Adoption of Multiple Sustainable Land Management Practices among Irrigator Rural Farm Households of Ethiopia

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Abstract

Using a household and plot-level survey conducted in 2016/17 in ten districts of Ethiopia, this study explores whether there is a difference in farmers' adoption of sustainable land management (SLM) practices between their rainfed and irrigated plots. The paper also investigates the varying influence of different types of irrigation water management systems and associated irrigation technologies on the adoption of SLM practices in irrigated plots. Our findings show only a small difference in the average number of SLM practices between rainfed and irrigated plots, even though significant differences are observed between many of the practices applied individually among these plots. The econometric estimation shows that the role of the combined effect of irrigation water management system and irrigation technology on adoption of SLM practices is quite varied and very significant. The evidence highlights that farmers adopt more SLM practices in their plots with pump irrigation compared to those plots where gravity irrigation is applied. This finding implies that pump irrigation systems enhance complementarities with SLM practices. Furthermore, the results indicate that the type of irrigation water management and the technology applied could play an important role in restoring degraded lands and maintaining soil fertility, even when farmers' adoption of irrigation were not explicitly triggered by concerns for soil health.

Key words: irrigation water managements- irrigation technologies- sustainable land management- soil and water conservation methods- Ethiopia

1. Introduction

Sub-Saharan African countries are trying to improve the sustainability of agriculture and land management within the context of severe poverty and food insecurity (Gebremedhin and Swinton, 2002; Nkonya et al., 2008). Vicious circles of poverty and land degradation coupled with transmission effects from rural poverty and food insecurity to macro economies, crucially impede the development process (von Braun et al., 2013). It has been recognized that with the land frontier for further agricultural expansion shrinking, future growth in agriculture will increasingly have to come from improvements in productivity and resource use efficiency rather than from area expansion (Eicher, 1995, Otsuka & Larson 2012, and FAO 2017). Thus, innovation systems that protect and enhance the natural resource base, while increasing productivity have been fundamental requirements for sustainability (von Braun 2014).

As in most regions in sub-Saharan Africa, land degradation is a prevalent problem in Ethiopia. Over 85% of the land in Ethiopia is estimated to be moderately to very severely degraded, and about 75% is affected by desertification (The Global Mechanism, 2007). A result by Le et. al. (2016) shows that land degradation occurred in about 23% of total land area between 1982 and 2006 in Ethiopia. Gebreselassie et. al., (2016) reported that there was a decline in the total economic value of ecosystem services between 2001 and 2009, by about 5% due to land use and land cover changes in Ethiopia as a whole but reaching up to 30% of losses in ecosystems values in the Harari region. This environmental challenge has several adverse impacts that have threatened the sustainable production of agricultural goods. This has wider implications in Ethiopia, since agriculture accounts for 35% of the country's GDP, employs 70% of the labor force, and provides a livelihood to 80% of the more than 100 million people (NBE 2017/18).

The government of Ethiopia has focused on the irrigation sector with the aim of ensuring poverty alleviation in the face of extreme weather conditions and population growth. According to FAO AQUASTAT country profile 2016, between 2004 and 2015, the area under agricultural water management in Ethiopia increased from 510 thousand hectares to 1.96 million hectares. Despite its high potential benefits, use of irrigation water have caused adverse environmental conditions. Water management in medium and large-scale irrigated areas is hampered by institutional, technological, capacity, and market constraints that lead to waterlogging, salinity, acidity, soil erosion, sedimentation, inadequate subsurface drainage, and related problems (Umali 1993; Hordofa et al. 2008; Awulachew et al. 2010). In addition, since most of the irrigation schemes in the country are in the arid and semi-arid lowlands of major river basins (Ruffeis et al. 2007), the challenge of sustainable irrigation is more substantial in these regions (Wichelns and Qadir 2015). In addition to soil quality degradation, Loiskandl et al. (2008) and Amdihun (2007) discussed the negative environmental impacts from land use change, including deforestation that results in high soil erosion and sediment transportation which, in turn, affect irrigation canals. Siltation of canals has become severe in some schemes. If current irrigation practices do not improve, the emerging soil degradation problems may outweigh the benefits of irrigation projects. Thus, in order to combat land degradation due to poor irrigation management, the promotion of various kinds of sustainable land management (SLM) practices has been suggested (Nkonya et al., 2016), with additional benefits in terms of several other sustainable development goals (SDGs), such poverty eradication, zero hunger and attainment of climate and biodiversity protection targets.

Investments in SLM practices both to revert already degraded lands to productive uses and to proactively reduce future land degradation are important for sustainable irrigation development, management, and use. This is particularly true in Ethiopia, where the government considers irrigated agriculture as a primary engine of economic growth and has made investments to increase the irrigated land through rainwater harvesting as well as small, medium, and large-scale irrigation schemes. Most available empirical studies regarding sustainable land management in Ethiopia have concentrated on the social, economic, institutional, and biophysical factors that affect adoption of SLM technologies by small-scale farmers (Gebremedhin and Swinton 2003; Holden et al. 2004; Anley et al., 2006; Kassie et al. 2009;

Tekelewold et al., 2013; Teshome et al., 2014; Gebreselassie et al. 2016); on the impacts of Soil and Water Conservation (SWC) technologies on crop production in the Ethiopian highlands (Pender et al., 2001; Pender and Gebremedhen, 2007; Kassie et al., 2008a, 2010; Tekelewold 2013; 2019; Schmidt and Tadesse 2019); on the contribution of SLM technologies to water security for both crop and livestock production (Kato et al. 2019); on the impacts of SWC technologies on agricultural production risk (Kassie et al., 2008b; Yesuf et al., 2009, Kato et al. 2011), and on climate resilience (Tekelewold 2017). These earlier works are all focused on rainfed agriculture, with SLM issues in irrigated agriculture being given very limited attention so far.

This study contributes to the literature on SLM in irrigated systems, with two inter-related objectives. First, it investigates whether rural households make different decisions in adoption of SLM practices between their rainfed and irrigated plots. Second, it analyzes if irrigation water management systems and complimentary technologies affect the adoption of SLM practices on the irrigated fields.

2. Conceptual basis and hypotheses

There is ample evidence that mismanaged irrigated agriculture has adverse environmental impacts on natural resources (De Fraiture et al. 2010; Umali 1993; Hordofa et al. 2008; Ruffeis et al., 2007; Wichelns and Qadir 2015; Gebrehiwot, 2018) that include changes in soil quality such as water logging, soil salinity, and ecological damage, which have the potential to cause loss of soil fertility and productivity in irrigated agriculture (Rosegrant et al. 2009; The Malabo-Montpellier Panel 2018). As a result, investments in SLM practices to restore already degraded lands to productive uses and to proactively reduce future land degradation becomes vital for sustainable irrigation development, management, and use.

The United Nations 1992 Rio Earth Summit defines sustainable land management (SLM) as "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions". It is expected that adoption of sustainable land management practices to be affected by factors that influence farmers' awareness of different practices; the costs, benefits, and risks of the technologies; or the availability of productive factors used for the application of the practices.

Adoption of SLM practices and their comparative advantage depend on household level factors, village level characteristics (such as market access and other infrastructures), farm level factors (such as land size and land tenure security), and biophysical factors (such as soil type and slope of the plot, rainfall, temperature, and vegetation covers). In addition, household level factors such as access to training on natural resource management and experience of using irrigation are important factors that determine adoption of SLM practices. The choice of explanatory variables that explain the adoption of SLM in this study is based on economic theory and findings from earlier studies (Pender et al. 1999; Anley et al., 2006; Pender and Gebremedhin, 2007; Pender et al 2001; Kato et al 2011, Teklewold et al 2018; Schmidt and Tadesse, 2019).

For the past four decades, the role of local rural communities and households in irrigation water management has been increasing. The government and development partners have committed to the implementation of policy reforms that encourage irrigation management at lower level and adoption of irrigation technologies at micro and small scale to farm households. This study proposes that the type of water management system and complimentary irrigation technologies in use influence the adoption and intensity of sustainable land management practices applied on irrigated farms. The central hypothesis of this study is that using privately managed irrigation system may lead to increased mismanagement of natural resources and lower adoption of sustainable land management practices due to differences in the private and social discount rates in resource use. On the other hand, irrigation schemes that are initiated and managed by groups of farmers can more easily adopt sustainable land management practices. It is also assumed that irrigation schemes jointly managed by farmers and public entities have a greater incentive to use and manage the resource efficiently and invest in land management technologies, since most of these systems are equipped with modern structures. However, it is noteworthy to mention that the performance of each agricultural activity in this kind of system highly depends on the relation between the agents that manage the scheme at higher level of the irrigation infrastructure and the farmers that use the irrigation water with the responsibility to manage the resource at a lower level.

3. Typology of irrigation systems and technologies included in the study

Irrigation water management system for smallholder farmers in Ethiopia is diversified. It ranges from private access and use rights of an irrigation water source such as shallow well, to full participation of group of farm households in the inception, design, construction, and operation of an irrigation scheme, and to partial participation of farmers only at the low reaches of management level. In this section, we summarize the different irrigation systems included in this study as follows:

(i) Privately managed irrigation system is a “micro-scale private irrigation” which refers to individualized small-scale technologies for storing, lifting, conveying, and applying irrigation water. The main character of farmers in a privately accessed irrigation system is their reliance on drilled and hand dug wells or water harvesting ponds to store water for irrigation; treadle and motor pumps to lift water; and a variety of irrigation application technologies such as flooding, furrow, small buckets, and drip systems to apply water on a farm plot. Around 19% of the sample households and plots in the study fall in this category.

(ii) Users-managed irrigation system refers to irrigation schemes where farmers and water users’ associations (WUA) have full control and responsibility from inception to the construction and implementation of the scheme, including the utilization and management of the irrigation water. Usually, this kind of system is characterized as small scale and found in traditional irrigation schemes constructed using diversion weirs made from local materials and need annual maintenance. They may apply gravity or pump to lift irrigation water. Around 12.5% of the sample plots in the study apply pump to lift irrigation water and 22% of the sample plots use canal (gravity) to deliver irrigation water.

(iii) Jointly (users-agency) managed irrigation system refers to a system where farmers and a government agency manage irrigation schemes jointly. Since the schemes are usually medium or large-scale irrigation systems, a government agency has control of the water to the delivery point and is responsible for operation and maintenance at higher level; the use of water and operation and maintenance (O&M) thereafter is under the control of the farmers and their association. As farmer-managed irrigation systems, they may use gravity or pump irrigation technology to withdraw water from a source. Approximately, 10% and 37% of the total samples in the study apply pressurized pump irrigation and canal irrigation systems to withdraw water from a source, respectively.

The combinations of alternative irrigation management schemes and irrigation technologies are provided in Table 1. There are no private irrigators that use gravity for water application, resulting in five water management-technology alternatives.

[Insert Table 1 about here]

4. Method of analysis

4.1. Data description

The dataset for this study comes from a unique cross-sectional survey customized for capturing various aspects of irrigation management and use in Ethiopia. The survey was conducted in 2016/17 in the four regions of Ethiopia: Tigray, Amhara, Oromia and Southern Nations, Nationalities, and Peoples (SNNPR) covering both irrigated and rainfed farmlands.

The data were collected using a multi-stage stratified random sampling method. In the first stage of the sample selection process, among the nine regions in the country, Tigray, Amhara, Oromia and Southern Nations, Nationalities, and Peoples (SNNPR) were purposively selected due to the relatively higher irrigation project developments in these four regions. In the second stage, in consultation with irrigation experts at the federal and regional level, *woredas* (districts representing the third-level administrative divisions in Ethiopia) which fulfill the objective of the study (diversified irrigation practices with water management systems) were identified. The survey covered 10 districts in different agro-ecological zones of the country. From each region, we selected 1-4 *woredas*: Tigray (2 *woredas*), Amhara (3 *woredas*), Oromia (4 *woredas*), SNNPR (1 *woreda*). In the third stage, based on information from *woreda* office of agriculture and water resources, *kebele* (peasant associations or *tabias*) which constitute different scales of irrigation (large, medium, small, and micro) accessed by smallholders who produce various crops were selected. *Kebele*, Peasant Association, or *Tabia* are the smallest administrative units in Ethiopia. Finally, based on list of irrigation water users provided by *kebele* level Bureaus of Agriculture, Bureaus of Water Resources, Water User Associations, and Cooperatives on the households who have irrigation water access, 464 irrigation water beneficiary households were randomly selected. The analysis of this study is based on 1141 rainfed and 889 irrigated plots. The salient features of irrigation schemes included in the study is presented in the Appendices, Table A1 and Figure A1.

The survey data were merged with climate variables based on geo-referenced plot level latitude and longitude coordinates for the period 1981-2016. The climate variables (temperature and precipitation) were obtained from two different sources. The dataset on temperature was 0.5 degree by 0.5-degree gridded time-series data downloaded from Climate Research Unit, University of East Anglia (Harris & Jones 2017). The dataset for precipitation was downloaded from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) that incorporate 0.05-degree resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring (Funk et al., 2015). After downloading the datasets from the respective sources, the monthly temperature and precipitation data values for the study sample farms were extracted and interpolated from the gridded time series data to farm-level GPS coordinates measured during the survey. The Thin Plate Spline method of spatial interpolation was used to impute plot-specific rainfall and temperature values using geo-referenced information, following studies by Di Falco et al., (2012) and Teklewold et al., (2017). Furthermore, using geo-referenced points from the household and plot survey, Landsat images were extracted to compute a normalized difference vegetation index (NDVI). The Landsat series of images were acquired from NASA/ U.S. Geological Survey Earth Observation satellites space-based images of the Earth's land surface (U.S. Geological Survey, 2016).

In addition, qualitative information was gathered through focus group discussions with open-ended questions to enhance the validity and reliability of the quantitative data and augment the econometric results.

4.2. Econometric estimation strategy: Multivalued treatment effects approach

To estimate the effect of various combinations of irrigation water management systems and technologies on the number of SLM practices adopted, the multivalued treatment effects approach of Imbens (2000), Wooldridge (2007; 2010) and Cattaneo (2010) is applied. This method allows to estimate the treatment effects when there are more than two treatments among the individuals in the sample. In our case, this includes private individual irrigators with pumps, users-managed pump systems, users-managed gravity systems, government and users jointly managed gravity systems, and government and users jointly managed pump systems. The potential-outcome means (POMs) of number of SLM practices adopted in each alternative management and technology combinations are computed. The analysis is implemented at plot level to capture spatial heterogeneity across irrigated plots and to minimize omitted variable bias. Since the choice of irrigation technology may be endogenous with unobserved household characteristics, if they are not properly controlled for, the obtained results may be biased. The plot level analysis in this study enables us to control for unobserved household characteristics through household fixed effects.

As the first step to estimate the impact of adopting various combinations of water management systems and irrigation technologies on SLM, a conditional probability model is constructed to estimate the likelihood that each plot would be in each given alternative (see the Appendices, Figure A2-A6). In the second step, the conditional means (the average potential outcome for the specified alternatives) of the number of sustainable land management practices applied are estimated using Inverse Probability Weighted Regression Adjustment (IPWRA) estimators (refer the Appendix, section A1 for details). IPWRA is used to account for non-random nature of irrigation technology and irrigation management system adoption. This econometric estimation method helps to remove the known and explicitly modelled sources of self-selection and endogeneity. In our specification, the full list of covariates to predict alternative (treatment) status include age and education level of the household head, household size, number of trainings attended, access to extension service, assets as proxies for wealth (Tropical Livestock Unit), land tenure, distance to the nearest *woreda* (district) market, whether adverse weather conditions occurred, average *Meher* (the main rainy season) precipitation and annual temperature and NDVI. Summary statistics of relevant variables by the six combinations of water management and technology alternatives sub-groups is provided in Table 2. Multinomial logit model is used to predict treatment status as a function of the covariates and then use Poisson and Probit models to estimate the outcome variables (number of SLM technologies applied). Three kinds of SLM systems are used in the analysis: (i) sustainable cropping systems such as rotation, fallowing and legume planting, (ii) fertilizer use (chemical fertilizer with combination of manure (green) or compost), and (iii) soil and water conservation methods (physical land investments) such as contour ploughing, planting trees/bushes in rows (agroforestry), terraces, trenches, cover cropping and strip cropping.

[Insert Table 2 about here]

5. Results

5.1. Descriptive Analysis

Focus group discussions with irrigators in our sample indicate that the most frequent environmental impacts of irrigation are water logging, soil salinity, soil fertility, and soil erosion. Around 27% of irrigators reported that their soil fertility level has been deteriorating since they started to use irrigation. Similarly, around 18% of the irrigated plots face water logging problem, while soil salinity is observed in 27% of the plots, according to farmers' perceptions. The occurrence of erosion due to irrigation was observed in only 5% of the plots. However, the figure is much higher (21%) when farm households were asked about their perception towards soil erosion as a general environmental threat including their rainfed plots.

Understanding the ongoing land degradation problems, farmers apply diversified types of SLM practices on their farm plots. In this section, the analysis is based on farmers' rainfed and irrigated plots. Rainfed plots are plots that rely mainly on precipitation as a source of moisture to cultivate crops, however, irrigated plots are those plots that are equipped to provide irrigation water and cultivated in at least one irrigation season in a year.

Table 3 presents SLM practices applied on irrigated and rainfed plots in the study areas. In line with previous studies by Bekele and Drake (2003) and Gebreselassie et. al. (2016), crop rotation, fallowing, and chemical fertilizers are the most common practices adopted by most farmers in both irrigated and rainfed systems. Compared to irrigated plots, fallowing, crop rotation, and legume planting are more common in rainfed plots. This is partly due to larger land size holdings as well as higher number of rainfed plots than irrigated plots. Farm households use more chemical fertilizers on their irrigated plots (by 25 percentage points) than their rainfed plots. However, it is noteworthy to mention that use of chemical fertilizer alone is not counted as SLM practice. It should be combined with manure or compost. In this case, households applied chemical fertilizer with manure (green) or compost in only 8% and 19% of rainfed and irrigated plots, respectively. There is significant difference in the use of compost between plots that are used for irrigation (13%) and plots that are cultivated using rainfall (7%).

[Insert Table 3 about here]

The level of physical land management practices is comparable between irrigated and rainfed plots. Overall, physical land conservation investments such as construction of trenches, strip cropping, and cover cropping are the least adopted SLM measures by farm households. This is possibly because these land management practices could remove land out of agricultural production. Nonetheless, trenches and strip cropping are more common in rainfed plots than irrigated plots. On the other hand, contour ploughing, terraces, and tree planting are common soil erosion mitigating practices. Planting trees is more common in irrigated plots while there is no statistically significant difference in contour ploughing and terraces between rainfed and irrigated plots (Table 3).

Even if significant differences are observed between many of the practices applied individually among plots in irrigated and rainfed plots, the difference in the total number of SLM technologies applied on representative rainfed and irrigated plots is very small. The average number of SLM practices adopted in irrigated and rainfed plots stands at 2.22 and 2.08, respectively, out of 13 possible SLM practices that information is collected on. In the next section, we examine econometrically whether there is a difference in the number and type of SLM practices and investments among plots benefiting from different combinations of water management systems and irrigation technologies.

5.2. Multivalued treatment effect results

This section presents the conditional means (the potential outcomes means - POM) of the most widely applied SLM technologies in the irrigation sites by water management system and complementary irrigation technology, after controlling for other characteristics of each plot. The descriptive statistics of the number and type of land management practices among plots benefiting from different combinations of water management systems and irrigation technologies is presented in the Appendix, Table A2. The simple comparison based on the result from unconditional means of number of sustainable land management practices in different categories along the alternatives may be misleading because it does not account for other factors that may influence the outcome variables. The multivalued treatment estimation controls for such confounding factors and is appropriate when there are more than two treatments. We also estimated multivariate probit, probit, poisson and ordered probit estimation as robustness checks and found similar results with the multivalued treatment effect using Inverse Probability Weighted Regression Adjustment (IPWRA) estimation. The multivariate probit, probit, poisson and ordered probit estimation results are presented in the online Appendix Table A3-A4.

Table 4 presents the multivalued treatment effect results of potential mean outcome (sustainable land management practices applied) of each combination of water management and technology alternatives. The multivalued treatment effect results depict that there are significant differences in the number and type of land management practices among irrigated plots benefiting from different combinations of water management systems and irrigation technologies (see Table 4). Adoption of sustainable cropping systems such as crop rotation, fallowing, and legume planting is higher among pump irrigators in either of the management systems. Around 1.75, 1.53, and 1.02 average number of sustainable cropping practices are adopted in jointly-managed, privately-managed, and farmer-managed irrigated plots with pump irrigation, respectively. Overall, the use of organic fertilizer alone as well as combined with chemical fertilizers is negligible in the study areas (Appendix, Table S3). Table 4 depicts that only 14% of the plots located in jointly managed pump systems applied organic fertilizer (green manure or compost) alone or combined with chemical fertilizer such as DAP, Urea, and NPS.

[Insert Table 4 about here]

Compared with other categories of SLM, the adoption of physical soil and water conservation is not common in the alternative combination of water management systems and irrigation technologies applied. This is perhaps due to their labor-intensive nature of soil and water conservation investments and the high opportunity cost of labor in irrigated areas where farmers may have greater ability to use purchased inputs.

In all SLM categories, the evidence shows a greater number of sustainable land management practices in jointly managed pump irrigated plots (3.08). Usually, this kind of system uses pressurized irrigation which operates through drip and sprinkler water appliance systems. The higher number of SLM technologies in this kind of water saving irrigation system is explained by the nature of irrigation structures installed in the irrigated fields that influences adoption of SLM technologies such as contour ploughing, planting tree/shrubs in rows (agroforestry), strip cropping and fertilizer use. Pressurized system generally uses drips or sprinklers in fields that directly determine the spacing of crops. In addition to other features and equipment, filters are used, and fertilizers are generally applied with the irrigation water (Phocaide, 2007). Contrary to the hypothesis, gravity applied plots that are in user managed and jointly managed systems do not benefit more from SLM practices. On the other hand, plots that are in privately managed irrigation systems have a higher number of SLM practices than gravity irrigators in users-managed and jointly managed irrigation plots. The privately accessed irrigation systems may not suffer from collective action issues in their decision to practice or invest in sustainable land management – a problem that is likely to be a constraint in users- and jointly managed irrigation systems.

Gravity irrigators in users-managed systems have adopted the least number of SLM practices in almost all cases with mean 1.8 SLM practices adopted. This kind of irrigation system is mostly characterized as traditional irrigation system constructed using local materials which generally leads to large seepage losses and a deterioration of the water volume to be distributed. The fact that SLM practices and investments are the least common in this type of irrigation systems is a worrying sign for the sustainability of such systems and requires the attention of stakeholders and institutions.

Generally, the significant difference between the number of SLM adopted on a plot across different alternatives implies that the type of irrigation water management and the technology applied can play a role in restoring degraded soils and maintaining the current condition of the irrigated land, considering that improving and maintaining the soil condition of irrigating plots was not the explicit reason why farmers adopt irrigation.

6. Conclusion and Policy Implications

The government of Ethiopia has made a strong commitment to developing and expanding various types of irrigation systems for smallholder rural farm households. While the potential benefits of irrigation are multidimensional, the actual achievements in many irrigated areas are considerably below the potential due to poor water management leading to land degradation. However, the empirical foundation for understanding the role of water management systems and complementary technologies following the establishment of irrigation schemes on possible SLM strategies to overcome land degradation problems is far from being established. A clear understanding of the impacts of past investments in irrigation institutions and technologies and their impact on adoption of SLM practices is an essential prerequisite for improving future interventions and promote irrigation development. This enhances positive impacts while minimizing the adverse effects such as waterlogging and secondary soil salinization and to propose strategies for appropriate investments in soil and water conservation measures and land improvement.

The findings of this study underscore that a non-negligible part of farming households who adopted irrigation have observed some negative soil quality changes such as water logging (18%), soil salinity (17%), decline in soil fertility (27%) and soil erosion (5%) after the development of irrigation on their plots. To address the land degradation challenges, farmers apply various types of sustainable agricultural practices. Our findings show only a small difference in the average number of SLM practices between rainfed and irrigated plots, even though significant differences are observed between many of the practices applied individually among these plots. We find that on average, 2.22 and 2.08 average number of SLM practices and investments are adopted in rainfed and irrigated plots, respectively. Instead of sustainable cropping systems and soil erosion control practices, fertilizer use (both organic and inorganic fertilizer) is greater in the irrigated plots. This implies that due to labor intensive nature of irrigation activities, the opportunity cost of labor is higher in irrigated areas where farmers may have greater ability to use purchased inputs.

The Multivalued econometric estimation points out that the role of the combined effect of irrigation water management systems and irrigation technologies on adoption of SLM practices is quite varied and very significant. A greater number of land management practices has been adopted in plots irrigated with pump. The total number of SLM practices and investments adopted are 3.08 in jointly managed pumps systems, 2.67 by privately accessed irrigation systems, 2.27 by users-managed pump systems, 1.84 by jointly managed gravity systems, and 1.8 by users-managed gravity systems. The lowest number of SLM practices and investments adopted by user-managed gravity irrigation systems highlight the need for interventions that support SLM in traditional gravity irrigation structures. These interventions include capacity building of irrigators on the adoption and application of various sustainable land management practices in conjunction with irrigation water use on their fields.

Overall, the significant difference between the number of SLM practices adopted on plots across different alternatives implies that the type of irrigation water management and the technology applied can play a role in famers' adoption decision of SLM practices. Therefore, sustainable land management programs and related interventions need to consider both the irrigation water management system and the irrigation technologies in use in their menu of policy responses meant to arrest land degradation in irrigated agriculture.

Authors' contribution

All the authors have contributed sufficiently. Rahel Deribe Bekele has made the conception and design of the research, data collection, analysis and interpretation of data and write-up; Alisher Mirzabaev has contributed substantially to the conception of the research questions and revising the study critically for important intellectual content; Dawit Kelemwork has contributed substantially in providing continuous critical feedback to the intellectual content as well as in helping to shape the research analysis and manuscript as a whole.

Declaration of interest statement

The authors declare that there is no conflict of interest.

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Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author.

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Table 1. Combined alternatives of water management systems and irrigation technologies included in the analysis

Choice	Alternatives	No of plots	%
1	Privately managed pump users	168	18.94
2	Users-managed pump users	111	12.51
3	Users-managed gravity users	195	21.98
4	Jointly managed pump irrigators	87	9.81
5	Jointly managed gravity irrigators	326	36.75

Total	887	100.0 0

Source: the household survey, described in the data section.

Table 2. Summary statistics of relevant variables by the six combinations of water management and technology alternatives sub-groups

Variable Name	Private +pump	Farmer +pump	Farmer +gravity	Jointly +pump	Jointly +gravity
Household Human capital					
Age of the household head (in years)	42.11	44.83	46.67	44.40	45.54
Education level of the household head (in years)	6.25	4.18	4.51	3.99	4.99
Family size, (in number)	6.92	5.93	6.01	5.71	6.06
Number of training attended in 2015/16	0.67	1.13	1.32	0.71	1.36
Frequency of contact to extension worker in 2015/16, (in number)	18.39	19.23	16.80	13.6	16.89
Household physical capital					
Livestock ownership (TLU)	4.02	3.30	4.80	3.30	5.96
Village level characteristics					
Distance to the woreda market in min, one way	28.89	33.98	44.97	19.67	40.58
1=if there was adverse weather condition in 2015/16	0.35	0.72	0.35	0.78	0.24

Plot Characteristics					
Irrigation plot size (in ha)	0.23	0.30	0.19	0.37	0.33
1=if the soil type loamy	0.79	0.59	0.51	0.67	0.57
1= if the plot is flat	0.98	0.97	0.96	0.94	0.87
1=if the plot is allocated by the government	0.17	0.54	0.49	0.69	0.44
1=if the plot is certified	0.97	0.98	0.81	0.92	0.74
Bio-physical variables					
Mean annual temperature	17.4	18.7	17.1	19.1	17.0
Meher mean total precipitation	528	445	726	439	781
Belg Mean total precipitation	366	220	254	189	243
Normalized Difference Vegetation Index(NDVI)	0.34	0.18	0.21	0.14	0.23

Source: Author’s computation using own survey data

Table 3. Mean separation tests of sustainable agriculture practices applied in plots with and without access to irrigation

Sustainable agricultural practices	Rain-fed		Irrigated		Rain-fed vs irrigated (Diff)	
Sustainable cropping system	Mean	SE	Mean	SE	Mean	SE
Crop rotation	0.65	0.01	0.56	0.02	0.09***	0.02
Fallowing	0.30	0.01	0.21	0.01	0.09***	0.02
Legume planting	0.11	0.01	0.03	0.01	0.08***	0.01
Any one of the sustainable cropping systems are adopted	0.73	0.01	0.63	0.02	0.10***	0.02
Number of sustainable cropping system	1.06	0.02	0.80	0.02	0.26***	0.03
Fertilizer use						
Manure	0.14	0.01	0.19	0.01	-0.05***	0.02
Compost	0.07	0.01	0.13	0.01	-0.06***	0.01
Green manure	0.00	0.00	0.02	0.00	-0.02***	0.00
Chemical fertilizer (DAP, Urea, NPS)	0.50	0.01	0.75	0.01	-0.24***	0.02
Combining use of chemical fertilizer and manure or compost	0.08	0.01	0.19	0.01	-0.11***	0.01
Soil erosion control practices						
Contour ploughing	0.17	0.01	0.15	0.01	0.02	0.02
Planting trees/bushes/ in rows (agroforestry)	0.11	0.01	0.16	0.01	-0.05***	0.01
Terraces or bunds	0.33	0.01	0.30	0.02	0.03	0.02
Trenches	0.09	0.01	0.04	0.01	0.05***	0.01
Cover cropping	0.09	0.01	0.09	0.01	0.00	0.01
Strip cropping	0.05	0.01	0.03	0.01	0.02***	0.01
Any of the S & W conservation practices used	0.52	0.01	0.50	0.02	0.02	0.02
Average number of soil erosion control practices adopted	0.52	0.01	0.50	0.02	0.02	0.02
Number of SLM technologies applied	2.22	0.05	2.08	0.06	0.14*	0.07
No of observation	1,141		889			

Note: Statistical significance at * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Use of chemical fertilizer is presented for additional information but not included as SLM practice alone

Table 4. Estimated average potential number of sustainable management technologies adopted in plots with various combinations of water management and water lifting technologies

Potential outcome means	Privately accessed + pump (1)	Users-managed+ pump (2)	Users-managed+ gravity (3)	Jointly managed +pump (4)	Jointly managed +gravity (5)
Sustainable cropping system (out of three practices)	1.53**	1.02***	0.55***	1.75**	0.49***
	(0.65)	(0.21)	(0.07)	(0.70)	(0.05)
Fertilizer use (compost/manure/green manure alone or with chemical fertilizer) (=1 if organic fertilizer or organic fertilizer with chemical fertilizer is applied)	0.28***	0.30***	0.45***	0.14**	0.30***
	(0.06)	(0.08)	(0.07)	(0.07)	(0.45)
Physical soil and water conservation (out of six practices)	1.24*	0.72***	0.46***	1.19	0.81***
	(0.69)	(0.11)	(0.08)	(1.08)	(0.10)
Total number of SLM practices adopted (out of ten practices)	2.67***	2.27***	1.80***	3.08**	1.84***
	(0.39)	(0.34)	(0.18)	(1.56)	(0.15)

Standard errors in parenthesis
Note: Statistical significance at * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Appendices

Table A1. Salient features of irrigation schemes included in the study
Figure A1. Location of the study sites
Section A1 Identification strategy
Figure A2. Conditional probability for being a plot in private managed pump irrigation system
Figure A3. Conditional probability for being a plot in farmer managed pump irrigation system
Figure A4. Conditional probability for being a plot in farmer managed gravity irrigation system
Figure A5. Conditional probability for being a plot in jointly managed pump irrigation system
Figure A6. Conditional probability for being a plot in jointly managed gravity irrigation system

Table A2. Summary statistics of sustainable agricultural practices applied in irrigated plots with various alternative

Table A3. Estimates of the multivariate probit model of categories of Sustainable land management

Table A4. Estimates of Sustainable land management in different models