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The tilling of land in a changing climate: Empirical evidence from the Nile Basin of Ethiopia

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ABSTRACT

Empirical studies point to reduced tillage as a means to increase yields and reverse land degradation. A relatively neglected avenue of research concerns why farmers increase tillage frequencies. Using household-plot level panel data from the Nile Basin of Ethiopia, this article applies a random effects ordered probit endogenous switching regression model to empirically investigate the impact of weather events and other conditioning factors on farmers' choice of tillage intensity and the effect of changing tillage frequencies on differences in farm returns. Results indicate that, while low frequency tillage is more likely in drier areas, plot-level shocks (such as pests and diseases) are key variables in the choice of high-frequency tillage. Adoption of a low-till approach leads to increasing farm returns in low-moisture areas but high-frequency tillage provides higher returns in high-rainfall areas. Understanding how farmers' tillage options correlate with climatic conditions and farm economies is salient for developing effective adaptation and mitigation plans.

1. Introduction

Soil tillage has long been one of the key components of smallholder farming systems, although reduced or zero tillage is being increasingly promoted as part of conservation agriculture as a sustainable agricultural practice (Ding et al., 2009; Kassie et al., 2015; Teklewold et al., 2013a, 2013b). Conventional tillage, which uses the traditional ox-plow with subsequent repeated tillage, is aimed at loosening the soil, controlling weeds and enhancing the penetration of moisture deep into the soil (Temesgen et al., 2008). However, there is a great concern that excessive tillage is a leading cause of high levels of surface runoff and soil erosion from arable fields, contributing to losses of soil and water, plant nutrients and organic matter (Hoogmoed et al., 2004). Soil erosion by water or wind due to intensive cultivation, deforestation and overgrazing represents the most important soil degradation process and affects more than 1 billion hectares globally (FAO, 2003). A similar soil degradation trend, with annual levels ranging from 16 to over 300 ton per hectare, is observed in Ethiopia (Tesfaye et al., 2014). Intensive tillage also tends to engender accelerated oxidative breakdown of organic matter, with accelerated release of increased volumes of CO_2 to the atmosphere, which have the potential to contribute to greenhouse gas emission (Lal et al., 1998; Kassam et al., 2009). IPCC (2001) reported that land use and land cover change and agricultural practices contribute about 20% of the global annual emission of carbon dioxide.

The agricultural and resource management literature has thoroughly documented the biophysical benefits of a minimum tillage system, a key component of conservation agriculture.[1] With its capacity for moisture conservation, reduced tillage is an important climate change adaptation strategy that farmers can use as a means to increase crop-water use efficiency to stabilize the variability of yield which is particularly important in dry land farming (Ding et al., 2009;; El-Shater et al., 2016; Grabowski et al., 2016). Less frequent tilling promotes the sequestration of carbon in agricultural soils, leading to improved soil organic carbon and subsequently promoting soil fertility and enhancing yields (Wilman, 2011).

The synergies between adaptation and mitigation due to reduced tillage are attractive because they offer the chance to make more efficient use of limited resources for reducing the effect of climate damage. Low-tillage agriculture offers mitigation potential by increasing the ability of soil to store carbon while simultaneously enriching the soil (Paustion et al., 1995). A similar study found that, under sub-tropical conditions, zero-tillage increases soil carbon from 0.1 to 0.7 t per hectare per year. Lal (2004) also shows that the carbon equivalent (CE) emissions for different tillage methods are 35.3 kg CE/ha for the

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[1] Conservation agriculture, constituting a set of principles such as reduced tillage with minimum soil disturbance, permanent soil cover through retention of crop residues, and crop diversification, has been promoted as an important resource management strategy to sustainably increase crop yields and alleviate land degradation problems (FAO 2014).

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conventional till method of seedbed preparation and 7.9 kg CE/ha for minimum till.

Despite the aforementioned benefits, uptake of reduced tillage by smallholder farmers in developing countries remains sluggish and a number of important constraints to widespread adoption have been highlighted (Kassam et al., 2009; Andersson and D'Souza, 2013; Tessema et al., 2015; Grabowski et al., 2016; Ngoma et al., 2016). There is also growing evidence that the benefits from conservation agriculture come from the interaction of reduced tillage with mulching and crop rotations (Thierfelder et al., 2013). However, in a situation where there are various market imperfections and institutional failures, competition for resources among alternative uses in the crop-livestock mixed farming system is an important factor limiting the diffusion of conservation agriculture, through constraining on-farm labor use and retention of crop residue (Valbuena et al., 2009; Magnan et al., 2011; Baudron et al., 2014; Tessema et al., 2015). Specifically, farmers have to make trade-offs between using crop residue for soil mulching and livestock feeding.

In many parts of the developing world, conventional tillage in smallholder farming systems typically includes a sequence of soil plowings, from 2 to 12 passes, to get a fine seedbed for ease of crop germination (Hobbs and Gupta, 2003; Mouazen et al., 2007) and as a means of weed control, both before and after the crop has emerged, which allows for higher farm productivity (Hobbs et al., 2008; Givens et al., 2009). For instance, in Ethiopia, wheat and teff[2] farm land is prepared by ox-plow three to five times before planting (Ito et al., 2006; Temesgen et al., 2008). Agronomic research results in Ethiopia also indicate that grain yield increased with an increasing number of plowings (IAR, 1998). While low tillage facilitates the intensification of crop production, due in part to reduced land preparation time, as well as reduced risk of soil erosion, low tillage also permits a greater accumulation of weeds, which increases labor demand for weeding or reliance on agro-chemical weed control (Chan and Pratley, 1998; Uri, 1998; Fuglie, 1999; Knowler and Bradshaw, 2007; Teklewold et al., 2013a, 2013b).

The purpose of changing tillage frequency generally falls into the following three categories: to achieve improved productivity, a private economic decision for the individual farm households; to improve the welfare (lifestyle) of the household, a private non-economic decision for the farm households; and/or to improve or preserve the environment and the natural resource base, a decision with possible benefits or costs to the society.

A relatively neglected avenue of research concerns farmers' actual options for tillage frequency, as well as short-term productivity differences due to repeated cultivation. Previous empirical studies have examined the determinants and impacts of reduced tillage, considering farmers' tillage options to be limited to the dichotomous choice of whether or not to switch to a long-term no-till regime (Kassie et al., 2015; Kassie et al., 2010; Teklewold et al., 2013a, 2013b; Wilman, 2011; Grabowski et al., 2016; Ngoma et al., 2016). While these studies concluded that reduced tillage increases farm productivity, they are imposing an *apriori* restriction that this effect is constant across the number of times that a farmer tills. To the best of our knowledge, empirical evidence on the heterogeneous effect of tillage frequency on farm economies is scarce, and discussions of the implications of such evidence are virtually non-existent. For this reason, our paper aims to fill this gap in the literature. In addition, despite the recent evidence that drought significantly increases the adoption of soil and water conservation systems (Asfaw et al., 2016), understanding the ways in which climatic conditions affect the intensity of tillage is badly lacking.

Therefore, we wonder how household, farm and climate characteristics affect tillage frequency, and how the farm return is impacted due to differences in tillage frequency. By using an ordered selection equation instead of a binary selection equation, we are able to take into account the extra information available from observing tillage frequencies. Thus, instead of only correcting for systematic differences between those who till and those who do not till, we also take into account unobserved differences among those who use different tillage intensities, to better understand individual farmers' decisions and the impact of changing tillage on farm economies.

In this paper, we address three methodological issues that have not received much attention in the literature. Firstly, from a data point of view, our analysis uses a comprehensive household and plot-level panel data set with detailed farm characteristics and rich socio-economic information, combined with a set of geo-referenced weather variation indicators. This helps us to control unobserved heterogeneity and to examine the role of various socio-economic, biophysical and weather variables in determining variation in the frequency of tillage among farmers, as well as the effect of tillage intensity on farm households' income. Second, because land preparation is costly, farmers may decide to reduce frequency of land preparation in poor growing seasons. In other words, the data on farm outcomes could be non-random and estimation using ordinary least squares could be biased. Furthermore, we observe frequency of tillage, and thus a conventional sample selection approach is not applicable. We overcome this issue by using a recent development in econometrics – a random effects ordered probit endogenous switching regression – and extend the binary sample selection process (till or not till) to ordinal sample selection to control potential sample selection bias in multiple tillage options, in order to disentangle the effects of additional tillage (Bourguignon et al., 2007). Third, the moisture-conserving effect of reduced tillage implies that weather variation is an additional driver determining tillage, given that farmers respond to the impacts of climate change on their production base and land management. Given the lack of evidence on the potential effects of increased frequency of extreme weather events on tillage intensities in the Sub-Saharan African countries at large, our detailed study of Ethiopia is important to account for its potential for climate change adaptation and mitigation for smallholder agriculture.

2. Study areas, data sources and sampling procedure

The current study is based on plot-household level data from the farm household survey conducted as part of the "Adaptation to Increase Resilience to Climate Change in Ethiopian Agriculture" project, which was implemented by the Environment and Climate Research Center at the Ethiopian Development Research Institute. The survey was conducted from March to May, in both 2013 and 2015. The target population is drawn from the five regions in the Blue Nile Basin of Ethiopia: Amhara, Oromia, Tigray, Benshangul-Gumuz and the Southern Nations and Nationalities People's (SNNP) Region. The basin covers about two-thirds of the country's land mass and contributes nearly 40% of its agricultural products and 45% of its surface water (Erkossa et al., 2014). The areas selected represent different agro-ecological settings, with altitudes ranging from 800 to over 3000 m above sea level. The farming system of the basin can be broadly categorized as a mixed crop-livestock farming system, where over 98% of the area is covered by annual crops (Erkossa et al., 2014). We thus limit our analysis to the annual crop plots, where repeated plowing is common.

The sampling frame considered the traditional typology of agro-ecological zones in the country. These are *Dega* (cool, humid, highlands), *Weina-Dega* (temperate, cool sub-humid, highlands), *Kolla* (warm, semi-arid lowlands), and *Bereha* (hot and hyper-arid). The sampling frame selected *woredas*[3] in such a way that each class in the sample matched the proportions for each class in the entire Nile basin. Accordingly, the survey was carried out in a total of twenty *woredas*

[2] Teff (*Eragrostis tef*) is a fine grain predominantly grown in Ethiopia.

[3] A *woreda* is an administrative division equivalent to a district. It is the third-tier administrative unit in Ethiopia, after region and zone.