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The farm income and food security implications of adopting fertilizer micro-dosing and tied-ridge technologies under semi-arid environments in central Tanzania

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ABSTRACT

Adopting fertilizer input and rainwater harvesting techniques play a significant role in minimizing soil nutrient deficiency and moisture stress impact, both prime causes of low crop productivity in Sub-Saharan Africa. This study analyses the extent to which fertilizer micro-dosing (MD) and tied-ridge (TR) technologies can improve smallholder farmers' food security and farm income. A household survey data along with on-farm trial data collected from semi-arid Tanzania is used for the analysis. The trade-off analysis for multi-dimensional impact assessment model (TOA-MD) is applied for the income and food security impact assessment. The on-farm trial shows a yield increase ranging from 10 to 300 percent for millet, and between 60 and 400 percent for sunflower. The TOA-MD analysis shows that between 52 and 79 percent of farms could be positively influenced to adopt the technologies. The increase in mean net return per farm ranges between 186 and 305 PPP USD. Adoption of the technologies would decrease the percentage of food insecure farmers between 1.8 and 7.1 percent. The study concludes that the technologies have the potential to improve yield and farm income for many farmers. However, these technologies alone would not bring significant change in terms of reducing poverty and food insecurity.

1. Introduction

Soil nutrient deficiency and moisture stress are prime causes of low crop productivity in many parts of Sub-Saharan Africa (SSA) (Mueller et al., 2012). The continuous and unsustainable use of land without adequate replenishment of soil nutrients is the major driver of land degradation in the region. In addition, over 85% of land in SSA is affected by moisture stress due to insufficient rainfall and poor land management practices (Eswaran et al., 1997). To address these challenges, adopting agricultural technologies, such as fertilizer input and rainwater harvesting techniques, are critical for minimizing the impact of nutrient and water deficiencies on crop productivity (Chianu et al., 2012). For example, evidence suggests that in SSA, if moisture and nutrient conditions are optimized through fertilizer application and improved irrigation, it is possible to close up to 75% of the crop yield gap of attainable yields for major crops (Mueller et al., 2012). Improving crop productivity has direct and critical implications for the food security of rural populations in developing countries as their household food requirements are typically fulfilled by local production (Matshe, 2009; World Bank, 2007). In addition, it is expected that improved productivity subsequently increases the income available to access diversified food from the market, thus linking it to household food security and nutrition (World Bank, 2007).

However, in SSA, not only is the use of fertilizer input quite limited, but water harvesting practices are also not widely adopted (Liverpool-Tasie et al., 2017; Recha et al., 2015). Fertilizers are not widely used because it is an expensive, risky investment, especially, considering the erratic rainfall; along with insufficient and untimely fertilizer supply (Liverpool-Tasie et al., 2017; Morris et al., 2007; Mwangi, 1996). Besides economic and market factors, the minimal response rate of fertilizer when applied in marginal lands can discourage farmers from investing in fertilizer inputs (Burke et al., 2017). Although, policy instruments and institutional arrangements, such as government subsidies (Crawford et al., 2006; Jayne et al., 2013) and credit programs

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(Morris et al., 2007), have been pursued to promote the use of fertilizer, its use remains low in the region (Liverpool-Tasie et al., 2017).

In the past decades, there has been a major effort to promote efficient and strategic fertilizer application innovations, such as 'microdosing (MD),' which promotes use of fertilizer at rates affordable to resource-poor smallholders (Tabo et al., 2006), and 'tied-ridge (TR)' technology, which improves rainwater retention to increase the amount of water available to plants (Biazin and Stroosnijder, 2012). While several on-station and on-farm studies indicate the potential of these technologies to significantly enhance yield (Araya and Stroosnijder, 2010; Ibrahim et al., 2015b; Twomlow et al., 2010); the technologies are not widely implemented by smallholder farmers. As crop production will become more difficult under climate change, in the future large-scale adoption of these technologies will be necessary, particularly in semi-arid regions. As a result, agricultural development projects are implementing farm-trials to further demonstrate and evaluate the technologies under a variety of agro-ecology and field soil conditions.

This study emphasizes analysing the extent to which MD and TR technologies can improve the food security and income conditions of farmers in semi-arid Tanzania. Although a considerable literature on the yield impact of the technologies (Biazin and Stroosnijder, 2012; Ibrahim et al., 2015b; Twomlow et al., 2010) and a few studies on the cost-benefit (Camara et al., 2013) exist, much less is known about the food security and income implications of the technologies. Presently, the income and food security implications of agricultural technologies are important criteria to evaluate and scale-up agricultural technologies. Furthermore, most existing studies on MD are conducted in west and central Africa and focus on crops like millet, sorghum, and maize (Fatondji et al., 2016). Thus, other geographical contexts and other crops are less emphasised. Further, the combined effect of MD and TR is not adequately studied. Focusing on semi-arid Tanzanian agriculture, this paper attempts to answer the following research questions:

1. What is the yield impact of MD and TR technologies on millet and sunflower systems?
2. Is adopting MD and TR technologies economically profitable for the majority of farmers?
3. Does adopting MD and TR technologies improve household income and food security?

We use household survey data that includes information on output, costs, and prices on various production activities performed by farmers in the current system and household food consumption patterns; along with representative farm trial data on MD and TR technologies to quantify outcomes associated with the new technologies. The trade-off analysis for multi-dimensional impact assessment (TOA-MD) model applied in the study allows for representing the heterogeneous socio-economic and physical farm conditions across farm populations that affect the yield and economic profitability of the two technologies and farmer adoption decisions. The modelling approach is particularly useful for our case because of the characteristics of MD and TR technologies: existing studies indicate that the impacts of the technologies are influenced by environmental and physical conditions such as soil and climate. This paper contributes to the literature by addressing the gap regarding the household income and food security implications of adopting MD and TR technologies. The output provides information relevant to decision making with respect to promoting technologies that improve the food security and livelihoods of smallholder farmers in the study area and in areas with similar environmental and socio-economic conditions.

This paper proceeds as follows: section 2 discusses the characteristics of MD and TR technologies. Section 3 describes the materials and methods used in the study, while the results and discussion are found in Section 4. Finally, conclusions and policy implications are presented in Section 5.

2. Characteristics of fertilizer micro-dosing and tied-ridge technologies

2.1. Fertilizer micro-dosing

Fertilizer micro-dosing is a precision farming technique in which small and affordable quantities of fertilizer are applied directly to the crop at planting or shortly after planting in order to increase fertilizer use efficiency and improve productivity (Ibrahim et al., 2015a; Tabo et al., 2011). The main objective behind MD is to minimize the cost of fertilizer and investment risk, and to increase investment return to poor farmers who cannot otherwise afford to apply the recommended amount of fertilizer (Camara et al., 2013). The MD method typically uses between a third and a fourth of the typically recommended fertilizer rate (Camara et al., 2013). The cost of MD as compared to using the recommended rate therefore reduces by a similar ratio, between a third and a fourth. However, the labour requirements of MD method is higher and, due to this, farmers are trying a new method of applying MD that mixes fertilizer with seed to minimize additional labour costs (Pender et al., 2008).

In earlier on-station and on-farm MD research, yield increases of up to 130% yield over the farmers' common practice of no fertilizer application is reported (Camara et al., 2013; Hayashi et al., 2008; Ibrahim et al., 2015b). Other ex-post studies also indicate the positive yield impact of MD (Murendo and Wollni, 2015). The 'agronomic efficiency' of crops and varieties (Mwangi, 1996), agro-climatic variables and existing soil quality conditions are deemed as important drivers for improving crop productivity through fertilizer use. Studies on the economic returns of MD report profit increases ranging from marginal (Abdoulaye and Sanders, 2006) to 88% (Abdoulaye and Sanders, 2005) using partial budgeting analysis. Other than yield benefits, the MD technology is further promoted for its potential to reduce fertilizer-related emissions and water contamination problems.

2.2. Tied-ridges

Tied-Ridging is an *in-situ* rainwater harvesting technique that collects rainwater in the field to facilitate water infiltration, subsequently increasing crop productivity. The technology improves water use efficiency of plants and minimizes the risk of drought. It is particularly relevant in regions where water is limited and rainfall distribution is not optimal. The technology is considered to be a more affordable method for smallholder farmers than high investment *ex-situ* irrigation technology. Besides enhancing soil moisture, the technology helps conserve soil.

The positive effects of tied-ridges to increase crop productivity is found in several studies (Araya and Stroosnijder, 2010; Biazin and Stroosnijder, 2012). The effectiveness of tied-ridging is suggested to be lower in crops sensitive to waterlogging and soil types that have the less water holding capacity (Wiyo et al., 2000) as well as in weather regimes with above normal rainfall (Araya and Stroosnijder, 2010; Wiyo et al., 2000). In addition, tied-ridges have been combined with various nutrient management techniques including fertilizer application in which the greatest yield was observed by integrating tied-ridges with nutrient management (Jensen et al., 2003; Nyamangara and Nyagumbo, 2010). Its intensive labour requirements may be a reason for the limited adoption of the technology by farmers. However, it is thought to be a promising strategy for sustainable intensification in the long-term. The promotion of the technology can be successful in areas where labour is not a major constraint; for example, in areas with low land-labour ratio. Furthermore, identification and prioritization of crop activities that produce the highest returns from tied-ridging, and focusing labour allocation for these crops might be a strategic approach when labour is constrained.

3. Materials and methods

3.1. Study area

This study is based on household survey and farm-trial data collected from two villages in the Chamwino district of Tanzania. Located in the region of Dodoma, the district features a semi-arid climate with annual rainfall of 350–500 mm and a mean temperature of about 23 °C. Households in the area primarily depend on crop production with some level of livestock integration and with partial access to off-farm income generating activities. The area is characterized by extremely low yield productivity and a high incidence of crop failure due to the unsuitable climate and limited use of technology. The prevalence of food insecurity is particularly high in the region as compared to other regions of Tanzania (Graef et al., 2014).

3.2. Data

The data used in this study come from a household survey and farm-trial collected as part of the Trans-SEC project implemented in the Ilolo and Idifu villages of Chamwino district. The Trans-SEC project aimed to test and upscale promising upgrading strategies across the various components of the food value chain to increase the food security and improve the livelihoods of smallholder farmers in Tanzania and beyond. The project and its framework are further described in Graef et al. (2014). At the start of the project, in 2014, baseline household data was collected from 300 (150 from each village) randomly selected households using a household questionnaire. Detailed information was collected at the household level on various issues, including household characteristics, income generating activities, expenditure, and food security depicting the household activities for the year 2013.

Fertilizer micro-dosing and water harvesting techniques were among the upgrading strategies identified as having promising potential to secure food in the area. The technologies were tested during the project targeting millet and sunflower crops in Chamwino district. Millet is one of the most important staple crops in the study area and in many parts of Tanzania with direct implication for food security. Sunflower is an increasingly important cash crop in Tanzania, with the government developing various initiatives to realize the full potential of the sector. The study region is among those areas in Tanzania with high potential for sunflower production. However, crop yield productivity is generally low, even as compared to other regions of Tanzania. Among the main production constraints are soil fertility problems and limited soil moisture in the area, as the region is located in a semi-arid environment. Thus, fertilizer inputs and water retaining technologies have a good potential to minimize nutrient and moisture problems.

Given the limited capacity that resource poor farmers in the region have to apply the recommended rate of fertilizer, fertilizer micro-dosing was chosen as one potential upgrading strategy to improve crop productivity. Further, due to the moisture stress that the region faces, tied-ridging is seen as a potential technique to harvest rain water. Experiences on TR from different parts of Africa highlight that the high labour requirement of TR is a potential bottle neck for adoption. Given the average household size of about 5 persons and average farm size of 2 ha and the limited job opportunities for family members outside of farm in our study area; it can be assumed that labour may not be a major constraint for adoption should the economic returns be found to be acceptable. Supporting this conjecture, a previous study identifying production constraints in Tanzania livestock farming did not find labour to be a major production constraint (Baker et al., 2015). Therefore, we assume that households have adequate available labour to apply the technologies on at least a section of their land. In the Trans-SEC project, to test the MD strategy, farm-trials were conducted on a 14.4 m^2 parcel of farmer's land, applying fertilizer micro-dose rates at 25% of the recommended rate (7.5 kg P/ha) on pearl millet and sunflower. For TR technology, ridges of 20 cm height and ties of 15 cm high and between 1.5 and 2 m apart were tested on a similar plot size. The two technologies were tested separately and in combination. Detailed information including yield output, costs, and soil were recorded during the trial phase. The total number of farm-trial plots with full information required for our analysis ranged between 26 and 68.

3.3. Method

In this study, we use an economic simulation approach implemented in the TOA-MD model, developed by Antle and Valdivia (2011), to simulate the potential adoption rates of MD and TR technologies in our study area and to estimate the household income and food security impacts of adoption. The conceptual foundation of the TOA-MD model assumes economically rational behaviour by economic agents (Antle, 2011), in which farmers are expected to choose the profit-maximizing production technology when offered the opportunity to either continue using an old technology or switch to a new one. Accordingly, the TOA-MD model compares the expected net returns associated with alternative production systems to estimate the adoption decisions and rates in a farm population. The TOA-MD modelling approach has been validated against other adoption assessment methods and actual adoption rates (Antle, 2011) and the model has been further used in several studies for the analysis of the adoption and impacts of agricultural technologies and climate change (e.g., Habtemariam et al., 2017; Ilukor et al., 2014; Murshed-E-Jahan et al., 2013).

In our study, the characteristics of MD and TR technologies necessitates a method that accounts for farm heterogeneity in environmental and physical conditions, such as soil and climate, because these technologies are shown to perform differently across landscapes and crops in previous studies. Although, our study focuses on one administrative region, it is expected that farm characteristics, in terms of soil, micro-climate, production activity, and farmer's behaviour, will vary among farms within the region. The TOA-MD model can represent this variability in farms.

In the TOA-MD model, a farmer at a site using the current system earn an expected net return of x_1; if the farmer switches to the new system, the farmer expects to earn x_2. If ω represents the expected opportunity cost of switching to the new system defined as $\omega = x_1 - x_2$, it follows that a farmer would decide to adopt the technology if $\omega < 0$ (Claessens et al., 2012). The ω is assumed to be a function of climate, soil, price, and other farm characteristics variables, and is spatially distributed according to the normal probability density $\varphi(\omega)$ (Antle, 2011). From this, the proportion of farms adopting the new system, defined as $r\ (2,a)$, can be estimated from cumulative distribution function (Antle, 2011):

$$r(2, a) = \int_{-\infty}^{a} \varphi(\omega) d\omega \tag{1}$$

a is an adoption threshold, for those using the new system, $\omega < a$. When $a = 0$ it represents a case where the adoption decision is influenced strictly by the opportunity cost decision concept. However, the model simulates the impact of a full range of technology adoption rates. This has implications for decision makers, as this information enables them to specify and target a certain adoption level to achieve a targeted minimum impact in the population.

The TOA-MD model is designed to represent agricultural activities related to production of crops, livestock, and aquaculture. For our study area, crop and livestock are the relevant production activities. Accordingly, based on the household survey data, we first identify the major crop and livestock production activities to represent the current agricultural system in our study area. We then stratify our farm households into two strata based on which of the two study villages (Ilolo and Idifu) the farmers are located. The two villages are considered similar in terms of climatic characteristics but, in terms of market access, Ilolo village has better access, which may also have

Table 1
Characterization of the current system.

Strata	HH size	Farm size	Herd size	Non-agricultural income	Activity	Yield (Kg/Ha)	Net return (PPP USD)
Ilolo	4.9 (2.3)	2.04 (2.37)	3.8	527 (811)	Millet	503.2	384.7
					Ground nuts	715.5	301.7
					Sorghum	523	308.8
					Maize	391.6	178.4
					Bambara nuts	477.6	189.5
					Sunflower	506.5	184.8
Idifu	5.0 (2.3)	2.04 (1.96)	4.6	373 (481)	Millet	352.6	139.9
					Ground nuts	413.4	119
					Sorghum	402.5	213.5
					Maize	281.6	99.3
					Bambara nuts	216.7	88.9
					Sunflower	203.9	127.5

The values in parenthesis are standard deviations.

implications for technology adoption and productivity. Stratification helps to approximate normal distribution of expected returns assumed in the TOA-MD model. Following stratification, and using the household survey data, yield and economic variables are estimated for each production activity of the current system in each village. Net returns of each crop and livestock activity are calculated as total return minus variable costs of seed, fertilizers, chemicals, and hired labour.

The mean and standard deviation of socio-economic variables, such as household size, farm size, and income from non-agricultural activities, are also estimated for the sample farms. Information on non-farm income and household size distributions are used to calculate household income distributions associated with technology adoption. The various crop and livestock activities performed by farmers and the associated yield and net returns in our study area are presented in Table 1. The importance of the crop activities and the respective average yield productivity values estimated from our data set are comparable in many aspects to the agricultural yield data statistics from the region (URT, 2012). Estimates of the yield and economic variables of the alternative system (i.e., with MD and TR technologies) are based on the farm trial data, which shows expected gains in yield and changes in costs related to the technologies for millet and sunflower crops. The various crop and technology combination alternative systems considered in our study and the associated changes are shown in Fig. 1.

Other than economic outcomes, our study considers the food security implications of adopting MD and TR technologies. For this, we use the income-based food security approach, as proposed by Antle et al. (2015), to estimate a food security threshold indicator. The approach measures household food security status by comparing household per capita income and the income needed to purchase nutritionally adequate food (Antle et al., 2015). In this approach, the income needed to purchase nutritionally adequate food per person is calculated as a ratio of the cost of nutritionally adequate food per person to the share of income devoted to purchase food. By comparing the ratio and the household per capita income, it is decided whether the household is food secure or not; or, in other words, whether the household can afford to purchase nutritionally adequate food.

The cost of a nutritionally adequate food basket in our study area is calculated using the household survey information on household food dietary patterns and yearly per capita food consumption calculated in purchasing power parity adjusted US dollar (PPP). In the household survey, respondents were asked about their food dietary pattern over a recall period of seven days. From this, the Food Consumption Score (FCS) indicator for each household is calculated based on food items grouped into eight standard food groups, the consumption frequency of each food group, and each group's nutrient content. Based on the value of the FCS, we selected those households that have an *acceptable* food consumption score (with FCS value greater than 35). Following this, and using information collected in the household survey, we calculate the average per capita food consumption in PPP for the households with acceptable FCS value. The estimated average cost of nutritionally adequate food (i.e., average food consumption in PPP for households with acceptable FCS) for our study area is found to be 366 PPP. The share of income devoted to food purchases is specified as 0.73 based on available literature that estimates the value for smallholder farmers in Tanzania (Antle et al., 2015).

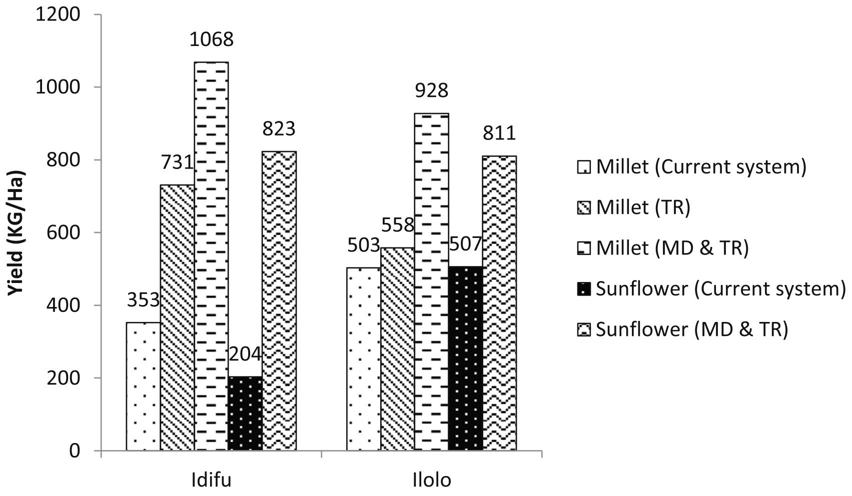

Fig. 1. Yield benefits of MD and TR technologies in millet and sunflower crops.

4. Result and discussion

4.1. Impact of MD and TR technologies on yield

The yield impacts of fertilizer MD and TR technologies are presented in Fig. 1. Yield impact is assessed for TR technology alone for millet crop, and for the combination of TR and fertilizer MD for millet and sunflower. The yield benefit is found to vary between villages and crops. In the current system, data indicates lower crop productivity for both millet and sunflower crops in Idifu than in Ilolo. In the farm trial data, higher yields are observed in Idifu village for both crops and all the technologies considered. This implies that the technologies are more beneficial in low productive Idifu village than in the better-off Ilolo village. It is also an indication that often the yield gap in smallholder system can be narrowed using such low cost technologies in unproductive regions. The combined effect of MD and TR technologies is found to be much greater than the effect of TR alone in millet crop. Under the combined effect of MD and TR, the level of millet yield per hectare found in our farm trial is within (e.g., Adams et al., 2016; Camara et al., 2013) or higher than (Abdoulaye and Sanders, 2006; Tabo et al., 2006) the ranges reported in previous MD trial studies under Sub-Saharan Africa environmental conditions. The result is also in line with other studies showing uneven implications of MD and TR technologies across locations and crops. Other technology adoption studies also suggest that the impacts of agricultural technology adoption is not uniform across households (Adekambi et al., 2009).

In terms of biophysical characteristics, the two villages are believed to be similar with regards to climate characteristics. Other than physical factors, other factors, such as proximity to market, might be also relevant factors to consider. Proximity to market is an important variable explaining the adoption of agricultural technology as it affects information exchange and motivation for market oriented production innovations. Farmers in Ilolo, who are close to the market, might already be innovative in terms of exploring the potential of crop productivity on their farms.

4.2. Adoption

The results of the adoption analysis are presented in Fig. 2. The points where the adoption curves cross the x-axis show the percentage of the farm population where adoption is economically feasible for each respective scenario. Adoption analysis is done for the four scenarios we consider: adopting TR for millet, MD combined with TR for millet, MD combined with TR for sunflower, and adopting MD combined with TR for both millet and sunflower. The results suggest that the proportion of farms positively impacted by the technologies (i.e., with 0 or negative opportunity cost) in Idifu ranges between 63 and 79 percent. For Ilolo, the proportion of farms positively impacted by the technologies ranges between 52 and 63 percent. For millet crop in Ilolo, the combined effect of MD and TR has a positive impact for a higher proportion of the population than does the single effect of TR. However, in Idifu, the predicted adoption rate is similar in the two scenarios, despite a higher yield benefit in the case of the combined application of MD and TR. This is due to a relatively higher increase in the cost of production associated with a combined application of MD and TR technologies as compared to the current system in Idifu.

In case of sunflower, the proportion of farms that are positively impacted by the combined effect of MD and TR is higher in Idifu than in Ilolo. If farmers apply both MD and TR technologies to both millet and sunflower crops, about 79% of the farmers in Idifu will be positively impacted, while 63% will be in Ilolo. The overall impacts suggest higher impacts of the technologies in Idifu than in Ilolo. The simulated adoption rates are overall higher than observed adoption rate of the technologies among smallholder farmers, which suggests that factors other than economic profitability may play an important role for farmers in the adoption decision of these technologies, as is the case for many other technology adoption decisions.

4.3. Impact on income, poverty and food security

A summary of the results of the net return per farm, per capita income, poverty and food security implications of adoption are presented in Table 2, while a more detailed result showing impacts at the various levels of adoption is presented in Fig. 3. As indicated in Table 2, the increase in mean net return per farm is found to be similar across the two villages for the millet TR scenario. This is despite the significant yield increase observed in millet yield trial under TR technology in Idifu than in Ilolo. The similar impact in mean net return per farm, while having different yield impacts, could reflect the land allocation for millet production in Idifu. It is likely that farmers in Idifu allocate less land for millet production and, thus, are not able to exploit fully the opportunities of adopting TR. For the millet MD & TR scenario, the

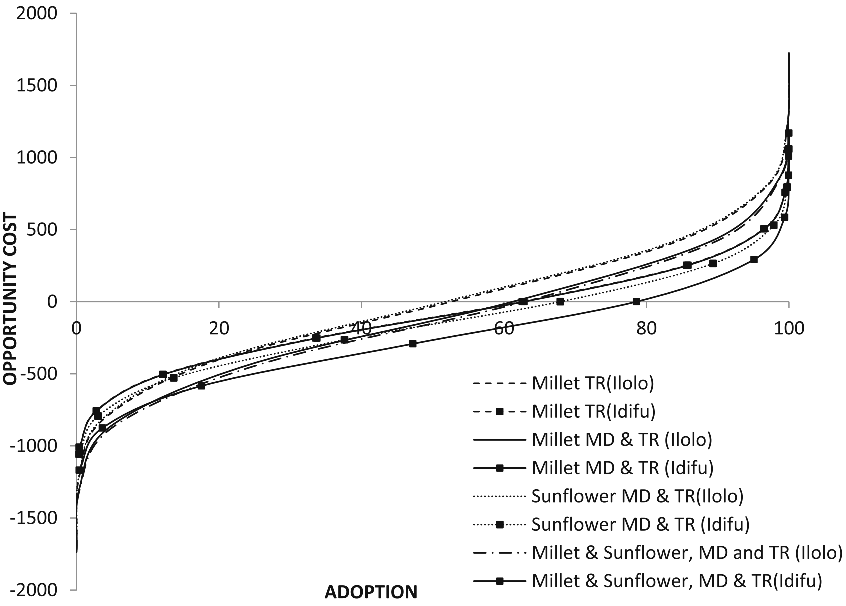

Fig. 2. Simulated adoption percentage under various scenarios.

Table 2
Summary of simulated adoption rate and the impact on mean return, per capita income, poverty, and food insecurity.

Village	Crop	Technology	Adoption rate	Mean net return per farm (increase)	Per capita income (increase)	Poverty rate (decrease)	Food insecurity rate (decrease)
Ilolo							
	Millet	TR	53	191.1	39.1	−5.6	−5.1
	Millet	MD & TR	61	247.2	50.5	−7.4	−6.7
	Sunflower	MD & TR	52	186.2	38.1	−5.5	−5
	Millet and Sunflower	MD & TR	63	258.8	52.9	−7.8	−7.1
Idifu							
	Millet	TR	63	191.9	38.4	−3	−1.8
	Millet	MD & TR	63	193.5	38.7	−3.1	−1.8
	Sunflower	MD & TR	68	223.8	44.9	−3.7	−2.3
	Millet and Sunflower	MD & TR	79	304.7	61	−5.7	−3.7

increase in mean net return is higher in Ilolo than in Idifu. However, the increase in net return is higher for Idifu in the sunflower MD & TR scenario and for the millet and sunflower MD & TR scenario.

In terms of values, the increase in mean net returns across technologies and villages ranges between 186 and 305 PPP USD, which translates to 23 to 38 percent of the mean net per farm return. The resulting increase in per capita income ranges between 38 and 61 PPP USD. In terms of the decrease in poverty and food insecurity rates, the decrease is higher for Ilolo than Idifu in all the simulated technology scenarios. The impact on poverty and food insecurity reduction is found to be modest specifically in Idifu in all the scenarios. This is due to existing high levels of poverty and food insecurity in Idifu that, even with a high yield benefit of the technologies in millet and sunflower crops, only a few households would escape poverty and food insecurity by adopting the technologies only in the two crops. One important issue coming out of our study is that it is important to take into consideration land allocation for different crop activities when analysing the impact of technologies. This is because the translation of yield impacts into income impact is always proportional to the amount of land allocated to that particular crop activity.

Fig. 3 indicates that, overall, farm populations in Ilolo are predicted to experience higher net returns per farm, higher per capita income,

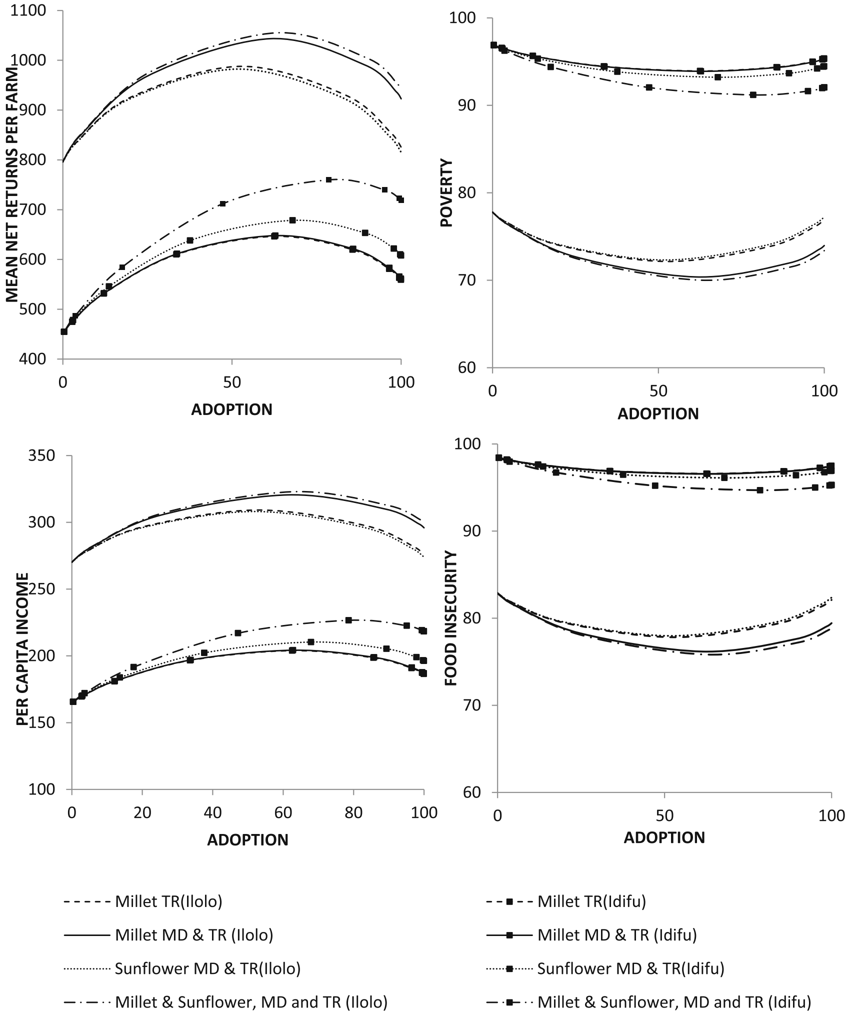

Fig. 3. The implications of various levels of adoption on mean net return per farm, per capita income, poverty, and food security.

and lower levels of poverty and food insecurity in all scenarios as compared to farmers in Idifu. This is mainly derived from the current system's higher productivity for other agricultural activities in Ilolo, which are assumed not to change under the new system in the model. The maximum mean net return, per-capita income, and the minimum poverty and food insecurity rate are realized at the predicted economically feasible adoption level. Various levels of improvements in net return per farm and per capita income are predicted associated with the different scenarios and level of adoption.

The positive income impacts of the technologies observed in our study are in line with other technology studies finding similar implications of MD and TR technologies (Abdoulaye and Sanders, 2005; Tabo et al., 2006). Our result suggests that if the technologies are expanded or implemented at large scale and multiple crops, then there are yield benefits that may help farmers in terms of income and food security, thus reducing poverty in areas with marginal soils and low rainfall.

5. Conclusion and policy implications

Agricultural technologies, such as fertilizer input and water harvesting technologies have promising potential to improve yield productivity, farm income, and food security. In the current study, household survey data is combined with farm trial data to quantify outcomes associated with adopting MD and TR technologies in a semi-arid region of Tanzania. Overall, the farm trial shows various levels of yield increases associated with the technologies. The gains in yield are found to be higher in areas where the current crop productivity is low. Furthermore, our findings suggest that the combined effects of fertilizer MD and TR are higher than the single effect of TR. The income and food security impact analysis shows a positive overall welfare impact of MD and TR technologies for the majority of the farm population. Therefore, MD and TR technologies have potential benefits for farmers who cannot otherwise afford to apply full recommended rate and in areas where water is a production constraint. However, despite the positive welfare impacts of the technologies and some associated improvements in poverty and food insecurity rate, the poverty and food insecurity rate will remain high under the scenarios we assumed in the analysis.

The potential positive effect of agricultural technologies can only be realized when farmers adopt the technologies. Economically feasible adoption rates indicate the economic profitability of the technologies; however, actual adoption rates might be affected by many other factors. To realize the simulated (potential) adoption rate and the impact, it is important to provide information to farmers about the benefit of the technologies as well as demonstrate the techniques at a wider scale, as information is one main factor. Effort should particularly target areas where the current productivity is low, as these areas would benefit the most. In addition, decision makers need to understand what incentives farmers need to adopt the new technologies. It would benefit the farmers if they allocate more land to those crops that would benefit the most from the technologies. Further, for a larger number of famers to overcome poverty in our study area and in areas with similar poverty levels, major effort should be put into promoting the application of the technologies to multiple crops.

Declarations of interest

None.

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