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Choice of Tillage Technologies and Impact on Paddy Yield and Food Security in Kilombero Valley, Tanzania

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Abstract
This paper analyses choice of alternative tillage technology options and their impact on paddy yield and food security in Kilombero valley of Morogoro Region, Tanzania. The results show that the choice of any tillage technology option combining hand hoe with animal traction and/or tractor is influenced by characteristics of household head (sex, age and education), access to extension, dependency ratio, land size and livestock assets. As hypothesized the three improved tillage technology options above the hand hoe enhance paddy yield and improve household food security. Factors other than tillage technology options that influence paddy yield and food security are characteristics of household head(sex, age and education), access to extension, use of fertilizer and herbicides, dependency ratio, farm size and livestock assets. The study recommends promotion of tillage technology options involving use of animal traction and yield enhancing inputs.
Keywords: Kilombero valley-Tanzania, tillage technology, paddy yield, household food security
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1. Introduction

Despite various measures taken to alleviate the world hunger problem, food insecurity and under nutrition remain serious problems in many countries (Pawlak and Kołodziejczak, 2020). Yet food insecurity is greatest among rural people in sub-Saharan Africa (SSA) (Giller, 2020, Sasson, 2012) where agriculture is the mainstay of the majority of rural people in (Senbet and Simbanegavi, 2017). The key cause of food insecurity is low agricultural productivity and output (Olasehinde-Williams *et al*., 2020). Low use of modern farm implements (such as tractors and animal traction) and productivity enhancing inputs (such as quality seed, fertilizer, herbicide and pesticides) is among the major seasons for low agricultural productivity is SSA (Bjornlund *et al*., 2020). Other reasons include but not limited to low use of irrigation and overwhelming dependence on rain-fed agriculture coupled with climate change (Abdulai, 2018), lack of market access (Poulton *et al*., 2006) and conflicts and war (Bjornlund *et al*., 2020).

Although studies on the effect of use of animal and tractor power for farm operations on agricultural productivity and output are fewer than studies on effect of use of productivity enhancing inputs (quality seed, fertilizer, herbicide and pesticides) on agricultural productivity and output, the consensus appears to be that reliance on manual labour using hand hoe for most farm operations is dominant and limits productivity increases in SSA (Sims and Zienzle, 2017). Using FAOSTAT/AGS data, Mrema *et al*. (2018) found that there were 2 tractors per 1000 ha of arable land in 1980 but only 1.3 in 2003, while in Latin America and Asia tractor prevalence doubled over the same time period.

In a context of short rainfall seasons in SSA, the use of hand hoe in farm operations often leads to labour bottlenecks at critical points in the cropping cycle, resulting not only in a limitation of cropping area per household, but also in extremely low productivity rates. Therefore use of modern farm implements dependent on tractor or animal power is a promising strategy to increase agricultural productivity and output by facilitating timeliness of farm operations, improving efficient use of resources and supporting opportunities that relieve the burden of labour shortages (Fuad and Flora, 2019). For this reason, many SSA governments have at various times introduced schemes, development projects and incentives, designed to encourage farmers to make more use of four-wheeled tractors, power tillers and animal traction. In general, the efforts by governments have increased the number of tillage technology options available to farmers. Nevertheless the choice of a particular option is determined by several factors including the cost of accessing the technology.

Despite the increase in the number of tillage technologies for farmers to choose from, studies on determinants of choice of tillage technologies and impact of the choices on crop yields and livelihood of smallholder farmers in SSA are relatively scant. Numerous studies have examined the determinants of adoption of modern farm implements in smallholder farms but without analyzing the impact of using them on yield and livelihoods (Makki *et al*., 2017), while others (Mondo *et al*., 2020) have examined the profitability and efficiency of modern farm implements over the traditional hand hoe for smallholder farms. This study examines the determinants of choice of tillage technologies and the impact of the chosen tillage technology option on paddy yield and household food security among paddy farmers in Kilombero valley of Morogoro Region in

Tanzania.

The traditional hand hoe (HH) dependent on human power has been the predominant tillage implement among paddy farmers since the introduction of paddy into Kilombero valley during the last century (Ashimogo *et al*., 2003). The introduction tractors (T) by large-scale farmers during the late 1980s and animal traction by agro-pastoralists who have been immigrating into Kilombero valley since 2000 increased the number of tillage options that smallholder farmers could choose for paddy production (Walsh, 2012).

Although the introduction of the AT and T has reduced the use of HH as the only tillage technology to a greater extent, the HH has not been completely replaced by AT and T because of limitations of using the AT and/or T in some farm operations and in some parts of a farm where the AT and T could not be used. Also, paddy farmers using a T are compelled to use AT in swampy areas of Kilombero valley where a T cannot be used (Isinika *et al.*, 2020). Considering these limitations, farmers in Kilombero valley either use the HH alone or combination of hand hoe and animal traction (HH&AT), or a combination of hand hoe and tractor (HH&T), or combination of hand hoe, animal traction and tractor (HH, AT&T). The choice of any of the above four tillage technology options among paddy farmers depends on the resources available to the farmer and the limitations of using a given tillage implement in his/her paddy farm. It is hypothesized that farmers choosing any of the three tillage technology options (HH&AT, HH&T, and HH, AT&T) would achieve higher paddy yields and be more food secure than farmers using the HH alone since they can plant larger areas and have timely farm operations thereby producing more paddy for consumption and sale.

The reminder of this paper is organized as follows. Next to this introduction is the methodology employed, describing the analytical frameworks and data set. Section three presents and discusses the results. Finally, section four presents conclusions and policy implications.

2. Methodology

2.1 Data Used

This paper uses pooled cross-sectional data from 537 and 801 paddy producing households in Kilombero valley of Morogoro District, collected during the 2016/17 and 2019/20 agricultural years. The study was supported by the Agricultural Policy Research in Africa (APRA) programme being implemented in Tanzania, Ethiopia, Malawi, Zimbabwe, Nigeria, and Ghana. Kilombero valley in Kilombero District of Morogoro Region was purposely selected for the study because it fits well with the government ambition of linking smallholder farmers with large-scale farmers under the Southern Agricultural Growth Corridor of Tanzania (SAGCOT). A two-stage sampling design with stratification was used to select representative samples of paddy farmers. The first stage involved the selection of 10 villages from three strata established on the basis of electricity status of a village. The first stratum consisted of villages with electricity in 2017 while the second stratum consisted of villages expected to have electricity connection by 2018 and the third stratum consisted of villages expected to remain without electricity connection by 2019 the year of the second round data collection. The selection of villages from each stratum was done with probability proportional to size. During the first round of data collection in October 2017, 559 households were selected from a population comprising of 7,156 households in the sampled villages, but only 537 were used for analysis due to missing data. During the second round of data collection, the sample was increased to 807 households, but only 801 were used for analysis due to incomplete information for the remaining six. The sample composition by village is given in Table 1.

Table 1: Distribution sampled households by village for round 1 and round 2

Village	Round of data collection	
	Round 1 (October 2017)	Round 2 (January 2020)
Njage	48	76
Mkusi	44	81
Mchombe	67	106
Nakaguru	58	91
Ijia	64	77
Luvilikila	52	63
Itongoa	47	91
Mngeta	63	77
Makutano	52	68
Chita	54	77
Sample total	539	807

2.2 Analytical Framework

This paper analyses choice of tillage technology option and the effect of using the chosen technology option on paddy yield and household food security. The analysis involved establishment of a measure of household food security and determining the effect of chosen tillage technology option on paddy yield and household food security.

2.2.1 Developing Indicators for Household Food Security Status

Household food security was measured using nine food insecurity situations (Table 2). Households facing five situations or more were classified as food-insecure and those facing less than five situations were classified as food-secure.

Table 2: List of food insecurity situations used to classify households into food-secure and food-insecure households (HFSS

S/N	Food Insecurity Situations
1	Worries about not having enough food to eat because of a lack of money or other resources
2	Household members being unable to eat healthy and nutritious food because of a lack of money or other resources
3	Household members eating only a few kinds of foods because of a lack of money or other resources
4	Household members skipping a meal because there was not enough money or other resources to get food
5	Household members eating less than they thought they should because of a lack of money or other .resources
6	Household running out of food because of a lack of money or other resources
7	Household members being hungry but did not eat because there was not enough money or other resources
8	Household members going without eating for a whole day because of a lack of money or other resources
9	Household head not having enough food to meet family's needs

2.2.2 Determining the effect of chosen tillage technology on paddy yield and household food security

The paper uses the multinomial endogenous treatment effects model. The choice of the model is motivated by the following: a) the observed choices of tillage technology cannot be considered random, implying the possible existence of selection bias; b) some unobservable factors influencing the choice of type of tillage technology can also influence yield and food security. In this case, the tillage technology variables will be correlated with the error term in the outcome equations, leading to biased and inconsistent parameter estimates. The key to this is to identify the variables that influence the choice of tillage technology option in a multinomial setting. Accordingly, farmers were classified into four mutually exclusive groups: namely, users of the hand hoe only (HH) as a tillage technology option (control group); users of the hand hoe combined with animal traction (HH&AT) (group 1); users of the hand hoe combined with tractor (HH&T) (group 2); and users of a combination of hand hoe, animal traction and tractor (HH, AT&T) (group 3). As indicated above, all four options of tillage technology include the use of a hand hoe, although its use is less pronounced in groups 1, 2 and 3 compared to the control group. Farmers will choose a tillage technology option that can provide maximum utility to them, subject to various constraints. Random utility theory is used to support the empirical analysis. Assuming that U_{ij} is the utility derived by i^{th} farmer from using j^{th} tillage option, an i^{th} farmer will choose a tillage technology option j, over any other alternative k, if $U_{ij}>U_{ik}$, for all $k \neq j$. **Since** there is a possibility of endogeneity in farmers' decision to choose a certain tillage technology option or otherwise, decisions are likely to be influenced both by observed and unobservable characteristics that may be correlated with the outcome variables (Kassie ***et al***., 2013). In order to separate the impact of choice of tillage technology and to effectively analyze the factors influencing the choice and the impact in a joint framework, a multinomial endogenous treatment effects model proposed by Deb and Trivedi (2006) was adopted in this paper. This approach has the advantage of evaluating both an individual type of technology and a combination of tillage technologies, while capturing the interactions between choices of alternative types of tillage technologies (Obayelu *et al.*, 2017). A similar analytical approach based on multinomial endogenous switching regression (MESR) is used by Kassie *et al*. (2013) to study the **adoption** of multiple sustainable agricultural practices in smallholder systems.

The specified multinomial endogenous treatment effects model consists of two stages. In the first stage, a farmer chooses one of the tillage technology options mentioned above. Following Deb and Trivedi (2006), U^*_{ij} utility latent variable reflecting the net benefits associated with the use of the j^{th} tillage technology option (j = 0, 1, 2..., J) instead of any other type of tillage technology k by farmer i. The latent model is specified as:

$$U^*_{ij} = x_i^{'}\alpha_j + \delta_j l_{ij} + \varepsilon_{ij} \qquad (1)$$

where x_i is a vector of household-head characteristics (age, sex, years of schooling), household-level factors (household size, farm size, number of livestock, non-farm income) and services (extension, mobile money) associated with parameter vector αj. lij is a latent factor that incorporates unobserved characteristics common to farmer i's choice of tillage technology type j and outcome, and are assumed to be independent of ϵ ij. Furthermore, εij are independently and identically distributed error terms.

The control group is denoted by j = 0, which in this case is use of hand only for tillage which and where U*i0 is set to zero since the other technology options are assessed relative to the control. The variable d_j is binary reflecting the choice of jth tillage technology type, assigned a value of 1 if the option is chosen and zero otherwise. Thus, $d_i = (d_{i1}, d_{i2}, \ldots, d_{iJ})$ is a vector of observable binary variables representing the choice options of various types of tillage technologies available to ith farmer. Similarly, $l_i = (l_{i1}, l_{i2}, l_{iJ})$ is the associated vector of latent factors. Thus, the probability choice of tillage technology by ith farmer can be represented as:

$$\Pr(\mathbf{d}_i|\mathbf{x}_i, \mathbf{l}_i) = g(\boldsymbol{x}_i^{'}\alpha_1 + \delta_1 l_{i1} + \boldsymbol{x}_i^{'}\alpha_2 + \delta_2 l_{i2} + \ldots + \boldsymbol{x}_i^{'}\alpha_J + \delta_J l_{iJ} \quad (2)$$

Assuming that g is a mixed multinomial logit (MMNL) structure, then:

$$\Pr(\boldsymbol{d}_i|\boldsymbol{x}_i, \boldsymbol{l}_i) = \frac{\exp(\boldsymbol{x}'_i\alpha_j + \delta_j l_{ij})}{1 + \sum_{k=1}^{J}\exp(\boldsymbol{x}'_i\alpha_k + \delta_k l_{ik})} \quad (3)$$

Table 3 presents the variables used in equation 3.

Table 3: Selection equation variables

Variable	Type	Expected sign
Household and farm characteristics		
• Age of household head (years)	Quantitative	+/-
• Years of schooling of household head	Quantitative	+
• Sex of household head	Dummy: 1 if female	-
• Household size (number)	Quantitative	+
• Farm size (hectares)	Quantitative	+
• Livestock income	Quantitative	+/-
• Non-farm income	Quantitative	+/-
Type of farmer (MSF)	Dummy variable: 1 if small scale and 0 if medium scale	-
Type of toilet	Instrumental variable: 1 if flush toilet and zero otherwise	+

Analysis of the effect of chosen tillage technology option on household paddy yield and household food security was undertaken in the second stage where household food security was assigned a value of 1 if a household is food-secure and zero if not food-secure. The expected outcome for ith household can be defined as:

$$E(y_i|\boldsymbol{z}_i, \boldsymbol{d}_i, I_i) = \boldsymbol{z}_i^{'}\beta + \sum_{j=1}^{J}\gamma_j d_{ij} + \sum_{j=1}^{J}\lambda_j I_{ij} \quad (4)$$

where y_i represents paddy yield or HFS status for paddy farmer i and z_i **is a vector of exogenous variables with associated parameter vector** β, γ_j denote the effect of tillage technology j relative to the control group, i.e. use of the hand hoe which is a manually operated tillage implement and λ_j is a factor loading reflecting the impact of unobservable factors influencing the probability of choice of tillage technology option j. Given that food security is binary, a logistic distribution is assumed while for paddy yield normal distribution is assumed. Assuming log-linear functional form for yield, the average treatment impact from tillage option j is expressed $100*(\exp\lambda_j-1)$. Table 4 presents the specification of the variables and expected signs of the coefficients for the outcome equation 4.

The multinomial endogenous treatment effect model is identified even when the exogenous variables in the selection equation (x_i) are exactly the same as in the outcome equation (z_i), Deb and Trivedi (2006) recommend identification by inclusion of instrumental variables in the selection equation.

Table 4: Specification of the Explanatory Variables and Expected Signs of the Coefficient

Variable	Type	Expected sign
Tillage options		
• Ox plough	Dummy: 1 if ox plough	+
• Tractor	Dummy: 1 if tractor	+
• Ox plough	Dummy: 1 if tractor and ox plough	+
Household and farm characteristics		+/-
• Age of household head (years)	Quantitative	+
• Years of schooling of household head	Quantitative	-
• Sex of household head	Dummy: 1 if female	+
• Household size (number)	Quantitative	+
• Farm size (hectares)	Quantitative	+/-
• Non-farm income	Quantitative	+/-
• Type of farmer (MSD)	Dummy: 1 if small scale and 1 if medium scale	+
Community and location variables		
• Distance to nearest paddy mill (km)	Quantitative	-

2.2.3 Estimation

Due to the possibility of endogeneity for the tillage option variables as was previously explained, it is necessary to define the appropriate instruments to be included in the selection equation. A reasonable proxy demonstrating farmers' curiosity and willingness to adopt new tillage technologies is the use of mobile money service. It is assumed that the use of mobile money service will be partially correlated with each tillage option after controlling for other factors, but the use is the service affects the outcome variables only through the tillage technology options. The validity of the instrument was performed through a falsification test. According to Di Falco et al (2011), an instrument is valid if it affects the choice or selection while remaining without effect on the outcome for the control group. The falsification test results of the instrument are presented in Table 5 but are mixed, being supporting for yield outcome and contradictory for food security. The model was estimated by simulated likelihood (MSL) using mtreatreg in stata and 200 simulation draws (Varma 2017).

Table 5: Test on the Validity of the instrument

Independent variables	**Paddy yield**	**Food Security Status**
	Coefficient and s.e	**Coefficient and s.e**
Year dummy (2019/20=1)	-0.0224 (0.0970)	-0.1727 (0.1287)
Age classification of household head (Youth=1)	0.1451 (0.0952)	0.0012 (0.1377)
Sex of household head female=1)	0.1819 (0.1819)	0.1120 (0.1392)
Years of schooling of Household Head	0.0050 (0.0049)	0.0215 (0.0175)
Access to extension service (yes=1)	0.0868 (0.0991)	0.0805 (0.1313)
Use of inorganic fertilizers (yes=1)	0.3894** (0.1908)	-0.2894 (0.2749)
Use of herbicides (yes=1)	0.1068 (0.0957)	0.2495** (0.0520)
Dependency ratio	0.0238 (0.0426)	-0.0034 (0.0160)
Total land (ha)	0.0042 (0.0141)	0.0514*** (0.0160)
Number of livestock (TLU)	0.0081 (0.0075)	0.0014 (0.0044)
Use of mobile money service (yes=1)	0.0934 (0.7323)	0.2932** (0.1335)
Constant	0.7323 (0.1237)	0.0497 0.1521)

3 Results and Discussion

3.1 Descriptive Statistics

3.1.1 Use of tillage implements

The use of AT and T does not only reduce the drudgery of farmers in using manually operated implements such as HHs but also enhances the precision and timelines in implementing different farm operations. This section examines the use of different tillage implements in paddy production. The HH is the basic farm tool used by all paddy farmers because of the limitations of using AT and/or TR in some farm operations or in parts of the farm where AT or T cannot be used. Results in Table 6 indicate that the HH&AT tillage technology option was used by a relatively larger percentage of farmers than the other tillage technology option irrespective of the agricultural year. The proportion of sample paddy farmers who used HH alone declined from almost 11% in 2016/17 agricultural year to 6% in 2019/20 agricultural year. Interestingly, the proportion of sample farmers using the tillage technology option that combines AT and T is almost the same in both agricultural years. According to Isinika *et al.* (2020) this tillage technology option was employed by farmers who were compelled to use AT in swampy areas of Kilombero valley where a T cannot be used.

Table 6: Distribution of sampled paddy farmers by tillage technology option and by agricultural year in Kilombero valley in Kilombero District, Tanzania

Tillage technology option	**Agricultural year**			
	2016/17		2019/20	
	N	%	N	%
HH	54	10.7	46	6.0
HH&AT	218	43.1	408	52.8
HH&T	150	29.6	196	25.4
HH, AT&T	84	16.6	123	15.9
All	506	100	773	100.0

3.1.2 Tillage technology and land area cultivated for paddy production

Irrespective of the agricultural year, Table 7 shows that land area under paddy production varied across tillage technology options. It is evident from Table 7 that the users of HH&AT, HHT, and HH, AT&T technology options cultivated significantly ($p<0.01$) more land for paddy production than those who used a HH. However, the advantages of using the HH&AT option among smallholder farmers outweigh those of using the HH&T option, not only in terms of capital requirement, availability, and affordability, but also because of the possibility of using it to expand the land for paddy production in marshy land where tractors *cannot* be used.

Table 7 Land area under paddy production by tillage technology option and agricultural year used[a]

Tillage technology options	Agricultural Year					
	2016/17			2019/20		
	N	Mean	Median	N	Mean	Median
HH	54	1.8(2.46)	0.8	46	1.7(2.68)	0.8
HH&AT	214	3.2(3.93)	1.6	408	2.0(3.05)	1.0
HH&T	150	2.3(3.94)	1.6	196	2.6(6.90)	1.4
HH, AT&T	84	3.1(5.33)	1.6	123	3.0*(5.79)	1.8
Total	501	2.8(4.10)	1.4	773	2.3(4.78)	1.2
		F=2.48*	***		F=1.97	***

[a]*Hand hoe only is used as control and One sided Dunnet test is used to compare mean areas of other tillage options with the control. Independent sample median test is used to test for effect of tillage technology on median paddy area.*

*Note: *** is significant at $\alpha=0.01$, ** at $\alpha=0.05$ and * at $\alpha=0.1$.*

3.1.3 Paddy yield by tillage technology option and agricultural year

Table 8 shows levels of paddy yield across the different tillage technology options used for paddy cultivation. Overall paddy yield is significantly higher for all tillage options involving animal traction and or tractor power when compared to using hand hoe only across the two agricultural years. However the observed yield difference cannot be attributed to tillage technology options before controlling for other factors. It cannot be ruled out that farmers using more efficient tillage options also use other yield enhancing inputs such as fertilizers as well as hired labour and herbicides.

Table 8 Paddy yield (t/ha) by tillage technology option and agricultural year[a]

Tillage technology option	**Agricultural Year**					
	2016/17			**2019/20**		
	n	**Mean**	**Median**	**N**	**Mean**	**Median**
HH	53	2.0(1.35)	1.5	46	1.9(1.17)	1.8
HH&AT	214	2.4**(1.50)	2.2	408	2.6**(2.02)	2.2
HH&T	150	2.7***(1.35)	2.6	196	2.6**(2.33)	2.2
HH, AT&T	84	2.6**(0.94)	2.7	123	2.4(1.37)	2.2
All	501	2.5(1.37)	2.4	773	2.5(1.98)	2.2
		F=3.66**	***		F=2.38*	n.s

[a]*Hand hoe only is used as control and one sided Dunnet test is used to compare mean paddy yield of other tillage options with the control. Independent sample median test is used to test for effect of tillage technology on median paddy yield.*

*Note: *** is significant at $\alpha=0.01$, ** at $\alpha=0.05$ and ** at $\alpha=0.1$*Crop

3.2 Results of the multinomial endogenous treatment effects model

As indicated in Section 2.1.3, four mutually exclusive tillage technology options for paddy farming were identified including HH, HH&AT, HH&T and HH, AT &T. Therefore, the first stage of the multinomial endogenous treatment effects model analyzed the factors influencing the choice of tillage technology option to be used in commercial paddy farming other than the HH which is used as a control. This was followed by an analysis of the effect of the chosen tillage technology option on paddy yield and household food security.

3.2.1 Factors influencing choice of tillage technology

Table 9 presents parameter estimates of the first stage of the mixed multinomial Logit model for factors influencing choice of tillage technology. The model fits the data well with Wald X^2=413.55, p> X^2=0.000. As seen in Table 9, the coefficient of age category of household head is positive for HH&AT but negative for HH&T and HH, AT &T. The positive coefficient for the HH&AT implies that young farmers would likely choose HH&AT tillage technology option over HH only but would likely maintain HH only over tillage options involving tractor power (HH &T or HH, AT &T), probably because of owning small farms which do not justify use of tractor and/or limited their ability to afford use of tractor. Meanwhile the negative coefficient for HH&T and HH, AT &T tillage technology options suggest that these options are likely to be chosen by old famers. The coefficients of sex of household head for the three tillage technology options is positive, suggesting that being a female household increases the probability of choosing the three tillage technology options for paddy production rather than using HH only. Compared to use of HH only, use of HH&AT, HH&T or HH, AT&T are labor saving technologies which reduce drudgery and workload in farming among women who are also responsible for domestic activities (Badstue *et al*., 2020). As expected, the coefficient of education for all the three improved tillage technology options above the hand hoe is positive. This suggests that increase in education level increases the probability of choosing HH&AT, HH&T, and HH, AT&T tillage technology options for paddy production. This underscores the importance of education in creating awareness of the benefits of using improved technologies in agricultural production (Relebohile and Keregero, 2019). However, the coefficient of access to extension is negative for the HH&AT tillage technology option and positive for the tillage technology options involving the use of tractor i.e. HH&T and HH, AT&T tillage technology options. This suggests that extension advice was inclined towards promoting use of tillage technologies options that involve use of tractor.

The coefficient of dependency ratio is negative for HH&AT and HH, AT &T tillage technology options but positive for the HH&T tillage technology option. This suggests that households with high dependency ratio are less likely to choose HH&AT and HH, AT &T tillage technology options but more likely to choose HH&T tillage technology option for paddy production. The coefficient of access to nonfarm income is negative for HH&AT tillage technology option and positive for HH&T and HH, AT&T tillage technology options, implying that the probability of choosing HH&AT tillage technology option for paddy production declines as access to non-farm income increases while the probability of choosing HH&T and HH, AT&T tillage technology options for paddy production increases as access to non-farm income increases.

As expected total land size has a positive relationship with all the three improved tillage technology options that combine use of HH with AT and/or T, suggesting that these tillage technologies are likely to be chosen for paddy production as total land size increases. It is interesting to note that the coefficient of livestock assets is positive for tillage technology options that involve use of animal traction (AT) (i.e. HH & AT and HH, AT&T) and negative for the HH&T tillage technology option that does not involve use of AT. This suggests that households with more livestock assets are more likely to choose tillage technology options involving use of AT i.e. HH & AT and HH, AT&T. The coefficient associated with the dummy variable for use of mobile money service has a positive sign as expected and is highly significant ($p<0.01$) across the three tillage options.

Table 9: Determinants of choice of tillage technology option: Mixed Multinomial Logit Results[a]

Independent Variable	Tillage options		
	HH & AT	**HH & T**	**HH, AT &T**
Farming season (2019/20=1)	0.8017*** (0.2819)	-0.1832 (0.2965)	0.1596 (0.3186)
Age category of household head (youth=1)	0.0798 (0.3164)	-0.6764** (0.3424)	-0.6061 (0.3753)
Sex of household head (female=1)	0.3499 (0.4156)	0.8065* (0.44420)	0.8306* (0.4639)
Education (Years of schooling of household head)	0.0284 (0.0507)	0.1575*** (0.0550)	0.1619*** (0.0590)
Access to extension (yes =1)	-0.2234 (0.2797)	0.5543** (0.2971)*	0.3642 (0.3178)
Dependency ratio	-0.1057 (0.1138)	0.0091* (0.1224)	-0.1553 (0.1356)
Access to nonfarm income (yes=1)	-0.3208 (0.3081)	0.0907 (0.3327)	0.2779 (0.3569)
Total land size (ha)	0.0385 (0.0456)	0.0316 (0.0478)	0.0807* (0.0457)
Livestock assets (TLU)	0.0178 (0.0156)	-0.0141 (0.0234)	0.0183 (0.0158)
Use of mobile money service (instrument)	1.0082*** (0.2939)	1.6689*** (0.3621)	1.2444*** (0.3521)
Constant	0.8412* (0.4762)	-1.5032*** (0.5356)	-2.0479*** (0.5708)
Wald X^2=413.55, p> X^2=0.000			

[a]Sample size=1245. 200 simulation draws were used. Figures in parentheses are robust standard errors, *** =p<0.001 **=p<0.05 and *=p<0.10.

3.2.2 Effect of the chosen tillage technology option on paddy yield and household food security

Table 10 presents the estimates of the effect of chosen tillage technology options on paddy yield as an intermediate outcome contributing to household food security after controlling for both observable and unobservable factors. As seen in Table 6, all the three tillage technology options above the HH (i.e. HH&AT, HH&T, and HH, AT&T) are positively related to paddy yield and household food security, implying that paddy farmers who chose these tillage technology options were more likely to achieve higher paddy yields and improve household food security. However, only HH&AT and HH&T have significant impact on yield while in the case of food security significant impact is observed only for HH&T tillage option. The estimated average increase in yield above HH only is about 15.3 % and 48.9% for HH&AT and HH&T respectively.

Factors other than tillage technology options found to have a significant effect on paddy yield are age category of the household head, sex of household head, access to extension services, use of organic fertilizers, dependency ratio and farm size (Table 10). The positive effect of age category of household head (youth=1) on yield suggests that young household heads are more likely to attain higher paddy yield than old household heads, possibly due to the young farmers' willingness of taking risk in using new improved technologies (Donkoh *et al.*, 2019). The coefficient of sex of household head was negative for both paddy yield and HFSS. The negative coefficient for yield suggests that female household heads are more likely to achieve lower paddy yields than male household heads while the negative coefficient for household food security suggests that a female-headed household is likely to be more food-insecure than male headed household. The coefficient of education of household head is negative and significant for household food security, suggesting a high likelihood of increase in household food security as the education level of the household head increases. As expected the coefficient of access to extension was positive and significant, implying that access to extension services enhance paddy yield (Danso-Abbeam *et al.*, 2018, Toma *et al.*, 2018). The coefficient of use of inorganic fertilizer was positive and significant, implying that use of inorganic fertilizers enhances paddy yield. This finding supports the findings by Komarek *et al.* (2018). The coefficient of dependency ratio was negative and significant for paddy yield, suggesting that paddy yield is likely to decline as the number of dependent household members aged zero to 14 years and over the age of 65 years increases relative to the number of those of people in the working age of 15 to 64 years. The coefficient of farm size was negative and significant for paddy yield but positive and significant for household food security, suggesting that paddy yield is likely to decline as farm size increases. Meanwhile the positive coefficient for household food security implies a high probability of a household being food-secure as farm size increases. The factor loadings for food security are all negative but insignificant but for yield the signs are mixed for paddy yield, being positive and insignificant for HH&AT, negative and significant for HH&T and positive and significant for HH,AT&T. The negative selection bias is yield reducing while positive selection bias is yield increasing.

Table 10: Coefficient estimates for yield and food security for multinomial endogenous treatment effects model

Variable	Log yield	HFSS
HH&AT	0.1425**(0.0695)	0.811(0.6607)
HH&T	0.3979***(0.0653)	1.1678**(0.5843)
HH,AT&T	0.0769(0.0674)	0.6083(0.4319)
Farming season (2019/20=1)	-0.0138(0.0293)	0.1776(0.2223)
Age category of household head (youth = 1)	0.1119***(0.0312)	0.1701(0.2412)
Sex of household head (female=1)	-0.0054**(0.0413)	-0.6679**(0.2629)
Education of household head (yrs)	0.0033(0.0058)	0.1132***(0.0338)
Access to extension service	0.0545**(0.0272)	-0.0015(0.1944)
Use of inorganic fertilizer	0.2283***(0.0346)	1.2200***(0.3005)
Use of herbicides	0.0246(0.0275)	0.3096(0.1953)
Dependency ratio	-0.0268**(0.0118)	-0.0714(0.0812)
Farm size (ha)	-0.0041*(0.0022)	0.1435*(0.0836)
Livestock assets (TLU)	0.0005(0.0004)	-0.0071(0.0107)
Constant	0.9461***(0.0699)	-1.0274**(0.0107)
Selection terms (λ)		
λ (HH&AT)	0.0407(0.0644)	-0.1982(0.6571)
λ (HH&T)	-0.2741***(0.0496)	-0.6392(0.5143)
λ (HH, AT&T)	0.1194**(0.0508)	-0.0272(0.2354)

Note: Figures in parentheses robust are standard errors. *** = $p<0.01$, ** = $p<0.05$, and * = $p<0.1$.

4 Conclusions and recommendations

This paper examined the effect of choice of tillage technology options on paddy yield and food security in Kilombero valley, Morogoro Region, Tanzania. The tillage technology options examined were combinations of hand hoe and animal traction, hand hoe and tractor, and hand hoe, animal traction and tractor, with the hand hoe only used as a basis for comparing the effect of the three improved tillage technology options. Descriptive statistics show that use of HH&AT was more prominent than the other tillage technology options. Paddy farmers using HH&AT, HH&T and HH, AT&T technology options cultivated significantly more land and achieved significantly higher paddy yields than farmers using HH alone in paddy production. The results of the first stage Mixed Multinomial Logit indicate that the choice of improved tillage technology options above the HH alone was influenced by sex category of household head, age category of household head, education of household head, access to extension, dependency ratio, total land size and livestock assets. The impact of the improved tillage options on paddy yield and food security showed mixed results. Significant positive impact on paddy yield and food security was observed in the case of HH&T, while HH&AT has significant impact on yield only. The combination of HH, AT &T had no impact on both yield and food security. While the superiority of animal traction based tillage and tractor power tillage on yield is clear, mixing the two doesn't seem to have any added advantage on welfare. Factors other than tillage technology options that have positive effect on both yield and food security are young age of the household head, education, use of inorganic fertilizer and use of herbicides.

Although the results suggest promoting the use of all three improved tillage technology options (HH&AT, HH&T, and HH, AT&T) to enhance paddy yield and improve food security among paddy farmers, emphasis should be on the promotion of the use of HH&AT, not only because it is more inclusive (widely used) in the study area than the other options, but also because it can be used in swampy areas where tractors cannot be used. Also oxen have the additional advantage of being used for pulling ox carts to transport inputs to paddy farms and harvested paddy to homesteads or paddy mills. Promotion of use of animal traction should go hand in hand with ensuring timely availability and application of fertilizers to enhance paddy yield. There is an urgent need for the local government authority to ensure that extension workers are available to advise farmers on appropriate paddy husbandry practices such as seed selection, spacing between plants, watering, and application of fertilizers (inorganic and organic fertilizers) and herbicides. Education and family-planning programs to reduce the household dependency ratio will be effective interventions to improve household food security.

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