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Factors influencing Adoption of Irrigation Technologies among Smallholder Farmers in Machakos County, Kenya

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Abstract
The study examined the factors that drive decisions to adopt and use irrigation technologies among smallholder farmers in Machakos County, Kenya. Data were collected from a sample of 300 smallholder farmers. Cross-sectional survey design, a multistage sampling procedure and random sampling method were employed. Percentages, means and econometric analysis were used in data analysis. Results showed that, 31.7% of the respondents practiced irrigation. Sex of household head, education, farm size, off-farm income, credit accessed and access to extension services positively influenced adoption of irrigation technologies. Adoption intensity

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was positively influenced by gender, off-farm income, farming experience, primary occupation and extension services. As a result, it is suggested that while formulating development strategies and programs for smallholder farmers, agricultural extension organizations should give priority to these factors.

Keywords: Adoption of irrigation technologies

Introduction

Despite great unpredictability in rainfall, which is insufficient in many areas, Kenyan agriculture is still rain-fed (Nakawuka, Langan, Schmitter, and Barron, 2018). Kenyan communities are particularly vulnerable to droughts and periods of water shortage as a result of their heavy reliance on rain-fed agriculture, which has a considerable impact on crop and livestock production (Nakawuka *et al*., 2018; Lilly N. Kabata, Makhoka, and Obiero, 2021). Crop failure and animal losses as a result of climate change and seasonal variability, have resulted in food insecurity in the country, posing serious concerns to society's well-being (Lilly *et al*., 2021; Musafiri, Kiboi, Macharia, Ng'etich, Kosgei, Mulianga, and Ngetich, 2022). As a result, interventions such as adopting irrigation technologies in arid/semi-arid areas are called for to mitigate the effects of climate change and variability.

Irrigation technology is critical in the agricultural sector because it allows the world to keep pace with a growing population and rising food demands (Kadiresan & Khanal, 2018). In addition, introduction of irrigation technology and its widespread use has contributed to higher agricultural yields by allowing crop cultivation in desert and semi-arid regions where rainfall is insufficient to meet crop water demands (Kukal & Irmak, 2020). Irrigation contributes the most to food security, and future agricultural production advances are likely to come from irrigated land (Kadiresan & Khanal, 2018). Irrigation technology also enables farmers to shift to commercial farming of more profitable crops (Jordán & Speelman, 2020). As a result, encouraging the transfer, dissemination, and use of irrigation technologies among smallholders is a critical component of reducing poverty and food insecurity in Kenya.

Despite sustained donor support, huge technical and economic potentials of irrigation, adoption rates of irrigation technologies are still low, and the situation of the most vulnerable people and communities in terms of food insecurity has not improved (Harrison, 2018). Because cultivatable land is scarce, agricultural production must be expanded to boost yields and provide economic development, food security, and poverty reduction (Nakawuka *et al*., 2018). Agriculture, particularly in Kenya's dry and semi-arid regions, requires long-term intensification.

Previous studies show that technology adoption and intensity of adoption is influenced by a number of factors with the farmer at the centre to adopt and accept the technology (Kumar, Takeshima, Thapa, Adhikari, Saroj, Karkee, and Joshi, 2020; Nejadrezaei, Sadegh, Mina, and Anastasios, 2018; Pokhrel, Paudel, and Segarra, 2018; Ruzigamanzi, Mulyungi, Wanzala, and Ntaganira, 2019; Yatribi, 2021). Education level, farm size, distance to nearest market, financial availability, household size, extension access, and farming experience have been found to strongly influence adoption decisions of agricultural technologies (Adebayo, Bolarin, Oyewale, and Kehinde, 2018; Kumar, Tripathi, and Joshi, 2020; Mahama, Awuni, Mabe, and Azumah, 2020). However, little research has been done on the factors that determine the intensity or degree of adoption of technology after it is made available to farmers (Mwaura, Kiboi, Bett, Mugwe, Muriuki, Nicolay, and Ngetich, 2021).

A binary framework model is used in the majority of studies on smallholder farmers' adoption decisions of agricultural technologies, which is insufficient to represent the socio-economic factors that influence adoption intensity (Yatribi, 2020; Mutunga, Ndungu, and Muendo Patricia, 2018; Ruzigamanzi *et al*., 2019). The employment of a binary model would result in the loss of important data. As a result, a thorough investigation of smallholder farmer characteristics, farm, and institutional components linked to adoption, as well as intensity of adoption, is necessary (Mwaura *et al*., 2021). In light of this, the study sought to determine the factors that influence farmers' decision to adopt irrigation technologies in Machakos County. These factors must be considered by policy makers, diffusers of these technologies, and researchers examining the determinants of technology adoption. In order to design a strategy for the development of modern irrigation technologies, government officials must first comprehend the dynamics that drive farmers' decision to adopt agricultural technologies.

Methodology

The study was conducted in Machakos County which is located at latitude 0° 45'S and longitude 36° 45'E, with an estimated population of 1,421,932 persons, covering an area of 6,208_km^2 (KNBS, 2019). The county is also classified as a lower midland zone (LM3, LM4, and LM5), with annual rainfall ranging from 500mm to 1300mm and falling in two seasons. Long rains occur from March to May, while short rains occur from October to December, with temperatures varying from 18°C to 25.7°C. The soils are mostly alfisols and vertisols, with maize, beans, cowpeas, pigeon peas, and cassava as the principal food crops. Sorghum, mangoes, and French beans are the main cash crops cultivated in the area. Small-scale farmers were the target population, which included both those who had practiced irrigation in the previous year (adopters) and those who had not (non-adopters). The study used a cross-sectional survey design, a purposive and multistage sampling procedure to draw sampling units. Random sampling method was used to obtain the number of households to be interviewed. Mwala sub-county was purposively chosen for the first stage. In the second step, the six wards in the sub-county were chosen and two villages chosen from each ward in the third step. A random sample of 300 farming households was chosen from the villages where, 31.7% and 68.3% for the users and non-users of irrigation was obtained respectively. The specification of the selected areas was driven by the irrigation project proposed by the Kenya Climate Smart Agriculture Programme (KCSAP) in the County.

The Heckman two-stage selection model was used to evaluate the determinants of irrigation technology adoption and intensity of adoption. A Probit model is used in the first stage, with a binary dependent variable (1=if a farmer uses irrigation technology,

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0=if a farmer does not use any irrigation technology). For ease of interpretation of the significant variables, a post-estimation of the selection equation findings was used to calculate the marginal coefficients. This is because the coefficients of the first regression results consists of values that maximize the likelihood function; hence they have no direct meaning. An Ordinary Least Square (OLS) regression model is used in the second stage to assess the determinants of intensity of adoption. Intensity of adoption was measured in terms of the proportion of the area of land devoted to irrigation. The Heckman two-stage model (selection equation) is specified as;

$$Z_i = \alpha X_i + \cdots + \alpha X_n + \varepsilon i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..1$$

Where; Z_i = adoption decision of the i^{th} farmer, Xi = vector of explanatory variables, α = vector of parameters to be estimated, and εi = is an error term distributed with mean 0 and variance 1. The observed binary variable can be expressed as; $Z = 1\ if\ Z_i > 0$ (For adopters), $Z = 1\ if\ Z_i \leq 0$ (For non-adopters).

The second step (outcome equation) estimated by an Ordinary Least Square (OLS) estimator is given as;

$$\Upsilon_i = \theta X_i + \cdots \theta X_n + \mu_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.2$$

Where; Υ_i = proportion of the area of land devoted to irrigation, X_i= Vector of independent variables, θ = vector of parameter estimates of the independent variables.

Results and Discussion

Characteristics of Users and Non-users of Irrigation Technologies

Households that used at least one of the irrigation technologies in the last one year, were considered as adopters while those who did not use any of the technology were considered as non-adopters. Results showed that, 31.7% of the respondents practiced irrigation in the study area where drip (5.7%), furrow (14.7%), and basin (11.3%), were the commonly practiced irrigation technologies (Table 1).

Table 1: Adoption of irrigation technologies

Variable	Percentage Yes (%) n=95
Adoption (yes)	31.7
Technologies used	
Furrow	14.7
Basin	11.3
Drip	5.7

Results of the descriptive statistics (Table 2) shows that most households were led by men for both adopters (91.6%) and non-adopters (75.6%). This indicates that males were more likely than females to practice irrigation since males have control over

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production resources such as land and labor. Sex of the household head influences farm households' decision-making processes (Gebre, Isoda, Rahut, Amekawa, and Nomura, 2019). In addition, (23.2%) of the adopters possessed land with title deed, compared to (34.2%) of the non-adopters. This demonstrates that farmers' inability to utilize agricultural innovations in their farms was hampered by a lack of title deed. This explains the low adoption levels of irrigation technology (31.7%). Insecurities in land tenure explains the unwillingness of the farmers in investing effort to utilize Zai pits for increased farm productivity (Muchai, Ngetich, Baaru, and Mucheru-Muna, 2020). Adopters' major occupation was crop farming (60.3%). This means that farmers who rely on crop farming will devote more time and effort to agricultural technologies that produce higher output. This corroborates to the study by Muchai *et al*. (2020), that majority of farmers (85.0%) dependent on farming activities for income generation. Further, (54.6%) of the adopters had access to extension services compared to (45.5%) of the non-adopters. Farmers' adoption behaviour of irrigation technology would be changed if extension services played a key role in providing information and disseminating knowledge to them. This is consistent with the study by Oyetunde-Usman, Olagunju, and Ogunpaimo (2021), that extension services create awareness and demonstration of improved production technologies.

There was a significant mean difference ($\chi^2 = 0.0052$) in average daily labour cost between irrigation technology adopters ($\bar{x}$ =1.79 USD) and non-adopters ($\bar{x}$ = 1.22 USD). This means that irrigation technology adopters use more labour in their irrigation practices than non-adopters since irrigation farming is labour-intensive. This is consistent with Jones, Kondylis, Loeser, Magruder, Barrett, Christian, De Janvry, Djankov, Duflo, Foster, Gollin, Karpe, Sadoulet, Strauss, Thomas, and Udry (2020), that irrigation technology requires large construction and maintenance costs as well as increased labour costs. Furthermore, there was a substantial difference ($\chi^2 = 0.0543$) in the mean off-farm income between farmers who used irrigation ($\bar{x}$ = 49.44 USD) and those who did not ($\bar{x}$ = 72.89). This means that farmers who did not practice irrigated agriculture were more involved in off-farm activities. Off-farm income plays a key role in small-scale irrigation farming (Mango, Makate, Tamene, Mponela, and Ndengu, 2018). Moreover, there was a substantial mean difference in the amount of credit accessed ($\chi^2 = 0.0004$) between the adopters ($\bar{x}$ =169.53 USD) and non-adopters ($\bar{x}$ =126.91 USD) of irrigation technologies. This implied that farmers who practiced irrigation allocated more credit for irrigation practices due to high capital requirement. Credit is more required in irrigation technology and lack of it can be an impediment to irrigation technology adoption (Tesfaye, Balana, and Bizimana, 2021).

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Table 2: Socio-economic characteristics of users and non-users

Variables	Users (95)	Non-users (205)	
	Mean	**Mean**	χ^2
Sex of HH(1=male, 0=female)			0.0001*
Male (%)	91.78	75.61	
Female (%)	8.42	24.39	
Land ownership (title deed)	23.16	34.15	0.0550*
Main occupation(farming)	60.27	39.73	0.0000*
Extension access (yes %)	54.55	45.45	0.0000*
Access training (yes %)	58.33	41.67	0.4470
			t-test
Age of HH (years)	48.82	48.64	0.8662
Education (years)	13.14	12.80	0.2020
Household size (count)	5.26	5.02	0.6771
Farm size (acres)	1.80	1.74	0.2509
Farming experience(years)	17.74	15.47	0.0954
Labour cost (USD, per day)	1.79	1.22	0.0052*
Off-farm income (USD)	49.44	72.89	0.0543*
Market distance (km)	4.3	4.2	0.5711
Amount of credit (USD)	169.53	126.91	0.0004*

*P≤0.05; HH= Household Head; 1 USD= KES 112

Determinants of Adoption of Irrigation Technologies among Smallholder Farmers

The first stage of the analysis showed that the inverse mills ratio (Table 3) is positive and significant (P<0.0004). This meant that the error term was positively correlated in the two stages and thus, the model was fit for analysis. Results in (Table 3) indicate that, sex of households' head positively influenced adoption of irrigation technologies. This meant that, males were more likely than females to adopt irrigation technologies. This could be because, males have better access to information on new agricultural innovations and agricultural services than their female counterparts. Due to cultural prejudices, males are known to enjoy exclusive rights in farm decision-making procedures. The outcome corroborates the study by Oyetunde-Usman *et al*. (2021); Serote, Mokgehle, Du Plooy, Mpandeli, Nhamo, and Senyolo (2021), that the sex of the households' head is a significant factor in agricultural technology adoption decisions.

The findings demonstrated that years of education positively influenced adoption of irrigation technologies. The plausible explanation is that, literate smallholder farmers had a higher probability than illiterate smallholder farmers to adopt irrigation technologies. It's possible that this observation is due to educated farmers' knowledge of the most effective irrigation technology for increasing agricultural yields. Farmers

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who have spent more years in school may have gained skills and knowledge on the benefits of adopting irrigation technology. Our findings were in line with Jordán & Speelman (2020); Musafiri *et al*. (2022); Mwangi and Crewett (2019); Chinasa, Alagba, Ifeyinwa, and Chukwuneke (2022), that households' heads education level is a significant determinant in adoption decisions of agricultural technologies.

The adoption of irrigation technologies was positively and significantly influenced by farm size. The findings suggested that, farmers with larger farm sizes had a substantially higher chance of adopting irrigation technologies than those with smaller farms. It's probable that, the expanding use of irrigation technology is linked to the need for larger farms to install multiple irrigation systems for increased crop yields. Our findings corroborates the study by Ali, Awuni, and Danso-Abbeam (2018); Marie, Yirga, Haile, and Tquabo (2020); Shang, Heckelei, Gerullis, Borner, and Rasch (2021); Cipriano, Onautsu, Tarassoum, Adejumobi, and Bolakonga (2022), that farm size was a significant positive factor in the adoption of climate change adaptation strategies.

Irrigation technology adoption was positively influenced by farming as the primary occupation. This meant that adoption of irrigation technologies was higher among smallholder farmers with farming as the primary occupation than those who did not depend on farming alone. The necessity to boost crop productivity and projected income may account for the growing adoption of irrigation technologies among smallholder farmers who rely on farming. As a result, smallholder farmers' awareness of the importance of irrigation farming may have prompted them to adopt irrigation technologies. The findings were consistent with Shang *et al*. (2021), that farmers' primary occupation as farming is a significant factor in agricultural technology adoption decisions.

Off-farm income positively and significantly influenced adoption of irrigation technologies. The findings suggests that, smallholder farmers were more likely to use irrigation technologies if they earned more money from off-farm activities. This could be attributed to off-farm income providing an additional source of agricultural financing, allowing smallholder farmers to try out new agricultural methods. Off-farm revenue boosts farmers' financial power, allowing them to invest in innovative agricultural technologies. Off-farm income also covers the labor costs associated with the technology's operation and upkeep. The findings are in agreement with that of Armel Nonvide (2020); Mutunga *et al*. (2018); Mwangi & Crewett (2019), that off-farm income, is a significant determinant of adoption of adaptation strategies to climate change.

However, cost of labour exhibited a negative influence on the adoption of irrigation technologies. This meant that as labour costs increased, smallholder farmers were less likely to employ irrigation methods. A 0.06% drop in the probability of a farmer adopting irrigation technologies was caused by a one-unit rise in labour costs. This is because irrigation technology is labour-intensive in terms of maintenance and operations, and a high cost of labour could deter smallholder farmers from using it. Farmers are discouraged from adopting irrigation methods due to inability to meet labour requirements as labour costs rise. This finding concurs with Ng'ang'a, Jalang'o,

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and Girvetz (2020), that high cost of labour would prevent a household from adopting soil-carbon enhancing technologies.

Amount of credit accessed exhibited a significant positive relationship with adoption of irrigation technologies. This meant that smallholder farmers with more financing had a better chance of implementing irrigation technologies. The increased adoption could be due to the availability of cash to purchase necessary technology equipment, as well as farm inputs for operation and maintenance. Credit improves a household's purchasing power and could also aid in labour wages for the farm work. This finding was similar to that of Adebayo *et al*. (2018); Armel Nonvide (2020); Feyisa (2020), that access to credit is a significant determinant in adoption decisions of improved agricultural technologies.

Access to extension services positively predicted the adoption of irrigation technologies. This meant that, irrigation technologies were more likely to be used by farmers who had access to extension services. This could be because access to extension services is linked to the adoption of agricultural technologies, especially in terms of expanding knowledge and demonstrating better production methods. Farmers that have access to extension services understand how to implement new agricultural technologies better. Extension agents may have played a key role in providing farmers with the practical skills and technical knowledge they needed to correctly operate irrigation equipment, reducing water loss and increasing agricultural yields. Our finding agrees with Massresha, Lema, Neway, and Degu (2021); Muchangi, Ruzungu, Njiiri, and Mukiri (2021); Wang, Yin, and Yang (2021), that access to extension services by farmers, plays a central role in adoption decisions of agricultural interventions.

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Table 3: Determinants of adoption of irrigation technologies

Adoption of Irrigation Technologies	Marginal effects	Coef.	Std. Err.	Z
Age(years)	-0.0078	-0.0340	0.2276	-1.4900
Sex of HH (1=Male 0=Female)	0.2157	1.2267	0.3293	3.7300*
Education(years)	0.0099	0.1163	0.0581	2.0000*
Household size	0.0157	0.1333	0.0818	1.6300
Farm size in acres	0.0718	0.6792	0.1638	4.1500*
Land ownership (title deed)	0.0783	0.3504	0.2588	1.3500
Farming experience(years)	0.0078	0.0184	0.0193	0.9500
Main occupation	0.3309	1.2879	0.3512	3.6700*
Off-farm income (USD)	0.1704	1.0163	0.3217	3.1600*
Labour wages (USD)	-0.0006	-0.0271	0.0947	-0.2800*
Amount of credit (USD)	0.0110	0.0425	0.0158	2.6800*
Extension access	0.0363	0.4985	0.2543	1.9600*
Distance to nearest market (km)	0.0013	0.0492	0.0437	1.1200
Training on irrigation	-0.0131	-0.2484	0.5473	-0.4700
Inverse Mills Ratio		0.6997	0.2461	2.8400*

*$p \leq 0.05$; HHH= Household Head; 1 USD = KES 112

Determinants of Intensity of Adoption of Irrigation Technologies

The results in Table 4 revealed that, sex of households' head positively and significantly predicted the intensity of adoption of irrigation technologies. The finding suggested that, male-headed households were likely to devote more land for irrigation technologies than their female counterparts. This is because, male-headed households have more control over production resources such as land and labour, which strengthens agricultural practices. Female farmers who are also involved in domestic tasks have less time to focus on agricultural activities than male farmers. Our findings concur with Mwaura *et al*. (2021); Oyetunde-Usman *et al*. (2021), that, households' head gender plays a significant role in land intensification for sustainable agricultural technologies.

Households' primary occupation as farming positively and significantly influenced the intensity of adoption of irrigation technologies. This implied that, proportion of land for irrigation technologies was more likely to increase among smallholder farmers whose primary occupation was farming. The need to improve crop yield may have driven smallholder farmers to dedicate additional land for irrigation methods. Farming as the primary occupation would enhance farmers' focus and efforts in cultivation and as a

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result, extend the area of land available for multiple irrigation technologies. Our findings concur with Kumar *et al*. (2019) that, smallholders' primary occupation as farming is a key driver of the intensity of adoption of paddy seed variety.

Off-farm income had a positive influence on the intensity of adoption of irrigation technologies. This meant that adoption intensity of irrigation technologies increased as off-farm income increased among smallholder farmers. This may be because off-farm income would offer quick funding for land acquisition and expansion, as well as irrigation technology installation. Income from off-farm activities also boosts smallholders' financial power allowing them to apportion land for multiple technologies and thus intensify the land under irrigation. Our finding was in line with Thinda *et al*. (2020); Thanh and Duong (2020); Workineh, Tayech, and Ehite (2020), that off-farm income is a significant determinant in intensification of any agricultural technology.

Access to extension services positively predicted the intensity of adoption of irrigation technologies. This meant that as extension services became widely available, the propensity to increase land under irrigation technology increased. The necessity to employ numerous irrigation technologies, which would necessitate larger tracts of land, could be the driving force behind this. Extension agents are known to equip farmers with practical skills and knowledge of better farming methods based on the technology. As a result, smallholder farmers with access to extension services were better informed about the benefits of expanding irrigated land for higher agricultural outputs and revenues. This finding resonated the study by Awuni, Azumah, and Donkoh (2018); Yigezu, Mugera, El-Shater, Aw-Hassan, Piggin, Haddad, and Loss (2018); Mahama *et al*. (2020), that access to extension services is a significant determinant in adoption intensity of agricultural technologies.

Table 4: Intensity of adoption of irrigation technologies

Intensity of adoption (Proportion of land area devoted to irrigation)	Coef.	Std. Err.	Z
Age in years	0.0226	0.0157	1.4400
Sex of HH (1=Male, 0=otherwise)	0.6232	0.2450	2.5400*
Household size	-0.0453	0.5222	-0.8700
Education in years	0.0284	0.0373	0.7700
Farming experience (years)	0.0224	0.0126	1.7700
Main occupation (1=farming, 0=otherwise)	0.9557	0.3502	2.7300*
Land ownership (1=title deed 0=otherwise)	0.2261	0.1704	1.3300
Off-farm income (USD)	0.0492	0.2318	2.1200*
Access to extension services	0.1969	0.1545	1.2700*

*P≤0.05; HH= Household Head; 1 USD = KES 112

Conclusions and Recommendations

Because of disparities in socioeconomic and institutional characteristics among the sampled households, adoption and the intensity of adoption of irrigation technologies differed. Sex of the households' head, farm size, farming as main occupation, off-farm income, labour cost, access to credit, and extension services were all important predictors of irrigation technology adoption. Sex of the household's head, farming as the primary occupation, farm size, off-farm income, access to extension services, access to credit were all important drivers of adoption and intensity of adoption of irrigation technologies.

Policymakers should devise pro-farmer policies that encourage the adoption of irrigation systems. Rural cooperatives and organizations should be encouraged to be formed in order to have easier access to loans from various financial institutions such as microfinance and agricultural banks. The extension message could be made more straightforward and appropriate to the circumstances of the farmers. Furthermore, extension programmes should concentrate on teaching more farmers on the benefits of adopting irrigation technologies in dry land areas particularly those with limited experience and education.

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Conflict of interest
The authors declare that no competing interest existed to influence the work reported in this paper.

Authors contribution
KMM (50%) Conceptualization of research, data collection and analysis, and reporting.
MHR (18%) Conceptualization of research, data collection and analysis, and reporting.
MJN (17%) Conceptualization of research, data collection and analysis, and reporting.
IHN (15%) Conceptualization of research, data collection and analysis, and reporting.

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