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EFFECT OF CHOICE OF TILLAGE TECHNOLOGY ON COMMERCIALISATION AND LIVELIHOOD OF SMALLHOLDER FARMERS IN MNGETA DIVISION, KILOMBERO DISTRICT, TANZANIA

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ACRONYMS

AAAE	African Association of Agricultural Economists
AGRA	Alliance for a Green Revolution in Africa
APRA	Agricultural Policy Research in Africa
DFID	Department for International Development
FAO	Food and Agriculture Organization of the United Nations
FS	food security
HCI	Household Commercialisation Index
HFSS	household food security status
HH	hand hoe
HHOP	hand hoe and ox plough
HHOPTR	hand hoe, ox plough, and tractor
HHTR	hand hoe and tractor
ILRI	International Livestock Research Institute
IMF	International Monetary Fund
IPMS	Improving Productivity and Market Success
IUCN	International Union for Conservation of Nature
IWGIA	International Work Group for Indigenous Affairs
km	kilometre
KPL	Kilombero Plantation Limited
KV	Kilombero Valley
MDD-W	minimum dietary diversity for women
MESR	multinomial endogenous switching regression
MMNL	mixed multinomial logit
MLE	Maximum Likelihood Estimation
MPI	Multidimensional Poverty Index
MSF	medium-scale farmer
MSL	maximum simulated likelihood
OC	ox cart
OP	ox plough

OPHI	Oxford Poverty & Human Development Initiative
PAICODEO	Parakuiyo Pastoralists Indigenous Community Development Organization
QMLE	quasi-maximum likelihood estimate
RCI	Rice Commercialisation Index
SAGCOT	Southern Agricultural Growth Corridor of Tanzania
SRI	System of Sustainable Rice intensification
SSA	Sub-Saharan Africa
SSF	small-scale farmer
TAZARA	Tanzania Zambia Railway
TR	tractor
UN	United Nations

EXECUTIVE SUMMARY

This paper examines the effect of choice of tillage technology options on rice, commercialisation, yield, and livelihood of smallholder rice farmers in Mngeta Division, Kilombero District, Tanzania. There are four options comprising: (i) the hand hoe (HH), a basic tillage implement traditionally widely used in Kilombero District and Tanzania as a whole; (ii) the hand hoe and ox plough (HHOP); (iii) the hand hoe and tractor (HHTR); and (iv) the hand hoe, ox plough, and tractor (HHOPTR). The ox plough (OP) was introduced into Kilombero Valley (KV) by agro-pastoral immigrants in 2000 while the tractor (TR) was introduced by large-scale farmers in the late 1980s. The introduction of ox ploughs and tractors widened the choice of tillage technology options that farmers could choose and use in rice production besides the hand hoe. It was expected that the use of any of the three tillage technology options (HHOP, HHTR, and HHOPTR) would have a higher level of effectiveness than the HH alone on rice commercialisation and rice yield as an intermediate outcome contributing to livelihood, household food security, (FS), minimum dietary diversity for women (MDD-W), and poverty level as measured in terms of the Multidimensional Poverty Index (MPI).

It was expected that a farmer would likely choose a tillage technology option that would provide maximum utility to him/her, subject to various constraints, including affordability. Random utility theory is used to support the empirical analysis. A two-limit Tobit model was used to determine the effect of HHOP, HHTR, and HHOPTR on rice commercialisation while a multinomial endogenous treatment effects model was used to determine the effect of choice of tillage technology option on rice yield, household food security, minimum dietary diversity for women, and MPI. Data for the analysis were extracted from the Agricultural Policy Research in Africa (APRA) first round data set of 537 rice-producing households selected randomly from ten villages in Mngeta Division, Kilombero District, Tanzania. The villages were randomly selected from all villages located within 30km of Kilombero Plantation Limited (KPL) a large-scale rice farm in Mngeta Division which is the study area.

The results of the descriptive analysis indicate the wider use of HHOP and HHOPTR tillage technology options compared to the use of HH and HHTR in commercial rice production. Factors that increase the likelihood of the HHOP tillage technology option to be chosen instead of HH were education of household head, farm size, non-farm income, and extension services. Factors that reduce the likelihood of its choice are age of household head, being a female household head, household size, and being a medium-scale farmer (MSF). In the case of HHTR, factors that increase the probability of its choice instead of HH are education of household head, farm size, non-farm income, and extension services, while factors which reduce the likelihood of its choice are age, being a female household head, household size, and being an MSF. The likelihood of choosing the HHOPTR tillage technology option is enhanced by five factors including age of household head, education, farm size, total household non-farm income, and extension services, while being a female head of household, household size, and being an MSF reduces the probability of its choice.

As expected, the use of HHOP, HHTR, and HHOPTR tillage technology options were found to have a significant and positive effect on rice commercialisation, suggesting that these technology options enhance rice commercialisation. Factors other than the use of improved tillage technologies found to have a significant positive effect on rice commercialisation are land planted with rice, extension, the use of organic fertiliser, and the use of inorganic fertiliser, suggesting that these factors enhance rice commercialisation as expected.

On the other hand, coefficients of age of household head and distance to the nearest rice mill as a proxy of market access are negative. The negative coefficient of age of the household head suggests a decline in commercialisation tendency as the household head ages, while the negative coefficient of the distance to the nearest rice mill suggests an increase in rice commercialisation level as the distance decreases, or declines in commercialisation level as the distance increases.

Livestock income was hypothesised to have either a positive influence on rice commercialisation through the use of the ox plough as a tillage technology for expanding

the land area for rice and the use of livestock manure (organic fertiliser) to enhance rice yield, or a negative effect if the share of livestock income is significantly higher than the share of rice income, to the extent of suppressing rice commercialisation. The coefficient of livestock income is negative but insignificant, indicating that the share of livestock income was significantly lower than the share of income from rice; hence, it didn't suppress the rice commercialisation tendency among rice farmers.

As expected, all three improved tillage technology options were found to have a positive effect on rice yield, HFSS, and MDD-W, suggesting that use of these tillage technology options enhance rice yield, HFSS, and MDD-W. Also, as expected, all three improved tillage technology options had a negative or inverse relationship with the MPI, suggesting that their use increases the likelihood of reducing poverty. Factors other than tillage technology options found to have a significant effect on at least one of the livelihood outcomes are age of the household head, being a female household head, education of household head, household size, farm size, and distance to the nearest rice mill. The age of the household head was found to have a significant negative effect on rice yield and a significant positive effect on the MPI, while being a female household head had a significant negative effect on HFSS and a significant positive effect on the MPI. As in the case of the female household head, household size has a significant negative effect on HFSS and a positive effect on the MPI while distance to the nearest rice mill which was used as a proxy for market access was found to have a significant negative effect on rice yield and a significant positive effect on the MPI.

As far as policy implications are concerned, although the results suggest promoting the use of all three improved tillage technology options (HHOP, HHTR, and HHOPTR) to enhance rice commercialisation and improve the livelihood of rice farmers, emphasis should be on the promotion of the use of HHOP, 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 ox carts in transporting inputs to rice farms and transporting harvested rice to homesteads or rice mills.

Since the use of the tractor might be more beneficial than using the OP, it can be promoted through the establishment of tractor hire services where farmers can access tractor services at an affordable cost. This should go hand in hand with ensuring timely availability and application of fertilisers to enhance rice yield. There is an urgent need for the local government authority to ensure that extension workers are available to advise farmers on appropriate rice husbandry practices such seed selection, spacing between plants, watering, and application of fertilisers (inorganic and organic fertilisers) and herbicides. Education and family-planning programmes to reduce the household dependency ratio will be effective interventions to improve household food security, the ability to meet minimum dietary diversity, reducing poverty, and improving the overall welfare of commercial rice-producing households.

Keywords: tillage technology, rice commercialisation, multidimensional poverty index, food security, smallholder farmers, Kilombero-Tanzania.

INTRODUCTION

The majority of sub-Saharan Africa's (SSA) population live in rural areas and depend directly or indirectly on agriculture for livelihood, employment, food security, and poverty reduction (World Bank 2007; AGRA 2014; Pingali *et al*. 2019). However, agriculture in most SSA countries has not been fully utilised to improve livelihood, create employment, ensure food security, and reduce poverty among farmers, largely due to the failure to shift from consumption-oriented subsistence agriculture to market-oriented commercial agriculture (Barrett 2008; World Bank 2007). Besides the positive impacts of agricultural commercialisation, it is important to bear in mind that agricultural commercialisation can also have negative or unintended impacts at household and community levels.

For example, commercialisation has been criticised for the failure to improve household nutrition and livelihood of the poor and reducing food security (Mutabazi, Mdoe and Wiggins 2013; Zhou, Minde and Mtigwe 2013; Gebremariam and Wünsher 2016; Ogutu, Gödecke and Qaim 2017), widening regional income inequality (Mitiku 2014), enhancing land degradation through the use of chemicals (Pingali 2001), and being an expensive and risky undertaking process, especially among poor farmers (Mutabazi *et al*. 2013). In general, the empirical evidence indicates that commercialisation affects different socioeconomic groups differently (rich and poor, landowners and landless farmers, and women) under different biophysical, socioeconomic, institutional, and policy environments (Wallace and Moss 2002; Fountas *et al*. 2006; Linderhof, Janssen and Achterbosch 2019). This calls for more empirical research in different geographical locations with different socioeconomic, institutional, and policy environments in order to strengthen the need for agricultural commercialisation.

There are several factors that enhance or inhibit the process of agricultural commercialisation. These can be categorised into physical, technological, sociocultural, economic, institutional, and policy-related factors (Louw *et al*. 2008; Gupta, Vemireddy and Pingali 2019; Pingali *et al*. 2019). While recognising that the success or failure of the agricultural commercialisation process cannot be attributed to any single factor but a combination of several factors complementing each other, this study is concerned with the effect of choice of tillage technology on rice yield, income, commercialisation, and livelihoods of rice farmers in Mngeta Division in Kilombero District, Tanzania.

Rice was introduced into KV during the last century (Ashimogo, Isinika and Mlangwa 2003) and it remained a subsistence crop for many years. Among other things, the rice commercialisation process going on in the KV is associated with the use of the ox plough (OP) which is one of the tillage technologies in rice production introduced by agro-pastoralists who have been immigrating into KV since 2000. Apart from the traditional hand hoe, the introduction of the ox plough was preceded by the tractor (TR) which was introduced by large-scale farmers during the late 1980s. The use of the ox plough as a tillage implement increased after 2012, following the purchase of livestock by indigenous people at very low prices from the agro-pastoralists. These agro-pastoralists were subsequently evicted from KV to reduce the number of livestock in order to avoid environmental damage (Walsh 2012; Pingo's Forum 2014; IWGIA 2013, 2016).

Livestock production built on the purchases from the agro-pastoralist immigrants provides a new commercialisation pathway to the rice farmers which is expected to complement rice commercialisation through the use of OP and livestock manure, but could suppress rice commercialisation if the share of livestock income becomes substantially high compared to income from rice. The introduction of the OP and TR increased the number of tillage implements from which the farmers can choose to use based on the resources available to them and the perceived benefits.

Although the introduction of the OP and TR has reduced the use of the hand hoe (HH) to a greater extent, the HH has not been completely replaced by the OP and TR because of limitations of using the OP and/or TR in some farm operations and in some parts of a farm where the OP and TR could not be used. Also, rice farmers using a TR are compelled to use an OP in swampy areas of the KV where a TR cannot be used (Isinika *et al*. 2020). Considering these limitations, farmers in Mngeta Division either use the HH alone or the ox plough complemented with the hand hoe (HHOP), or a tractor complemented with a hand hoe (HHTR), or a tractor complemented with an ox plough and hand hoe (HHOPTR). The HHOPTR tillage technology option is used by rice farmers with farms where some parts are swampy. The choice of any of the above four tillage technology options among rice farmers depends on the resources available to the farmer and the limitations of using a given tillage implement in his/her rice farm.

This paper endeavours to determine the effect of choice of tillage technology on rice yield, commercialisation, and livelihood of rice farmers in Mngeta Division of Kilombero District, Tanzania. The study is motivated by the fact that several studies have examined the productivity, profitability, and efficiency of draft power over the hand hoe for smallholder farms (Jansen 1993; Guthiga, Karugia and Nyikal 2007; Amejo *et al*. 2018; Mondo *et al*. 2020), while others (Mbata 2001; Sanni 2008; Grabowski *et al*. 2016; Owolabi *et al*. 2016; Makki, Eltayeb and Badri 2017) have investigated the determinants of the adoption of animal traction in traditional agriculture. However, there is limited literature on the impact of animal traction technology on agricultural commercialisation and the livelihoods of farmers (Komba and Mahonge 2018). Apart from contributing to the existing empirical literature on the impact of tillage technologies on the commercialisation and livelihood of rice farmers, it is expected that the evidence generated from the study will inform the formulation of policies and strategies for appropriate interventions to promote rice commercialisation and other strategic crops for better livelihood outcomes and economic development.

2 METHODOLOGY

2.1 Conceptual and analytical frameworks

As pointed out in the introduction, rice farmers in Mngeta Division have the following four options of tillage technology: hand hoe only (HH), hand hoe and ox plough (HHOP), hand hoe and tractor (HHTR), and a combination of hand hoe, ox plough, and tractor (HHOPTR). Ox ploughs and tractors enhance land area expansion and timely tillage which allows farmers to increase rice production and consequently commercialisation. The focus of this paper is to determine the effects on rice commercialisation of using HHOP, HHTR, and HHOPTR for rice production (HH is used as a basis for comparison) after controlling for other factors, and to analyse the factors influencing choice of tillage technology option and the effects of such choices on the rice yield and livelihood of the rice farmers.

2.1.1 Determining the effect of the ox plough and other tillage technologies on rice commercialisation

The determination of the effect of the ox plough on rice commercialisation is started by establishing an indicator of rice commercialisation and then identification of the factors influencing the level of rice commercialisation as described below.

Measuring rice commercialisation

Agricultural commercialisation has been measured either by examining the extent of use of purchased inputs (Wiggins *et al*. 2014; Afework and Geta 2016; Kibiti *et al*. 2016; Alawode, Abegunde and Abdullahi 2018) and/or the volume and value of agricultural output (Gebremedhin and Jaleta 2010; Muriithi and Matz 2015; Dube and Guveya 2016). This paper adopted the Rice Commercialisation Index (RCI)[1] used by Isinika *et al*. (2020) in which the RCI was computed as a percentage of rice that is marketed out of what was produced. The computed commercialisation index varies from zero per cent where no rice was sold to 100 per cent where all rice produced was sold. The sample was divided into four RCI categories; namely, a category of no sales (0 per cent) and terciles for the remaining households with sales (low sales, same as the first tercile, medium sales as the second tercile, and high sales as the third tercile). In order to examine the effect of the ox plough and other factors on different groups of farmers, the commercialisation levels were compared for the following categories of rice farmers: (i) sex of household head (male- versus female-headed household); (ii) small-scale farmers (SSFs) and medium-scale farmers (MSFs); and (iii) farmers using different tillage technology options (HH, HHOP, HHTR, and HHOPTR). The results of these comparisons are presented in Section 3.

Determining the effect of the ox plough and other tillage technologies on rice commercialisation

The Rice Commercialisation Index can be expressed either in proportions or in percentages. Both forms of presentation lead to a continuous interval from 0 to 1 and 0 to 100 per cent respectively, with both limits included. A two-limit Tobit model is appropriate as a corner solution model if there is a pile-up at both limits with positive probability. However, according to Wooldridge (2010), if the interest is to estimate the conditional mean of the dependent variable, then a two-limit Tobit model can lead to inconsistent parameter estimates (ibid.). Although a two-limit model has been used in similar studies, such as by Kirui and Njiraini (2013), Bekele and Alemu (2015), and Dube and Guveya (2016), we follow Wooldridge's specification of a model for a conditional mean based on the logistic or probit function, and which leads to consistent parameter estimates. The model has been applied in similar studies by Ogunleye *et al.* (2018). The logistic model is presented in equation 1 and specified as:

$$Ey|X = \exp X\beta / [1+\exp](X\beta) \qquad (1)$$

Vector X represents the explanatory and control variables categorised into household-level attributes (farm size, household size, level of education of household head, sex of household head, household total non-farm income, livestock income, and farmer type), community-level or locational-level factors (access to extension services and distance to the nearest rice mill), and agricultural technology variables (type of tillage technology, use of purchased seed, use of inorganic fertilisers, use of organic fertiliser, and use of herbicides)

The parameters of equation 1 are estimated by the Bernoulli quasi-maximum likelihood estimation (QMLE) fractional logistic regression.

The specification of the variables used for the fractional logistic regression is presented in Annex 1.

2.1.2 Determining the effect of the ox plough and other tillage technologies on the yield and livelihood of rice farmers

The determination of the effect of tillage technologies on the rice yield, commercialisation, and livelihood of rice farmers comprised two steps. The first step was the development of outcome indicators while the second step involved determination of the effect of tillage technologies and other factors on the paddy yield and livelihood of rice farmers in the study area.

Developing indicators of livelihood

The common approaches in the literature to measure the level of livelihood uses income, assets, food security, subjective well-being, or multidimensional poverty (Alkire, Roche and Vaz 2015). This paper used three indicators of livelihood: namely, household food security status (HFSS), minimum dietary diversity for women (MDD-W), and the Multidimensional Poverty Index (MPI) as proposed by Alkire and Santos (2014) and Alkire *et al*. (2015). Rice yield as an intermediate outcome contributing to livelihood is also examined.

The HFSS was measured using nine food insecurity situations (see Annex 2.1). Households facing five situations or more were classified as food-insecure and those facing less than five situations were classified as food-secure. On the other hand, MDD-W was measured using 20 food groups considered to provide the required nutrients for women (see Annex 2.2). Households with women eating at least five of these food groups were classified as meeting MDD-W and those eating less than five were classified as not meeting MDD-W.

The MPI has been adopted as it captures a wider range of variables including assets, health, education, and nutrition that reflect the quality of life within a household. The MPI therefore represents the proportion by which a household is deprived – higher scores representing more deprivation, and hence more poverty.

2.1.3 Determining the effect of choice of type of tillage technology on rice yield and livelihood outcomes (household FS, MDD-W, and MPI)

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 the livelihood outcomes. 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 in a multinomial setting.

Accordingly, farmers were classified into four mutually exclusive groups: namely, users of the hand hoe (HH) which is manually operated in rice production (group 1); users of the hand hoe and ox plough (HHOP) (group 2); users of the hand hoe and tractor (HHTR) (group 3); and users of a combination of hand hoe, ox plough, and tractor (HHOPTR) (group 4). As indicated above, all four options of tillage technology include the use of a hand hoe, although its use is less pronounced in groups 2, 3, and 4. 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 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 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 analyse 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 choice of alternative types of tillage technologies (Mansur, Mendelsohn and Morrison 2008; Obayelu *et al*. 2017). A similar analytical approach based on multinomial endogenous switching regression (MESR) is used by Tecklewold, Kassie, and Shiferaw (2013) and 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 technologies mentioned above. Following Deb and Trivedi (2006) and Gebremariam and Wünsher (2016), U^*_{ij} denotes the indirect utility reflecting the net benefits associated with the use of the j^{th} type of tillage technology (j = 0, 1, 2..., J) instead of any other type of tillage technology k by farmer i. The indirect utility model is specified as:

$$U^*_{ij} = X_i\alpha_j + \delta_j l_{ij} + u_{ij} \quad (1)$$

where Xi is a vector of household-head characteristics (age, sex, years of schooling), household-level factors (type of farmer – small or medium scale), and community-level or locational factors (distance to the nearest rice mill) associated with parameter α_j. In order to generate the estimate, l_{ij} 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 U_{ij}. Furthermore, U_{ij} are independently and identically distributed error terms. Annex 3.1 presents the specification of the variables and expected signs of the coefficients for the outcome equations.

The control group is denoted by j = 0, which in this case is the hand hoe which is a manually operated implement and where $U^*_{i0} = 0$. The variable dj is a binary variable reflecting the choice of jth tillage technology type. Thus, di = (di1, di2,…, diJ) is a vector of observable binary variables representing the choice options of various types of tillage options by the ith farmer. Similarly, $l_i = (l_{i1}, l_{i2}, l_{iJ})$. Thus, the probability of the jth type of tillage option to be chosen can be represented as:

$$\Pr(d_j|z_i, l_i) = g(z'_i\alpha_1 + \delta_1 l_{i1}, z'_i\alpha_2 + \delta_1 l_{i2}, + \ldots\ldots\ldots, +z'_i\alpha_J + \delta_j l_{iJ}) \quad (2)$$

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

$$\Pr(d_i|z_i, l_i) = \frac{\exp(z'_i\alpha_j + \delta_j l_{ij})}{1 + \sum_{k=1}^{J}\exp(z'_i\alpha_k + \delta_k l_{ik})} \quad (3)$$

Analysis of the effect of tillage technology options on livelihood outcomes is undertaken in the second stage. The welfare outcome variables are all zero one variables specified as follows:

a. Household food security status (HFSS): assigned a value of 1 if a household is food-secure and zero if not food-secure;

b. Satisfaction of minimum dietary diversity for women (MDD-W): assigned a value of 1 if satisfied and zero if not satisfied;

c. Multidimensional Poverty Index (MPI) – assigned a value of 1 if the household is MPI-poor and zero if not MPI-poor.

The expected outcome equation for i[th] household can be defined as:

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

where y_i represents the welfare outcome variable (HFSS or MDD-W or MPI) for rice farmer i and x_i is a set of exogenous variables with associated parameter vectors β and γ_j which denote the treatment effects relative to the control group, i.e. use of the hand hoe which is a manually operated tillage implement. Given that the outcome variables are binary, a logistic distribution is assumed. Annex 3.2 presents the specification of the variables and expected signs of the coefficients for the outcome equations.

2.1.4 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 presence of a flush toilet in the house. It is assumed that the presence of a toilet will be partially correlated with each tillage option after controlling for other factors, but the presence of a flush toilet is not correlated with any of the outcome variables. The maximum simulated likelihood (MSL) approach was used using mtreatreg in stata (Varma 2017).

2.2 Data

This paper uses first round data collected in October 2017 for the rice commercialisation study in Kilombero District supported by the Agricultural Policy Research in Africa (APRA) programme being implemented in Tanzania, Ethiopia, Malawi, Zimbabwe, Nigeria, and Ghana. Kilombero District 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). The study covered ten villages in Mchombe, Mngeta, and Chita wards in Mngeta Division. The geographical area for the study was restricted to within 30km from Kilombero Plantation Limited (KPL), a large-scale farmer with about 5,800 hectares of land surrounded by numerous small-scale and some medium-scale farmers in neighbouring villages.

Three sampling frames were used for the random selection of small-scale farmers (SSFs), medium-scale farmers (MSFs), and small-scale farmers practising the System of Rice Intensification (SRI). Small-scale farmers were defined as having up to 25 acres (ten hectares) while medium-scale farmers were those with more than 25 acres (ten hectares). As explained below, post-stratification was done based on a smaller land area to address the inconsistencies encountered in the data and to reflect the criterion of medium-scale farmers in the study area (the local definition of farm size ranges in acreage). The sampling frames for SSFs and MSFs were constructed with the assistance of key informants from each selected village while the sampling for SRI farmers was provided by KPL.

A two-stage sampling design with stratification was used to select random samples of small-scale and medium-scale farmers. The first stage involved the selection of villages from three strata established on the basis of electricity status of a village. In the 2016/17 season, 11 villages had electricity and these were grouped in the first stratum. Three villages were expected to have electricity connected by 2019 and were defined as switch villages and formed the second stratum. Stratum 3 contained eight villages which were not expected to have electricity connected by 2019. The sample of ten villages from stage 1 was distributed as follows: four villages from the first stratum, all three villages from the second stratum, and four villages from the third stratum. The sampling of the villages from the first and third strata was done with probability proportional to size using the cumulative method. In the second stage, simple random sampling was used to select an equal number of small-scale farmers.

The predefined number was 40 small-scale farmers, making a total of 400 small-scale farmers. In order to allow for possible non-responses or failure to find the farmers, oversampling by ten small-scale farmers per village was done. A simple random sample of 100 SRI farmers was obtained from a list provided by KPL. Owing to the wide variation in the number of MSFs across the sampled villages, it was decided to use proportionate allocation of the total sample of 50 MSFs. The total sample from the three sub-populations had 559 households comprising 408 SSFs, 50 MSFs, and 101 SRI members.

During data cleaning, it was found that based on the land size criterion for classification of SSFs and MSFs, some farmers in both groups were misclassified. In addition, some farmers with land area less than ten hectares were considered to be medium-scale farmers. Therefore, a post-stratification of the SSFs and MSFs was done such that farmers with less than five hectares were considered SSFs and those with five hectares and above as MSFs. The categorisation was based on the classification used in recent studies on the emergence of medium-sized farms which classify farms as medium-sized if they are between five and 20ha (Jayne *et al*. 2016).

Some respondents had to be dropped from the sample because of incomplete responses. The final sample after re-categorisation and dropping the farmers with incomplete responses was 537 farmers comprising 337 SSFs, 74 MSFs, and 106 SRIs. The SRI farmers are also small-scale farmers, with a key distinguishing attribute being SRI training and membership to the SRI association. However, after data collection, it was found that some SSFs also attended SRI training but didn't join SRI associations and in both groups not all farmers ended up adopting SRI principles. It was therefore decided for the purpose of this paper to merge the SRIs and SSFs into one group of 447 SSFs.

3 FINDINGS

3.1 Descriptive results

3.1.1 Ownership and use of tillage implements

The use of OP and TR 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 ownership and use of different tillage implements in rice production. The HH is the basic farm implement owned and used by all rice farmers because of the limitations of using OP and/or TR in some farm operations or in parts of the farm, as pointed out previously.

As seen in Table 3.1, differences exist in the ownership of OP and TR between different categories of farmers. The percentage of MSFs owning an OP, an ox cart (OC), and a TR is higher than that of SSFs. The percentage of male household heads who own an OP is higher than that of female household heads. None of the female household heads owned an OC and a TR. Irrespective of farmer category, the percentage of rice farmers who owned an OP is higher than the percentage of farmers who owned a TR (Table 3.1). Only three of the sample farmers owned a TR, while 95 and 23 of the sample rice farmers owned an OP and an OC respectively. This is largely due to the relatively high cost of acquiring a TR compared to the cost of a pair of oxen and an OP, and therefore most users of such tillage implements depended on hire services.

Farmers owning the different tillage implements may use and/or lease them to other farmers. The leasing costs normally depend on the operational cost of the implement. Although all sampled farmers owned a HH, only 12.9 per cent used a HH alone in rice production. As in the case of ownership of the implements, an OP was used by a relatively larger percentage of farmers than the other implements (Table 3.2). In total, 58.3 per cent of the farmers used an ox plough during the 2016/17 farming season, of which 42.2 per cent used an ox plough alone and 16.1 per cent used both an ox plough and a tractor for tillage services.

There is a significant association between the type of tillage technology used and farmer category ($p<0.01$) and between the tillage technology used and the sex of household head ($p<0.1$) as shown in Table 3.3. The percentage of smallholder farmers using a hand hoe and tractor-drawn implements alone for tillage is significantly higher than the percentage of medium-scale farmers using these implements. The use of an ox plough appears to be more popular among MSFs than SSFs. More than 50 per cent of the MSFs used OPs with HHs (as a package denoted by HHOP), while 22 per cent used a combination of OP and TR with HH (as a package denoted by HHOPTR). On the other hand, nearly 40 per cent of the SSFs used the HHOP package, while about 15 per cent used the HHOPTR package in rice production (Table 3.3).

3.1.2 Tillage technology and land area cultivated for rice production

This section compares land area under rice production for farmers using different types of tillage implements. Table 3.4 shows that both land area owned and land

Table 3.1 Percentage of households owning different types of farm implements by farmer category and sex of household head

Type of implement	Ownership	Farmer category		χ^2	Sex of household head		χ^2
		SSF	MSF		Male	Female	
Ox plough	Yes	11.6	52.8	81.5***	20.1	9.8	3.7*
	No	88.4	47.2		79.9	90.2	
Ox cart	Yes	1.2	20.2	60.9[a]	5.2	0	3.3[a]
	No	98.8	79.8		94.8	100.0	
Tractor	Yes	0.2	2.3	5.1[a]	0.7	0	0.42[a]
	No	99.8	99.7		79.3	100	

Note: a = expected cell count less than five, making test invalid. *** = $p<0.01$ and * = $p<0.1$.
Source: Authors' own, based on analysis using round one data from APRA Tanzania survey (2017).

Table 3.2 Distribution of sampled farmers by type of tillage option used in rice farming

Tillage technology options	Frequency	Percentage
HH	67	12.9
HHOP	220	42.2
HHTR	150	28.8
HHOPTR	84	16.1
Total	521	100.0

Source: Authors' own, based on analysis using round one data from APRA Tanzania survey (2017).

Table 3.3 Percentage of households using different tillage options by farmer category

Tillage technology options	Farmer category				Sex of household head			
	SSF		MSF		Male		Female	
	N	%	N	%	N	%	N	%
H	48	11.5	6	6.7	43	9.7	11	17.7
HH	168	40.4	50	55.6	199	44.8	19	30.6
HH	136	32.7	14	15.6	128	28.8	22	35.5
HHOPTR	64	14.4	20	22.2	74	16.7	10	16.1
All	416	100	90	100	444	100	62	100
X^2	15.0***				6.67*			
P	0.002				0.08			

Note: *** = p<0.001 and * = p<0.1.

Source: Authors' own, based on analysis using round one data from APRA Tanzania survey (2017).

area under rice production during the 2016/17 farming season varied across tillage technology options. It is evident from Table 3.4 that the users of HHOP, HHTR, and HHOPTR technology options cultivated significantly (p<0.01) more land for rice production than those who used a HH. It is interesting to note from Table 3.4 that the users of HHOP cultivated significantly (p<0.01) larger land areas for rice production compared to the users of HHTR. This is largely because the OP has enabled rice farmers to produce rice in previously uncultivated marshy areas of the KV, away from the road and unsuitable for TR operations.

Apart from the variation in the mean area under rice production, the maximum cultivated land for rice production varied widely across the different tillage technology options. The maximum land area under rice production in the 2016/17 farming season varied from 9.7ha per household for users of a HH to 24.3ha, 37.7ha, and 40.5ha per household for users of HHOP, HHOPTR, and HHTR tillage technology options respectively. These findings suggest that the use of the OP and TR in addition to the HH are more effective tillage technology options than the use of the HH alone for expanding the land area under rice production in the study area. However, the advantages of using the HHOP option among smallholder farmers outweigh those of using the HHTR 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 rice production in marshy land where tractors cannot be used.

Apart from differences in land areas planted with rice by the type of tillage technology option used, differences were also found in the area planted with rice between

Table 3.4 Land area under rice production in 2016/17 by type of farm implement used

Tillage technology options	N	Land area under paddy (ha per household)			
		Mean	Median	Minimum	Maximum
HH	67	1.9	0.8	0.1	9.7
HHOP	220	3.3	1.6	0.2	24.3
HHTR	150	2.3	1.6	0.2	40.5
HHOPTR	84	3.2	1.9	0.4	37.7
Total	521	2.8	1.6	0.1	40.5
		F=437.03***			

Note: F = ***; implies F value is significant at p<0.01.

Source: Authors' own, based on analysis using round one data from APRA Tanzania survey (2017).

SSFs and MSFs as well as between male- and female-headed households. Table 3.5 shows that MSFs cultivated significantly larger mean land areas for rice production than SSFs. The maximum land area planted with rice by MSFs was 50.6ha compared to 4.9ha for SSFs. Also a comparison between male- and female-headed households shows a significant difference in the mean and maximum land area planted with rice in the 2016/17 farming season. The mean land area planted with rice by male-headed households was almost twice the land area planted with rice by female-headed households, while the maximum land area under rice for male-headed households was more than six times the land area for female-headed households.

3.1.3 Rice yield (land productivity) and output by type of tillage technology option used

The use of efficient types of tillage implements to enhance crop productivity and expand the land area under rice production is necessary in sustaining the commercialisation of crops. Table 3.6 shows levels of rice yield (land productivity) and output across the different tillage technology options used for rice cultivation. Comparing users of the HH option (manual human power) and users of other tillage technology options, a bigger difference is observed in rice production (output) than rice productivity, suggesting that the observed differences in rice output is largely due to an increase in land area cultivated using tillage technology options other than a manual HH. The maximum rice output in the 2016/17 farming season varied from 23,550kg per household for HH users to 56,250kg, 66,000kg, and 83,700kg per household for users of HHOP, HHTR, and HHOPTR tillage technology options respectively. Overall rice output increases as the farmer moves from manual cultivation using a HH

Apart from differences in rice yield and rice output per household across tillage technology options, differences were also found in yield and rice output between SSFs and MSFs as well as between male- and female-headed households (Table 3.7). It is interesting to note that SSFs obtained significantly higher rice yields than MSFs, suggesting that more SSFs were using yield (land productivity) enhancing

Table 3.5 Land area (ha) under rice production in 2016/17 by category

Item	Farmer category					
	Farm size category		Significance of difference of the mean	Sex of the household		Significance of difference of the mean
	SSF	MSF		Male	Female	
Mean land area	1.9	10.9	F=517***	3.7	1.8	F=8.37***
Median	1.6	8.5		2.0	1.4	
Minimum	0.1	5.1		0.1	0.1	
Maximum	4.9	50.6		50.6	8.1	

Note: F = ***; implies F value is significant at p<0.01.
Source: Authors' own, based on analysis using round one data from APRA Tanzania survey (2017).

Table 3.6 Rice output (kg) and productivity (kg/ha) in 2016/17 farming season by type of tillage technology option

Tillage implement	Rice yield (kg/ha)			Rice output (kg per household)		
	N	Mean	Median	N	Mean	Median
HH	53	2,010 (1,352.3)	1,520	54	0.1	1,485
HHOP	2,214	2,423 (1,496.0)	2,224	217	0.2	3,600
HHTR	150	2,675 (1,349.9)	2,595	150	0.2	3,555
HHOPTR	84	2,643 (938.5)	2,718	84	0.4	3,750
All	501	2,492 (1,368.7)	2,409	505	0.1	3,300
		F=3.66**	p=0.000		F=1.56	p=0.012

Note: Figures in parentheses are standard deviations. A non-parametric test was used to compare the medians. *** = p<0.01 and F = **; implies F value is significant at p<0.05.
Source: Authors' own, based on analysis using round one data from APRA Tanzania survey (2017).

Table 3.7 Rice yield (kg/ha) and output per household (kg) in 2016/17 farming season by farmer category

Tillage implement	Category	Paddy yield				Paddy output			
		N	Mean	Median	Mean diff	N	Mean	Median	Mean diff
Farmer type	SSF	411	2,552 (1,419.4)	2,471	334** (158.7)	415	3,592 (3,343.6)	3,592	13,103*** (1,540.1)
	MSF	90	2,218 (1,072.5)	2,002		90	16,695 (14,527.1)	13,800	
Sex of household head	Male	443	2,501 (1,379.9)	2,427	-77.1 (187.1)	443	6,344 (8,896.7)	3,600	3,392.1*** (557.5)
	Female	62	2,424 (1,293.7)	2,372		62	2,951 (2,861.7)	2,100	

Note: Figures in parentheses below means and mean difference are standard deviations and standard errors respectively. An independent sample t test was used to compare the means. *** = p<.01 and ** = p<0.05.
Source: Authors' own, based on analysis using round one data from APRA Tanzania survey (2017).

inputs compared to MSFs. With respect to rice output per household, MSFs harvested significantly more rice than SSFs, largely due to large land areas cultivated for rice as indicated in Table 3.5 above.

3.1.4 Distribution of Rice Commercialisation Index (RCI) across different categories of rice farmers

The RCI was computed as the percentage (%) of rice that was sold out of what was produced. The results of RCI by different categories of farmer are summarised in Table 3.8. The mean RCI for the whole sample was 59.2 per cent. The RCI varies between different categories of farmers. MSFs had a significantly higher mean RCI than SSFs while male-headed households had a significantly higher RCI than female-headed households. Also, the RCI varied across farmers using different tillage technology options, being smallest for HH users (44.4 per cent) and highest for users of the HHTR tillage technology option (64.9 per cent) (Table 3.8).

3.1.5 Food security and poverty status across different categories of rice farmer

As pointed out earlier, agricultural commercialisation remains widely pursued in low-income countries to improve agricultural productivity, farm income, food security, and the general welfare of farmers. This section compares the food security and poverty situation among farmers involved in commercial rice production in Kilombero. The percentage of FS households and households that meet the MDD-W for women was used as an indicator of household food security status while the MPI was used as an indicator of poverty.

Table 3.8 RCI in percentage by farmer category

Farmer category	Mean	Median	Significance of the effect
Farmer type:			
SSF	57.4	62.9	F = 9.91***
MSF	67.4	71.2	
Sex of household head:			
Male	60.0	66.7	F = 3.462*
Female	53.1	59.0	
Tillage option:			
HH	40.4	46.7	F = 9.91***
HHOP	58.2	62.5	
HHTR	64.9	72.4	
HHOPTR	63.6	65.4	
Whole sample	59.2	65.2	

Note: F = *; implies F value is significant at p<0.1. F = ***; implies F value is significant at p<0.01.
Source: Authors' own, based on analysis using round one data from APRA Tanzania survey (2017).

Differences exist in both food security status indicators across farmer categories (Table 3.9). For the whole sample, the percentage of food-secure households is 69.3 while the percentage of households that meet the MDD-W is 69.6. However, the percentage of MSFs with FS households is significantly higher than that of SSFs. Similarly, there was no significant difference in the percentage of households that met the minimum dietary requirement for women between MSFs and SSFs. When farming households are classified by sex of household head, the percentage of male-headed households that are food-secure is significantly higher than that of female-headed households but there is no significant difference in the proportion of households meeting the minimum dietary requirement between male- and female-headed households.

According to Table 3.9, household food security status varied significantly across users of tillage technology options, being lowest for the HH and highest for the HHOPTR tillage technology option. There was no significant difference in the percentage of households meeting the MDD-W across the different tillage technology options (Table 3.9). Also, the percentage of both food-secure households and of households meeting the MDD-W varies significantly by the level of rice commercialisation, with the users of the HH having the lowest percentage in both cases. While the percentage of food-secure households increased from 48.6 for farmers who did not commercialise (0 per cent RCI) to 80.9 per cent for rice farmers with a high commercialisation level, the percentage of households meeting the MDD-W increased from 60 per cent for farmers who did not commercialise (0 per cent RCI) to 78.7 per cent for farmers with a medium commercialisation level, and then declined to 69.6 per cent for farmers with a high level of rice commercialisation (Table 3.9).

Like the food security status, the percentage of households that were not MPI-poor and households which were MPI-poor varied across different categories of rice farmer. For the whole sample, 45.9 per cent of the sample farmers were not MPI-poor while 54.1 per cent were MPI-poor. The percentage of MPI-poor households varied across rice farmer categories (Table 3.10). The highest percentage of MPI-poor households was recorded among users of the HH alone in rice production (75.0 per cent) followed by female-headed households (69.5 per cent), with the lowest being for farmers in the highest RCI tercile (31.3 per cent) (Table 3.10).

3.2 Econometric results

3.2.1 Effect of tillage technologies on rice commercialisation: results of fractional logistic regression

The use of tillage technology options above the HH (HHOP, HHTR, and HHOPTR) was hypothesised

Table 3.9 Percentage of households that are food-secure and meeting the MDD-W by farmer category

Farmer category	Food-secure	χ^2	MDD for women	χ^2
Farm size:				
SSF	66.6	7.64***	68.0	2.44
MSF	83.6		77.6	
Sex of household head:				
Female head	72.2	9.15***	69.6	0.11
Male head	52.5		69.5	
Tillage option:				
HH	54.5	6.62*	61.4	1.60
HHOP	73.2		70.9	
HHTR	66.9		70.2	
HHOPTR	73.4		70.3	
Level of RCI:				
Zero	48.6		60.0	
Low	57.6	25.01***	62.4	9.88**
Median	75.7		78.7	
High	80.9		69.6	
Whole sample	69.3		69.6	

Note: F = *; implies F value is significant at p<0.1. F = **; implies F value is significant at p<0.05. F = ***; implies F value is significant at p<0.01.
Source: Authors' own, based on analysis using round one data from APRA Tanzania survey (2017).

Table 3.10 Multidimensional Poverty Index across farmer categories

Farmer category	Incidence of multidimensional poverty (% of hh)	Households not multidimensional poor (%)	χ^2
Farm size:			
SSF	48.0	52.0	1.89
MSF	38.8	61.0	
Sex of household head:			
Male	49.1	50.0	7.06***
Female	30.5	69.5	
Tillage option used:			
HH	25.0	75.0	19.25***
HHOP	40.6	59.4	
HHTR	58.1	41.9	
HHOPTR	53.1	46.9	
RCI:			
Zero	37.1	62.9	χ2= 43***
Low	35.2	64.8	
Medium	40.4	59.6	
Whole sample	45.9	54.1	

Note: F = ***; implies F value is significant at p<0.01. Source: Authors' own, based on analysis using round one data from APRA Tanzania survey (2017).

to have a positive effect on commercialisation in the study area. Table 3.11 presents the marginal effects for factors influencing rice commercialisation while Annex 4 presents parameter estimates of the fractional logistic regression model for determinants of rice commercialisation. The base tillage option is the HH against which other tillage technology options are compared. The model fits the data very well with F=4.86 and P>F=0.00. As expected, the use of HHOP, HHTR, and HHOPTR tillage options relative to the HH have a significant and positive effect on rice commercialisation (Table 3.11 and Annex 4). The use of HHOP, HHTR, and HHOPTR instead of the HH alone increases the quantity of rice harvested (Table 3.6), leading to an increase in marketed surplus (commercialisation) through the expansion of cultivated land and increased timeliness of carrying out farm operations (Maina 2004; Guthiga *et al.* 2007; Sanni 2008, Umaru *et al*. 2013; Zhou *et al*. 2013, 2018).

As seen in Table 3.11, the marginal effect of HHTR tillage technology is higher than those of HHOP and HHOPTR, suggesting that the use of HHTR is more likely to increase rice commercialisation than the use of HHOP and HHOPTR. Factors other than tillage technology options that have a significant and positive effect on rice commercialisation are land planted with rice, extension services, the use of organic fertiliser (livestock manure), and the use of inorganic fertiliser. Education of the household head and the use of herbicides show a positive but insignificant effect on rice commercialisation.

Among these factors, the use of inorganic fertilisers has a higher marginal effect than the other factors with a positive influence on rice commercialisation, suggesting that the use of inorganic fertilisers is more likely to increase the level of rice commercialisation than the other factors (Table 3.11). For example, the level of rice commercialisation would increase by 28.3 per cent for an additional unit of inorganic fertiliser applied, compared with an increase of about 1.7 per cent for an additional ha of land planted with rice, suggesting significant gains in rice commercialisation through intensification as opposed to extensification.

It is interesting to note that the coefficient of formal education is not significant while the coefficient of extension is positive and highly significant. This is due to the fact that success in improving agricultural productivity and hence commercialisation depends largely on enhancing farmers' technical and managerial skills, rather than the level of formal education (Gêmo, Stevens and Chilonda 2013; Danso-Abbeam, Ehiakpor and Aidoo 2018; Toma *et al*. 2018).

On the other hand, factors with a negative and significant effect are age of household head and distance to the nearest rice mill, while being a female household head, the use of purchased seed, and livestock income have a negative but insignificant effect. The negative

Table 3.11 Marginal effects for factors influencing rice commercialisation

Independent variables	Marginal effect (dy/dx)	Standard error
HHOP (dummy=1)	0.1243**	0.0525
HHTR (dummy=1)	0.1630***	0.0569
HHOPTR (dummy=1)	0.1593***	0.0589
Age of household head (years)	-0.0027**	0.0011
Education of household head (years)	0.0091	0.0056
Female household head (dummy=1)	-0.0078	0.0399
Land planted with rice (ha)	0.0166***	0.0047
Extension services (dummy=1)	0.0684**	0.0287
Purchased seed (dummy=1)	-0.0411	0.0350
Inorganic fertiliser (dummy=1)	0.0883**	0.0420
Organic fertiliser (dummy=1)	0.2934***	0.1070
Herbicide (dummy=1)	0.0165	0.0300
Distance to nearest rice mill (km)	-0.0066*	0.0040
Income from livestock (Tsh)	-8.06e-10	6.74e-09

Note: *** = p<0.01, ** = p<0.05, and * = p<0.1.
Source: Authors' own, based on analysis using round one data from APRA Tanzania survey (2017).

coefficient for age suggests that farmers become less commercially oriented as they become old. This finding is consistent with the findings by Msuya, Isinika and Dzanku (2018). The negative coefficient for the distance to the nearest rice mill, used as a proxy of market access, suggests that rice farmers will become more commercialised with improvements in market access.

Livestock income was expected to have either a positive influence on rice commercialisation through the use of the OP as a tillage technology for expanding land for rice, or a negative effect if the share of livestock income is significantly higher than the share of rice income to the extent of suppressing rice commercialisation. The insignificance of the coefficient of livestock income suggests that the share of livestock income was significantly lower than the share of income from rice, and hence is unable to suppress the rice commercialisation tendency among rice farmers.

3.2.2 Effect of chosen tillage technology options on rice yield and livelihood of rice farmers: results of the multinomial endogenous treatment effects model

As indicated in Section 2.1.3, four mutually exclusive tillage technology options for rice farming were identified including HH, HHOP, HHTR and HHOPTR. Therefore, the first stage of the multinomial endogenous treatment effects model analysed the factors that influence the choice of tillage technology option to be used in rice 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 yield and three livelihood indicators: household food security (FS), minimum dietary diversity for women (MDD-W), and the Multidimensional Poverty Index (MPI) measured as indicated in the methodology section.

Factors influencing choice of tillage technology
Table 3.12 presents parameter estimates of the first stage of the multinomial endogenous treatment effects model for factors influencing choice of tillage technology. The model fits the data very well with χ^2=171.91; P>χ^2=0.000. As expected, the results show that choice of the three improved tillage technologies above the hand hoe is positively influenced by age of household head, education of household head, farm size being an MSF, non-farm income, and extension services. This suggests that these factors increase the probability of choosing HHOP, HHTR, and HHOPTR tillage technology options for commercial rice production.

It is interesting to note that both education of household head and extension have the expected positive relationship with the use of the improved technologies, suggesting the importance of education and extension advice in creating awareness of the benefits of using improved technologies in agricultural production (Altab, Filipek and Skowron 2015; Liu, Bruins and Heberling 2018; Relebohile and Keregero 2019). On the other hand, the coefficients of female household head and household size for the three tillage technology options are negative, suggesting that being a female household head and an increase in household size reduces the probability of choosing the three tillage technology options for commercial rice production. The negative influence of household on choice of the improved tillage technology options can be associated with increased

Table 3.12 Parameter estimates for the first stage of multinomial endogenous treatment effects model

Variable	Tillage technology options		
	HHOP	HHTR	HHOPTR
Age of household head (years)	0.0081 (0.0144)	0.0432*** (0.0157)	0.0194 (0.0174)
Female household head (1-female)	-0.7696 (0.5390)	-0.1235 (0.5691)	-0.1860 (0.6108)
Education of household head (years)	-0.0509 (0.0747)	0.1081 (0.0829)	0.0259 (0.0885)
Household size	-0.0649 (0.0764)	-0.1653** (0.0805)	-0.1746 (0.09857)
Farm size (hectares)	0.0994 (0.0985)	0.1626 (0.1050)	0.1748 (0.1042)
MSF dummy	0.2834 (0.9340)	1.8625 (1.1504)	0.8307 (1.1218)
Non-farm income (Tsh)	1.74e-08 (2.00e-07)	4.25e-07 (1.79e-07)	4.06e-07 (1.82e-07)
Extension services (dummy)	0.1378 (0.4080)	0.4691 (0.4313)	0.8369 (0.4597)
Use of mobile money (dummy)	1.0515** (0.4340)	1.6664*** (0.5175)	1.6000 (0.5429)
Constant	0.7795 (0.996)	2.9101*** (0.1626)	-1.8391 (0.1748)

Note: N=400; Wald χ^2=(37)=171.91; p>χ^2=0.0000. The reference tillage technology is the hand hoe. The use of mobile money is just an instrumental variable reflecting a willingness to try new technologies in farming. Figures in parentheses are standard errors. *** = P<0.01, ** = P<0.05, and * = P<0.1.
Source: Authors' own, based on analysis using round one data from APRA Tanzania survey (2017).

household labour available for rice production activities as the household size increases, reducing the need for using improved tillage technology options for rice production operations. However, this might not hold true for very large farmers who do not depend on household labour.

Effect of the chosen tillage technology option on livelihood outcomes

Table 3.13 presents the estimates of the effect of chosen tillage technology options on the four livelihood outcomes: rice yield as an intermediate outcome contributing to livelihood, HFSS, MDD-W, and MPI. As seen in Table 3.13, all the three tillage technology options above the HH (HHOP, HHTR, and HHOPTR) are positively related to rice yield, HFSS, and MDD-W, implying that rice farmers who chose these tillage technology options were more likely to: (i) achieve higher rice yields; (ii) improve HFSS; and (iii) meet the MDD-W than households that use the HH alone. On the other hand, all the three improved tillage technology options are negatively related to the MPI as expected, implying that the use of these technology options increases the probability of reducing poverty among rice-producing households.

Factors other than tillage technology options found to have a significant effect on at least one of the livelihood outcomes are age of the household head, being a female household head, education of household head, household size, farm size, and distance to the nearest rice mill. The age of household head was found to have a significant negative effect on rice yield and a significant positive effect on MPI. The negative effect on yield suggests the likelihood of attaining a lower amount of rice as the household head ages, possibly due to the fear of taking a risk in using improved technologies (Mwangi and Kariuki 2015; Donkoh, Azumah and Awani 2019). The positive significant effect on MPI implies a high likelihood of a household becoming poor as the age of the household increases.

Being a female household head has a significant negative effect on HFSS and a significant positive effect on MPI. The positive significant effect suggests that a female-headed household is likely to be food-insecure while the positive significant effect on MPI suggests a high likelihood of a female-headed household being poor. Education of household head has a significant negative effect on MPI only, suggesting a high likelihood of decline in poverty in a household as the education

Table 3.13 Multinomial endogenous treatment effects model estimates of tillage technology impacts on rice yield, HFSS, MDD-W, and MPI

Variable	Yield (kg/ha)	HFSS	MDD-W	MPI
HHOP	173.60 (2400)	0.2354 (0.5459)	0.1469 (0.5379)	-0.4644 (0.9709)
HHTR	531.74** (283.90)	0.3112 (0.5737)	0.8715* (0.5173)	-3.2289 (2.0085)
HHOPTR	999.68*** (242.94)	0.3826 (0.6205)	0.4571 (0.6238)	-1.1521 (1.2968)
Age of household head (years)	-19.14*** (7.10)	-0.2723 (0.019)	-0.0135 (0.0103)	0.0770** (0.0319)
Female household head	-110.04 (206.27)	-0.6783* (0.3907)	0.2280 (0.3960)	1.6332* (0.9903)
Education of household head (years)	14.54 (39.51)	0.0312 (0.0536)	0.0018 (0.0503)	-0.1658* (0.1004)
Household size	1.38 (21.38)	-0.1216** (0.0020)	-0.0257 (0.0619)	0.4183** (0.2040)
Farm size (ha)	2.54 (12.34)	0.3274*** (0.1184)	0.0246 (0.0372)	-0.1977** (0.0983)
MSF (dummy)	-4.43 (212.81)	-0.7961 (0.8911)	0.6884 (0.5932)	0.3334 (0.9430)
Distance to nearest rice mill	0.-80.55** (14.84)	-0.0687 (0.0376)*	-0.0024 (0.0354)	0.1733** (0.0743)
Constant	3404.2 (542.65)	1.9410** (0.8523)	1.1691 (0.8416)	-3.4166** (1.6065)
Selection terms (λ)				
HHOP	345.58* (59.98)	-0.0047 (0.4855)	0.2449 (0.4216)	-0.2338 (0.4940)
HHTR	62.95 105.69)	-0.1738 (0.4460)	-0.4797 (0.3390)	2.1068 (1.510)
HHOPTTR	-556.33*** (98.45)	-0.4073 (0.4122)	0.1020 (0.4115)	0.3226 (0.7703)

Note: Figures in parentheses are standard errors. *** = p<0.01, ** = p<0.05, and * = p<0.1.
Source: Authors' own, based on analysis using round one data from APRA Tanzania survey (2017).

level of the household head increases. As in the case of the female household head, household size has a significant negative effect on HFSS and a positive effect on MPI. As expected, farm size has a positive effect on HFSS and a negative effect on MPI, implying a high probability of a household being food-secure and having a decline in poverty as farm size increases.

Distance to the nearest rice mill which was used as a proxy for market access was found to have a significant negative effect on rice yield and a significant positive effect on MPI. The significant negative effect on rice yield suggests a high likelihood of attaining a higher rice yield as the distance to the nearest rice mill declines, while the significant positive effect suggests a high likelihood of a household being poor as market access improves.

4 CONCLUSIONS AND RECOMMENDATIONS

This paper examined the effect of choice of tillage technology options on rice commercialisation, yield, and livelihood of rice farmers in Mngeta Division, Kilombero District in Morogoro Region, Tanzania. The tillage technology options examined were the hand hoe and ox plough (HHOP), the hand hoe and tractor (HHTR), and the hand hoe, ox plough, and tractor (HHOPTR), with the hand hoe (HH) used as a basis for comparing the effect of the three improved tillage technology options. Data for the analysis were extracted from the APRA first round data set of 537 rice-producing households selected randomly from ten villages in the Mngeta Division. The results of the descriptive analysis indicate the wider use of HHOP and HHOPTR as compared to the use of HH alone and HHTR in commercial rice production.

Factors found to increase the likelihood of each of the three improved tillage technology options (HHOP, HHTR, and HHOPTR) being chosen instead of the HH alone are education of household head, farm size, non-farm income, and extension services. On the other hand, factors found to reduce the likelihood of each of these tillage technology options being chosen instead of HH alone are being a female household head, household size, and being an MSF. Interestingly, age of household was found to have a negative relationship with HHOP and HHTR but a positive relationship with HHOPTR, probably due to accumulated experience on the benefits of using a tillage technology option with more tillage implements suitable for different farm operations as the farmer ages.

As expected, the use of HHOP, HHTR and HHOPTR tillage technology options were found to have a significant and positive effect on rice commercialisation, suggesting that these technology options enhance rice commercialisation. Factors other than the use of improved tillage technologies found to have a significant positive effect on rice commercialisation are land planted with rice, extension, and the use of organic and inorganic fertiliser, suggesting that these factors enhance rice commercialisation as expected. On the other hand, coefficients of age of household head and distance to the nearest rice mill as a proxy of market access are negative. Livestock income was hypothesised to have a positive influence on rice commercialisation but it was found to have an insignificant coefficient, indicating that the share of livestock income was significantly lower than the share of income from rice, and hence was unable to suppress the rice commercialisation tendency among rice farmers.

As expected, all three improved tillage technology options were found to have a positive effect on rice yield, HFSS, and MDD-W, suggesting that the use of these tillage technology options enhance rice yield, HFSS, and MDD-W. Also as expected, all the three improved tillage technology options had a negative relationship with MPI, suggesting that their use increased the likelihood of reducing poverty. Factors other than tillage technology options found to have a significant effect on at least one of the livelihood outcomes are age of the household head, being a female household head, education of household head, household size, farm size, and distance to the nearest rice mill. Age of household head was found to have a significant negative effect on rice yield and a significant positive effect on MPI while being a female household head has a significant negative effect on HFSS and a significant positive effect on MPI. As in the case of the female household head, household size has a significant negative effect on HFSS and a positive effect on MPI, while distance to the nearest rice mill which was used as a proxy for market access was found to have a significant negative effect on rice yield and a significant positive effect on MPI.

As far as policy implications are concerned, although the results suggest promoting the use of all three improved tillage technology options (HHOP, HHTR, and HHOPTR) to enhance rice commercialisation and improve the livelihood of rice farmers, emphasis should be on the promotion of the use of HHOP, not only because it is more inclusive (widely used) in the study area than the others, 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 ox carts in transporting inputs to rice farms and transporting harvested rice to homesteads or rice mills.

Since the use of a tractor might be more beneficial than using an OP, it can be promoted through the establishment of tractor hire services where farmers can access tractor services at an affordable cost. This should go hand in hand with ensuring timely availability and application of fertilisers to enhance rice yield. There is an urgent need for the local government authority to ensure that extension workers are available to advise farmers on appropriate rice husbandry practices such as seed selection, spacing between plants, watering, and application of fertilisers (inorganic and organic fertilisers) and herbicides. Education and family-planning programmes to reduce the household dependency ratio will be effective interventions to improve household food security, the ability to meet the minimum dietary diversity requirements, reduce poverty, and improve the overall welfare of the commercial rice-producing households.

ANNEX

Annex 1 Specification of explanatory variables used in the Tobit model

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	+/-
Use of other agricultural technologies		
• Use of purchased rice seeds	Dummy: 1 if purchased seeds	+
• Use of inorganic fertilisers	Dummy: 1 if inorganic fertiliser	+
• Use of organic fertilisers	Dummy 1 if organic fertiliser	+
• Use of herbicides	Dummy: 1 if herbicides	+
Community and location variables		
• Distance to nearest rice mill (km)	Quantitative	-
• Access to extension services	Dummy: 1 if has access	+

Source: Authors' own.

Annex 2 Food insecurity situation and food groups used to classify households into food-secure versus food-insecure and households satisfying minimum dietary diversity for women

Annex 2.1 List of food insecurity situations used to classify households into food-secure and food-insecure households (HFSS)

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

Annex 2.2 Food groups used to determine minimum dietary diversity for women (MDD-W)

1. Foods made from grains: porridge, bread, rice, pasta/noodles, or other foods made from grains.
2. Wild roots and tubers and plantains: white potatoes, white yams, manioc/cassava/yucca, cocoyam, taro, or any other foods made from white fleshed roots or tubers or plantains.
3. Pulses (beans, peas and lentils): mature beans or peas (fresh or dried seed), lentils or bean/pea products such as hummus, tofu, and tempeh.
4. Nuts and seeds: any tree nut, groundnut/peanut, or certain seeds, or nut/seed 'butters' or pastes.
5. Milk and milk products: milk, cheese, yoghurt, or other milk products but NOT including butter, ice cream, cream, or sour cream.
6. Organ meat: liver, kidney, heart, or other organ meats, or blood-based foods, including from wild game.
7. Meat and poultry: beef, pork, lamb, goat, rabbit, wild game meat, chicken, duck, or other bird.
8. Fish and seafood: fresh or dried fish, shellfish, or seafood.
9. Eggs: eggs from poultry or any other bird.
10. Dark green leafy vegetables: any medium-to-dark green leafy vegetables, including wild/foraged leaves.
11. Vitamin A-rich vegetables, roots, and tubers: pumpkin, carrots, squash, or sweet potatoes that are yellow or orange inside (or other vitamin A-rich vegetables).
12. Vitamin A-rich fruits: ripe mango, ripe papaya.
13. Other vegetables.
14. Other fruits.
15. Insects and other small protein foods.

16. Red palm oil: * Can be omitted if not relevant in the area.
17. Other oils and fats (not red palm oil): added to food.
18. Savoury and fried snacks: crisps and chips, fried dough.
19. Sugary foods, such as chocolates, candies, cookies.
20. Sugar-sweetened beverages: sweetened fruit juices.

Annex 3 Specification of explanatory variables used in the endogenous treatment effect model

Annex 3.1 Selection equation variables

Variable	Type	Expected sign
Tillage options		
• 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	+

Source: Authors' own.

Annex 3.2 Outcome evaluation variables

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 rice mill (km)	Quantitative	

Source: Authors' own.

Annex 4 Factors influencing paddy commercialisation: fractional regression (logit) results (base category = use of hand hoe only)

Independent variables	Coefficient	Robust standard error
Tractor (dummy=1)	0.6115***	0.2368
Ox plough (dummy=1)	0.5196**	0.2187
Tractor & ox plough (dummy)	0.6661***	0.2456
Age of hh head (years)	-0.0113**	0.0048
Education (years)	0.0379	0.0235
Female head (dummy=1)	-0.0329	0.0236
Plot size (ha)	0.0694***	0.0195
Extension services (dummy=1)	0.2859**	0.1197
Purchased seed (dummy=1)	-0.1718	0.1460
inorganic fertiliser (dummy=1)	0.3692**	0.1756
Organic fertiliser (dummy=1)	1.2266***	0.4482
Herbicide (dummy=1)	0.0691	0.1251
Distance to nearest mill (km)	-0.0277*	0.0165
Income from livestock (Tsh)	-3.37e-09	2.82e-08
Constant	-0.1767	0.3686

N=399 Wald $\chi^2_{(14)}$=70.07; p>χ^2=0.000; pseudo R^2=0.04. Note: *** = p<0.01, ** = p<0.05, and * = p<0.1.
Source: Authors' own.

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ENDNOTES

1 The detailed methodology is presented in another APRA working paper from Tanzania titled: *Does Rice Commercialisation Impact on Livelihood: Experience from Mngeta in Kilombero District, Tanzania* (Isinika *et al*. 2020).

Mdoe, N., Boniface, G., Isinika, A., Magomba, C. and Mlay, G. (2020) *Effect of Choice of Tillage Technology on Commercialisation and Livelihood of Smallholder Rice Farmers in Mngeta Division, Kilombero District, Tanzania,* Working Paper 37, Brighton: Future Agricultures Consortium

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