. 64, (2013) pp. 597–623.

Temesgen, M., Rockstrom, J., Savenije, H. H. G., Hoogmoed, W. B. and Alemu, D. 'Determinants of tillage frequency among smallholder farmers in two semi-arid areas in Ethiopia', *Physics and Chemistry of the Earth*, Vol. 33, (2008) pp. 183–191.

Tessema, Y., Asafu-Adjaye, J., Rodriguez, D., Mallawaarachchi, T. and Shiferaw, B. 'A bio-economic analysis of the benefits of conservation agriculture: The case of smallholder farmers in Adami Tulu district, Ethiopia', *Ecological Economics*, Vol. 120, (2015) pp. 164–174.

Tew, B. V., Rafsnider, G. T., Lybecker, D. W. and Chapman, P. L. 'The relative risk efficiencies of alternative tillage practices for irrigated corn production', *North Central Journal of Agricultural Economics*, Vol. 8, (1986) pp. 83–91.

Tolemariam, A., Jaleta, M., Hodson, D., Alemayehu, Y., Yirga, C. and Abeyo, B. *Wheat Varietal Change and Adoption of Rust Resistant Wheat Varieties in Ethiopia 2009/10–2013/14* (Addis Ababa: CIMMYT, 2016).

Weiner, J., Griepentrog, H. and Kristensen, L. 'Suppression of weeds by spring wheat *Triticum aestivum*', *Journal of Applied Ecoology*, Vol. 38, (2001) pp. 784–790.

Williams, J. R., Llewelyn, R. V. and Barnaby, G. A. 'Risk analysis of tillage alternatives with government programs', *American Journal of Agricultural Economics*, Vol. 72, (1990) pp. 172–181.