COMPATIBILITY AND COMPLEXITY IN FARMERS' ADOPTION OF MODERN IRRIGATION TECHNOLOGIES: EVIDENCE FROM THE UPPER PANGANI RIVER BASIN, TANZANIA

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ABSTRACT

This study examined the factors influencing the adoption and performance of modern irrigation technologies, with a focus on drip and sprinkler irrigation in the Upper Pangani River Basin, northern Tanzania. A mixed-methods approach was applied, combining questionnaire surveys, semi-structured interviews, field water application trials, and crop yield measurements. Data were collected from 156 smallholder farmers across Lekitatu and Mtakuja irrigation schemes during the 2018 dry season and 2019/2020 rainy season, representing adopters and non-adopters of modern irrigation systems. Additional information was obtained from village offices and grey literature. Experimental plots comparing drip and furrow irrigation were established on tomato fields, with treatments designed to assess the effects of spacing, flow rates, and water application efficiency. Cost–benefit analysis (CBA) was conducted to evaluate profitability, while water use efficiency (WUE), field application efficiency (FAE), and water productivity (WP) were calculated to assess technical performance. Findings indicate that farmer adoption decisions are shaped by perceptions of subsidies, credit access, market availability, and training opportunities. Empirical results show that drip irrigation consistently outperformed furrow irrigation in terms of crop yield, revenue, WUE, and WP, though high initial investment costs constrained profitability in the short term. Sprinkler irrigation also proved superior to furrow irrigation for maize production. Overall, the study highlights both the agronomic and economic benefits of modern irrigation technologies, while underscoring the need for supportive institutional measures—including targeted subsidies, extension services, and credit access—to overcome adoption barriers and ensure sustainable agricultural intensification.

Keywords: Water saving technologies, water use efficiency, water scarcity, crop profitability, Farmer-led irrigation.

INTRODUCTION

Smallholder farmers still make up most of the agricultural production in Sub-Saharan Africa (SSA), even though climate change is making it harder for them to grow crops. Recent regional evaluations reveal that more than 85% of smallholders continue to depend on rainfall, despite the expansion of farmer-led irrigation initiatives across numerous agro-ecological zones (Lefore et al., 2019; Giordano et al., 2022). Smallholders are using shallow groundwater, rivers, and seasonal streams more and more for irrigation. Surface methods, especially furrow and flood irrigation, are still the most common. But the use of pressurized systems like drip and sprinkler irrigation has been slowly growing, thanks to private suppliers, NGOs, and donor-supported extension programs (van Koppen et al., 2020; Magwenzi et al., 2023).

Even with these changes, many smallholder systems still don't work well for irrigation. Recent evaluations in Tanzania indicate that overall irrigation efficiencies range from 10% to 30%, primarily due to unlined conveyance canals, excessive field flooding, and inadequately maintained infrastructure (Kangile et al., 2021; Mdemu et al., 2022). In response, TAHA, Balton Tanzania Limited, the Green Agriculture Project, and government and NGO extension programs are all working to promote better irrigation technologies like drip, sprinkler, border irrigation, and the System of Rice Intensification (SRI) (Materu, 2020; Mligo & Semali, 2021).

Recent empirical evidence shows that these technologies have significant benefits for agriculture and saving water. Drip irrigation, for instance, has been shown to improve yields by 10% to 45% and save water by 35% to 70%, depending on the crop and how it is managed (Alhassan et al., 2021; Sharma & Singh, 2023). In smallholder settings, sprinkler systems and better border methods have also increased yields by 15% to 60% and decreased water use by 20% to 35% (Tesfaye et al., 2021; Kakar et al., 2023). Even with these clear benefits, not many people are using them, especially farmers who don't have a lot of money (Nakawuka et al., 2018; Magwenzi et al., 2023).

This slow adoption shows that there are problems that go beyond how well the crops grow. These include high initial costs, limited access to credit, high costs of operation and maintenance, unreliable supply chains for spare parts, lack of technical knowledge, and worries about the system's durability and profitability (Mirzaei & Azarm, 2021; Rouzaneh et al., 2019). Also, most small farmers in Tanzania only grow enough food to feed themselves, which makes it hard for them to buy modern irrigation equipment (URT, 2022; Kangile et al., 2021). Market uncertainty further diminishes investment incentives: smallholders often encounter fluctuating prices and inadequately organized markets, deterring the adoption of technologies that necessitate stable production to recoup expenses (Mmasa & Mwaseba, 2020; FAO, 2023).

Additionally, a lot of the current research focuses on technical performance metrics and doesn't do much to look at farm-level financial analyses like crop budgets, cost structures, and sensitivity tests. This is especially true for the diverse horticulture, rice, and coffee systems that are common in northern Tanzania. Smallholders, extension agents, and private investors cannot properly judge how economically attractive different irrigation technologies are under real-world production and market conditions without clear profitability assessments.

To address these gaps, this study examines both profitability and adoption-related factors in the Upper Pangani River Basin, northern Tanzania. Specifically, the study (1) assesses crop-level profitability and water-use efficiency of selected irrigation techniques used by smallholders; (2) quantifies water costs as shares of total input costs and gross margins; and (3) identifies socioeconomic, institutional, and perception-based factors that influence farmers' decisions to adopt (or not adopt) water-saving irrigation technologies. Key inputs and costs (land preparation, seed, labour, agrochemicals, water fees, mechanization, transport), yields and market prices (including variation for sensitivity analysis) were recorded from farms to provide a transparent, farm-level financial context for technology appraisal.

MATERIALS AND METHODS

Study Area

The study was conducted in Meru District area in Arusha Region, and Moshi District Council area in Kilimanjaro Region, northern Tanzania. In Meru District, the study was carried out at the Lekitatu irrigation scheme, located at latitude 3.40148S and longitude 36.8419167E. Rainfall received in the study area ranges between 590 mm and 1400 mm. The average annual temperature is 22.03°C. Main crops cultivated within the area includes paddy, beans, maize, and vegetables, whereas Ngarasero spring, Nurangimam spring, and Tengeru River are the main water sources in the area (Nono-Womdim et al., 2002). Drip and furrow irrigation systems are the irrigation systems used within the scheme.

In Moshi District Council, the study was carried out at the Mtakuja irrigation scheme. The Mtakuja scheme covers an area of 80 hectares, of which 40 hectares were developed first. The scheme lies at latitude 3.533614S and longitude 37.351109E and is located 30 km away from the base of Mount Kilimanjaro, at an altitude of 708 m above mean sea level. Farmers within the scheme use boreholes as a source of water. Sprinkler and furrow irrigation are the irrigation systems adopted within the scheme. Main crops cultivated within the area include maize, beans, and tomatoes.

The selected study areas Meru District and Moshi District Council (Figure 1) were purposively chosen because they host a high concentration of smallholder farmers who utilize a diverse range of irrigation technologies. Within these districts, farmers operate under varying agro-ecological conditions and employ sprinkler, drip, and furrow irrigation systems, making the locations suitable for comparative analysis of irrigation performance and adoption factors. Notably, sprinkler irrigation has an established presence in the Kilimanjaro region, particularly among smallholder and estate coffee growers, where it has been used for decades to enhance water distribution uniformity, stabilize yields, and reduce labour requirements during dry spells. The integration of sprinkler systems into coffee production has made the region one of the key demonstration areas for pressurized irrigation in northern Tanzania. By including districts that differ in altitude, climate, and cropping systems, the study captures variations in irrigation practices and constraints across two distinct agroclimatic zones, providing a broader understanding of smallholder irrigation dynamics in the Upper Pangani Basin.

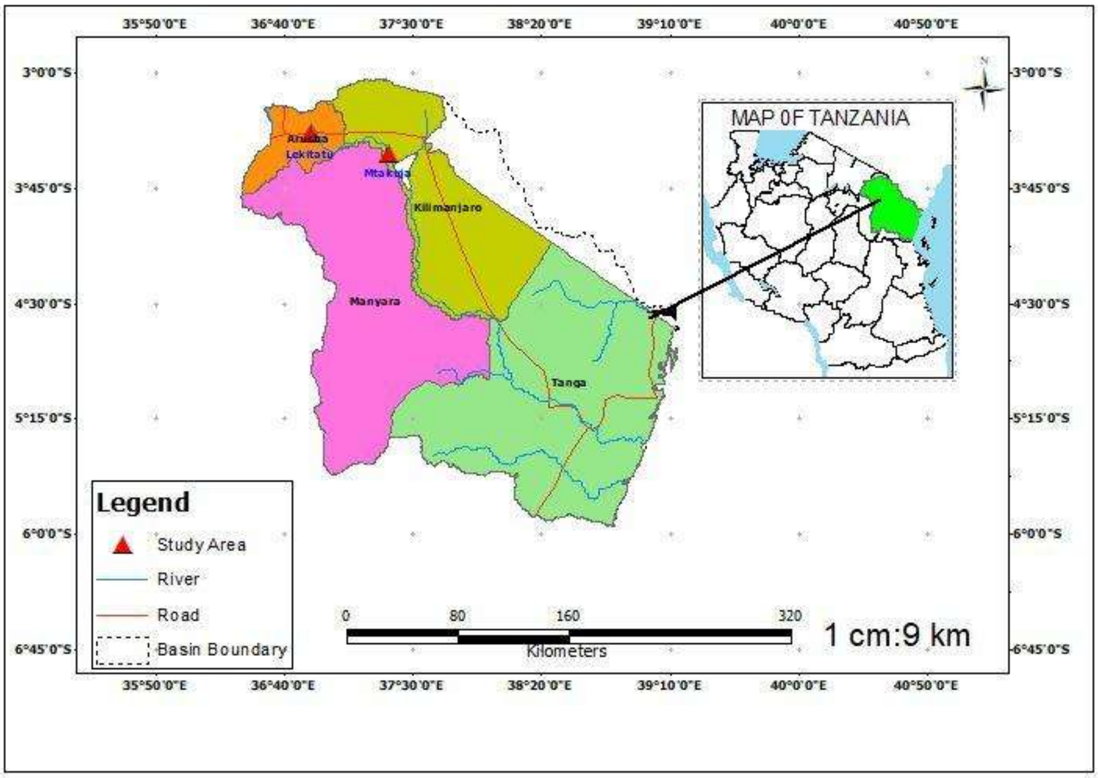

Figure 1: Map of the Study Area

Data Collection Methods

The study was conducted through questionnaire survey, and semi-structured interviews as well as field water applications and crop yield measurements. Primary data were obtained from selected farmers through field survey by assessing farmers practice for two seasons namely dry season (September 2018 to December 2018) and rainy season (October 2019 to March2020). Also, data were collected through Semi-structured interviews that were conducted with smallholder farmers both adopters and non-adopters of drip and sprinkler irrigation technology. Additional data were obtained from review of grey literature obtained from Mtakuja and Lekitatu Village Offices.

Semi-structured interviews were conducted in the farmers' fields. The information collected includes demographic data, farming characteristics, and socio-economic data, irrigation practice, farm size, production volume, production cost and income gained. Data regarding Farmers' field were collected in the local units and later converted to a standard measure for analysis. Composition of those interviewed is described in Table 1.

Table 1: Composition of interview participants

Fundamental areas	Mtakuja Village	Lekitatu Village
Drip irrigation users	0	6
Sprinkler irrigation users	48	0
Furrow irrigation users	58	44

Additional data such as total number of farmers in each scheme and their demographic distribution were obtained from reports and other documentary material from relevant institutions and organizations.

Population and Sampling

The sampling frame consisted of smallholder farmers practicing either of the irrigation technology (drip, furrow and sprinkler irrigation systems). A total of 50 farmers out of 58 farmers and 106 farmers out of 148 were obtained at Lekitatu and Mtakuja schemes, respectively. The sample size was determined by the sampling formula proposed by (Gupta & Kapoor, 2020). Total population was 293 farmers.

$$n = \frac{N}{1+N(e)^2} \text{-----} (1)$$

$$= \frac{293}{1+293(0.05)2} \approx 170$$

Where n = sample size, N = population size (total number of farmers), and e = level of precision, (0.05)

Determined sample size was 170. However, a total of 156 respondents (91.8% response rate) were interviewed basing on irrigation practice and crop type. Table 2 gives the distribution of Sample farmers by selected Region, District and Village.

Table 2: Distribution of sample farmers by selected region, district and village

Region	District	Village	Total
Arusha	Meru	Lekitatu	50
Kilimanjaro	Moshi	Mtakuja	106
Total			**156**

Data Collection Process

Field data collection was done at Lekitatu irrigation scheme in two seasons: dry seasons (September 2018 to December 2018) and one rainy season (October 2019 to March 2020). A total of 51 farmers were selected randomly to participate in the study. Two of the 51 farmers practicing different irrigation systems were also assessed. One farmer was practicing drip irrigation while the other was practicing furrow irrigation system on a 0.25-acre plot whereby all farmers planted tomato crop. An experimental field of 1225 m^2 was prepared at each plot of drip and furrow system in the farmers field plots. Each plot was divided into three treatments (Table 3). The purpose of each treatment (T1, T2, and T3) were as follows: Treatment T1 aimed to compare the standard spacing used in drip irrigation (0.50 m x 0.6 m) with the spacing in the furrow irrigation system (0.45 m x 0.6 m). It helped to assess how different spacings affect water distribution, plant growth, and overall efficiency. Treatment T2 introduced a variation within each irrigation system. It involved adjusting the flow rate, altering plant density, or modifying other parameters. T2 helped explore the impact of specific changes on crop performance. Treatment T3 involved comparing the two irrigation systems directly. It enabled to determine which method (drip or furrow) is more effective in terms of water conservation, crop yield, and other relevant outcomes.

Table 3: Treatment details on the experimental plots

Drip Irrigation System		Furrow Irrigation System	
Treatments	**Spacing(m)**	**Treatments**	**Spacing(m)**
T1	0.5 X 0.6	T1	0.45 X 0.6
T2	0.5 X 0.6	T2	0.45 X 0.6
T3	0.5 X 0.6	T3	0.45 X 0.6

In the furrow system, the plot (Figure 2) was prepared using ox-plough before manually making a total of 175 furrow rows whereby the length of each ridge per treatment was 116 m and the spacing between ridges was 0.45 m. A V-Notch weir was installed at the top of each plot to measure amount of water entering the plot during irrigation. A soil moisture sensor was installed in the middle of the plot to measure volumetric water content. Planting was done at a spacing of 0.45 m within rows and 0.6 m between rows, with one seedling planted per hole.

Figure 2: Furrow irrigation system plot layout at Lekitatu irrigation scheme

In the second plot using drip irrigation (Figure 3) a total of 18 rows were prepared and divided into three treatments, whereas as each treatment comprised 6 lines of laterals. Also, crops were planted at a spacing of 0.50 m within rows and 0.6 m between rows, with one seedling planted per hole. A second soil moisture sensor was also installed to record volumetric moisture content at the middle of the plot and near the plant.

Figure 3: Drip irrigation system plot layout at Lekitatu irrigation scheme

The crop profitability and water use efficiency analysis were conducted by collecting data for two seasons for farmers who practice drip and furrow irrigation system at Lekitatu. Cost Benefit analysis (CBA) Tool was used to calculate the crop profitability. The analysis was based on production inputs, outputs, cost of production and revenue gained from farmers. Results were expressed in monetary term. All data were recorded in the designed sheets and the water-costs as a percentage of the total input costs and as a percentage of the total 'gross-margin' were produced. Also, net profit and cost-benefit ratio (CBR) were calculated for both methods of irrigation. The Water use efficiency, water application efficiencies and water productivity were calculated using the following equations:

Water use efficiency (WUE) is defined here as the percentage of water supplied to the plant that is effectively taken up by the plant. It is expressed as the amount of water at different points in the system.

$$WUE = \frac{Amount\ of\ water\ consumed\ by\ the\ plant(m^3)}{Amount\ of\ water\ supplied\ to\ the\ plant(m^3)}.\ \text{(Heydari, 2014))} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Field application efficiency (FAE) is defined as amount of water stored in the root zone to meet crop water need in relation to the water applied to the field.

$$FAE = \frac{Amount\ of\ water\ needed\ by\ crop\ (m^3)}{Amount\ of\ water\ delivered\ to\ the\ field\ (m^3)}\ \text{(Irmak et al. 2011)} \ldots\ldots\ldots\ldots\ldots (3)$$

Water productivity (WP) is defined as the yield produced per unit of irrigation water used (Heydari, 2014; (Sharma et al., 2015)

$$WP = \frac{Yield(kg)}{Amount\ of\ water\ consumed\ by\ plants(m^3)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Data analysis

This study used economic analytical methods. They included descriptive statistics, regression, correlation, and data envelopment methods of data analysis. In descriptive statistics, graphic displays were used to illustrate key features of the study variables (Boslaugh, 2012). The descriptive analysis included means, standard deviations, graphs, and frequency distributions, which were developed using an Excel spreadsheet and StataSE version 14 inbuilt functions. The yield, WUE, WP, and net return data were statically analysed using analysis of variance (ANOVA) and Tukey's Multiple Comparison Test at a 5% level of significance. A total of 156 farmers were interviewed, out of which 112 (72%) were males and 44 (28%) were females.

RESULTS AND DISCUSSION

Socio-demographic characteristics of farmers

Age

Results from Table 4 indicate that majority of farmers (76%) were above 35 years and only 24% were between 19-35 years old. From the two villages, the results show that drip and sprinkler irrigation systems were highly used by farmers with age between 35-50 years old. This might be due to the reasons that people with this age are adults who always work to ensure survival of their families. But also, they are better in understanding their farming system challenges and ready to adopt Water Use Efficient Technologies. This study agrees with Geza, et al., (2021), but contrasts with previous findings on age by Chuchird et al., (2017), which indicate that younger farmers are more likely to adopt improved irrigation systems, the situation which may cause most of them to buy land for their families. Farmers' ability to own land may influence adoption of expensive agriculture technology, which may not be easier to be installed on rented land.

Farming Experience

Farming experience has significant relationship with adoption of Water Use Efficient Technology (WUET). The study findings show that farmers with farming experience of above 5 years are more likely to adopt WUET as indicated in Table 4. Those farmers with greater farming experience are aware of irrigation challenges, but also have had the chance to observe and learn from fellow farmers on benefits that come from the use of WUETs. This study findings agree with other researchers, for instance, Selahkwe et al., (2021) whose findings revealed that farmers' experience, number of follow-ups, and access to extension facilities after training had a significant positive effect on the adoption of new technologies.

Farm type

Statistical test results (Table 4) show that farmers doing both substantial and commercial farming ($\chi 2$=4.1947, Sig.=0.123) are more likely to adopt WUET, unlike those who are practicing only subsistence farming. Those farmers practicing both methods are termed to be large scale farmers who are seeking ways to minimise water usage and increase productivity. On the other hand, farmers practicing only subsistence farming seems to be small-scale farmers who have no enough resources and income needed to invest in the irrigation technology. Also, these farmers think they are using less water compared to commercial farmers; thus, their water usage cannot have any effect in the level of water resources. This study agrees with Mirzaei and Azarm (2021).

Table 4: Demographic characteristics, farming experiences, farm size, farming type and farming environment.

	Location				
	LEKITATU		**MTAKUJA**		
Variable	**Drip**	**Furrow**	**Sprinkler**	**Furrow**	**Total**
Gender					
Female	0(0.0)	9(20.5)	15(31.3)	18(31.0)	42(26.92)
Male	6(100.0)	35(79.5)	33(68.8)	40(69.0)	114(73.08)
χ^2=2.9779, Sig=0.084					
Level of education					
None			33(68.8)	49(84.5)	1.55

	Location				
	LEKITATU		MTAKUJA		
Variable	**Drip**	**Furrow**	**Sprinkler**	**Furrow**	**Total**
Primary	5(83.3)	39(88.6)	13(27.1)	8(13.8)	82(52.56)
Secondary		3(6.8)	2(4.2)	1(1.7)	65(41.67)
University	1(16.7)	2(4.5)			6(3.85)
χ^2=83.8397, Sig.=0.000***					
Age					
> 50	2(33.3)	11(25.0)	14(29.2)	18(31.0)	45(28.84)
19-35	1(16.7)	3(6.8)	18(37.5)	15(25.9)	37(23.71)
36-50	3(50.0)	30(68.2)	16(33.3)	25(43.1)	74(47.43)
F=2.34, Sig.=0.1285					
Farming experience					
> 10	4(66.7)	23(52.3)	13(27.1)	18(31.0)	58(37.18)
0-5	1(16.7)	4(9.1)	9(18.8)	16(27.6)	30(19.23)
6-10	1(16.7)	17(38.6)	26(54.2)	24(41.4)	68(43.59)
F=9.86, Sig.=0.0020**					
Farming type (mean)					
Both	5(83.3)	43(97.7)	42(87.5)	49(84.5)	139(89.10)
Commercial			1(2.1)	5(8.6)	6(100.00)
Subsistence	1(16.7)	1(2.3)	5(10.4)	4(6.9)	11(7.05)
$\chi2$=4.1947, Sig.=0.123					
Farming environment					
Individual plot out				23(39.7)	23(14.74)
Individual within	3(50.0)	20(45.5)			23(14.74)
Rental plot within		24(54.5)	48(100.0)	33(56.9)	108(69.23)
Rental out of irrigation	3(50.0)			2(3.4)	2(1.28
$\chi2$=63.0181, Sig.=0.000***					

Farmer's Perception

Regarding the farmers knowledge, study findings in Table 5 show that farmers were aware and have noted the benefits of the WUET. However, the ability to initiate and maintain the use of the technology become an issue to them. The famers knowledge about WUET was obtained from their fellow farmers practicing the technology and from farmers' day exhibitions, which are conducted every year on 8th August.

Table 5: Farmers Perception on adoption Water Use Efficiency technology

Farmers Perception	Lekitatu		Mtakuja		Total	
	Frequency	%	Frequency	%	Frequency	%
Government Extension Officer need	42	84	51	48	93	60
Provision of Credit to smallholder farmers	22	44	72	68	94	60
Subsidies of PI Equipment	32	64	87	82	119	76
Training on operation, maintenance	40	80	61	58	101	65
Definite market	47	94	91	86	138	88
Training on good agronomic practice	18	36	13	12	31	20
Land ownership	31	62	84	79	115	74
Time Management	20	40	98	92	118	76
Type of farming system	28	56	83	78	111	71

Concerning farmers perception, 60% of the farmers perceived that adoption of WUET requires high assistance from Government Extension Officers to be able to acquire knowledge that will motivate the adoption of WUET. This is due to the fact that they will have more information on the irrigation technology. The study findings conform with Rouzaneh et al. (2019) who established that government extension officers highly contribute to farmers adoption of WUET, and showed that the extension officers are the first and most crucial resource with regard to disseminating the information that is needed to the farmers. Manjunatha et al. (2013) in their study highlighted that the largest number of adopters in agricultural technologies and new forms of agriculture, which is 55.8% of the population, had interacted with extension officers.

Meanwhile, 60% of respondents believed that provision of credit to smallholder farmers will motivate the adoption of WUET. Also, regarding perceptions of WUET, 76% of farmers feel the WUET performs better in large scale farms as farmers could be able to produce more food that can be sold within a season and recover the investment cost incurred. Moreover, 71% perceive that many companies owning WUET would prefer to invest in larger-scale farmers as they are sure of recovering their cost within a short period of time. Also 60% believe that existence of readily available market could attract more farmers to adopt WUET as they believe that adoption of WUET will result in increase of the produce. Correspondingly, 60% of the surveyed farmers perceived that buying on credit increases farmers ability to pay for the technologies. The surveyed farmers prefer either semi-annual or annual credit terms as a payment option for the technologies to immediate cash payment.

A total of 65% believe that having frequent training on operation and maintenance of irrigation technologies will motivate adoption of the technology as they think this technology requires more technical support for better operation and sustainability. Also 74% perceive that WUETs need to be adopted with a farmer who owns his/her own land to avoid being removed from the farm unexpectedly and causing a farmer to lose the purpose of the investment. Moreover, 76% of farmers perceive that WUET allows a farmer to continue working with other activities while irrigating, thus enhances time saving. About 71% of the surveyed farmers perceive that adoption of WUET is more ideal for business-oriented farmers as they can afford the cost of acquiring, installing and using the technology, and later recover the costs through increased output. About 20% of the surveyed farmers perceive that the use of water saving technology such as drip and sprinkler irrigation system is influenced by knowledge that has been impacted from training on good agronomic practices, or experience obtained from farmers who have succeed from adoption of the technology (champion farmers). However, about 8% of the surveyed farmers did not provide any opinion on the subject.

Crop Profitability under Drip and Furrow Irrigation Technology during Dry Season

To evaluate the economic performance of different irrigation systems, crop profitability analysis was conducted for tomato production under drip and furrow irrigation during the dry season. The assessment considered farm revenue, variable and fixed costs, yields, and profitability indicators, with results expressed per acre in USD. Statistical tests were also performed to compare the two systems and determine whether observed differences were significant. This comparison provides evidence on the relative cost-effectiveness of the technologies, highlighting both the economic opportunities and challenges faced by smallholder farmers when adopting modern irrigation methods. The detailed results are presented in Table 6;

Table 6: The farm revenue, cost and net farm income per acre of tomatoes cultivation under Drip and furrow irrigation system in USD ($) during dry season.

Item	Furrow Irrigation System	Drip Irrigation System	Overall Average	F-test (Sig)
Farm Revenue	734.66	1015.56	875.11	<0.001***
Total Variable Cost	1276.19	1247.1	1261.645	<0.001***
1st ploughing	30.25	30.25	30.25	<0.001***
Making Furrow Ridges	30.25	30.25	30.25	<0.001***
Seeds	151.25	151.25	151.25	<0.001***
Nursery preparations	43.22	43.22	43.22	<0.001***
Planting/transplanting	25.93	25.93	25.93	<0.001***
Supporting Poles	153.41	140.45	146.93	<0.001***
Making Holes for Poles	34.57	34.57	34.57	<0.001***
Wires	95.07	108.04	101.555	<0.001***
Ropes	73.47	73.46	73.465	<0.001***
Cost for poles Installation	25.93	25.93	25.93	<0.001***
Industrial fertilizer	160.16	94.21	127.185	<0.001***
Application of industrial fertilizer	86.4	25.92	56.16	<0.001***
Pesticides/herbicides	77.78	144.86	111.32	<0.001***
Labor for spraying	34.57	33.28	33.925	<0.001***
Weeding	84.27	37.6	60.935	<0.001***
Irrigation	114.52	66.98	90.75	<0.001***
Harvesting	32.41	43.21	37.81	<0.001***
Fuel cost		113.05	113.05	
Packaging bags/baskets	22.69	24.63	23.66	0.0004**
Fixed cost	109.77	3205.49	1657.63	0.0009**
Total Cost= (2+3)	1385.96	4452.59	2919.275	0.004**
Yield crates/acre)	34	47	40.5	0.0023*
Gross margin=1-2	-541.52	-231.55	-386.535	0.0051*
Net farm income (crop value per acre= (1-4)	-651.3	-3437.04	-2044.17	0.0071*
Operating expense ratio= (2/1) *100	1.74	1.23	1.485	
Depreciation Expense ratio= (3/1) *100	0.149	3.17	1.6595	
Net farm income ratio= (7/1) *100	-0.89	-3.38	-2.135	
Benefit to cost ratio= (1/4)	0.53	0.23	0.38	

*, ** Denote the 5% ($p < 0.05$) and 1% ($p < 0.01$) significance levels, respectively.

The research study revealed, as shown in Table 6, that the lowest operating expense ratio of 1.23%, which is a measure of what percentage of farm revenue is allocated to the variable operating expenditures, was achieved under a drip irrigation system.

This is similar to a previous study that documented that farm operated under drip irrigation systems tended to incur low operating expenses (Agide et al., 2016). This is contributed by a reduction in labour costs in different operating activities. However, the depreciation expense ratio was higher under the drip irrigation system (3.71%) compared to the furrow irrigation system (0.15%).

The highest farm revenue per acre of tomatoes was gained under the drip irrigation system (USD=1015.56) compared to the furrow irrigation system (USD=734.66). The highest yield was achieved under the drip irrigation system and this is likely because water is applied directly to the crop roots, and also the presence of weeds is small compared to the furrow irrigation system. Thus, the tendency of the crop to be attacked by diseases also becomes low, resulting to high yield. However, the Drip irrigation system is associated with high initial costs, thus making its cost per acre the highest (USD=3205.54).

The results further indicate that a farmer may recover the initial investment after cultivating tomatoes for 5 seasons if the yield at drip irrigation system remain to be 2350 kg and sold at the price of $ 21.61 per 50 kg. However, based on the survey conducted, tomato harvests per acre can reach 9000 kg and recover the initial cost within 2 seasons. Due to that farmers using drip irrigation system will be able to gain more profit in future as the lifespan of drip irrigation system is up to 15 years (Sharmasarkar, 2001). These results indicate that production cost and net farm income were statistically different between the two irrigation systems (P<0.01). Nevertheless, adoption of WUET by mainstream smallholder farmers engaged in tomato farming may also be constrained by price volatility of the product, which is also easily perishable.

Crop Profitability under Drip and Furrow Irrigation Technology during Rainy Season

Table 7 shows crop profitability per unit acre of tomato cultivated under drip and furrow irrigation systems. By comparison during the rainy season, the farm revenue per acre of tomato crop was largest for drip irrigation system (USD = 475.38) compared to furrow irrigation system (USD = 280.90). The highest yield was achieved under drip irrigation system and this is likely because less water was applied to the crops, as a result the presence of weeds was small compared to the furrow irrigation system. Moreover, crops get less diseases and pests, which are the result of the growth of tall grasses. Operating cost under drip and furrow irrigation systems was USD = 380.29 and USD = 414.65, respectively. The findings also show that the total cost, farm revenue, and net farm income were statistically different between the two-irrigation systems (P<0.01).

Table 7: The farm revenue, cost and net farm income per unit area of Tomatoes cultivation under Drip and furrow irrigation system in USD ($) during the rainy season

Item	Furrow Irrigation System	Drip Irrigation System	Overall average	F-test (Sig.)
Farm Revenue	280.9	475.38	378.14	<0.001***
Total Variable Cost	414.65	380.29	397.47	<0.001***
1st ploughing	12.96	12.96	12.96	<0.001***
Making Furrow Ridges	12.96	6.48	9.72	<0.001***
Seeds	37.81	51.86	44.835	<0.001***
Nursery preparations	. 648	6.48	6.48	<0.001***
Planting/transplanting	17.29	17.29	17.29	<0.001***
Supporting Poles	9.51	21.61	15.56	<0.001***
Making Holes for Poles	6.48	6.48	6.48	<0.001***
Wires	15.13	15.13	15.13	<0.001***
Ropes	7.35	8.64	7.995	<0.001***
Cost for poles Installation	25.93	25.93	25.93	<0.001***
Industrial fertilizer	60.93	49.26	55.095	<0.001***
Application of industrial fertilizer	32.41	19.45	25.93	<0.001***
Pesticides/herbicides	34.57	28.09	31.33	<0.001***
Labor for spraying	21.61	12.96	17.285	<0.001***
Weeding	54.02	24.63	39.325	<0.001***
Irrigation + water fee	32.41	6.48	19.445	<0.001***
Harvesting	12.96	23.77	18.365	<0.001***

Item	Furrow Irrigation System	Drip Irrigation System	Overall average	F-test (Sig.)
Fuel cost	-	19.45	19.45	-
Packaging (crates)	11.24	19.01	15.125	<0.001***
Fixed cost	109.77	3205.49	1657.63	<0.001***
Total Cost=(2+3)	524.42	3585.78	2055.1	<0.001***
Yield (crates /acre)	13	22	17.5	<0.001***
Gross margin=1-2	-133.75	-95.09	-114.42	0.0117*
Net farm income (crop value per acre=(1-4)	-243.52	-3110.4	-1676.96	0.00525*
Operating expense ratio=(2/1)*100	147.61	79	113.305	
Depreciation Expense ratio=(3/1)*100	39	674	356.5	
Net farm income ratio=(7/1)*100	-48	-574	-311	
Benefit to cost ratio=(1/4)	2.56	0.13	1.345	

*** Denote the 5% ($p < 0.05$) and 1% ($p < 0.01$) significance levels, respectively.

Crop profitability under Sprinkler and Furrow Irrigation Technology

The profitability of maize production can vary considerably depending on the irrigation technology applied, as it influences both costs and returns. Sprinkler and furrow irrigation are among the most commonly used systems, each with distinct implications for farm revenue, labour use, and input requirements. While furrow irrigation is traditionally widespread due to its low setup costs, it often leads to higher labor demand and less efficient water use. In contrast, sprinkler irrigation enhances water distribution efficiency and crop yields but involves higher initial and operational costs. Table 8 presents a comparative analysis of farm revenue, production costs, and net farm income per unit area of maize cultivation under sprinkler and furrow irrigation systems, highlighting their relative economic performance.

Table 8: The farm revenue, cost and net farm income per unit area of Maize cultivation under Sprinkler and furrow irrigation system in USD ($).

Item	Furrow Irrigation System	Sprinkler Irrigation System	Overall average	F-test (Sig)
Farm Revenue	328.44	410.54	369.49	<0.001***
Slashing	17.29	25.93	21.61	<0.001***
1st ploughing	8.64	17.29	12.965	<0.001***
2nd plough		15.13	15.13	<0.001***
Making Furrow Ridges	25.93		25.93	
Seeds	15.21	15.21	15.21	<0.001***
Planting	15.12	15.12	15.12	<0.001***
Industrial fertilizer	47.5	72.17	59.835	<0.001***
Application of fertilizer	12.96	12.96	12.96	<0.001***
Pesticides/herbicides	38.89	38.89	38.89	<0.001***
Labor for spraying	17.29	17.29	17.29	<0.001***
Weeding	25.93	19.45	22.69	<0.001***
Irrigation	25.93	17.29	21.61	<0.001***
Harvesting	8.64	12.96	10.8	<0.001***
Fuel cost	19.45		19.45	
Hydroelectric power+ water charges		123.16	123.16	<0.001***
Packaging bags/baskets	17.29	21.61	19.45	<0.001***

Item	Furrow Irrigation System	Sprinkler Irrigation System	Overall average	F-test (Sig)
Fixed cost	682.37	950.73	816.55	<0.001***
Total Cost= (2+3)	1007.56	1371.87	5689.715	<0.001***
Yield(bags/acre)	8	10	9	0.6747
Gross margin=1-2	3.24	-10.59	-3.675	0.7095
Net farm income (crop value per acre = (1-4)	-679.13	-540.19	-609.66	0.7534
Operating expense ratio= (2/1) *100	99.01	102.58	100.795	
Depreciation Expense ratio= (3/1) *100	207.76	231.58	219.67	
Net farm income ratio= (7/1) *100	-206.78	-131.58	-169.18	
Benefit to cost ratio= (1/4)	0.33	0.3	0.315	

*** Denote the 5% ($p < 0.05$) and 1% ($p < 0.01$) significance levels, respectively.

Research findings from Table 8 show that farm revenue in 0.5 acres of maize is high under sprinkler irrigation system (USD = 410.54) compared to furrow irrigation system (USD = 328.44). This is because labour savings and increased crop yields with sprinkler irrigation are significant factors in profitability.

Irrigation Water Used

Total volume of water applied on different dates through irrigation and rainfall to crop under furrow irrigation system was 4653.45 m^3. Also, total volume of water applied to the crop under drip irrigation system was 4787.22 m^3. The number of irrigation events between two irrigation systems did not vary much since both systems received same amount of precipitation during growing season as shown in Table 9.

Table 9: Comparison of Water use efficiency and productivity for drip and furrow irrigation system.

	Drip irrigation system				Furrow irrigation				Average (Drip and Furrow)		
Treatment	Spacing	Irrigation water use (m^3/m^2)	WUE %	WP (kg/m^3)	Spacing	Irrigation water use (m^3/m2)	WUE%	WP (kg/m^3)	Irrigation water use (m^3/m^2)	WP (kg/m^3)	WUE%
T1	50x 60	1595.74	40.9	0.157	45 x60	2220.64	25.28	0.068	1908.29a	0.1120a	33.095
T2	50x 60	1595.74	40.9	0.313	45 x60	2220.77	25.27	0.09	1908.23a	0.2017b	33.095
T3	50x 60	1595.74	40.9	0.219	45x60	2212.04	25.37	0.136	1903.815a	0.1774c	33.145

* Different letters within the same column indicate significant difference at $P<0.05$

Calculation was done in m^3/m^2 based on the Duncan Multiple Range Test at $P<0.05$, statistical difference between the two-irrigation system was observed.

Results further indicate that the total volume of water used under different treatments in drip was less compared to amount of water used under different treatments in furrow irrigation system. Reason for the observed difference is due to the fact that, farmers who applied furrow system tend to supply more water to the field as compared to those who use drip irrigation. Application of more water in furrow system is a result of fear of unknown as most of the farmer lack storage facility. Also, most of furrow farmers convey water directly from surface source of water such as canal, which is paid at flat rate, that is why they don't consider economic use of water. The observed effects of applying excessive amount of water in a furrow field were excessive runoff, evaporation and deep percolation.

Water use efficiency under drip and furrow irrigation systems

Results show that average WUE for drip irrigation system outsmart that of furrow irrigation system by 15.59% as indicated in Table 9 and Figure 4. The average higher water use efficiency of about 40.92% was obtained under drip irrigation system, whereas lower water use efficiency of about 25.31% was obtained under furrow irrigation system. This indicates that furrow irrigation is associated with more loses of water.

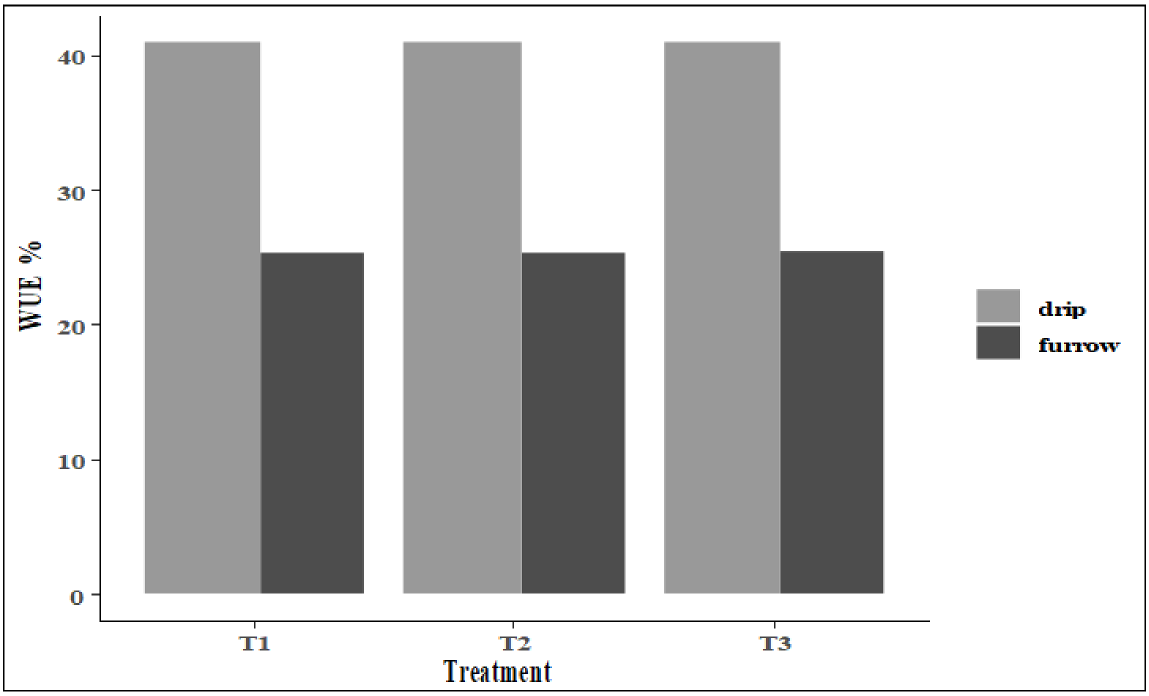

Figure 4: Water use efficiency under different treatment in drip and furrow irrigation system

Water productivity under drip and furrow irrigation system

This study revealed that highest WP of 0.31 kg/m^3 was obtained in T2 under drip irrigation system followed by T3 (0.22 kg/m^3), which was also found in drip irrigation system as shown in Table 9 and Figure 5. The lowest WP of 0.06 kg/m^3 was found in furrow irrigation system. Results confirm that determinants for high WP are good application of water, crop spacing and farm management. The cropping space in furrow irrigation system was 0.45 m x 0.6 m whereas in drip irrigation system was 0.5 m x 0.6 m. The motive behind good farm management observed in drip irrigation system is the aim to get returns from higher investment placed compared to that of furrow irrigation system. Statistically, WP at T2 under drip irrigation system was significantly different at $P<0.05$.

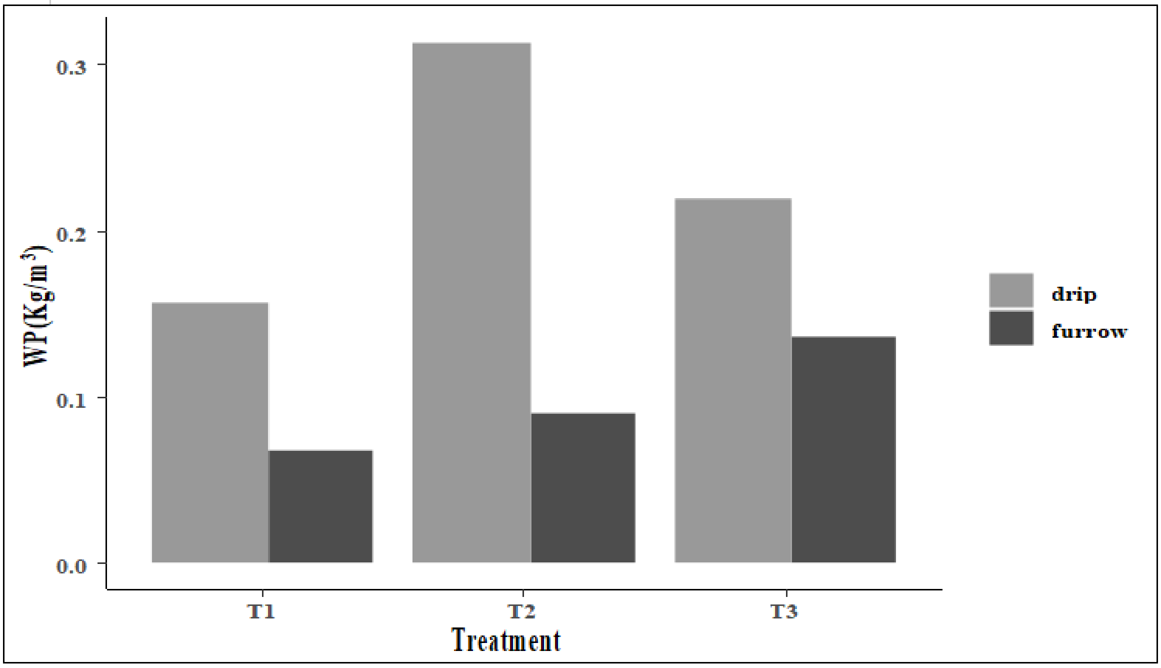

Figure 5: Water productivity under different treatment in Drip and Furrow irrigation system

CONCLUSION

This study demonstrates that drip irrigation offers significant advantages over furrow irrigation for smallholder farmers in the Upper Pangani River Basin, Tanzania. Despite higher initial investment, drip systems deliver higher yields and incomes exceeding furrow irrigation returns by up to 25% while also improving water savings and productivity. By reducing water losses, drip irrigation can alleviate resource conflicts and support more sustainable water management in a water-scarce environment. However, adoption remains limited due to farmers' perceptions that modern systems are complex, costly, or more suitable for commercial farms. Addressing these barriers requires targeted education, training, and demonstrations to show compatibility with existing practices and to highlight long-term profitability. Policies and programs that reduce upfront costs, provide access to credit, and strengthen supply chains for equipment and maintenance can further support adoption. Overall, bridging the gap between the proven benefits of drip irrigation and farmers' decision-making is crucial for improving agricultural productivity, conserving water resources, and promoting sustainable livelihoods in the region.

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