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Adoption of Soil and Water Conservation Technologies among Smallholder Farmers in the Face of Climate Risks

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Abstract

Using plot level farm household survey data, this paper aims at highlighting the role of SWC technologies in the face of climate risks using organic manure as an example of most widely adopted SWC technology. It underscores the need to enhance the adoption of organic manure among smallholder farmers in Malawi as a means of increasing household's resilience to prolonged dry spells. It investigates factors affecting households adoption decisions of organic manure and the potential effect of organic manure in improving maize yield when prolonged dry spells occur. To assess the factors that affect adoption of organic manure, the paper uses a binary probit model. While the effect of manure on yield was measured as treatment effect on the treated (ATT). Since adoption of manure suffers endogenous problems, due to the fact that in adoption studies, households and farm plots are not randomly assigned to groups as adopters or non-adopters but rather, they make their own choices to adopt or not, or plots are systematically selected based on their characteristics resulting in selection bias. The study attempted to control for this endogeneity by using minimum-biased and corrected-bias estimators to calculate the ATT. The study concludes that higher household labor endowment enhances the probability of adoption of organic manure while higher opportunity cost of labor reduces the probability of adoption organic manure. Implying that market imperfections are constraining adoption of organic manure, that calls for policies that reduce market imperfections. The study did also find a positive effect of organic manure during dry spells, that on average manure increased maize productivity by 31%.

Key words: dry spells, maize yield, ATT, soil and water conservation, minimum-bias, corrected-bias, propensity score, unconfoundness

Dedication

I dedicate this thesis to my beloved father

Freedom Chatsika

For making me feel like the special one since the day I was born

And

To the loving memory of my late mother

Sellina Gonkho (Anambewe)

Your hard work and inspiration have successfully made me a person I am becoming

I will always remember you

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List of Acronyms

ATT	Average treatment effect on the treated
BMPS	Bias-minimizing propensity score
CB	Corrected-Bias estimator
cdf	Cumulative density function
CI	Confidence interval
CIA	Conditional Independence Assumption
CIMMYT	International Maize and Wheat Improvement Center
DT	Drought tolerant
FISP	Farm Input Subsidy Programme
GDP	Gross Domestic Product
GPS	Global Positioning System
ha	hectare
IV	Instrumental variable
kg	kilograms
KM	Kernel matching
MB	Minimum-Biased Estimator
MSCE	Malawi School Certificate of Education
N	Number of observations
NGO	Non-Governmental Organisation
PSM	Propensity score matching
SDGs	Sustainable Development Goals
SWC	Soil and water conservation technologies
US\$	United States Dollars

Introduction

The United Nation's Sustainable Development Goals (SDGs) which is a successor of the Millennium Development Goals was officially adopted by nations of on January 1, 2016. For developing countries, much attention continues to be devoted to agriculture and the rural sector for the reason that agriculture plays a major role in their economies and the majority of the population lives in rural areas. For less developed countries like Malawi, sustainable agriculture production is central due to its role in the size of this economic sector as well as its crucial part in the development strategy. The persistent challenges of chronic poverty, land degradation, food insecurity, population growth and climate change remain the conflicting factors to sustainable development. The potentially damaging climate effects and risks pose serious threats to sustainable development in many parts of Africa (Müller *et al.*, 2011) .

The ever-present risks in Malawi threaten its sustainable development goals. Malawi's economic growth and food security are highly dependent on the performance of rain-fed agriculture, which is so prone to production risks. Annual losses from agriculture production risks for major crops amounted to US\$149 million, on average, between 1980 and 2012 (Giertz *et al.*, 2015). Due to the size of the agricultural sector, production risks do not only affect the smallholder farmers who are directly affected but they also put severe pressure on government finances. Rapid and frequent drops of agricultural production adversely affect the Government fiscal position as this means reduced tax revenues, exports, and increased recovery expenditures. It also means lost expenditures as the government spends a lot of money in providing agricultural input subsidies to resource-poor farmers in preparation for the growing season.

Weather-related production risks are more frequent in Malawi. Common extreme weather events are localized dry spells, seasonal droughts, intense rainfall, riverine floods and flash floods. Pauw *et al.* (2010) noted floods and droughts are unpredictable part of life for many Malawians, this means a more water-constrained agriculture production. On average, Malawi loses 1.7 percent of its gross domestic product (GDP) every year due to the combined effects of droughts and floods (Pauw *et al.*, 2010). For

individual actors in the sector which are mostly smallholder farmers, these risks reinforce poverty traps through cycles of shock-recovery-shock and result in lower returns on investments in productive assets (Giertz *et al.*, 2015). The uncertainty over when droughts and floods will occur makes climate risk management important for Malawian farmers.

Production risks can be spread and buffered by a broad range of land management practices and technologies (Bockel & Smit, 2009). In the mid-1990's, the Government of Malawi intensified campaigns on soil and water conservation programs in an attempt to reduce land degradation and to improve food security (Barungi & Maonga, 2011). According to Barungi and Maonga (2011), following the campaigns, farmers adopted a range of soil and water conservation technologies, including planting vetiver grass, constructing contour bunds, contour and box ridges, terraces, and adding organic manure into the soil. However, the data we collected from in 2009, 2012 and 2015 indicated that farmers have also adopted other soil and water conservation (SWC)¹ technologies like pit planting, mulching with crop residues and agroforestry.

As Holden and Fischer (2015) noted, the magnitude and speed of the predicted changes in climate suggest that the farm-level measures used to cope with climate variability in the past will not be sufficient adaptation measures in the future. In their papers, Holden and O'Donnell (2015), as well as Holden and Fischer (2015), show a remarkable adoption of drought tolerant (DT) maize varieties especially by those that have recently experienced drought. This suggests that farmers are trying to adopt new technologies that would help reduce the weather-related risks. Although this is so remarkable, adoption of soil and water conservation technologies remains important as it is not only drought that the farmers face but also too much water due to heavy rains that sometimes is followed by a long dry spell.

Kato *et al.* (2011) also observed that soil and water conservation technologies perform differently in different rainfall areas and regions of Ethiopia, suggesting that

¹ SWC technologies includes organic manure, pit planting, use of contours, agroforestry, permanent etc.

appropriateness of such technologies might be specific to rainfall patterns. The type of soil, e.g. clay or sand may also affect the performance of different types of soil and water conservation technologies. Sandy soils are more drought-prone while clay soils are more prone to waterlogging if there is too much rain.

Currently, climate risks are seriously threatening agricultural productivity and food security in Malawi. In 2015, the Government of Malawi through its Ministry of Agriculture, Irrigation and Water Development launched a National Campaign on Manure, Irrigation and Fodder in an effort to enhance Malawi's food security. Among other SWC technologies, use of organic manure has been given a special attention in the campaign as one of the ways of improving soil fertility. However, very little off-station research has been done to assess the impact of organic manure on maize yield. The adoption of organic manure on maize in Malawi is still low despite the combined the long term efforts of both the Government of Malawi and NGO sector to promote its adoption.

However, Holden and Lunduka (2012) found households to be using organic manure as a complement to fertilizer. They also found that the government Farm Input Subsidy Programme (FISP) had a positive impact on manure adoption. In the sample used for this paper, maize plots treated with organic manure were only 33.11% of the total sample.

Apart from individual household constraints, studies have also shown that institutional constraints like imperfect markets to affect adoption of SWC technology (Yesuf and Köhlin (2009), Mduma (2007) and Shiferaw *et al.* (2009)). Outcomes of market imperfections, like limited access to credit, farm size, and high opportunity cost of labor negatively affect adoption decisions. Such that, in some cases low adoption rate of SWC can be attributed to imperfect factor markets. Farmers who would otherwise adopt the technology may be prevented from doing so if the imperfect markets persistent. Thus, getting rid (or reducing) of the existing market imperfections may likely increase the adoption rate SWC.

Grouping Soil and Water Conservation technologies into three categories we have: (a). Moisture/water-conservation technologies, (b). Technologies that protect against flood/too much water, and (c). Technologies that protect against soil erosion. With the current rate of extreme weather events, Malawian smallholder farmers require a higher resilience against both excess waters in flood periods and lack of water in prolonged dry spells or droughts. Unlike other SWC technologies, organic manure alters the structure of the soil by increasing the soil organic matter. This may in return, help the soil to retain soil water for a longer period, allow more water infiltration during floods hence, protecting the soil from erosion

Although organic manure use can be one of the promising SWC technologies, most Malawian farmers use organic manure as a compliment or supplement to chemical fertilizers because they are resource constrained. Using plot level household survey data, this paper investigates the potential role of organic manure in reducing production risks due to prolonged dry spells. The study aims at highlighting the role of SWC technologies in the face of climate risks using organic manure as an example of most widely adopted SWC technology. It underscores the need to enhance the adoption of manure use among smallholder farmers as a means of buffering production risks.

In water-constrained rain-fed agriculture production like in Malawi, rainfall (especially climate) driven variability leads to low and unstable productivity and production. When rainfall is less than crop water requirement, the resulting actual yield is lower than potential yield. Maize can grow and yield with as little as 300 mm rainfall (with 40% to 60% yield decline compared to optimal conditions), but prefers 500 to 1200 mm as the optimal range (Belfield & Brown, 2008). Low annual rainfall of less than 300 mm, leads to drought conditions that lead to significant loss of maize productivity.

The uneven seasonal distribution of rainfall (like dry spells) are also equally important. If rainfall satisfies 70% of crop water requirements every day, then a good yield may be possible, but if rainfall is 100% of crop requirements for 70% of the growing season and 0% for the rest, the yield can be significantly lower than the expected yield (Scheierling *et al.*, 2012). The longer the dry spell the more it affects yield, although

short but frequent dry spells within a season can also be of great importance. The impact of rainfall variation is strongly affected by the nature of the soil and the stage of the crop growth during the season. If the soil is capable of storing a large quantity of water in relation to crop demand, then a break in rainfall (dry spell) of a week or more may be endurable, particularly late in the season when the roots are well developed.

Thus, increasing the capacity of soil to store a large quantity of water is vital in reducing production risks. Use of manure (organic fertilizer) improves soil structure by binding soil particles together; it also increases the organic matter content of the soil hence improved water infiltration and greater water-holding capacity leading to decreased crop water stress, soil erosion, and increased nutrient retention. The impact of organic manure application on maize yield will depend on a number of factors. Factors may include; soil type, the slope of the plot, manure type and household characteristics.

In the data used for this paper, farmers divide their farmland into small fragmented plots from one big farm called a parcel. In this paper, I define a parcel as a unit of land with permanently defined borders based on ownership and spatial characteristics. A plot is a unit of land planted with the same crop or combination of crops during the previous growing season and has received similar management and input use including SWC technologies applied. For maize plots, the study also separates plots by maize variety. Similarly, if part of the maize field is intercropped with e.g. pigeon pea, the field is split as one mono-cropped and one intercropped maize plot. Plots with same characteristics may receive the same or different treatment during the same growing season. This is one of the strengths of this paper as it is able to control for plot characteristics.

Water constrained rain-fed agriculture is like a state-contingent production. Where farmers decide which inputs and technologies to use before the state of nature is revealed (Quiggin & Chambers, 2006). They make choices whether to use organic manure or not, before they know the state of nature for the following growing season. Then nature reveals its state, which is independent of farmers' decision. The state of nature can be a growing season with a prolonged dry spell or a growing season with no prolonged dry spell during the critical stages of crop growth. The impact of a bad state

of nature will depend on choices made before the state was revealed among other factors. Thus, this paper attempts to assess factors that determine households' adoption choices of SWC like organic manure and estimate the impact of the adoption decision if the household state of nature happens to be prolonged.

Statement of the Problem and Justification

Malawi is a small landlocked country located in South Eastern part of Africa, suffering from frequent droughts and floods and their effect on agricultural production that is most detrimental to food-insecure Malawi (Pauw *et al.*, 2010). Soil and water conservation strategies have received a lot of attention as a strategy to cope with climate change, however the emphasis has been on its ability to maintain and improve soil structure. Most previous work has concentrated on spatial scope and crop yield associated with soil and water conservation technologies (Kato *et al.*, 2011; Thomas, 2008). However, Kato *et al.* (2011) observed that soil and water conservation technologies perform differently in different rainfall areas and regions of Ethiopia, suggesting that appropriateness of such technologies might be specific to rainfall patterns. Analyzing if use of organic manure can be used to reduce risks by improving ex post changes in production levels in the face of climate risks facing Malawi, is thus timely as the country is facing recurrent dry spells.

On the other hand, even if the use of organic manure can be considered as a resilient tool against dry spells, its effectiveness would depend on adoption rate of the technology. It makes no change to have a working technology that is not being adopted by the intended people. There has been intensive campaigns in Malawi both from the Government and NGO side, advocating for adoption of organic manure since 1990's but the adoption still remains low among smallholder farmers. Thus, assessing factors that affect households' decision to adopt organic manure is timely and important as the country is currently looking for solutions for the recurrent dry spells.

Research Questions

This paper attempts to answer the following questions

1. What are the factors that determine adoption of organic manure?

2. Can adoption of organic manure improve smallholder farmers' maize yield in cases of dry spells?

Research Objectives

The following are the objectives of the research

1. To assess the factors affecting households' decision to adopt manure application
2. To evaluate the effect of organic manure on maize productivity in times of dry spells

Research hypothesis

To answer the research questions, I test the two hypotheses below:

1. Higher household labor endowment enhances the probability of adoption of organic manure while higher opportunity cost of labor reduces the probability of adoption organic manure.
2. In the face of dry spells, maize yield is higher when organic manure is adopted than when it is not adopted, *ceteris paribus*.

Literature Review and Methodology

Smallholder farmers and resource users continue to face difficulties in adoption and adaptation of soil and water conservation technologies (Shiferaw *et al.*, 2009). The analysis of these challenges and lessons from different examples show that several factors have indeed added to the ongoing challenges facing smallholder farmers in adoption of SWC technologies. The challenges range from poor performance of the technologies themselves to policy and institutional constraints at different levels (Shiferaw *et al.*, 2009).

Soil and water conservation technologies are state-contingent technologies; their impact on productivity and production risk are crucially dependent on the state of nature. Conventional stochastic econometric evaluation techniques fail to capture the state-contingent benefits of technologies (Blanke, 2011). The state-contingent production offers a theoretically attractive method for modelling but has proven notoriously difficult to implement empirically as states of nature may be too numerous or

unidentifiable. Again, production is only observed in one state which occurred and state allocations of inputs are rarely observed (Blanke, 2011). Unlike other technologies that involve physical inputs like seeds, machinery or fertilizer, soil and water conservation technologies may pose extra econometric challenges. For SWC technologies, an ex post econometric analysis may be vulnerable to selection bias problems. Changes may not be solely due to changes in the biological or genetic traits of the seeds, the biochemical attributes of nutrient amendments in fertilizer or the mechanical function of machinery. Farmer and plot heterogeneity lead to selection bias since more skilled farmers are commonly the first to adopt improved technologies and often apply them on their best plots (Barrett *et al.*, 2004).

In Malawi, farmers commonly cultivate many small plots such that for this paper, the mean number of plots per household was four with a minimum of one plot and a maximum of 12 plots. The mean number of parcels was two with one and nine being minimum and maximum, respectively. Farmers may apply SWC technology to all or some of the plots. Since our observations are from the same farmers cultivating these small plots simultaneously during a growing season, the researcher is able to control for the farmer and plot specific effects that may cause bias.

Soil and water conservation technology adoption Model

In adoption models, the first thing to do is to define who an adopter is. The definitions of an adopter vary widely across studies, even across the 22 studies that CIMMYT conducted in East Africa examining the adoption of improved varieties of wheat, maize and fertilizer (Doss & Doss, 2006). The definition will depend on whether adoption is a discrete state with binary variables (a farmer either is, or is not, an “adopter”) or whether adoption is a continuous measure and the appropriateness of each approach may depend on the particular context (Doss & Doss, 2006). Many researchers have defined adoption of SWC as a simple dichotomous variable approach (Abdela and Derso (2015), Obando *et al.* (2012) and Kassie *et al.* (2015). This approach is most appropriate when a farmer exclusively adopt a technology, or when the management practice is something that cannot be partially implemented (Doss & Doss, 2006). In the

data used for this paper, a plot is defined in such a way that management practices cannot be partially implemented. The farmer either adopts manure (adoption =1) or not (adoption =0) on that specific plot. Thus, this paper also adopts the binary variable approach, which calls for a latent variable model

Following Long and Freese (2006), a latent variable model assumes a *latent* or unobserved variable y^* ranging from $-\infty$ to ∞ that is related to the observed independent variables by the structural equation,

$$y_i^* = x_i\beta + \varepsilon_i \dots\dots\dots (1)$$

Where i indicates the observation and ε is a random error. For a single independent variable, we can simplify the notation to,

$$y_i^* = \alpha + \beta x_i + \varepsilon_i \dots\dots\dots (2)$$

Where, y^* is an outcome variable (adoption of manure) equal to 1 if plot i was applied with manure and 0 if no manure was applied. And x_i is a vector of values for the i th observation, β is a vector of parameters to be estimated while ε error term

Equation (1) and (2) above, are similar to the linear regression equations with the important difference that the dependent variable is not observed (Long & Freese, 2006). The measurement equation (3) below makes the link between the observed binary variable y and the latent variable y^* .

$$y_i = \begin{cases} 1 & \text{if } y_i^* > 0 \\ 0 & \text{if } y_i^* \leq 0 \end{cases} \dots\dots\dots (3)$$

Equation (3) implies that when y^* is positive $y = 1$ while when y^* is negative or zero, $y = 0$

The idea behind the latent variable is that it generates a tendency of behaving or responding in a particular way to a given situation. In this study $y = 1$ if a household applied manure on their farm plot and $y = 0$ if not. The independent variables include variables such as plot and household characteristics. Not all households are adopters of

manure for certainty, one household might be planning to dis-adopt while another household could be firm in its decision to adopt. In these two cases, we observe $y = 1$. The idea of a latent y^* is that an underlying *propensity to adopt* generates the observed state (Long & Freese, 2006). Again, while we cannot directly observe the propensity at some point, a change in y^* results in a change in what we observe, namely, whether a household is an adopter or not.

For the latent variable model of binary outcomes is illustrated as:

$$\Pr(y = 1|x) = \Pr(y^* > 0|x) \dots\dots\dots (4)$$

Logit and probit models are widespread statistical methods, in which the probability is of a dichotomous outcome. Both probit and logit models are known to yield the same results. In this paper, the study adopts the probit model to estimate the adoption equation where the error term is assumed to be distributed normally with $\text{Var}(\varepsilon) = 1$.

In a probit model, the probability of an event occurring is given by the cumulative density function (cdf) of the error term, ε evaluated at given values of independent variables, written as;

$$\Pr(y = 1|x) = \Phi(x\beta) \dots\dots\dots (5)$$

For a time series model, equation (5) becomes:

$$\Pr(y_{it} = 1|x_{it}) = \Phi(x_{it}\beta) \dots\dots\dots (6)$$

Where: $i = \{1, \dots, N\}$, is an individual specific index and $t = \{1, \dots, T\}$ is time specific index and Φ is the cumulative density function (cdf).

Evaluating the effect of manure during dry spells

Propensity Score Matching

To evaluate the effect of manure on yield if a household was affected by dry spells, the study estimates average treatment on the treated (ATT)². Since am looking at a binary treatment, where a household either adopted or or not adopted manure on the plot,

$D_i = 1$ if the household adopted manure on the plot

$D_i = 0$ if the household did not adopt manure on the plot

Inference about the impact of a treatment on the outcome of an individual involves speculation about how this individual would have performed had he not received the treatment. To estimate ATT there is need to determine the outcome (maize yield) of the counterfactual state, implying we need to observe the counterfactual outcome of the treatment group (adopter of manure at an untreated state (non-adoption state)).

$$ATT = E[\Pi(1)|D = 1] - E[\Pi(0)|D = 1] \dots\dots\dots (7)$$

Where Π is the outcome variable, in this case is maize yield on the plot. This is an ex-post outcome as we are observing it after an intervention already took place. The problem with casual inferences is that we cannot observe the outcome and its contourfactuals of the plot simultaneously. The mean of the counterfactual cannot be observed, implying we can not observe $E[\Pi(0)| = 1)$.

One way to solve this problem is to compare the ex-post outcome of control group i.e. comparing the maize yield on plots with no manure with those applied with manure by using $E[\Pi(0)|D = 0]$ and have,

$$ATT = E[\Pi(1)|D = 1] - E[\Pi(0)|D = 0] \dots\dots\dots (8)$$

² The ATT allows one to assess the expected effect of the program on current participants, and thus is relevant as an evaluation of the current program. The ATE allows one to assess the expected effect of current programs if near-universal participation, which is the goal of many, is achieved.³⁰ Moreover, the ATU, which is also relevant for assessing the effects of program expansion, may be deduced from the ATE and ATT (Millimet & Tchernis, 2013).

Again, equation (8) is likely to suffer from selection bias. It estimates the difference between the maize yield of the manure adopters and non-adopters. It is highly likely that the outcome of the adopters and non-adopters must be different in the absence of manure leading to a “self-selection bias”. This owes to the fact that many covariates (like number of plots owned by a household, intensity of soil erosion, age and gender of household head) that determines the adoption of manure also determines the outcome variable, maize yield (Caliendo & Kopeinig, 2008). Generally, the outcomes on the farm with no manure are not a true representative of what the outcomes would be if the plots were randomly selected for adoption of manure (Caliendo & Kopeinig, 2008). Therefore, the above estimator (8) is a biased estimator of *ATT*, this can be illustrated as;

$$E[\Pi(1)|D = 1] - [\Pi(0)|D = 0] = ATT + E[\Pi(0)|D = 1] - E[\Pi(0)|D = 0] \dots (9)$$

Where the difference between the left hand side of equation (9) and *ATT* is the so-called “self-selection bias”. The true parameter of *ATT* is only identified as,

$$E[\Pi(0)|D = 1] - E[\Pi(0)|D = 0] = 0 \dots\dots\dots (10)$$

One possible way of solving the selection bias is to use a matching approach. This approach is based on the simple notion that for each plot in treated state, i.e. adopter of manure there is a comparable group of untreated plots, i.e. non-adopters who have similar observable characteristics. Imposing a strong assumption that the outcome of one plot is not affected by application on manure on other plots including plots in the neighbourhood, the stable unit treatment value assumption (SUTVA). Another important assumption for matching method estimator to be unbiased is the strong ignorability or the unconfoundedness assumption. That states the requirement that treatment assignment is independent of the outcomes.

Assuming these assumptions hold, one can use propensity score matching (PSM) estimator to control for the self-selection bias. The PSM estimator is simply the mean difference in outcomes over the common support, appropriately weighted by the propensity score distribution of participants (Caliendo & Kopeinig, 2008). The propensity score matching (PSM) estimator for ATT can be specified as:

$$ATT(PSM) = E[\Pi(1)|D = 1, P(X)] - E[\Pi(0)|D = 0, P(X)] \dots\dots\dots (11)$$

Where Π is the outcome variable and in our case is maize yield. $P(Z) = P(D = 1|X)$ is a propensity score, that is the probability of a plot to be treated given its covariates X i.e. selection of the observables (Caliendo & Kopeinig, 2008)

Minimizing bias in selection on observables estimators when unconfoundness fails

The above estimator (11) will yield to unbiased ATT estimates based on the strong assumption of unconfoundness. However, if the unconfoundness assumption fails to hold, the resulting estimates are biased (Millimet & Tchernis, 2008, 2013). In adoption of manure, households and farm plots are not randomly assigned to groups as adopters or non-adopters but rather make their own choices to adopt or not, or plots are systematically selected based on their characteristics. Hence, there are enough reasons to believe that adoption of manure suffers from endogeneity problem. Implying that, the unconfoundness assumption may be violated making the resulting estimator to be biased due to unobservables.

The typical way, when there is a selection bias due to observable and unobservable characteristics, the strategy is to rely on an instrumental variable (IV) approach. However, a valid instrument is often unavailable. Here, our interest is identifying the casual effect of manure adoption on maize yield during dry spells. As discussed above that plots and households in the treatment and control groups may differ along important unobserved and observed dimensions. The challenge is that we do not have access to credible instruments to instrument the endogenous treatment, manure adoption. Thus, the usual approach for dealing with non-random selection of manure adoption – IV

using an exclusion restriction – does not seem viable. Millimet and Tchernis (2013), proposed two new estimators for the analysis of binary treatments when selection into a treatment is based on unobserved attributes, but one lacks an exclusion restriction. In their paper, Millimet and Tchernis (2008) proposed the *minimum-biased* (MB) estimator and the *bias-corrected* (BC) estimator.

According to the authors, the MB estimator entails minimizing the bias when estimating the effect of a treatment using an estimator that requires the conditional independence assumption (CIA), independence between treatment assignment and potential outcomes conditional on observed variables. This is accomplished by trimming the estimation sample to include only observations with a propensity score (pscore) – the conditional probability of receiving the treatment given the observed variables – within a certain interval. The MB estimator has the advantage of being unbiased when the CIA holds, but minimizing the bias associated with estimators that require the CIA when this assumption fails (under certain conditions). Millimet and Tchernis (2013) also warns that the MB estimator accomplishes this at the expense of changing the parameter being estimated.

On the other hand, the *bias-corrected* (BC) estimator relies heavily on the Heckman's bivariate normal (BVN) model to estimate the bias of estimators requiring the CIA when this assumption fails, it does not require specification of the functional form for the outcome of interest in the final step. Moreover, unlike the MB estimator, the CB estimator does not change the parameter being estimated, (Millimet & Tchernis, 2013).

When estimating the ATT under the CIA and the assumption is incorrect, the bias of the ATT at some value of the propensity score, $P(X)$, is given by

$$B_{ATT}[P(Z)] = \hat{\tau}_{ATT}[P(X)] - \tau_{ATT}[P(X)] = E[\Pi(0)|D = 1, P(X)] - E[\Pi(0)|D = 0, P(X)] \dots \dots \dots (12)$$

Where; $\hat{\tau}_{ATT}$ refers to some propensity score-based estimator of the ATT requiring the CIA.

To analyze the bias that arises when the CIA fails, consider the following two assumptions made by Millimet and Tchernis (2008),

(A1) Potential outcomes and latent treatment assignment are additively separable in observables and unobservables:

$$\begin{aligned}\Pi(0) &= g_0(X) + \varepsilon_0 \\ \Pi(1) &= g_1(X) + \varepsilon_1 \\ D^* &= h(X) - u \\ D &= \begin{cases} 1 & \text{if } D^* > 0 \\ 0 & \text{otherwise} \end{cases}\end{aligned}$$

(A2). $\varepsilon_0, \varepsilon_1, u, \sim N_3(0, \Sigma)$, where

$$\Sigma = \begin{bmatrix} \sigma_0^2 & \rho_{01} & \rho_{0u} \\ & \sigma_1^2 & \rho_{1u} \\ & & 1 \end{bmatrix}$$

Under assumptions (A1) and (A2), equation (12) summaries to;

$$B_{ATT}[P(X)] = -\rho_{0u}\sigma_0 \frac{\phi(h(X))}{\Phi(h(X))[1-\Phi(h(X))]} \dots\dots\dots (13)$$

Where; $\phi(\cdot)$ and $\Phi(\cdot)$, are the standard normal density and cumulative distribution function, respectively. The primary rationale behind the minimum biased estimator is to select an appropriate sample (based on $p(X)$) such that $B_{ATT}[p(X)]$ is minimized. The bias, B_{ATT} is minimized when $h(X) = 0$, which implies that $P(X) = 0.5$. The value of $P(X)$ that minimizes the bias of the ATT, is referred to as the bias-minimizing propensity score (BMPS) denoted by P^* .

The Minimum-Biased Approach

Millimet and Tchernis (2013), in their paper proposed to minimize the bias by getting an estimator using only observations with a propensity score in a neighborhood around the BMPS, P^* . Because the bias of the ATT is minimized by minimizing the bias for each component obtaining draws from a particular trivariate normal distribution and the BMPS is one-half within each component, the bias of the ATT is minimized at $P^* = 0.5$. Furthermore, because a mixture of a sufficient number of trivariate normal distributions can approximate almost any joint distribution, this implies that joint normality is not needed to conclude that one-half is the BMPS for the ATT. Thus, when the CIA holds, MB provides a consistent. Formally, the following is a MB estimator of the ATT,

$$\hat{\tau}_{MB,ATT}[0.5] = \sum_{i \in \Omega} \Pi_i D_i - \left[\sum_{i \in \Omega} \frac{\Pi_i (1-D_i) \hat{P}(X_i)}{1-\hat{P}(X_i)} / \sum_{i \in \Omega} \frac{(1-D_i) \hat{P}(X_i)}{1-\hat{P}(X_i)} \right] \dots\dots\dots (14)$$

Where $\Omega = \{i | \hat{P}(X_i) \in C(P^*)\}$ and $C(P^*)$ denotes a neighborhood around P^* and is defined as $C(P^*) = \{\hat{P}(X_i) | \hat{P}(X_i) \in (P, \bar{P})\}$

The Bias-Corrected Approach

However, given the estimates of P^* , and $\rho_{0u}\sigma_0$, a natural extension is to estimate the bias itself using equation (13), this would lead to the following:

$$\widehat{B}_{ATT}[P = 0.5] = -\widehat{\rho_{0u}\sigma_0} \left[\frac{\phi(\Phi^{-1}(0.5))}{0.5[1-0.5]} \right] \cong -1.6 \widehat{\rho_{0u}\sigma_0} \dots\dots\dots (15)$$

According to Millimet and Tchernis (2013) the above estimate would then be used to obtain bias corrected estimates (MB-BC). The minimum bias-corrected estimator, for the ATT is then given by;

$$\widehat{\beta}_{MB-BC,ATT}[P = 0.5] = \widehat{\beta}_{MB,ATT}[P = 0.5] - \widehat{\beta}_{ATT}[P = 0.5] \dots\dots\dots (16)$$

Data

Data collection

The data used in this paper is from a three-year panel data collected from Malawi using a stratified random sample of farm households from 2009, 2012 and 2015. The data was collected from six districts in the southern and central regions of Malawi. This gives enough variations in the data as Malawi had close to regular rainfall in 2009, almost a nationwide drought in 2012 and national wide floods in 2015. The researcher was personally involved in data collection as an enumerator in 2012 and as a field supervisor in 2015. Before going to the field, enumerators were trained on how to administer the questionnaire during a five day training plus a one day field trial to test the questionnaire. To ensure data quality, The researcher did a careful analysis in ensuring that the data really comes from the same household by verifying the location of farm plots using GPS coordinates across the years and households. Only households whose plots matched at for least two years qualified to be included in the analysis such that we deleted 10 households from the sample. As such, the study remains with 362 households with 1773 maize farm plots.

On average, the number of plots per household was four with a minimum of one and a maximum twelve plots. All households at least grow maize, as it is Malawi's most preferred staple food. Maize is the most important staple food crop in Malawi such that insufficient maize production means the country is food insecure.

Identifying dry spells

To determine whether a plot was affected by dry spells or not, the study uses daily rainfall data collected from the nearest weather station. I used rainfall data from seven weather stations. Table 1, below gives a summary on the rainfall information for 2009, 2012 and 2015 for specific weather stations.

Table 1: Weather Stations used and rainfall information

<i>District</i>	<i>Traditional Authority</i>	<i>Weather Station</i>	<i>Longitude</i>	<i>Latitude</i>	<i>2009 Total Rainfall</i>	<i>2012 Total Rainfall</i>	<i>2015 Total Rainfall</i>
Thyolo	Bvumbwe	Bvumbwe Met.	35,06670	-15,91670	1257	989,4	1287,63
Zomba	Kumtumanji	Chancellor College	35,35000	-15,38330	1114,7	650,3	1180,5
Chiradzulu	Mchemba	Chiradzulu Agric	35,18330	-15,70000	1069,29	820,97	952,69
Machinga	Kawinga	Ntaja Met.	35,53333	-14,86670	1128,2	722,5	1025,61
Zomba	Chikowi	Makoka Met.	35,18330	-15,53330	1052,8	888,9	1163,8
Kasungu	Kaomba/Chilowa-matambe	Kasungu Met.	33,46667	-13,01670	645,7	856,5	703,1
Lilongwe	Malili	Chitedze Met.	33,63333	-13,96670	814,4	853,6	542,1

Dry spells in Malawi are very common in farming season. Almost every year some sort of dry spells may be helpful for the crop to get some sunshine. However, if the dry spell gets longer than what the crop requires, it leads to lower than the potential productivity of the crop. Only dry spells of more than ten days are included as prolonged dry spells in this paper. I define a prolonged dry spell as a period of extended duration of dry days with a rainfall of less than 1.2 mm for at least ten days. Rain season in Malawi stretches from the month of November to April of the next year. A prolonged dry spell can happen during any stage of the crop growth, in this paper, I consider the months of December through March as the most critical months for dry spells. During these months, rain-fed maize in Malawi is at tasseling and grain filling stage. A very critical stage as maize requires sufficient soil water (daily rainfall > 1.2 mm) to keep up with the processes.

Using the above definition of dry spell, prolonged dry spells affected all weather stations in 2015 but only some during the other years. During the study period, dry spells affected 1,057 plots. The table 2 below shows an overview status of nature for weather station in respective years.

Table 2: Distribution of dry spells

Weather Station	2009	2012	2015
Bvumbwe Met.	No dry spell	No dry spell	Dry spell
Chancellor College	Dry spell	No dry spell	Dry spell
Chiradzulu Agric	No dry spell	No dry spell	Dry spell
Ntaja Met.	No dry	Dry spell	Dry spell
Makoka Met.	No dry spell	Dry spell	Dry spell
Kasungu Met.	No dry spell	Dry spell	Dry spell
Chitedze Met.	Dry spell	No dry spell	Dry spell

Outcome variable

A dummy variable for adoption of manure was used as an outcome variable for the adoption model.

While in estimation of the effect of manure on yield during dry spells, The paper used maize yield measured in kilograms per hectare. Data collected as yield per square meter are converted to yield per hectare for easy inferences. To avoid upward bias measurement errors due to farm size reported by farmers as found by Holden and Fisher (2013), in this paper, the study uses farm size measured by GPS.

Explanation of explanatory variables and hypotheses

With respect to adoption literature, (e.g. Maiga (2005), Barungi and Maonga (2011), Obando *et al.* (2012) and Kassie *et al.* (2015)), below the researcher discusses the explanatory variables included in the adoption model.

Household Characteristics

Household characteristics like age, highest education level attained, gender of household head and household labor endowment may affected the decision of a household to adopt SWC technologies.

Education Level of Household Head

Households with a more educated household head may have a better understanding of the importance of the technology (Kassie *et al.*, 2015). Again, households with more education may have greater access to non-farm income and thus be more able to purchase inputs required to implement the technology. Some type of manure like compost may require some level of technical expertise to make. That may include the formulae and raw materials to use. Educated farmers may have a greater ability to decode new information, and analyze the importance of new technologies. Furthermore, household with a more educated household heads may also be less likely to invest in labor-intensive technologies and practices, since they may be able to earn higher returns on their labor and capital if they are used in other off-farm activities. That being said, the impact of education on adoption of manure is assumed ambiguous before estimation.

Age of Household Head

In their paper, Kassie *et al.* (2015) also argued that age of the household head may capture experience in farming and exposure to technologies implying the ability to plan for unforeseeable shocks while on the other hand, it may also be associated with short term planning, risk aversion and loss of energy. Implying that the impact of age like education, on adoption may be ambiguous prior to estimation.

Gender of Household Head

In many developing countries like Malawi, men and women do not have equal access to education, and other productive assets. In most cultures women are discriminated, thus this can obviously have an impact on adoption of SWC technologies. It has been argued that women have less access to critical farm resources (land, labor, and cash) and are generally discriminated against in terms of access to external inputs and information. This makes women less likely to adopt new technologies like organic manure on their farm plots. The gender variable in this paper, is a dummy (1 =female & 2 male) and the researcher hypothesises the sign of a coefficient of gender to be positive.

Area of Residence

In Malawi, there are two main types of resettlement after marriage which normally follow the customary inheritance laws. These are formally known as *Chikamwini* (patrilineal) and *Chitengwa* (matrilineal). In *chikamwini*, the husband moves to the wife's village and lives together with relatives of his wife. On the other hand, *chitengwa* is the opposite, wives move and stay with their husbands. In some cases both the husband and wife may come from the same village or they may decide to move to a neutral village. Area of residence in this study is defined as whether the household was living in a village of a wife or husband or the village was neutral to both. Area of residence may define who has power over decisions related to what can be done on the farm and how between a husband and a wife. We capture the impact of area of residence on household's decision to adopt manure on their plot by categorizing the variable "area" into three categories (1 = wife's, 2=husband's and 3=neutral). We expect the adoption decisions to be likely positive if the husband has more power on the plot so, we expect "2" and "3" to be positive while 1 to be negative.

Household Capacity and Assets Endowment

Livestock Ownership

Ownership of livestock can act as a ready source of manure to household. Crop-livestock interaction is a common practice in developing countries in Malawi, where livestock serve as source of manure and draft power, and crop enterprises generate fodder for livestock. Those households who own livestock are more likely to adopt SWC technologies like manure, thus the hypothesis for the indicator of this variable is positive.

Access to Free Input Subsidy Coupon

The Malawi government implements a targeted Farm Input Subsidy Programme (FISP), which targets resource poor farmers. In the program, the beneficiaries are given a coupon, which they use to purchase fertilizer and seed at a price extremely lower than the market price. Holden and Lunduka (2012) in their paper, found a positive relationship between manure use and being a beneficiary of the subsidy programme. Implying that beneficiaries of the subsidy programme may be more likely not to afford

enough to buy enough fertilizer, thus may resort to manure to compliment a few fertilizer they bought at a lower price. However, there may be some concerns that the wealthier households may in reality be more likely to get subsidy and they are also more likely to use manure and there are no strong indications that fertilizer and manure are substitutes. Thus, there may be an endogeneity problem. To cast these doubts of endogeneity, the researcher conducted two-step probit regression method to test for endogeneity. The test involves running a probit regression using the suspected variable as a dependent variable, predicting the residuals, then run a probit again using the original dependent variable with the predicted residuals as part of the regressors. One then performs a straightforward t-test for significance of the coefficient on the estimated error term. If the coefficient of the predicted residuals is not significantly different from 0, one would "accept" the null hypothesis that access to free coupon is an exogenous variable in the adoption equation (Bollen *et al.*, 1995). The t-test for the residuals found a p-value of 0.7710, implying the suspected variable (access to free coupon) is not endogenous in the adoption equation. In this paper, households are categorised into two groups, either a beneficiary or not (1=yes & 0 =no), therefore, from the above discussion, the researcher hypothesizes a positive coefficient of this covariant of adoption.

Quantity of Fertilizer Applied

Although the impact of farmers' ability to purchase enough fertilizer for a plot can be complex as manure can be taken as a substitute or complement to chemical fertilizer. Wealthier households may have the ability to buy enough fertilizer and see manure application as unnecessary. However, Holden and Lunduka (2012) found that fertilizer and manure were found to be used as complementary inputs and not as substitutes. This suggests that households, who are capable of accessing fertilizer on their farm plots, may also be likely to adopt manure on the same plots. Following the discussion on access to free fertilizer coupon above, fertilizer may also be endogenous. To verify the suspicion, the researcher also run a two-step probit model, the resulting p-value was 0.7700, and again there is not enough statistical evidence that fertilizer quantity is endogenous in the adoption model. Again, we assume a positive impact of amount of fertilizer applied on the plot, and the adoption of manure on the plot.

Household Labor Endowment

Labor is one of the important factors in agriculture production. Farm households are differentially intergrated into the labor market, with some being net sellers of labor, others net buyers of labor and others opting for self-sufficiency. Household that may not be endowed with enough household labor may supplement the labor with what is known as *ganyu* in Malawi. By definition, *ganyu* is a system in which a household of any socioeconomic status that lacks adequate labor can access additional labor on a seasonal basis, but it is typically associated with the sale of labor by people from poorer households to wealthier households in exchange for cash or goods (Bryceson & Fonseca, 2006). The authors also observed that, during peak agricultural seasons, *ganyu* labor demand increases and often causes disadvantaged casual wage laborers to divert work from their own fields when they can least afford it. Implying that supplying *ganyu* can be an opportunity cost to the household of the member providing it.

Household health may also affect the household labor needs. Poor health will mean reduced energy and attention to attend to farm needs, implying that illness can be an opportunity cost to the household labor. We capture household health as a dummy variable where “1” means the household head was sick for three or more weeks and “0” otherwise.

The quality of labor may also matter in the adoption decisions. Generally, male household labor force is associated with being physically strong and able to do more manual work than the female labor force. Households with many male members who can supply farm labor are considered to be better endowed with labor than households with a larger proportion of female labor force. By labor force, the paper refers to number of workers of that specific age. A household member is considered part of the work force is older than 12 years old in this study.

That being said, hired labor like *ganyu* is much associated with imperfect information due to high transaction costs, seasonality of agriculture production, farmers liquidity constraints and moral hazard making the labor market imperfect. With the above discuss

in mind, in general, the researcher hypothesizes that higher household labor endowment enhances the probability of adoption while higher opportunity cost of labor reduces the probability of adoption.

Plot level Characteristics

Distance from home to plot

Farmers may have their plots located in different places. Some very close to their homes while some may be located very far from home. Most rural areas in Malawi have very poor road network and infrastructure that may make household's access to far distant plots a bit challenging. The situation can be worse for poor household who do not have other cheap reliable means of transport like bicycles. Such that distant plots are more likely to receive less attention (Kassie *et al.*, 2015) again distance plots may provide additional transport constraints for the organic manure if it has to be made around homestead. Thus, we hypothesize a negative coefficient of plot distance in the adoption model.

Soil type or texture

Soil type defined as the texture of the soil as either being loam, clay or sandy may have important implications on the household's decision to adopt manure on the plot. Sandy soils are associated with poor soils as it has poor water and nutrient holding capacities, on the other hand clay with hold more water and nutrients but it becomes too dry when water is not available. While loam soils are defined as more moderate, they have moderate water and nutrient holding capacity and they are the most preferred soils for maize production. Farmer's may have undefined strategy to how they decide on which soils to apply manure, some may want to use the manure on the soils they believe it will have a more significant impact, applying it on already good soils. While others may want to improve the poor soils, hence applying the manure on the poor soils. Such, the impact of soil type of farmers decision to adopt manure is undefined before estimation.

Intensity of Soil erosion on plot and slope on the plot

Farmers were asked to rate the intensity of soil erosion on their plots during the previous growing season. The rank of intensity was; no erosion, slight erosion, moderate and severe erosion. Like soil type characteristic above, soil erosion may also have a mixed

impact on household's decision. Some households may want to apply manure on plots with severe erosion to correct for the lost nutrients while others may want to apply it on less eroded soils to avoid losing the manure to erosion on plots that are so prone to erosion. Therefore, the impact of soil erosion intensity is ambiguous before estimation. This is may also be applied on slope characteristic of the plot, farmers may have ambiguous reaction to the slope.

Farm size

Soil and water conservation technology adoption literature seem to indicate an inverse relationship between adoption farm size. Some have attributed it to the fact that farm size may be a proxy variable for household wealth, and that because wealthy farmers may focus on other income-generating activities and they may give less attention to SWC measures (Teshome *et al.*, 2015). Again, larger farm size may demand more time and resources in order for the technology to be efficient, this may also add to the negative effect of farm size on adoption of manure. However, other authors like Obando *et al.* (2012), argue that if the farm size are smaller, farmers will have less incentives to adopt a technology because they may not benefit from the economies of scale. Holden and Fisher (2013) found evidence inverse relationship of farm size and productivity which they attributed to imperfect land rental markets. Implying that challenges in accessing addition land may force farmers to put more effort on their small farmers, thus increasing the probability adopting new technologies like organic manure. Such, we hypothesize that the effect of farm size on adoption is undefined before estimation.

Number of plots owned by a household

Although number of plots owned by a household can also be proxy for a household wealthy, it might also imply that the household has divided its parcels into too many small plots. The more the plots a household has, the less likely the household can adopt as it implies that the land has been divided into many small pieces of land hence the farmer cannot benefit from the economies of scale (Obando *et al.*, 2012). Again, the more the plots the household owns, the more the divided attention it may have regarding investments on the plots. Therefore, let the hyponthesis for this variable have a negative effect on adoption.

Land tenure

Lovo (2016) found that tenure insecurity, the informal short-term tenancy contracts, and customary gender-biased inheritance practices has a negative effect on adoption of SWC investments in Malawi. Better tenure security increases the likelihood that farmers will capture the returns from their investments. As a result, demand for short-term inputs (farm chemicals, labor) will increase as well. Again, land tenure matters in adoption decision of manure, farmers are more likely to apply manure on the plot that they own unlike on rented plots.

Estimation Strategy

Adoption of manure

After verifying that the variables suspected to be endogenous in the model are actually exogenous, the researcher proceeded to estimate the model. To evaluate factors affecting adoption of manure, the study assumes a probit model implying that I assume that the error term are normally distributed. Probit models rely on the strong assumption that the error term are normally distributed otherwise a logistic model would be more appropriate. Logistic models assumes that the error term are logistically distributed.

The probit regression model with panel specification used in this study is to identify factors affecting adoption of manure is:

manure

$$= \beta_0 + \beta_1 \text{soiltype}_{it} + \beta_2 \text{hhage}_{it} + \beta_3 \text{plotdistance}_{it} + \beta_4 \text{fertilizerQty}_{it} + \beta_4 \text{area}_{it} + \beta_5 \text{farmsize}_{it} + \beta_6 \text{tenure}_{it} + \beta_7 \text{female}_{it} + \beta_8 \text{male}_{it} + \beta_9 \text{plots_owned}_{it} + \beta_{10} \text{hhsex}_{it} + \beta_{11} \text{freecoupon}_{it} + \beta_{12} \text{hheduc}_{it} + \beta_{13} \text{ownlivestock}_{it} + \beta_{14} \text{Ganyu}_{it} + \beta_{15} \text{soilerosion}_{it} + \text{year_dummies}$$

Casual effects of manure on yield during dry spells with Propensity Score Matching Estimator

The paper will follow Millimet and Tchernis (2013) proposed approaches to deal with the problem of selection bias due to the endogenous behavior of our treatment variable, adoption of manure. For comparison, the paper will also estimate the ATT with the

ordinary PSM estimator, as well as both the *minimum-bias* (MB) estimator and the *Corrected-bias* (CB) estimator. The estimation will use the same covariates used in estimating the PSM above.

The propensity score matching (PSM) estimator for ATT, the researcher first computes the PSM. Following Caliendo and Kopeinig (2008), below are the steps followed when computing the PSM.

Step 1: Propensity score estimation

Since this study is interested in a manure as a binary treatment, it estimates the probability of being treated given the observed factors using the probit model then predicted the pscore. In this model, the researcher included both household and plot characteristics. The researcher used the same variables used in adoption model to estimate a pooled probit model as shown below.

manure

$$= \beta_0 + \beta_1 \text{soiltype} + \beta_2 \text{hhage} + \beta_3 \text{plotdistance} + \beta_4 \text{fertilizerQty} + \beta_4 \text{area} + \beta_5 \text{farmsize} + \beta_6 \text{tenure} + \beta_7 \text{femalelf} + \beta_8 \text{malelf} + \beta_9 \text{plots_owned} + \beta_{10} \text{hhsex} + \beta_{11} \text{freecoupon} + \beta_{12} \text{hheduc} + \beta_{13} \text{ownlivestock} + \beta_{14} \text{Ganyu} + \beta_{15} \text{soilerosion} + \beta_{16} \text{year_dummies}$$

Step 2: Choosing a matching algorithm

I apply Kernel Matching algorithm. Unlike other matching algorithms that only use that only a few observations from the comparison group to construct the counterfactual outcome of a treated individual Kernel matching (KM) use weighted averages of all individuals in the control group to construct the counterfactual outcome (Caliendo & Kopeinig, 2008). By using the weighted averages of all individuals, kernel matching allows for a small variance as more information is used. However, the main drawback of kernel matching is that it may increase the possibility of bad matches. Thus, Caliendo and Kopeinig (2008) suggested that the proper imposition of the common support condition is of major importance for kernel matching.

Step 3: Check overlap common support between treatment and comparison group

In propensity score matching methods, we can consider only the observations whose propensity score belongs to the intersection of the supports of the propensity score of treated and controls. To improve the quality of the matches, imposing a common support restriction may be necessary. The study adopts a maxima and minimum comparison. Imposing dropping treatment observations whose pscore is higher than the maximum or less than the minimum pscore of the controls.

Step 4: Assessing the matching quality

Ideally, to balance the observed distribution of covariates across the plots where there was manure adoption and plots where there was no adoption. Thus, after matching it is important to check the quality of the matching by checking whether the difference between the covariates in the adoption group and non-adopting groups still exists. There are so many methods of testing the quality of matching, for this study two sample t-tests is used. When implementing you do t-tests for equality of means in the treated and non-treated groups, both before and after matching and if you have a good balancing, t-tests should be non-significant after matching. Again using the formulae by Rosenbaum and Rubin, 1985, the standardized bias before and after matching should be less than 5% after matching.

Casual effects of manure on yield during dry spells with Minimum-Bias and Corrected-Bias Estimators

The researcher's logic behind using the *minimum-bias* and *Corrected-bias* estimators to identify the impact of manure on maize yield during dry spells is as follows: the absence of a valid exclusion restriction for the manure dummy in the SWC technology adoption literature. In addition to that, the notion that both selection on unobservables and essential heterogeneity are likely to be present among the households and plots in the data set. As noted above, MB and BC estimates the impact of a binary treatment when one lacks a valid exclusion restriction and it allows us to estimate impacts in the presence of essential heterogeneity and when conditional independence assumption fails, which is not possible using the Heckman estimator. For the sake of comparison,

the study estimates both the models first with untransformed maize yield as an outcome variable, and then estimates the same models using a log-transformed maize yield variable.

Results and Discussions

Descriptive statistics for adopters and non-adopters

To compare the household and plot characteristics of adopters and non-adopters, Table 4 below, presents the descriptive statistics of the two groups.

Table 3: Comparing descriptive statistics of adopters and non-adopters

Characteristic	Adopters			Non-adopters			t-statistic
	N	Mean	SD	N	Mean	SD	
Soil type	573	1.977	0.643	1130	1.942	0.644	-1.082
Age of household head	587	49.027	14.601	1186	49.798	16.300	0.9698
distance from home to plot (m)	587	1030.10	2255.50	1186	1157.14	2170.99	1.1446
Qty of Fertilizer applied per mm ²	587	0.007	0.029	1186	0.01	0.043	1.462
Area of residence (wife's or husband's)	587	1.385	0.55	1185	1.489	0.594	3.540***
Farm size in ha	587	0.445	1.788	1186	0.614	3.719	1.0380
Tenure (owned or rented in)	587	0.949	0.22	1186	0.927	0.259	-1.7158*
Household female labor force	587	1.869	1.001	1186	1.930	1.036	1.1717
Household male labor force	587	2.041	1.243	1186	1.884	1.194	-2.5706***
Number of plots owned	587	4.049	1.780	1186	4.153	1.965	1.0820
Household head sick for >3 weeks	587	0.102	0.303	1186	0.127	0.333	1.5365
Gender of household head	587	1.261	0.439	1186	1.271	0.444	0.4480
Access to free fertilizer coupon	587	0.746	0.436	1186	0.68	0.467	-2.853***
Level of education for household head	587	1.186	1.127	1186	1.108	1.089	-1.398
Livestock Ownership	587	0.709	0.455	1186	0.626	0.484	-3.467***
Household member participation in Ganyu	587	0.492	0.5	1186	0.53	0.499	1.4743
Intensity of Soil erosion on plot	581	0.874	1.007	1162	0.791	0.994	1.5365
Maize yield (kg/ha)	587	186.337	349.321	1186	151.706	249.771	-2.3947***
Maize yield (kg/ha) in dry spell states	345	171.962	350.141	712	144.978	258.720	-1.4103

Note:SD= standard diversion, * significant at 10%, *** significant at 1%

Soil type

Farmers were asked to describe the type of soil on their farm plot as either clay, loam or sandy that was later verified by the enumerators. Soil type was also hypothesized to be a driving factor of adoption although their impact is ambiguous. However, the results

of descriptive statistics shows that there is no statistically differences in the soils on plots owned by adopters and non-adopters.

Age of household head

The average age of a household head in the sample was 49.5 with a minimum of 15 and maximum of 97. Comparing the means between the adopters and non-adopters, results shows that there is no statistically significant differences among the groups. For the adopters the mean was 49 while for the non-adopters was 49.8 although the standard deviation of the non-adopters was a bit higher.

Distance from home to plot

To evaluate the factors affecting adoption of manure, distance from home to plot was considered to one of the key variables. Literature indicates that plots that are located very far from home do not receive more attention than those located very close to farmer's home. The mean distance from home to plot in the sample was 1115.1 meters. Evaluating if there are differences in the mean distances for the plots that were manure-applied plots and those that were not, I find no statistically significant differences in their means.

Quantity of fertilizer applied

Most soils in Malawi are degrade such that many farmers apply chemical fertilizer on the plots although most of the amount applied are less than the recommended. In this paper, on average, farmers in the sample applied 0.0089078kg/mm^2 , and a minimum was 0kg and the maximum was 0.936kg/mm^2 . There was no significant difference on the means of quantity of fertilizer applied on plot per unit area of the adopters and non-adopters. The use of manure did not stop the farmers from using fertilizer on the plots.

Farm size

An average farm size of maize plots among the sampled households was 0.56 ha. Land holding size was not significantly different in there means between the adopters and non-adopters. However, the data shows that households living in the Southern region

had a smaller land holding size than those in the Central region. For the South, the mean farm size was 0.47ha and for the Central was 0.7ha.

Area of residence

Area of residence defined as whether the household was living in a village of a wife or husband or the village was natural to both. Depending on culture, after getting married some move to stay in the village of their husbands while in other cultures a husband moves to the wife's village. The descriptive statistics indicate that 59.1% of the households were living in a wife's village, 36.4% in husband's village and only 4.5% were living in a neutral village. The mean differences for the adopters and non-adopters are very significant at 1%. A further analysis shows that 36.1% of the plots owned by households living in wife's villages manure was applied, while 29.1% and 23.8% of plots owned by households living in husband's and neutral villages, respectively, reported being applied with manure.

Land Tenure

Land ownership and tenure security are among most important features in SWC technology adoption. The households are feeling more secure, the more likely they will be willing to implement long-term SWC technologies on the farm. On the other hand, if they feel like they may be pushed out of the land any time soon, or if they rent the land for a few seasons, the household is not likely to invest on that farm. In this paper, the t-statistic for the difference in means for the adopters and non-adopters was negatively significant at 10% level. Implying that owner operated plots were more likely to be applied with manure than rented in plots.

Household female labor force

Household female labor force was measured as number of female members in the household who are able to provide farm labor. I set a limit of a household member should be not less than 12 years old qualify because even school going children do help on farm before or after school hours. There was no statistically differences in the means of the adopter and non-adopter groups.

Household male labor force

Like female labor force, I measured the male labor force as household members who can help with farm labor from the age of 12 and above. The differences in mean for the households with manure-applied plots (adopters) and no manure applied (non-adopters) was highly significant and negative at 10% level. Households with more male labor force seem to be more likely to adopt manure on their plots than their counterparts.

Number of plots owned by household

On average, a household in the sample owned four plots. The descriptive statistic results shows no statistically significant differences in means adopters and non-adopters. That imply that manure adoption may not be related to how many plots a household might have.

Household head sick for more than three weeks

A household head is mostly the main decision maker in a household and most likely, she/he takes the lead in the farm activities. If the household head happened to be seriously ill for more than three consecutive weeks, that may have an implication on farm activities. In addition to that, the other household members may also divert their attention to their sick family member. The descriptive statistics of the data shows that there is no statistically differences in the means of adopters and non-adopters in terms household head illnesses.

Gender of household head

Adoption literature shows that gender differences of household heads may bring some implications where one gender may be more likely adopt a technology than the other gender. The study, find no statistically significant differences in the means for the gender variable of adopters and non-adopters.

Access to free fertilizer coupon

The Malawi government implements a targeted Farm Input Subsidy Programme (FISP), which target resource poor farmers. In the program, the beneficiaries are given a coupon, which they use to purchase fertilizer and seed at a price extremely lower than

the market price. Test of mean differences of beneficiaries among the adopters of manure and non-adopters indicate that there is a highly negative statistically significant difference. FISP beneficiaries were more likely to apply manure on their plots than non-beneficiaries.

Level of education for household head

The study measured education level as the highest level of education completed by the household head. The six categories included; none, standard 1-4, standard 5-8, attended secondary school, holds a Malawi School Certificate of Education (MSCE), attended technical college and attended university education. About 89.5% of the household heads in this study did not reach up to secondary school level and only 0.34% attended technical colleges. Comparing the mean differences in the education level between adopters and non-adopters, results show no statistically differences between the means.

Livestock ownership

Livestock is one the most important asset for a farm household. Apart from being a source of income and food, livestock naturally may also provide manure to the household through their waste (animal dung). The descriptive statistics of the data shows that there is a highly significant difference between the means of livestock ownerships for adopters and non-adopters. The relationship is negative and significant at 10% level. Implying that households who owned livestock are more likely to use manure on their farm plots unlike those who do not own livestock.

Household member participation in Ganyu

Household engagement into *ganyu* as a supplier may be a trade-off between labor for their own farm which may reduce the likelihood of a household to adopt manure on the own farm. However, the t-tests for the mean differences between the adopters and non-adopters did not show any statistically significant differences of *ganyu* supply.

Intensity of Soil erosion on plot

The measured the intensity of soil erosion on the based on the owners perception. The rank of intensity was; no erosion, slight erosion, moderate and severe erosion. About

62% of plots reported no soil erosion in 2009, 54.3% and 40% reported soil erosion on the plots in 2012 and 2015 respectively. However, there seem to be no statistically differences in the means between the plots applied with manure and where no manure was applied.

Maize yield

Maize yield was measured in kilograms per hectare. Comparing the differences in means of yield between adopters and non-adopters shows a statistically significant difference. Maize yield was higher on manure-applied plots than on non-manure applied plots. For the adopters, the mean yield was 186.3 kg/ha while for non-adopters was 151.7 kg/ha.

Maize yield in dry spell states

On the other hand, comparing the means of maize yield in dry spell state shows the statistical significance seems to disappear. Although the adopters seem to have a higher mean yield than non-adopters do, the t-test is not significant at any acceptable levels.

Results from adoption model

Running the probit model with and without bootstrap standard errors gives the following variables as statistically significant. I present part of the output in the tables showing only relevant significant variables. However, one can find full detailed outputs of the analysis in the appendix 1 &2 below. Our dependent variable is manure, a binary variable indicating whether a household is an adopter on that plot or not.

Table 4: Probit regression analysis of factors affecting households' decision to adopt organic manure ³

	Model with regular SD b/se	Model with bootstrap SD b/se
Manure		b/se
Tenure (dummy)	0.406** (0.166)	0.406*** (0.148)
Malelf	0.077* (0.040)	0.077 (0.048)
Seriousillness (dummy)	-0.260** (0.130)	-0.260* (0.147)
Ownlivestock (dummy)	0.253*** (0.094)	0.253*** (0.091)
Ganyu (dummy)	-0.173* (0.089)	-0.173* (0.097)
0.soilerosion (none)	0.000 (.)	0.000 (0.000)
1.soilerosion (slight)	0.052 (0.099)	0.052 (0.093)
2.soilerosion (moderate)	0.240** (0.114)	0.240* (0.141)
3.soilerosion (severe)	0.120 (0.149)	0.120 (0.201)
Constant	-1.056*** (0.330)	-1.056*** (0.348)
Insig2u		
Constant	-0.682*** (0.179)	-0.682*** (0.221)
rho	.3357771	.3357771
N	1679	1679

Note: b : coefficient, se = standard errors, * statistically significant at 10%, ** statistically significant at 5%, and *** statistically significant at 1%, SD= standard errors

³ Only statistically significant covariants are included in this table, aa full output ttable is presented in appendix 1 and 2 below

i. The model with regular standard errors

In this model specification, land tenure defined as whether the household owned the plot or rented in, seems to have a positive significant relationship with manure adoption on a plot at 5% level. Household male labor force “malelf” also shows a positive and statistically significant relationship but at 1% level of significance. The health of a household head captured a dummy of whether a household head was sick for more than three weeks during the growing season “seriousillness” is statistically significant at 5% level. Ownership of livestock also is positively related to adoption with a high significance level of 1%. The variable indicating the household member involvement in providing *ganyu*, is negatively and statistically significant at 10%. Moderate soil erosion on the plot have a positive and significant relationship with manure adoption at 5% level.

ii. The model with bootstrapped standard errors

When bootstrapped standard errors are imposed, the land tenure variable becomes more significant from being statistically significant at 5%, now it is significant at 1% level. The household male labor force “malelf” becomes insignificant at all acceptable levels. The health of the household head “serious illness” becomes less significant, it was significant at 5% confidence level, now significant at 10% with bootstrap standard errors. While ownership of livestock remains the same, it is still highly significant. Involvement in *ganyu* labor also did not change, still significant at 10% level as when no bootstrapping was imposed. Soil erosion is still significant at rank two, however, the level of significant has dropped from 5% level to 10% level.

Because by calculating the bootstrapped standard errors, one can measure the precision of the estimates, I will base the interpretation of the results on the results from bootstrapped model because it is more robust as it takes into account of possible heterogeneity in the model. Following the results above, it can be suggested that factors that affect adoption of manure on a plot include the following;

Land tenure

The household is more likely apply manure on a plot if it owns that plot unlike on rented plots. This is shown by the positive significant coefficient of the variable tenure. This

may be because land rentals in Malawi are mostly on short-term basis that may range from one growing season to two or three seasons. This finding is in line with what other researchers on adoption of SWC technologies found (Kassie *et al.* (2015) and Maiga (2005) etc.). They suggested that these type of technologies are more likely to be implemented on owner-operated land due to tenure insecurity reasons that may threaten the long-term benefits. If the tenure security is weak, households are not willing to commit resources that would otherwise have long-term benefits.

Health of household head

The other important factor according to our findings is the health of the household head. Health is a very important human capital that when is compromised many things might also be compromised. As expected, if a household head was sick for a significant time, which consecutive was at least three weeks in this study, that has a significant impact on the adoption decisions. The more people they get sick, the less the adoption of the technology. This implies that development initiatives should include health components.

Livestock Ownership

As expected, livestock ownership is a strong factor affecting adoption of manure on a plot. Consistent the the findings of previous, Maiga (2005) and Kassie *et al.* (2015), owning livestock increases the probability that a household will adopt manure application on its plot. This may be supported with the fact that it is easy to use animal manure than other typppes of manure. Animal manure just involves collecting the manure from the animal houses (*khola*) and apply them on the plot. While other manure types like compost may need to go some processes that may require special technics like making pits for composting and mixing the ingrediates.

Household member participation in Ganyu

Although *ganyu* is a source of extra off-farm income, it might also be a trade-off between household farm labor to supplying the labor to others who equally need it at a cost. In this analysis, as expected, *ganyu* has a negative significant effect on adoption

of manure. Households whose members were also involved in ganyu are less likely to adopt manure application on the plots. However, this might also imply that poor households are less likely to apply manure as provision of ganyu is more associated with poor household supplying labor to richer households during peak periods.

Intensity of Soil erosion on plot

While severe soil erosion seem not to have an impact on adoption, moderate soil erosion seem to have a positive impact. The probability of the household to apply manure on its plot seems to increase when the plot is moderately affected by soil erosion. This implies that when the soil is moderate, the household have some faith that not all the manure will be washed away hence they have incentives to apply manure on these plots.

Other Convariates in the model

The discussion above only focused on the statistically significant factors in the model. The analysis found that factors like age and gender of a household head did not significantly affected on adoption. Number and size of plots owned by the household were also insignificant, this is inconsistent with other previous findings on adoption literature (Kassie *et al.* (2015)). Again, distance from home to plot was found to be negative but not statistically significant implying that it does not affect adoption of manure. However, this may be due to the fact that plot distance is correlated to land tenure, in that most rented-in plots are likely not to be very close to homestead, therefore, the impact of distance may be hidden in the tenure variable. Access to free fertilizer coupon, although positive, it seems not have a statistically significant impact on adoption. There is also not enough evidence in the results to indicate whether fertilizer is used as a substitute or complement to organic manure. Household ability to use or access enough fertilizer did not affect the probability of adoption consistent with the impact of subsidy.

Estimating ATT with Propensity Score Matching Methods

The first step in PSM matching is to generate a pscore, with a pooled probit model with the same covariates used in the adoption model. The sum of the pscore indicated that our propensity to participate in the treatment for all plots is 33.8%. I also conducted a specification test for this model. The first is Lagrange Multiplier Test for Normality of

residuals; the p-value was 0.4015 suggesting that the assumption for normally distributed residuals was not violated.

To estimate the casual effect I use maize yield in its log form as an outcome variable if the state was a dry spell state. The total number of manure applied plots in dry spells was 335 and non-adopting plots were 712. After matching 3 manure-applied plots were dropped remaining with 332 plots treated and on support, while for the non-treated 27 plots were dropped from and 685 plots were on common support. The empirical results of the casual effect on the outcome estimated by a kernel matching are shown in Table 6 below.

Table 5: Results for the kernel matching with common support

Variable	Sample	Treated	Controls	Difference	S.E.	T-stat	Treated on support	Control on support
Log of maize yield	Unmatched	4.1095	3.9100	0.1994	0.1172	1.70		
	ATT	4.1097	3.8005	0.3091	0.1187	2.60	332	685

Note: S.E. is standard error, T-stat is test statistics

From the t-static of ATT, manure application on the plot seem to have a significant positive impact on yield when dry spells occurs. However, before further concluding about the preliminary findings, we have to check for the common support requirement.

Figure 1 and Figure 2 shows the distributions of the propensity scores between the two groups before and after matching, respectively. Together the figures suggest matching was well done that the pscore between the groups do seem to have almost the same distribution. Figure 3 shows the distributions on and outside the common support the Propensity Score Graph. The Propensity Score Graph implies that matching procedures eliminated the observation of the adopters whose propensity score is greater than the maximum or lower than the minimum propensity score of the non-adopters.

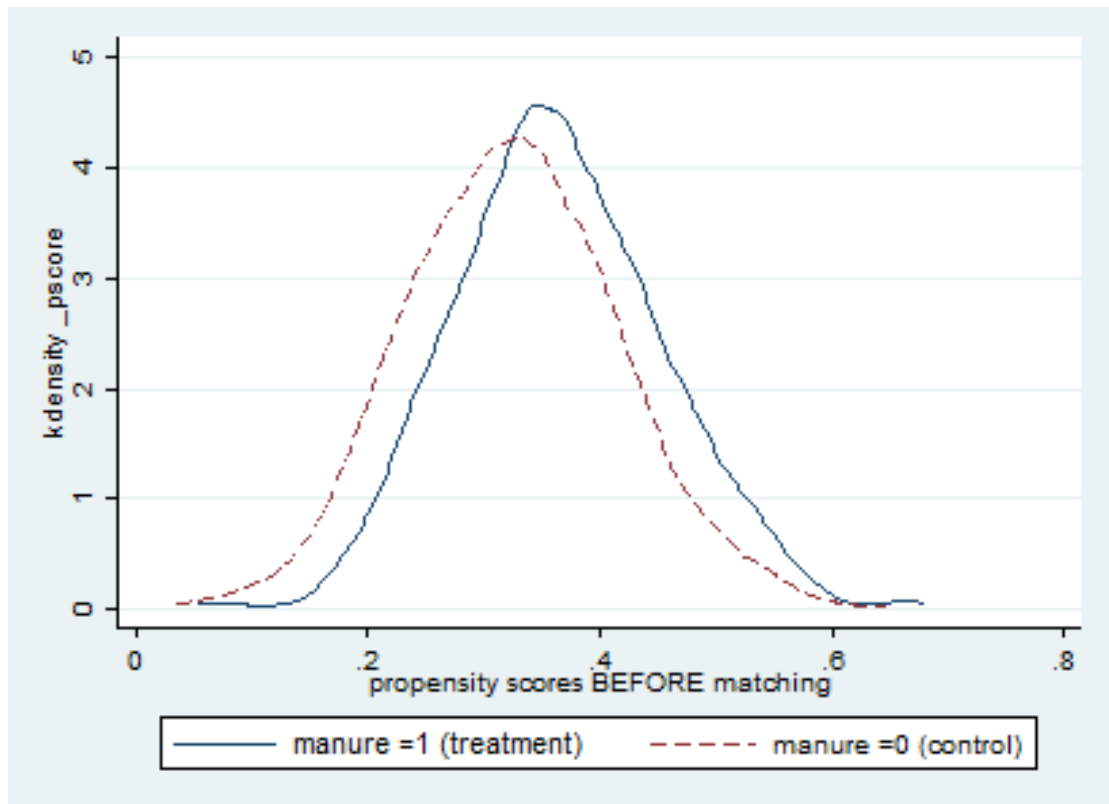


Figure 1: Distribution of propensity score before matching

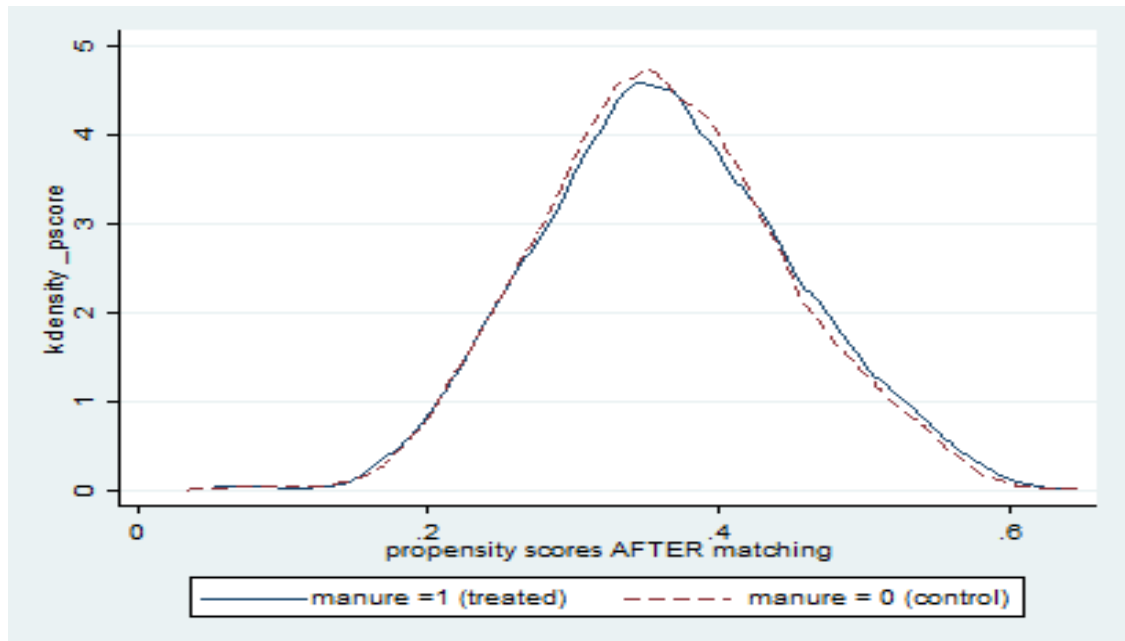


Figure 2: Distribution of propensity score after matching

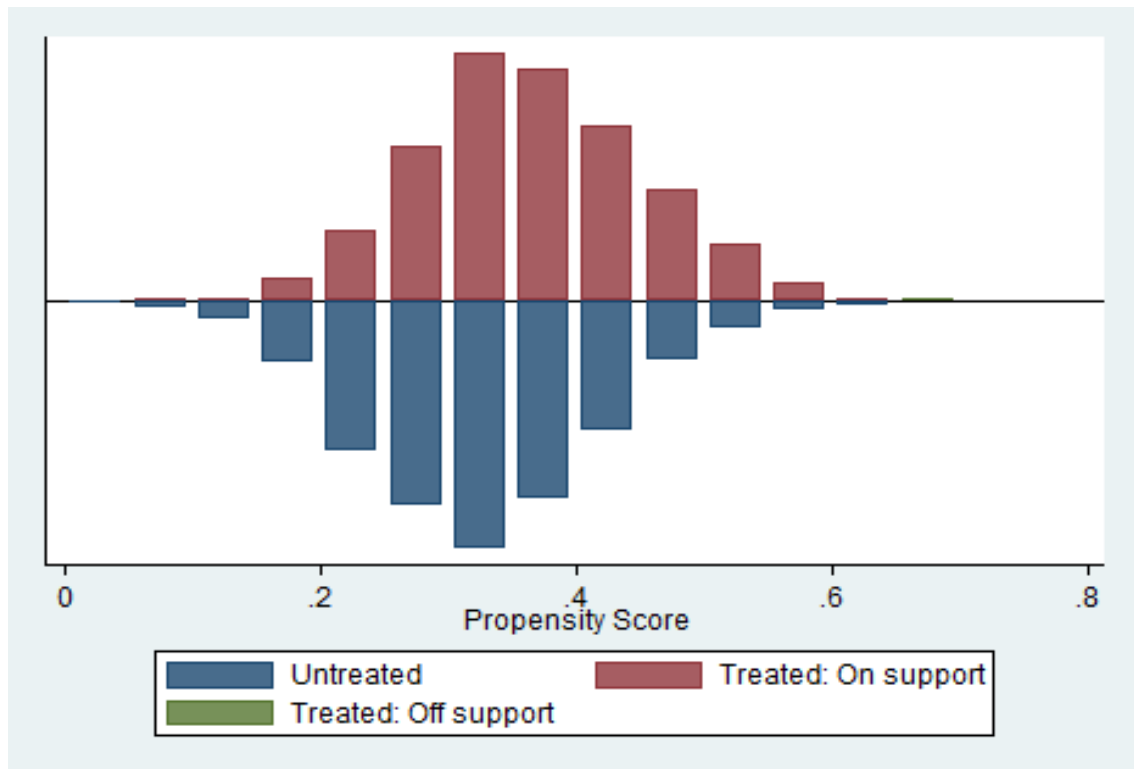


Figure 3: Propensity Score Graph

To test for the common support requirement, all the p-values of all covariants after matching were insignificant and the standard mean bias after match was 1.1%. All the convariants seems to have a standard bias of less 5% which is an indication of a quality common support. Figure 4 below is a graph showing the visual distributions of the standard biases before and matching. The the graph presented, all the standard biases are accumulated around zero.

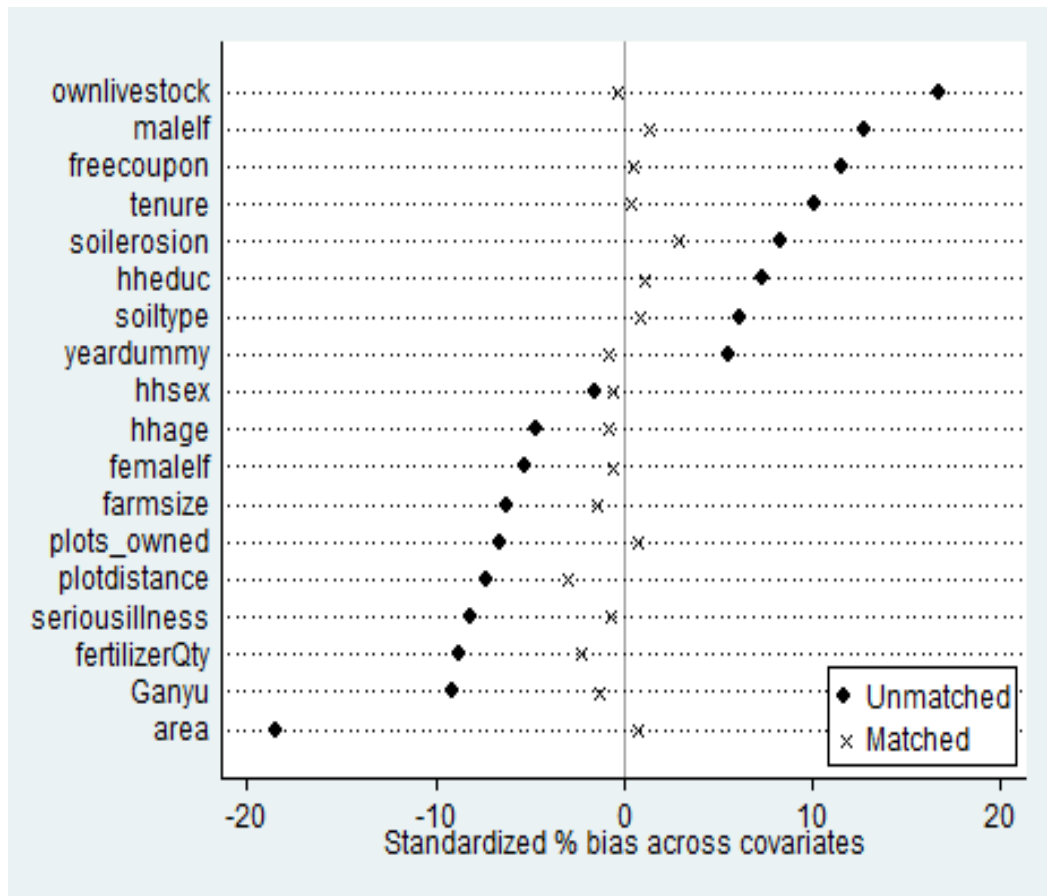


Figure 4: Distribution of standard % biases across covariates before and after matching

Analysis of the maize yield distribution before and matching, shows that the matching did not really change the distribution. Figure 5 and Figure 6 below shows the distribution of maize yield (log-transformed) for adopters and non-adopters in dry spell state before and after matching. Generally, manure seems to increase the yield as the distribution curve seems to shift to the right for manure-applied plots. In addition to that, there are fewer zero yield for manure-applied plots than the non-treated. Implying that, generally organic manure helped to reduce the losses from the dry spells.

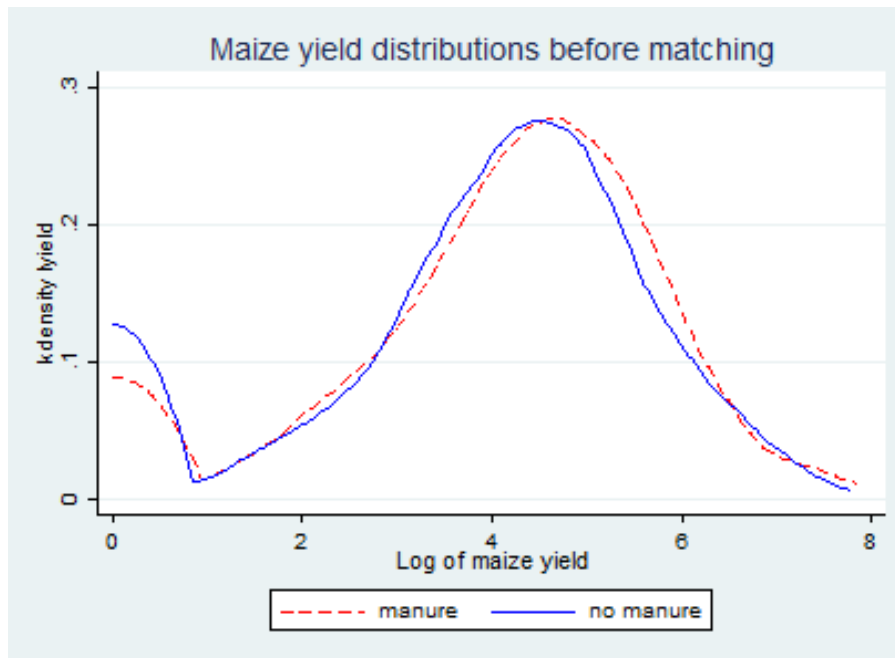


Figure 5: Maize yield distributions for manure-treated and control plots before matching

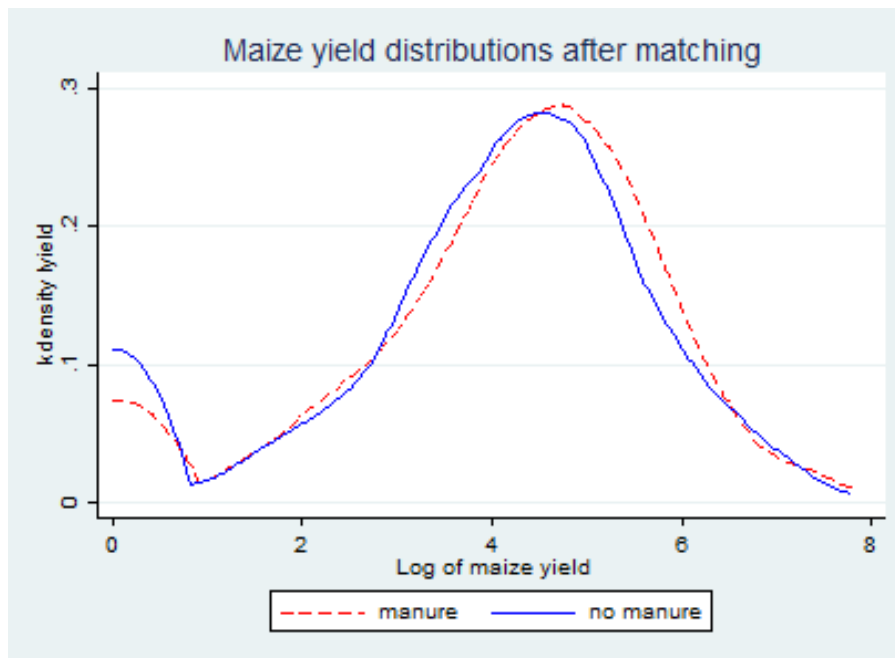


Figure 6: Maize yield distributions for manure-treated and control plots after matching

Following the above discussions and analysis, I go back to the positive significant t-statistic of ATT. The above results implies that we can trust the findings. The t-statistic is 2.60, implying a statistics significance at 1% level of confidence. It implies that maize

yield on the plot where manure was applied and dry spells occurred are 31% higher than on plot with no manure but also affected by dry spells.

Estimating ATT Minimum-bias and Corrected-Bias Estimators

To estimate the casual effect of manure on maize yield using MB and CB, I try use both untransformed and log-transformed yield as outcome variables. The covariants use are the same as the ones used in pooled probit from estimating pscore in PSM method above. Table 7 and 6 and 8 below, presents the statistical results of the the analysis.

Table 6 : Estimation of the effect of manure on yield during dry spells (Untransformed maize yield) with minimum-bias and Corrected-bias Estimators

Using untransformed maize yield as outcome variable	
Estimator	ATT/CI
Minimum-bias (Quiggin & Chambers)	14.811 [-9.941, 66.687]
Corrected-bias (MB-CB)	568.441 [-1.5e+03,4118.415]
P^*	0.500 [0.500, 0.500]
$P^* - EE$	0.787 [0.301, 0.979]

Note: bootstrapped confidence intervals [CI] in paranthesis

Table 7: Estimation of the effect of manure on yield during dry spells (log-transformed maize yield) with minimum-bias and Corrected-bias Estimators

Using log-transformed maize yield as outcome variable	
Estimator	ATT/CI
Minimum-biased (MB)	0.123 [-0.196, 0.374]
Corrected-bias (MB-CB)	4.511 [-12.007, 27.863]
P^*	0.500 [0.500, 0.500]
$P^* - EE$	0.760 [0.097, 0.960]

Note: bootstrapped confidence intervals [CI] in paranthesis

Using the BM and BC estimators, the positive sign on β indicate the average increase in maize yield during the dry spells when the plots are applied with manure. Both table 7 and 8 consistently estimate the positive impact of manure on yield during dry spells. Regardless of the measurement form of yield, the coefficients *corrected-bias* (MB-CB) estimators seem to have a higher value than the *minimum-bias* (MB) estimators do. ATT is much stronger when MB-CB. Using the minimum-biased estimator in Table 7, ATT shows an average increase of 14.8kg/ha during dry spells if a plot with a relatively high probability of being applied manure is applied with organic manure, while after corrected for the bias by using the Corrected-bias estimator, the ATT is indicates an average increase of 568kg/ha. One can observe the same trend when considering a log-transformed outcome in Table 8. ATT is 12.3% increase when a *minimum-biased* estimator is used and an impressive 451% increase when the bias is corrected. Implying that when the bias is corrected, the relationship between manure is much stronger and positive. In should be noted that, the huge difference in ATT can be attributed to the fact that, the MB approach of estimating ATT, changes the outcome variable while the CB-CB do not change the outcome variable (Millimet & Tchernis, 2013). From the Table 7 & Table 8 above, the BMPS given as $P^* - EE$ in the two tables above is always above 0.74. As such, we can interpret the results above as showing statistically

meaningful evidence of a positive causal effect of organic manure on yield for the average farm plot with a relatively high probability of being applied with manure. However, confidence intervals are large and typically uninformative; such the results can only be interpreted with caution. Nevertheless, the study can not reject that null that in the face of dry spells, maize yield is higher when organic manure is adopted than when it is not adopted.

Conclusion

The study attempted to assess factors affecting adoption decisions of manure as one of widely adopted SWC technology in Malawi and to evaluate the impact of using manure during dry spells. Using a panel plot farm household data drawn from three years, 2009, 2012 and 2015. The data contained detailed household and plot characteristics.

To assess the factors affecting the farmers' decision to adopt manure application, the study set a binary probit model using manure adoption as a dependent variable. Using the model, the study found plot level characteristics like land tenure and intensity of soil erosion as positively affecting the household adoption decisions for manure. On the other hand, household endowments like livestock also increased the probability of a household to adopt manure. Other household characteristics like health of the household head and household participation in *ganyu* negatively affected the household decisions of adoption. Labor constrained households, due to high opportunity cost of *ganyu* and sickness reduce the probability of a household to adopt organic manure on the plot implying an imperfect labor market as the hired labor is not perfect substitute of household labor.

Generally, the study could not reject null hypothesis that higher household labor endowment enhances the probability of adoption of organic manure while higher opportunity cost of labor reduces the probability of adoption organic manure. Implicitly, if a household has more labor, it will make more manure, and if household labor can be substituted by hired labor, the household would still make more manure by hiring if it is less endowed with labor or the labor is absent due to sickness.

Again, tenure security increases the probability of a household to adopt manure, suggesting that poor/imperfect land markets have a negative impact on adoption of manure. Further analysis, in general the results indicate that characteristics that seem to represent market factor imperfections specifically labor and land seem to have a negative effect on adoption.

On the other hand, the study did not find any statistical significance of FISP on adoption of organic manure as access to free fertilizer coupon although positively correlated the effect is not significant. Again the ability of the household to access more fertilizer did not seem to have an impact on adoption of manure yet the correlation was positive.

To evaluate the effect of manure on maize productivity during dry spells, the researcher first used Propensity Score Matching (PSM) without controlling for endogeneity in adoption of manure to estimate Average treatment effect on the treated (ATT). Using a probit model to predict the pscore and kernel matching algorithm with common support imposed, I matched the treated with the untreated. The balancing property was checked and was appropriate. The resulting ATT was 0.309 implying an average increase of 31% productivity when the plot was treated with manure and dry spells occurred. This is an interesting finding as it implies that manure application can be used as a resilient tool for dry spells. Although yield may be generally lower when dry spells occur, but the effect will be different on plots that are treated with manure and those not treated. Those treated with manure will have 31% more yield than the non-treated.

Controlling for the endogeneity on adoption of manure, by using estimators that minimize the bias and corrected the bias, the positive effect of manure on maize yield was still present. The study shows that there is statistically meaningful evidence of a positive causal effect of organic manure on yield for the average farm plot with a relatively high probability of being applied with manure. However, the test failed to measure the value of the positive change as the confidence intervals appeared to be so large. The positive impact implies that use of organic manure can be used as a resilient tool for smallholder farmer in adapting to prolonged dry spells.

Policy Implications

Although with some caution, the study has concluded that organic manure reduces the loss of yield due to dry spells. In other words, farmers can adopt manure as a resilient tool for climate change when it's associated with prolonged dry spells. Impliedly, promotion of organic manure can reduce the production risk in rain-fed maize production. Policies that will help in nudging farmer to adopt manure as one of the effective SWC technology may translate into an increase maize production even in the face of prolonged dry spells. Adoption of organic manure can be used as a tool to enhance food security.

On the other hand, the study has found some interesting results on the factors influencing adoption of organic manure. Among other factors, the study found land tenure to have a positive effect on the households' decision to adopt organic manure on the farm. Farmers are more likely to adopt organic manure if they own the plot unlike when they rent in. Owing to tenure security and long term benefits. Policies that aim at strengthening tenure security specifically, improving the land rental market will likely increase the adoption rate of organic manure among smallholder farmers. Thus, increasing food security and resilience to climate change.

The study have find enough evidence that factor market imperfections in labor market are constraining adoption of manure among smallholders in Malawi. Implying that policies that aim at removing the market imperfections would help increase adoption rate of organic manure. Since imperfect labor market imply higher shadow wage (opportunity) than labor wage, and we know that shadow wage is a factor of household asset endowment including agriculture assets and human capital like unskilled and skilled labor endowments. Policies that aim at improving household assets endowment like farm income diversification programs can help to increase adoption rate of manure.

Livestock ownership was also found to to be significantly affecting the households decision to adopt manure. Households who own livestock will also be likely to be resilient to dry spells through the use of manure. This implies a presence of an important link between promotion of intergated farming and climate change resilience among smallholder farmers. Livestock ownership is associated with household wealth, in most

cases it is the richer households who own livestock as they are capable of buying the stock and maintaining it even in stress times. Poor household may not have enough income to buy the livestock hence making them prone to shocks of dry spells. Introduction of programs that promote ownership of livestock among the poorest would be of high importance. The programmes may include the pass-on programmes that allow households to pass-on the young livestock to their neighbor on condition that, the neighbor will also pass-on the offsprings to another household.

Study Limitations

The main limitations was to accurately identify dryspells for sepcific farm plots. The study used rainfall data from the nearest weather station. However, for some villages, the nearest station is located more than 25 km away, such I cannot ignore some lack of accuracy in actual daily rainfall in those villages. However, though dry spells in Malawi may be localized, they mostly affect a wider area hence, we can still apply the information from the weather station.

Acknowledging that the study limited in scope by not going further to estimate how organic manure performs in flood states, there is need to do more research on other states of nature. This would add value to the work already done by this paper and others.

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Appendices

Appendix 1: xtprobit regression output with regular standard errors

```

Random-effects probit regression          Number of obs   =   1679
Group variable: hid                     Number of groups =   354

Random effects u_i ~ Gaussian           Obs per group:  min =    1
                                           avg =    4.7
                                           max =   13

Integration method: mvaghermite         Integration points =   12

Log likelihood = -984.21911              Wald chi2(23)   =   46.00
                                           Prob > chi2     =   0.0030

```

manure	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
soiltype						
2	.0694172	.0977922	0.71	0.478	-.122252	.2610864
3	.1079746	.1250268	0.86	0.388	-.1370734	.3530225
hhage	-.0003657	.0033875	-0.11	0.914	-.0070051	.0062737
plotdistance	-8.88e-06	.0000182	-0.49	0.627	-.0000446	.0000269
fertilizerQty	-1.650096	1.178469	-1.40	0.161	-3.959852	.6596598
area						
2	-.1340167	.107433	-1.25	0.212	-.3445815	.0765482
3	-.3927504	.2559039	-1.53	0.125	-.8943129	.1088121
farmsize	-.0105064	.0132378	-0.79	0.427	-.036452	.0154391
tenure	.4063197	.165542	2.45	0.014	.0818632	.7307761
femalelf	-.0406293	.0429797	-0.95	0.344	-.1248679	.0436093
malelf	.0770779	.0403548	1.91	0.056	-.002016	.1561719
plots_owned	-.0372485	.0243686	-1.53	0.126	-.0850099	.010513
seriousillness	-.2596425	.1300561	-2.00	0.046	-.5145478	-.0047371
hhsex	.0352238	.1202912	0.29	0.770	-.2005426	.2709902
freecoupon	.1360851	.0969568	1.40	0.160	-.0539467	.3261168
hheduc	.0544624	.0462911	1.18	0.239	-.0362666	.1451913
ownlivestock	.2530369	.0935731	2.70	0.007	.069637	.4364369
Ganyu	-.1724656	.0889241	-1.94	0.052	-.3467535	.0018224
soilerosion						
1	.0518298	.0986474	0.53	0.599	-.1415155	.2451751
2	.2398849	.1142576	2.10	0.036	.0159441	.4638257
3	.1202842	.1487899	0.81	0.419	-.1713387	.411907
year						
2012	-.0906517	.1014219	-0.89	0.371	-.2894349	.1081316
2015	.0324142	.1113672	0.29	0.771	-.1858615	.2506898
_cons	-1.055797	.3300274	-3.20	0.001	-1.702639	-.4089556
/lnsig2u	-.6821694	.1794382			-1.033862	-.3304769
sigma_u	.7109987	.0637902			.596348	.8476916
rho	.3357773	.0400203			.2623361	.4181246

Likelihood-ratio test of rho=0: chibar2(01) = 112.39 Prob >= chibar2 = 0.000

Appendix 4: Stata Do-file

```
gen yeardummy -.
replace yeardummy -1 if year ==2009
replace yeardummy -2 if year ==2012
replace yeardummy -3 if year ==2015

xtset hid

note: adoption model with regular standard errors

xtprobit manure 1.soiltype hhage plotdistance fertilizerQty 1.area farmsize tenure ///
femalelf malelf plots owned seriousillness hhsex freecoup hheduc ///
ownlivestock Ganyu 1.soilerosion 1.year

estimate store regulary_sd_errors

note: adoption model with bootstrapped standard errors

xtprobit manure 1.soiltype hhage plotdistance fertilizerQty 1.area farmsize tenure ///
femalelf malelf plots owned seriousillness hhsex freecoup hheduc ///
ownlivestock Ganyu 1.soilerosion 1.year, vce(boot)

estimate store bootstrap sd errors

estout regulary sd errors bootstrap sd errors, cells(b(star fmt(%9.3f)) se(par)) stats(r2
rho N, fmt(%9.3f %9.0g) ///
labels(R-squared)) varlabels( cons Constant) starlevels ///
(* 0.1 ** 0.05 *** 0.01) posthead("") prefoot("") postfoot("") ///
varwidth(16) modelwidth(12) delimiter("")

note: pooled model for generating pscore, considering only dry spell state state

probit manure 1.soiltype hhage plotdistance fertilizerQty 1.area farmsize tenure ///
femalelf malelf plots owned seriousillness hhsex freecoup hheduc ///
ownlivestock Ganyu 1.soilerosion 1.year if dryspell ==1

predict pscore
sum pscore

note: estimating ATT using PSM
psmatch2 manure, pscore(pscore) kernel outcome(lyield) common, if dryspell ==1

psgraph, treated(manure)pscore(pscore)

skprobit manure soiltype hhage plotdistance fertilizerQty area farmsize tenure ///
femalelf malelf plots_owed seriousillness hhsex freecoup hheduc ///
ownlivestock Ganyu soilerosion yeardummy

pstest soiltype hhage plotdistance fertilizerQty area farmsize tenure ///
femalelf malelf plots owned seriousillness hhsex freecoup hheduc ///
ownlivestock Ganyu soilerosion yeardummy, both graph

note: estimating ATT when unconfoundness fail

bmtc maizeyield hhage plotdistance area fertilizerQty farmsize tenure ///
femalelf malelf seriousillness hhsex freecoup hheduc ///
ownlivestock Ganyu soilerosion if dryspell ==1, group(manure) ee hetero bs

bmtc lyield hhage plotdistance area fertilizerQty farmsize tenure ///
femalelf malelf seriousillness hhssex freecoup hheduc ///
ownlivestock Ganyu soilerosion if dryspell ==1, group(manure) ee hetero bs
```



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