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Does Minimum Tillage Improve Smallholder Farmers' Welfare? Evidence from Southern Tanzania

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This study evaluated the welfare effects of minimum tillage among smallholder households in Southern Tanzania. A propensity score matching technique was employed to assess the causal impact of adopting minimum tillage using data from a random sample of 608 households. Results indicated that minimum tillage adoption is influenced by gender of the household head, asset index, training on personal values, drought experience, farmer organization and access to NGO information. Minimum tillage also impacts positively on smallholder households' per capita net crop income with the algorithms ranging between 162,430 – 192,208 Tanzania shillings. Further, it reduces the total household labor demands allowing the households to engage in other income-generating activities with an average of -15.67 labor per man-days. Based on this, the authors recommend supporting households to use complementary farm inputs, credit access, and extension-specific information to improve the intensity of adopting minimum tillage.

1. Introduction

Climate change has been documented as the most unnerving challenge instigating global poverty and food insecurity in Sub Saharan Africa (SSA) (Wekesa et al., 2019). In most parts of SSA, agriculture has been recognized as one of the most critical sectors since it is the primary source of livelihoods. Since the sector employs 75 % of the total labor force (Osewe, 2020), climate change effects are expected to be higher in this region. Changes in climate would ultimately affect agriculture, which generates a fifth of the national GDP and employs about two-thirds of the labor force in SSA (Shimeles et al., 2018).

In southern Tanzania, one of the dominant climate adaptation techniques is Minimum Tillage (MT) (Brown et al., 2017). While most of the climate change adaptative approaches have had a positive impact on smallholder welfare (Brussow et al., 2017), several pieces of research question the practical effectiveness of MT for the smallholder farmers in SSA. Besides, researchers have questioned MT's ability to improve the soil through carbon sequestration (De Graaff et al., 2011). Despite the recognition of adverse effects of climate change and accompanying farmer adaptation strategies, there is thin empirical literature on the impacts of MT on farmer welfare in the region.

MT majorly involves minimum soil disturbance, either through ripping or planting in basins. It is also a dry-season land preparation method and consists of planting crops into the soil's vegetative cover with less soil surface-breaking (Giller, 2011). The fundamental principles outlaying MT suggest a restriction of soil disturbance (Maneeintr et al., 2020) to an area leading to a minimum soil turnover (Giller et al., 2009). It improves the soil structure, influences plant growth and development and improves productivity (Grabowski et al., 2016). There is scanty empirical literature on the effects of minimum tillage practice on smallholder farmer welfare. As a result, the extent to which this practice can improve household wellbeing remains unprecedented. This study is designed to estimate the effects of minimum tillage on the outcome indicators such as household per capita crop income and labor demand requirements to contribute to the literature on MT. This article focuses on minimum tillage farming for any field crop to capture all the farmers using this practice.

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The analysis in this paper differs and compliments the other past literature in various ways. First, this study uses household farm survey data collected by the International Center for Tropical Agriculture in 2015 (Osewe, 2020), representative of the actual farming household situation. This is because of the geographical, season and crops covered in the data collected. Most of the previous surveys do not provide a true reflection of this representation. Second, this paper offers precise estimates on the contributions of MT to smallholder farmer welfare. This article is structured as follows – Section 2 expounds on the materials and methods; Section 3 provides the empirical results, and Section 4 offers the discussion, conclusions, and policy recommendations.

2. Materials and methods

2.1 Sampling

In this study, a stratified random sampling method was used to sample 608 farmers. The initial stage of sampling consisted of purposive selection of the two districts, Kilolo and Mbarali. The second stage of sampling encompassed using random number generator in Excel to create a full list of all the wards and randomly choosing 50 % to participate in the study. This resulted in 11 and 10 wards from Kilolo and Mbarali. Further, based on the desired total sample for the ward, 19 and 21 villages in Mbarali and Kilolo were randomly selected. Further, a proportionate random sampling approach was employed to select 608 smallholder farmers. This dataset was collected by the international center for tropical agriculture (CIAT) in 2015/16 with the main aim of evaluating the intra-household decision-making and smallholder agricultural productivity.

2.2 Empirical model specification

Conducting impact assessment using cross-sectional data is usually prone to selection bias. Farmers using MT practice could be doing so because of unobserved characteristics that predetermine this selection. As such, a household's choice of practicing or not practicing MT is not exogenous because it is not randomly assigned. The household's decision is influenced by a host of factors that might be correlated with the outcome variables (Issaka et al., 2019). This study employed the use of Propensity Score Matching (PSM) to address the selection bias. PSM has two steps. The first step entails running a binary choice model to estimate the determinant of the choice of whether to use MT or otherwise. The authors adopted Probit regression model to ascertain the factors influencing the farmer's decision to use MT because it overcomes the challenges of linear probability model and its predicted probabilities range between 0 and 1. The Probit model was specified as Eq(1):

$$I_i^* = \beta X_i + \mathcal{E}_{i;}\ 1 \text{ if } I_i^* > 0 \text{ and } 0 \text{ otherwise.} \qquad (1)$$

Where β is the model parameter, X_i is explanatory variables, and $\mathcal{E}_i$ is the error term assumed to have a random distribution, zero mean, and common variance (Kassam et al., 2019). The Probit model provides propensity scores (Kassam et al., 2009). Further, the matched clusters of adopters and non-adopters observations are generated and matched using different matching algorithms such as kernel matching, radius based matching, and nearest-neighbor matching approach. For each household, there are two possibilities; practicing MT or not. The adopters were denoted as $A_{i\,(1)}$ and non-adopters as $A_{i\,(0)}$, whereby the impact of practicing MT is the difference in outcome between the clusters ($\Delta = A_1 - A_0$). It is estimated and tested using a t-test for difference in mean values. Further, the average treatment effect on treated was specified as Eq(2);

$$ATT = E(\Delta \mid X, D=1) = E(A_1 - A_0 \mid X, D=1) = E(A_1 \mid X, D=1) - E(A_0 \mid X, D=1) \qquad (2)$$

However, because $E(A_0 \mid D=1)$ is not observed directly, a counterfactual of it should be generated. That is, the outcome the respondents would have attained had they not participated. Also, the matching is conducted over the common support area specified as Eq(3);

$$0 < Prob\{D=1 \mid X=x\} < 1 \text{ for } x\ \Omega\ X \qquad (3)$$

This matching guarantees the similarity of the matched pairs based on all the observable variables. The only difference is that the treated cluster has adopted, and the control cluster has not adopted minimum tillage (Brown et al., 2018). The literature has criticized PSM for not accounting for the unobservable variables during estimation (Kiboi et al., 2017), and to cater for this, the authors estimated sensitivity analysis as recommended by Rosenbaum (2002) (Knowler and Bradshaw, 2007).

3. Results and discussion

3.1 Factors influencing the adoption of Minimum Tillage

This section presents the results of the factors determining the adoption of MT. Table 1 illustrates the Probit regression model results to ascertain factors that influence the adoption of MT in southern Tanzania. The results indicate that gender of the household head, asset index, personal values, drought experience, farmer organization, and non-Governmental organizations information (NGO) influenced a farmer's decision to adopt MT.

Table 1: Probit analysis results on the adoption of MT by households

Variable	Marginal Effect	Standard Error	p-Value
Gender	0.1365	0.0515	0.008***
Household Head age	0.00054	0.0017	0.745
Years of Residence	-0.00060	0.0017	0.727
Household size	0.0095	0.0074	0.201
Literacy Index	0.0041	0.0973	0.967
Asset Index	0.01951	0.0091	0.033**
Personal Value Training	0.1429	0.0563	0.011**
Drought experience	0.0890	0.0350	0.011**
Future climate change	0.1393	0.1035	0.179
Government extension	0.00198	0.0350	0.955
Farmer organization	-0.1354	0.03617	0.000***
NGO information	0.1383	0.05131	0.007***
Agricultural group	-0.0328	0.0452	0.467
Water user group	0.06033	0.04556	0.185
Household arable land	0.00080	0.00324	0.825
Credit access	-0.0378	0.04161	0.364
Farming experience	-0.000828	0.001156	0.474
-cons	-1.6263	0.4890	0.001***

Note: *** significant at 1 %, ** significant at 5 %.

3.2 llage farming on per capita net crop income and labor demand

This section presents the estimation of the treatment effects based on the PSM. As a requirement the authors used similar variables in the first step of Probit regression model as in treated and control groups. Table 2 illustrates the PSM algorithms, that is, the Nearest Neighbor Matching (NNM), Kernel-based Method (KBM), and Radius Matching method (RM). All these matching algorithms found that the per capita net crop income is statistically significant among the adopters and non-adopters. The paper also assessed the impact of minimum tillage on the total household labor demand. The finding indicate that MT reduces the total household labor demand. The algorithms indicate that MT adopters employed significantly less labor per man-days compared to their counterparts, non-adopters.

Table 2: Average treatment effect of MT on per capita net crop income and labor demands

Outcome variables	Algorithms	ATT	S. E	t-values
Per capita net crop income	NNM	162,429.761	84,063.14	2.19
	KBM	192,207.55	88,474.76	2.17
	RM	174,432.369	80,252.65	2.24
Total household labor	NNM	-15.5478	3.3957	-4.58
	KBM	-14.1721	4.8622	-2.91
	RM	-15.8062	2.7974	-5.65

3.3 Discussion

From Table 1, gender of the household head affects the adoption of MT since the household head assumes the decision-making role. For instance, a unit increase of male headed household, the adoption of MT increases by 13.65 %. Men have more access to factors of production compared to women because of the cultural norms (Ndah et al., 2018). A unit increase in asset index influenced the adoption of MT by 1.9 %. This explains the fact that asset ownership boosts the farmer's decision making in terms of resources availability. Farmers who have access to a variety of resources are deemed to make solid decisions (Osewe, 2020).

Training farmers on personal values influenced the adoption of MT because farmers adopt the agricultural practices that offer them maximum satisfaction. It influenced the uptake of MT by 14.29 %. Farmers who had experience of drought were able to adopt the MT practice. This is because MT provides them with food security in the case of unpredictable rainfall (Myeni et al., 2019). A unit increase in a farmer experiencing drought influenced the adoption of MT by 8.9 %.

Institutionally, farmers who were members of different farming organizations adopted the MT. It influenced the adoption negatively because, in as much as farmers share new information amongst themselves, the probability of joyriding is also higher. Most farmers tend to experiment with others before they decide to adopt a particular practice (Ndah, et al., 2018). Farmers who had access to non-governmental organization information adopted the MT practice. This is because non-governmental organizations offer both the information and resources necessary to influence the adoption of any agricultural practice (Ndoli et al., 2018).

The main aim of this article was to determine the impacts of MT adoption on the smallholder farmers per capita net crop income and labor demand. The results indicate that adopting minimum tillage positively impacted on the household per capita net crop income as well as saving household labor demands as illustrated in Table 2. Labor-saving, in terms of the total household labor demand, is a significant welfare influencing effect. Similarly, the main research question of this paper was whether minimum tillage increases the household per capita net crop income as well as saving on the household labor demand, and the findings indicate significant effects. These results are in line with Kaweesa et al. (2018), who concluded that minimum tillage significantly saves on labor demand and Pannell et al. (2014), who observed that minimum tillage enhances the household income in the long run. Also, Ruiz et al. (2019) indicated that minimum tillage improves crop yield and incomes of smallholder farmers. Similarly, farmers are likely to adopt minimum tillage practices because it minimizes production costs or increases household income as well as reducing the farming risks.

However, the adoption of minimum tillage is low in Sub-Saharan Africa. Besides, from the informal discussions with the smallholder households, the authors could not ascertain why this is the case. However, the authors concluded that minimum tillage could profoundly improve farmers' welfare if it is supported by better agricultural practices such as clearing farm, planting, weeding, and harvesting at the right time. We also concluded that not much effort had been provided to practice minimum tillage in Sub-Saharan Africa (Tanzania being one of the countries). This is supported by Smith et al. (2011), who concluded that global cropland under conservation agriculture (CA) was only 9 % in 2012, and the most significant percentage of this was in South America. There is little or no success in conservation agriculture in South Asia and Africa (Swanepoel et al., 2018). Similarly, there are a lot of challenges that affect smallholder farmers when they adapt and adopt agricultural conservation practices in Africa (Thierfelder et al., 2018). Thierfelder et al. (2015) advocated for the identification of scenarios where MT can enhance the smallholder farmers' welfare intensely, and Wekesah et al. (2019) proposed several series of surveys to ascertain the minimum tillage approaches.

This discussion indicates that adoption and success of minimum tillage are context-specific considering the socio-ecological and agronomic factors. Further, it is observed that the positive effects of minimum tillage adoption take place in the context of complementary inputs, and lowering the costs of these inputs can assist farmers in trying out new farming practices such as minimum tillage. Similarly, investing in agricultural mechanization system can enable smallholder households to expand their land under minimum tillage to improve their welfare in terms of crop income and saving labor demand. While this paper offers significant evidence of the relevant essential policy variables for green agricultural development, it recognizes a handful of limitations. First, the authors do not know the period the smallholder households have been practicing minimum tillage, and the results are based on the cross-sectional data. The results can be translated as short-term impacts. Also, in this paper, the authors concluded from a small sample of the households and do not offer a national picture. Widely applying the results of this paper can enhance the uptake of minimum tillage practices among the smallholder farmers in Tanzania.

4. Sensitivity analysis

Most of the researchers have observed the essentials of testing the reliability of the PSM model estimates. As a result, it assists researchers in understanding the sensitivity of the estimates based on the small deviations of the propensity scores. Also, sensitivity analysis ascertains the quality of the matched groups as well as the effects of the unobserved variations on ATE and ATT values. The authors statistically determined the Rosenbaum bounds sensitivity analysis, whose outcome is presented in Table 2. The significant levels are not affected even after increasing gamma values by threefold and because of this, the authors concluded that no external deviations could change the estimated values of ATE and ATT.

Table 3: Sensitivity analysis results

Gamma	Sig+	Sig-
1	0.155612	0.155612
1.25	0.51926	0.018479
1.5	0.819905	0.001431
1.75	0.950879	$8.5*10^{-5}$
2	0.989301	$4.3*10^{-6}$
2.25	0.998014	$1.9*10^{-7}$
2.5	0.999672	$8.1*10^{-9}$
2.75	0.99995	$3.2*10^{-10}$
3	0.999993	$1.2*10^{-11}$

5. Conclusions and policy implications

This research found out that the adoption of minimum tillage is still low, 21.38 % in Southern Tanzania. This observation indicates that despite the increased promotion of conservation agriculture, specifically minimum tillage, households are still adamant about its suitability and profitability. This article assessed the impacts of adopting minimum tillage on smallholder households' welfare using per capita net crop income and total labor demand. This research used Probit regression to ascertain factors influencing the adoption of minimum tillage in Southern Tanzania. It was found that gender of the household head, asset index, training on personal values, the experience of drought, access to non-governmental information, and farmer organization membership influence the household's decision to adopt minimum tillage. Similarly, the authors observed from the three PSM algorithms, nearest neighbor method, kernel-based method, and radius method that adoption of minimum tillage positively and significantly impacts on households per capita net crop income. It also reduces the total household labor demand. This has more significant implications for both the smallholder households and researchers because a reduction in the labor demand would allow the households to engage in other income-generating activities in Sub-Saharan Africa (Tanzania). Supporting households to use complementary farm inputs such as inorganic fertilizers, access to credit facilities as well as access to minimum tillage extension specific information could improve the adoption intensity and welfare benefits. The authors also recommend the improvement of this research that could consist of randomized control trials and economic field experiment data collection methods to determine the impact on the adoption of minimum tillage.

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