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Does crop diversification outside a monocrop-based irrigation scheme affect profitability of the monocrop? Insights from Doho rice irrigation scheme in eastern Uganda

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ABSTRACT

Monocrop irrigation schemes in developing countries are usually characterised by participant farmers diversifying crop production outside the scheme. However, there is a lack of empirical evidence on how diversifying outside a mono-crop scheme affects the performance of the monocrop. Using a random sample of 385 smallholder farmers from the Doho rice irrigation scheme, this study examines the effects of crop diversification outside the scheme by participants on the profitability of the target monocrop, rice in this case. Results showed that only 6% of the farmers relied on the monocrop, with rest involved in the cultivation of an additional or more crops. The level of crop-diversification depended on the share of land in the scheme to total land accessed, gender of farmer, access to extension services and information, and the cost of irrigation services. These smallholder rice farmers earned about Uganda Shillings 3425,000 per acre (United States Dollars 951) annually from rice production. The instrumental variable regression results from a two stage least square analysis show that crop diversification had a positive impact on rice profitability. We conclude that in mono-crop irrigation schemes, outside crop diversification enables farmers tap into enterprise- combination synergies with positive benefits for farm profitability. This calls for policy and development interventions to support smallholder farmers operating in mono crop irrigation schemes to innovate and diversify farming activities.

1. Introduction

Irrigation schemes have been used as one of the ways of ensuring equitable access to irrigation water. Such irrigation schemes can be public, private or community owned. In Uganda, several public irrigation schemes have been established since colonial times [1,2]. Although these irrigation schemes can support the production of several crops, many of them focus on a single crop [3,4]. For instance, Doho irrigation scheme in Eastern Uganda, and Olweny irrigation scheme in northern Uganda are all rice-based irrigation schemes where there are no other crops grown in the scheme. Just like any other public irrigation schemes, smallholder farmers interested in cultivating the target crop or crops usually access the irrigation scheme land after meeting some set rules and regulations. However, in monocrop-based irrigation schemes such as the 1000 ha Doho rice scheme [4], farmers are commonly observed to diversify their crop production outside the scheme. The irrigation scheme land itself is largely dedicated to rice production in accordance with scheme regulations and management objectives. Consequently, opportunities for crop diversification within the scheme plots are limited. Smallholder farmers therefore tend to cultivate additional crops on non-scheme land such as upland fields, rain-fed plots, or other privately accessed land outside the irrigation scheme. In this study, crop diversification refers to the cultivation of crops other than rice on these non-scheme plots managed by the same household. This distinction is important because diversification occurring outside the irrigation scheme may influence household income, risk management, and resource allocation decisions, which can in turn affect the profitability of rice produced within the scheme.

This diversification of crop production enables farmers to spread production and income risk; and therefore, reduce livelihood vulnerability to weather and market shocks [5,6]. Crop diversification has been shown to impact positively on household production in different ways.

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According to Hien [7], larger diversified farms tend to have lower efficiency than smaller diversified farms. Similar studies have reported a positive effect of crop diversification on technical efficiency [8], economic efficiency [9], allocative efficiency [10], resource use efficiency [11], farm incomes [12–15], and overall risk preference of smallholder farmers [16,6].

None of these studies assessed the effect of outside scheme crop diversification on farm profitability similar to the context of a mono-crop irrigation scheme such as the Doho rice irrigation scheme in Eastern Uganda. For instance, Bellon et al. [13] studied the relationship between crop diversity, self-consumption and incomes by smallholder farmers in northern Ghana. Similarly, Kijima [16] investigated risk preferences in rice production in Uganda through crop diversification with no focus on any specific irrigation scheme. Additionally, Tesfaye & Tirivayi [6] studied crop diversification in the Ugandan context, with a focus was on the rural dryland parts of the country with no specifics on the irrigation schemes per say. A critical question thus remains on the effect of crop diversification in monocrop-based irrigation scheme. This study tries to answer this question by assessing the effect of crop-diversification outside a monocrop-based irrigation scheme on the profitability of the monocrop. By investigating the intricate relationship between crop diversification and profitability of the primary irrigation scheme crop, this study aimed to address the pivotal question of whether diversifying crops can enhance the overall economic sustainability of smallholder farmers who have the incentive to practice monoculture but still decide to diversify. This evidence is critical in guiding farmer's participation decisions in such irrigation schemes, especially given the existing evidence of poor performance of such irrigation schemes in developing countries [17,2].

2. Review of literature on crop diversification in smallholder farming systems

Crop diversification in smallholder farming systems is grounded in several complementary theoretical perspectives that explain farmers' production decisions under conditions of uncertainty and resource constraints. One of the central theoretical foundations is the risk management framework, which suggests that farmers diversify their crop portfolio to reduce exposure to production and market risks associated with climatic variability, pest outbreaks, and price fluctuations variability [18,19]. By allocating land and resources across multiple crops, farmers distribute risk in a manner similar to portfolio diversification in economic theory, thereby stabilizing farm output and income streams [20,21]. Diversification is also explained through the theory of economies of scope, where the joint production of multiple crops can allow farmers to utilize shared inputs such as land, labor, and farm equipment more efficiently than under specialized monocropping systems [22]. In addition, livelihood diversification theory highlights that rural households often pursue multiple agricultural enterprises as a strategy to smooth income and enhance resilience in contexts characterized by imperfect markets and limited access to insurance or credit [23]. Within smallholder production systems in Sub-Saharan Africa (SSA), these theoretical perspectives collectively explain why farmers may maintain diversified cropping patterns even when institutional arrangements, such as mono-crop irrigation schemes, promote specialization.

Empirical literature provides mixed but generally supportive evidence on the role of crop diversification in improving farm income and profitability among smallholder farmers. Several studies show that diversification can enhance household income by spreading risk across multiple enterprises and by enabling farmers to capture complementarities in resource use [14,15]. Diversified cropping systems may also increase profitability through economies of scope, where inputs such as labor, fertilizers, or machinery are shared across enterprises, lowering overall production costs [22]. In addition, diversified systems can create opportunities for farmers to respond to market signals by producing crops with varying price dynamics, thereby improving income stability over time [24]. Evidence from SSA further suggests that crop diversification can improve farm-level efficiency and resource use, which may translate into higher profits [9,10]. However, some studies report contrasting results, indicating that highly specialized farms may achieve higher productivity due to scale efficiencies and focused resource allocation [25]. These mixed findings highlight that the profitability effects of diversification are context-specific and may depend on farm size, market access, and institutional arrangements such as irrigation schemes. Consequently, understanding how diversification influences the profitability of a primary crop within mono-crop irrigation systems remains an important empirical question.

Crop diversification is heavily rooted in the principle of risk management, which in this context involves approaches to reduce the probable negative impacts of adverse events of specialized farming systems that include crop failures, price fluctuations, and climate variability [19]. This is especially relevant in SSA where the agricultural sector is largely dependent on natural conditions [23]. With dependence on natural conditions, smallholder farmers are usually more vulnerable to climate vagaries, with serious impacts on farmer's livelihoods. By cultivating many crops, smallholder farmers can mitigate these effects [20,21]. This practice aligns with the principles of income levelling as it enables farmers to generate income from multiple sources throughout the year [18].

Despite the risk mitigation and income diversification roles of crop diversification, several other factors drive smallholder farmers decision to diversify crop production. Existing studies suggests that several socio-economic characteristics, institutional, as well as market access factors differentially influence crop diversification decisions [26–28]. For instance, Mzyece & Ng'ombe [27], while, analysing the determinants of crop diversification in Zambia, reported that the size of landholding and distance to market among others factors significantly influenced farmers' probabilities to practice crop diversification. Similarly, Feliciano [18], reported that increasing land size greatly boosted crop diversification. The influence of these factors varies widely across the different geographical locations, and farming systems [13,26,29–34].

There are also an increasing number of studies exploring the importance of smallholder crop diversification with respect to poverty, food security and other outcomes. Their results present mixed findings on the effect of crop diversification on the smallholder farm household. For instance, crop diversification has been linked to better food nutrition security for smallholder farming households [35,13,36–41]. Specifically, Agitew et al. [35] reported a positive impact of on-farm crop diversity on household dietary diversity. Tobin et al. [41] reported that crop diversity was positively associated with dietary diversity and child's height for age. Chegere and Stage [36], and Kabir et al. [37] have shown that diversification of smallholder farming household's agricultural production was important for increased diversity of household diets, with minimal effects on nutritional outcomes. Bellon et al. [13] observed a positive association between self-consumption and crop diversification. Similarly, crop diversification is important for climate change resilience and adaptation among smallholder farming households [42–44]. Specifically, according to Birthal and Hazrana [43], crop diversification is important for creating resilience to severe long-run climate shocks. Crop diversification has also been linked to better incomes of smallholder farmers, and thus, has implications for poverty eradication. A study by Dagunga et al. [24] reported that incomes effects of crop diversification are highly dependent on the extent of diversification, with, relatively low or high diversification being associated with lower or higher incomes in a study conducted in Ghana. Additionally, a related study by Kansiime et al. [25], showed that more specialized farms in Uganda earned higher incomes. Crop diversification also has implications for overall farm efficiency. Ogundari [9] reported that crop diversification was associated with higher technical efficiency in Nigeria, while, Okello et al. [10] reported a positive effect of crop diversity on farm level resource use efficiency in northern Uganda. Additionally, Bhat et al. [45] observed lower energy use efficiency and profitability in monocropping, as opposed to an integrated farming system. Contrarily, Kansiime et al. [25] observed that more specialised farms were relatively more efficient in their agricultural production.

Thus, studies on the importance of crop diversification in smallholder farming, presents mixed findings. Despite these mixed findings, none of these studies was conducted in the context of a monocrop-based irrigation scheme. Additionally, these studies focus on the impact of crop diversification and assesses the impact on the whole farm. None of them focused on the impact of crop diversification on a primary crop such as rice which is the sole crop in Doho irrigation scheme. The current study adds to this debate by assessing how overall farm crop diversification affects the performance of a primary crop. This is especially important given that, in such monocrop-based systems, farmers have the incentive to practice monocropping. For instance, by providing irrigation water, the risk of climate vagaries, which is one of the main reasons for crop diversification, no longer exists. Consequently, a rational farmer's decision to diversify within the context of such a scheme should, in practice, only happen if the diversification either maintains or increase the performance of the monocrop for the farmers not to abandon the irrigation scheme monocrop altogether. However, without empirical evidence on the effect of crop diversification on the monocrop, policy makers and irrigation scheme managers do not have a basis to encourage or discourage outside scheme diversification. This study provides empirical evidence which has been lacking in the current literature on the impact of crop diversification in farming outcomes.

3. Materials and methods

3.1. Study area

The study was conducted in Butaleja District, where Doho (Uganda's biggest irrigation rice scheme) is located. The district headquarters, which is at Butaleja, is located approximately 38 km by road, southwest of Mbale, the nearest city. Doho Rice Irrigation Scheme, established in 1942 and sitting on 2500 Hectares of land was formerly a seasonal wetland on River Manafwa. It is located in both Mazimasa and Kachonga Sub-Counties of East Bunyole County in Butaleja District of Uganda. These two sub counties are also where most of the beneficiaries to the rice scheme hail from. According to Ayella et al. [46], the scheme bears several unique aspects which include among others a steady supply of regulated water from River Manafwa which flows through the Mt. Elgon's fertile slopes, existence of organized sets of farmer groups under the Doho Irrigation Scheme Farmers' Cooperative Society (DIFACOS) with benefits such as access to capital, inputs and collective action, as well as, the routine government rehabilitation of the scheme to improve flood management mechanisms and the transport networks.

3.2. Study population, sampling and data collection

The target population of the study were smallholder rice farmers who are beneficiaries of the scheme. This also formed the unit of analysis. The sample size was arrived at using Yamane's formula [47] as shown in Eq. (1).

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

Where: n represented the sample size, N=10,000 smallholder rice farmers [48] is the population from which the sample was drawn and e being the level of significance. The universally accepted level of accuracy in social science research is 0.05, corresponding to a confidence level of 95%. Thus, the sample size was 385 smallholder rice farmers.

The study employed multistage sampling to select a representative sample. The first stage involved selecting Butaleja district where Uganda's largest irrigation rice scheme - Doho, is located. In the second stage, the sub counties of Mazimasa, Kachonga and Nabiganda were selected due to significantly large number of scheme participants. Following this, the sampling frame – a list of scheme participants in these sub counties was obtained from the Doho Irrigation Rice Scheme Farmers' Cooperative Society (DIFACOS) which directly manages the scheme's rice farmers. From the sampling frame, study participants were selected randomly and interviewed. Given the need to achieve the sample size amidst voluntary participation, the study adopted sampling with replacement. In essences, any participant who declined to participate in the study was replaced with another.

Data was collected using semi-structured pretested questionnaires that constituted of four sections: socio-economic characteristics, institutional factors and support services, cost of rice production and lastly market-oriented variables were administered. The questionnaire was pretested to allow for testing of relevance and alignment of the study variables in line with the study objectives and thereafter a few modifications were adopted. Prior to data collection, informed consent was obtained from every participant with only voluntarily consenting farmers being included in the study.

3.3. Data analysis

Collected data was coded, entered and analysed using both SPSS (Statistical Package for Social Scientists) version 26 and STATA version 15. Data was then thoroughly cleaned and screened to identify the presence of outliers which could potentially influence the results. Descriptive statistics like frequency counts, means, percentages and standard deviation were used to summarize socio-economic characteristics of the respondents. The results from the selected sample helped to generalize about the smallholder farmer population from which it was drawn.

In this study, crop diversification was computed using the Simpson Diversity Index (SDI). The SDI which relates to the proportion of land allocated to each i^{th} crop *vis a vis* the total land holding is appropriate for this study due to its ability to capture both the number of crops grown and the proportional distribution of land allocated to each crop, thus providing a more comprehensive measure of diversification compared to simple crop counts or indices that consider only the presence of crops. In other words, it captures both species' richness and their abundance [49]. This is opposed to the physical count of species richness used by Sibhatu et al. [40]. Additionally, the index is less sensitive to extreme values and provides a stable measure of diversification in situations where farms cultivate several crops but allocate different land proportions to them [50]. Given that this study aims to measure the extent to which farmers allocate land to crops outside the mono-crop irrigation scheme, the SDI provided a suitable and widely accepted approach for capturing diversification intensity in land-use decisions. In this study, species richness is reflected as the number of crop species being cultivated by a given smallholder, while their abundance was measured as the proportion of land to total land allocated to the crop. This index consists of the lower value zero (0) denoting the farmer category that does not diversify and figures greater than zero but with an upper limit of one (1) capturing farmers that diversify at different intensities. The SDI computation follows Eq. (2).

$$D = 1 - \Sigma n(p_i)^2 \tag{2}$$

Where: D is the SDI, n is the number of crop enterprises, p_i is the proportion of land allocated to each crop enterprise. Drawing a scenario from our study and considering one of the farmers in the sample growing three crops: rice, maize and beans and with a total crop area of 2 acres. This farmer allocated 1 acre of land to rice, 0.5 acres to maize, and 0.5 acres to beans, giving a total cultivated area of 2 acres. The share of land allocated to each crop is therefore 0.5, 0.25, and 0.25, for rice, maize and beans, respectively. The SDI for this farmer would be computed as: $SDI = 1 - (0.5^2 + 0.25^2 + 0.25^2) = 1 - (0.25 + 0.0625 + 0.0625) = 0.625$. This value indicates a moderate level of crop diversification for this farmer.

Given that SDI values ranges 0 – 1, determinants of crop diversification was assessed using the fractional probit model. This is because for fractional responses such as the SDI, the effect of a given explanatory variable cannot be uniform throughout the range [51]. As such, models such as the ordinary least squares or the Tobit model would be inappropriate. The fractional probit regression model allows model estimates to fall within the bounds. In this study, we validated the fractional probit model by estimating the Tobit and fractional logit models. Model fit indices showed that the fractional probit model was the best for our dataset (Appendix Table A1). Specifically, the fractional probit model log-likelihood of −232.817 was the best. Similarly, the AIC and BIC values for the fractional probit regression model were also the lowest, indicating better fit for fractional probit. Consequently, the study presents results for the fractional probit model. However, results output from all three models are presented in Appendix Table A1 for comparative purposes. Additionally, to control for the inherent heteroskedasticity, we estimated robust standard errors.

To analyse the impact of crop diversification on profitability of the monocrop rice, the Two Stage Least Squares regression (2-SLS) was used. The instrumented variable was the SDI, while, the instruments employed were: the proportion of scheme land to total land holding, household size, age of household head, gender of household head, farmer experience at the scheme and its squared version, payment of scheme membership subscription fees, credit source (DIFACOS or VSLA), access to extension services from government, farmer association or private companies, rice buyer (middlemen or processor), rice variety super or K-98, other crop combinations grown besides rice being either perennials, legumes, roots or cereals. The impact of crop diversification was noted to be positively significant to profitability of rice alongside other variables that were used as illustrated in the first stage Eq. (3).

$$Y_i = \beta_0 + \beta_i X_i + \mu_i \tag{3}$$

Where; Y_i is crop diversification, β_0 is the intercept, β_i is the coefficient of endogenous variables (crop diversification), X_i are the exogenous variables that affect crop diversification, μ_i is the error term. The exogeneous variables which were variables that could potentially affect crop diversification are hypothesized in Table 1. The error term here therefore represents other unobserved variables that affect crop diversification.

In the second stage, the dependent variable – the profitability of rice farming – was regressed on the predicted values of crop diversification obtained from the first stage. In other words, the measure of crop diversification is instrumented. The error term in the second stage are other factors (unobserved) besides crop diversification, and the instruments used that may affect profitability but are not accounted for in the model. Refer to model specification in Eq. (4).

$$Y_{ii} = \beta_0 + X_2\beta_2 + \mu_2 \tag{4}$$

Where: Y_{ii} is rice profitability,[1] β_0 is the intercept X_2 is the exogenous variable, β_2 is the coefficient for the endogenous variable (crop diversification) and μ_2 is the disturbance term.

The two stage least squares method is therefore used to address the potential endogeneity bias arising from the correlation between crop diversification and unobserved variables that affect profitability. By using the predicted values of crop diversification from the first stage as instrumental variables, the two stage least squares method allows for the estimation of unbiased coefficients for the endogenous variable in the second stage. The Durbin-Wu-Hausman test for endogeneity test statistics of $X2 = 6.762$, $p = 0.009$, suggests that the endogenous regressor(s) are correlated with the error term, justifying the use of 2SLS over OLS. The first-stage regression F-statistics was 39.91, which exceeds the rule-of-thumb threshold of 10, indicating that the instruments are strongly correlated with the endogenous regressors. Just like in the fractional probit regression, we estimated robust standard errors to control for heteroskedasticity.

4. Results

4.1. Sample socio-economic characteristics

Results in Table 2 reveal that the household heads were averagely aged 43 years with the mean number of years of formal schooling of seven years. Average household size was nine members with a composition of four females and five males. Of the above listed, averagely four were children (0–17years), three were young adults (18–35years), a middle-aged adult (36–55 years) and no elder person (56 years and above). The mean total land under production for the respondents was 2.0 acres while the average land a household had at the scheme was 1.3 acres. On average, the distance from the households to the input and output markets was 2.1 km and 2.0 km, respectively. The respondents also had an average of 15.4 years of experience cultivating rice in general and 15.1 years for experience cultivating rice at the scheme. On average, the rice farmers were able to grow two other crops besides rice. The average cost of scheme irrigation water they incurred annually was Uganda Shillings (UGX) 119,825.

The farmers' categorical characteristics summarized using frequencies and percentages (Table 3) shows that majority of the households were male headed (90.4%) and married (79.7%). Of the sampled population, 81.6% were engaged in an off-farm activity, while 94.8% owned mobile phones. Almost all the respondents received farmer extension services (99.7%), the difference only being in the number of visits and type of extension agent who visited them. Specifically, 14%

Table 1
Explanatory variables and their *apriori* expectations as used in the Two Stage Least Square regression model.

Variable	Category	Units of measurement	Apriori Signs	Literature
Crop diversification index (SDI)	Continuous	Crops grown visa vis land allocated	+	[52]
Farmer Exp – scheme	Continuous	Number of years	-	[48]
Farmer Exp – scheme (squared)	Continuous	Number of years	+	[53]
Prop- scheme land total land	Continuous	Acres	+	[53]
Ext. Agent- farmer association	Dummy	1-Yes, 0-No	+	[54]
Ext. agent- private company	Dummy	1-Yes, 0-No	+	[54]
Source of credit- DIFACOS	Dummy	1-Yes, 0-No	+	[55]
Buyer rice processor	Dummy	1-Yes, 0-No	+	[56]
Grow super variety	Dummy	1-Yes, 0-No	+	[57]
Other crop category grown – Legumes	Dummy	1-Yes, 0-No	+	[58]
Other crop category grown – Roots	Dummy	1-Yes, 0-No	+	[16]

[1] In this study, profitability of the rice farming was calculated using gross margin analysis, which measures the difference between total revenue obtained from rice sales and the total cost of rice production incurred by the farmer. Specifically, total revenue was computed by multiplying the quantity of rice sold (in kilograms of milled rice) by the prevailing farm-gate price received by the farmer. Total production costs included all major cost components associated with rice cultivation at the scheme, namely capital costs (land lease, irrigation fees, and scheme membership fees), labor costs (both hired and imputed family labor), material costs (such as seeds, fertilizers, herbicides, and pesticides), and equipment-related costs. Profitability was therefore derived as: Profit = Total Revenue – Total Production Costs. This measure reflects the financial returns accruing to the farmer from the rice enterprise after accounting for all production-related expenses. The study focused on cost and revenue for the last one year prior to the study. This is why, the profits computed reflects annual rice profits.

Table 2
Descriptive statistics presenting the rice farmers continuous characteristics.

Variable	Unit	Mean	St. Dev
Age of household head	Years	42.89	11.68
Education level	Years (formal schooling)	6.82	3.88
Household size	Number of members	8.89	5.39
Female household members	Number of members	4.13	2.92
Male household members	Number of members	4.76	3.32
Household members ≤17yrs old	Number of members	4.21	3.06
Household members 18–35yrs old	Number of members	3.09	2.42
Household members 36–55yrs old	Number of members	1.36	1.42
Household members ≥56yrs old	Number of members	0.28	0.62
Distance to the nearest input mkt	Kilometres	2.10	1.24
Distance to the nearest output mkt	Kilometres	1.98	1.14
Rice farming experience - general	Years	15.44	9.56
Rice farming experience - scheme	Years	15.11	9.25
Total land under production	Acres	1.99	1.44
Land holding – scheme	Acres	1.25	0.97
Number of crop enterprises besides rice	Number of enterprises	1.62	0.98
Cost of irrigation	Uganda Shillings (UGX)	119,825	92,552

Source: Field survey.

Table 3
Descriptive statistics for rice farmers' categorical characteristics.

Variable	Category	Frequency	Percentage
Gender of household head	Female	37	9.6
	Male	348	90.4
Marital status of household head (Married)	Yes	307	79.7
	Otherwise	78	20.3
Engaged in non-farm activity	Yes	314	81.6
Own mobile phone	Yes	365	94.8
Received extension services	Yes	384	99.7
Extension agent – government	Yes	54	14.0
Extension agent - farmer association	Yes	59	15.3
Extension agent - private company	Yes	12	3.1
Access to farm credit	Yes	237	61.6
Source of credit – DIFACOS	Yes	236	61.3
Source of credit – VSLA	Yes	33	8.6
Scheme service – membership subscription fees	Yes	367	95.3
Belong to a farmer group	Yes	253	65.7
Used improved seed	Yes	19	4.9
Source of market info is radio	Yes	69	17.9
Sold rice to middlemen	Yes	334	86.8
Sold rice to rice processor	Yes	20	5.2
Variety grown – Super	Yes	32	8.3
Variety grown - K98	Yes	90	23.4
Grew any other crop besides rice	Yes	361	93.8
Other crop category grown – cereals	Yes	237	61.6
Other crop category grown – legumes	Yes	166	43.1
Other crop category grown – roots	Yes	120	31.2
Other crop category grown – perennials	Yes	43	11.2

Source: Field survey.

were visited by an agent from the government, 15.3% from the farmer association, 3.1% from private companies and the others from other sources. About 62% of the farmers had access to farm credit. Of these, 61.3% sourced from DIFACOS, 8.6% from VSLAs and the remaining 30.1% from microfinance institutions, commercial banks, friends and family. Over 95% reportedly paid for membership subscription fees at the scheme. Although, 65.7% belonged to a farmer group, only 4.9% used improved seeds and 17.9% accessed market information through the radio. Of the rice varieties grown, the variety K-98 was the most common, with other varieties include super, Basmati, Zain, Kaisoand Wita 9 also being cultivated. About 87% of the farmers sold their rice output to middlemen, 5.2% sold to rice processors and 8% sold either to urban traders, village collectors, other farmers or seed company. Over 94% of the respondents grew other crops besides rice, while 90.1% also reared livestock.

4.2. Crop diversification in the Doho rice irrigation scheme

Fig. 1 shows the intensity of diversification as a crop count variable categorized into the different crop combinations. First the crops were classified into rice (primary crop), other cereals (maize, millet and sorghum), legumes (beans and groundnuts), roots (cassava and sweet potatoes), perennials (bananas and coffee) and vegetables. Farmers who grew only rice is what is referred to as one crop combination. Two crop combination are farmers who grew rice and either other cereals, legumes, roots, perennials or vegetables. Three crop combination are farmers who grew rice and any two other crop classifications. Four crop combination are farmers who grew rice and any three other crop classifications, while five crop combination are farmers who grew rice and four other crop classifications. The study findings revealed that more than half (53%) had undertaken the two crop combinations. This was followed by those who had undertaken three crop combinations, four crop combinations, one crop combination and five crop combinations, respectively.

Table 4 presents the level crop diversification based on the SDI. The SDI is classified as specialisation (SDI≤0.0), Low (SDI between 0.01 – 0.5), moderate (SDI between 0.51 – 0.75) and high/upper (SDI between 0.76 – 1.0). Based on this classification, about 50% of the rice farmers of Doho irrigation scheme could be classified as has low levels of crop diversification.

Fractional probit regression model results for factors influencing crop diversification are presented in Table 5. It shows that the proportion of scheme land to the total land holding has a positive significant (p < 0.01) influence on crop diversification. However, the relationship between proportion of land in the scheme and level of crop diversification exhibits an inverted U-shaped trend. This implies that, initially, as the proportion of land in the scheme to the total land holding becomes higher, there is a proportional increase in level of crop-diversification, however once a maximum is reached, having more land in the scheme would be associated with declining level of diversification. It suggests that, as more and more land is acquired by a farmer in the scheme (for rice production), their willingness to run multiple crop enterprises consequently lowers as they begin to reap the benefits associated with economies of scale which result in lower costs of production for each additional unit of rice output produced. This therefore becomes an incentive for specialization in fewer crops. Farmer level of education ($p < 0.05$) significantly and negatively influenced crop diversification, suggesting that the more educated a household head is, the more likely a household specializes in a few crops. Gender of the household head positively and significantly ($p < 0.1$) influences crop diversification. Specifically, results suggests that there is a 2.7% likelihood that male headed households will grow more crops than the female headed ones. Results also show that access to extension services is associated with negative and significant ($p < 0.01$) influence on crop diversification. Farmers who receive extension services are more likely to specialize in a few crops. This could be attributed to the fact that most extension visits are crop specific. For access to market information, results show that possession of radios negatively and significantly ($p < 0.01$) influence crop diversification. Farmers who grow other crops besides rice will most likely adopt either a rice-roots crop combination or a rice-perennials crop combination since the listed crop combinations are both positive and significant ($p < 0.01$) to crop diversification. The cost of irrigation scheme water positively and significantly influences crop diversification ($p < 0.01$). However, there is an inverted -U- shaped relationship between crop diversification and cost of scheme irrigation water. This infers that, originally, crop diversification increases with each relative increase in the cost of scheme irrigation water to reach a maximum after which the higher the cost of irrigation water the lower the level of crop diversification. It is important to note that in this study, cost of irrigation water is tied to land acreage/size under production. So,

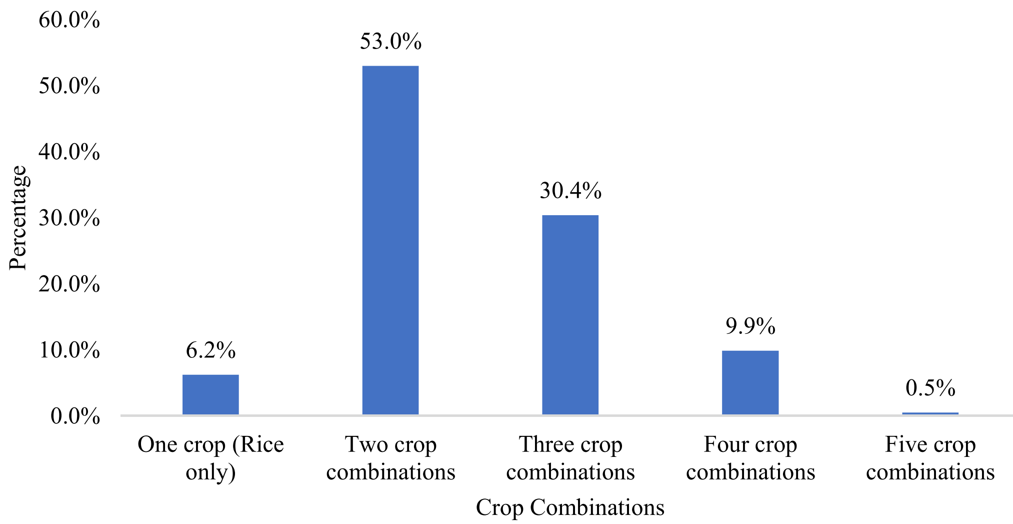

Fig. 1. Crop combinations grown by smallholder rice farmers.
Source: Field survey

Table 4
Level of crop diversification by the smallholder rice farmers.

Level of diversification	Range (SDI)	Frequency	Percentage (n = 385)
Specialization	SDI≤0.0	24	6.23
Low	SDI 0.01 - 0.5	191	49.61
Moderate	SDI 0.51 - 0.75	142	36.88
Upper	SDI 0.76 – 1.0	28	7.27

SDI= Simpson diversification index (Mean = 0.48, Standard deviation =0.21); Source: Field survey.

Table 5
Fractional Probit regression model results for determinants of crop diversification.

Explanatory variable	Coefficient	Robust Std. Err
Scheme land prop to total land	0.874***	0.194
Scheme land prop to total land squared	−0.258***	0.029
Farmer Scheme Experience	0.043*	0.024
Level of Education	−0.008**	0.004
Gender of household head	0.078*	0.042
Extension Services	−0.090**	0.044
Access - Farm Credit	−0.027	0.028
Distance to Input Market	−0.042	0.031
Seed used is improved	0.084	0.063
Radio - Mkt Info Source	−0.192***	0.050
Other crops - Cereals	0.064*	0.034
Other crops - Legumes	0.040	0.036
Other crops - Roots	0.104***	0.035
Other crops - Perennials	0.151***	0.047
Irrigation Cost	1.509***	0.504
Irrigation Cost squared	−0.060***	0.022
Rear Livestock	0.090*	0.046
Constant	−9.217	2.887

Note: ***, ** & * imply significance at $p < 0.01$, $p < 0.05$ and $p < 0.1$ respectively; Source: Field survey.

as a farmer pays more for cost of irrigation water because of accessing more land from the scheme, they begin to incline more to rice specialization to be able to earn benefits of rice monocrop.

4.3. *Rice enterprise profitability and crop diversification*

4.3.1. *Rice production costs*

Table 6 presents a summary of the costs incurred by rice farmers in the scheme. These costs are presented in 4 subsets to include capital costs, labour costs, cost of materials and cost of equipment. Capital costs that included cost of land lease, irrigation costs and scheme membership fees were 44.3% of the cost of production. Labour costs which were computed to include family labour or hired labour or a combination of both as per the rice farmers' preference constituted 31.3% of the total production costs. Cost of materials (seeds, fertilizers, pesticides and herbicides) was 23.4%, while cost of equipment (hoes, spraying pumps, knives or sickles, tarpaulins and sacks) was only 1% of the overall production cost. The annual cost per acre was UGX 3013,355 per farmer.

Table 6
A summary of production costs incurred by the rice farmers.

Variable (UGX)	Mean (SD) (Total land under rice production)	Cost item per acre
Hired Labour	295,843 (519,949)	246,790
Family Labour	835,272 (746,760)	696,777
Capital Costs	1598,968 (1210,648)	1333,845
Labour costs (Total hired & family labour)	1131,115 (829,228)	943,566
Cost of materials	844,543 (783,572)	704,510
Cost of equipment	37,681 (23,530)	31,433
Total cost of production	3612,307 (2782,667)	3013,355

SD=Standard deviation; Source: Field survey.

4.3.2. *Rice harvests, revenues and profits*

The rice output quantities (harvested, sold and consumed) presented in Table 7 are in milled form. The conversion rate from paddy to milled being an average of 70%. However, quantities saved for seed are

Table 7
A summary of the rice harvests, revenues and profits earned by the rice farmers.

Parameter	Mean (SD) (Total land under rice production)	Mean per acre
Rice quantity harvested (Kgs)	1195 (959)	997
Rice quantity sold (Kgs)	1149 (927)	958
Price of rice (UGX)	3341 (418)	2787
Rice quantity consumed (Kgs)	21 (18)	18
Rice quantity saved for seed (Kgs)	36 (39)	30
Rice revenue earned (UGX)	7717,380 (6306,381)	6437,770
Annual profit (UGX)	4105,431 (3699,638)	3424,714

SD=Standard deviation; Source: Field survey.

presented in paddy form. The results show that from the total harvest, 96.13% is sold off, 1.74% consumed at home and 2.13% saved for seed for the subsequent cropping season. Results for rice harvests, revenues and profits earned by the smallholder rice farmers show that the average rice yield was 1,195kgs, with approximately 1,149kgs taken for sale, 21kgs consumed and 36kgs kept for seeds in the subsequent season. Averagely rice is sold at UGX 3341 with average total revenues estimated at UGX 7717,380 fetching approximately 53.2% gross profits. For each acre, the average annual profit was UGX 3424,714 per farmer.

4.3.3. Influence of crop diversification on rice profitability

The two stage least square model results for influence of crop diversification on profitability of rice farming are presented in Table 8. The results show that crop diversification has a positive and significant influence ($p<0.01$) on rice profitability suggesting that the more crops a farmer grew alongside rice, the more likely they were to profit from rice production. The proportion of scheme land to a household's total land holding has a positive and significant influence ($p<0.01$) on profitability of rice. However, farmer experience cultivating rice at the scheme exhibits a U-shaped relationship with profitability of rice, suggesting that at the start, as a farmer begins to learn the dynamics of rice production, their inexperience costs them the likelihood of earning higher profits from their rice enterprise. They operate at a loss and once they reach a maximum, they begin to adopt to the rice production techniques and are consequently able to earn a 12.4% profit for each relative increase in the years they spend cultivating rice. Access to credit from the scheme SACCO (DIFACOS) is also a positive and significant ($p<0.01$) influencer of rice profitability. Sources of farmer extension services like farmer associations and the private companies are equally positively and significantly ($p<0.05$ and $p<0.1$, respectively) associated with rice profitability. Channel of sale for rice output shows an association with rice profitability with those selling to rice processors likely able to earn more profits at positive significance $p<0.01$. Super rice variety, widely believed to be a superior variety among farmers at the scheme has a positive and significant ($p<0.01$) influence on the profitability of rice. Some crop categories grown besides rice also have an influence on rice profitability. These include legumes and roots which both have positive and significant ($p<0.05$) influence. However, age and gender of the household head, membership subscription as a scheme service, VSLA as a source of farm credit, extension service from government, buyer of rice being middlemen and variety of rice grown being K98 do not have an influence on the overall profitability of rice farmers.

Table 8
Influence of crop diversification on rice profitability.

Variables	Coefficient	Robust Standard Error
SDI	1.304***	0.495
Scheme land prop to total land	0.704***	0.134
Household Size	0.056	0.067
Age of household head	0.002	0.005
Gender of household head	−0.032	0.145
Farming experience in the scheme	−0.457*	0.277
Farming experience in the scheme Squared	0.124**	0.062
Scheme service member Subscription	0.233	0.193
Credit – DIFACOS	0.316***	0.080
Credit – VSLA	−0.171	0.149
Extension Agent – Government	0.118	0.127
Extension. Agent - Farmer Association	0.277**	0.128
Extension Agent - Private provider	0.383*	0.196
Buyer – Middlemen	0.123	0.152
Buyer - Rice Processor	0.532***	0.187
Variety – Super	0.561***	0.135
Variety - K98	0.151	0.100
Perennials	0.155	0.123
Legumes	0.179**	0.077
Roots	0.202**	0.094
Constant	11.107***	0.819
Number of Observations	385	
Wald Chi2	185.02	
Prob > Chi2	0	
R-Squared	0.282	
Root MSE	0.706	

***, ** & * imply significance at $p < 0.01$, $p < 0.05$ and $p < 0.1$ respectively; Source: Field survey.

5. Discussions

This study finding reveals that most of the rice farmers in Doho rice irrigation scheme are practicing crop diversification. The intensity of diversification within the group of diversifiers was low as the average intensity of diversification was slightly below 50%. This implies the cropping system among smallholder rice farmers at Doho rice irrigation scheme is consisting of a few crops in addition to rice. In other words, it shows that farmers are allocating more of their land to the monocrop. This was expected given the incentives that comes with participating in an Irrigation scheme such as Doho where there is easy access to the mono-crop production resources, as opposed to the other crops. Farmers may focus on rice because it is a staple crop with a reliable market demand and stable prices. Additionally, diversifying into other crops may require additional investments in seeds, fertilizers, and equipment which farmers may not be able to afford. The study findings are contrary to the findings of Makate et al. [26] that reported that most of the of the farmers in Zimbabwe were practicing crop diversification and the intensity of diversification within the group of diversifiers was high as most farmers had an index score greater than 0.5. Additionally, Nandi et al. [59] revealed that farmers in India, Nepal and Bangladesh were highly diversified with diversification index of 0.99, 0.97 and 0.99, respectively.

Findings also revealed that most of the rice farmers practicing crop diversification are practicing two crop combinations. Two-crop combinations signify a balance between diversifying income sources and managing limited resources (e.g., land, labour, water, and capital). Farmers might be choosing combinations that complement each other in terms of resource use, such as pairing a high-water-demand crop with a low-water-demand crop. This observation suggests a risk preference diversifying approach of smallholder farmer where a farmer takes on an additional crop for purposes of countering the potential risks anticipated for the primary crop [16].

From this study, crop diversification appeared to have positive impacts on the profits of the monocrop. This finding corroborates those of Malaiarasan et al. [60] who, in a study on crop diversification in a paddy dominated production system, reported that diversifying farms had higher net income from rice. The positive effects of crop diversification on income from a monocrop can be attributed to synergistic effects of crop diversification on farm level efficiency [10]. This efficiency can manifest in input cost reduction, as well as increased output associated with crop diversification. According to Awiti et al. [61], crop diversification affects overall cost of production through its influence on costs of all major inputs. This influence varies in magnitude depending on the nature of the farm. In mono-crop rice production, Malaiarasan et al. [60], reported that crop diversification was associated with reduced total input costs per hectare. This reduction in costs was largely from diversification induced reduction in cost of labor, irrigation and labor. In the context of this study, such reduction in input cost could also lead to reduction in rice production costs. The mechanism with which crop diversification leads to cost reduction in diversified systems is not very clear. Crop diversification presents opportunity for maximising the impact of sharable inputs [12]. On the other hand, Hepelwa [62] reported that diversified farms were found to be credit worthy and able to access credit to buy improved inputs. Nevertheless, crop diversification input cost reduction appears to have positive impacts on profits. In addition to input cost induced efficiencies, there are also improvements in input use efficiency associated with crop diversification. A study on input use efficiency in a rice-based cropping system revealed that rice equivalent yield increased by between 72–217% in a diversified production system [63]. Similarly, Okello et al. [10], reported that crop diversification increase farm level allocative efficiency of rice farmers in northern Uganda. However, Kansiime et al. [25], reported that specialized farms in Uganda had lower input use efficiency than diversified farms. Such input use efficiency is always reflected in higher yields. For instance, Malaiarasan et al. [60], reported that rice yield per hectare in a diversified production system was higher than in a non-diversified system. Similarly, Baiyegunhi et al. [64], reported that maize yields under crop diversification were higher than in non-diversified production. Such efficiency improvements that lead to higher yield will also always lead to higher profits for the target crop.

Despite the positive relationship between crop diversification and rice profits, crop diversification is also influenced by several other factors. For instance, results of our study showed that a household's proportion of scheme land to a household's total land holding had a positive influence on crop diversification. This finding is supported by those of Ruzzante et al. [53] who reported that farmers with larger portions of land were more likely able to adopt farm technologies like improved crop varieties which improves their yields and consequently their incomes other factors held constant.

The U-shaped trend associated with a farmer's experience cultivating rice in regard to crop diversification can be traced back to earlier studies. For example, Ainembabazi and Mugisha [65], observed an inverted U-shaped relationship between farmers experience and agricultural technological adoption. Thus, it can be said that experience does not follow a linear relationship with certain farmers' outcomes including crop-diversification. In our case, we observe that, as a farmer continues to invest more time and resources to learn the rice production dynamics in the scheme, they would eventually be able to increase their profits. Farmer experience which is also positively associated with technology adoption [48,53] has the potential to influence farm yields thereby growing incomes.

Source of farm credit determined the direction of influence it has on the overall profit of their rice enterprise with those that accessed credit from DIFACOS registering positive influence. To access credit from DIFACOS, a farmer is mandated to have been fully registered with the SACCO. The SACCO besides other services extends credit to its members at modest interest rates and without collateral. This therefore explains why the farmers that access credit from DIFACOS were most likely able to earn a higher profit than their peers who get credit from sources like commercial banks, microfinance institutions and friends or family. This is in agreement with earlier studies by Abdul-rahaman & Abdulai [66] and Mojo et al. [55], that independently observed that limited access to credit countered farmers' productivity and efficiency levels by negatively impacting on their ability to procure inputs and source (hire) extra labour to meet the production requirements of their farm enterprises.

Farmers who receive extension services from the farmer associations and the private companies are able to earn higher profits from rice farming unlike their counterparts who received from government. It is important to note that if one is to receive extension services from a farmer association, there is a financial implication like membership subscription fees or farmer extension fees charged to willing members. Similarly, a private company offering extension service could be an output buyer or seed company who by the nature of their dealings are mandated to monitor the quality of rice right from production stages. There provision of extension services is thus linked to ensuring quality of the rice produce. Thus, the private company may also levy fees for registration or facilitating a memorandum of association. However, what characterizes a number of rural populations in SSA today is a mentality that Aliber [67] in his study on forms of agricultural support in Eastern Cape dubbed as – "a culture of dependency and entitlement", – that is explained by an innate desire to receive services at no cost synonymous to social grants. In as much as extension service from government is free, its quality has always been a subject of debate due to poor salaries and working conditions of extensions workers. Namyenya et al. [68] reported that some of the reasons that affected the quality of agricultural extension services in Uganda were low staffing, and low budget allocations. This is as opposed to non-state extension services which tend to be efficient since they focused on specific geographical location and contexts, making them to deliver even with small resource envelops. This could explain why, in this study, farmer group extension services were associated with higher profits for rice production.

In this study, rice profits were also influenced by choice of marketing channel. This was expected, given that competitiveness that comes with sale through certain channels. Donkor et al. [56] reported that although very few farmers sold their output to rice processors there received a better pricing than those that sold to middlemen. Exposure to direct marketing enables farmers to access profitable markets and eliminate middlemen who cheat them with very low pricing [69,70]. Similar observations were made by Ma-Azu et al. [71] in a study on rice marketing channels in Ghana. A study by Akite et al. [69] reported that marketing channel and marketing arrangement influences the status of and form of rice value chain upgrading in northern Uganda.

The positive relationship between legumes or roots crop categories on rice profitability is consistent with findings by Sánchez et al. [58] who in their study reported that net incomes were higher in diversified systems that combined cereals and pulses (classified as legumes in our study) as well as cereals and roots. To further support the above, De Roest et al. [22], asserted that diversified systems that provided for conditions where a farmer can use the same inputs to produce more than one output lowered the total costs of producing those outputs separately thus increasing their gross margin. The relatively lowered costs of production thereby translated to higher gross margins of the farm enterprises other factors held constant.

This study therefore affirms that in the context of a promoted crop, crop diversification enhances the profitability of the primary enterprise (rice farming). Thus, the evidence gathered in this study points to crop diversification as an important contributor in smallholder rice farmers' higher profitability in addition to being an effective risk management approach. Adopting these kinds of methods could make rice-growing businesses more robust and commercially successful.

6. Conclusion and policy recommendations

This study assessed the role of crop diversification outside a monocrop-based irrigation scheme on the profitability of the monocrop. The findings suggest that crop diversification outside a mono-crop irrigation scheme may be viewed as a calculated move to top into the synergistic effects of enterprise combinations, with an overall positive impact on profits. The positive influence of crop diversification on profitability of irrigation scheme produced rice signifies the complementarity of the diverse crops with the primary crop from the scheme. This is attributed to benefits accrued to using a diversified cropping system in such a monocrop-based irrigation scheme, from market potential to risk reduction and overall financial stability. The findings of this study also suggest the need for policies geared towards gender equality between male and female members in such monocrop-based schemes to be given priority. This is in a bid to create gender balance in terms of access to valuable resources that facilitate production processes. Governments and partner agencies ought to strengthen monitoring and evaluation of education programmes to ensure equitable and quality education is availed to the target population. In as much as there are several programs geared to the same, routine policy assessment in line with the core objective need not be ignored and this is paramount in facilitating deliverables. This study also suggests the need for the scheme to reform policies related to access and use of land. This is evidenced in the relatively smaller parcels of land reported in this study. Subsidies can be provided to farmers in relation to size of land they hire at the scheme which will act as an incentive for acquiring bigger land sizes that consequently improve the likelihoods of benefitting from larger production margins.

In as much as monocropping has its benefits, agricultural programs aimed at scaling up performance in multiple crop enterprises by households ought to be given priority by state and non-state actors. This can be by introduction of time saving technologies that are eco-friendly, affordable and tailored to suit the needs of the mono-crop irrigation farmer population, facilitate development of sound market information systems that clearly address demand and supply related parameters as well as address challenges related with access to finance so as to boost farmer capacities to run multiple crop enterprises.

Consent for publication

Not applicable.

Ethical approval

This study, which followed a survey research design involving farmers as participants. As such, ethical approval was necessary. Thus, the study was ethically approved by Gulu University Research Ethics Committee (GUREC), approval number: GUREC-2022–477. Following guideline from GUREC, informed consent was obtained from all participants and only consenting participants were included in the study.

Data of availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

CRediT authorship contribution statement

Lydia Amongin: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Daniel M. Okello:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Derrick O. Rubangakene:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Stephen W. Kalule:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Table A1
Model results for Tobit, Fractional probit and fractional logit. Model fit indices shows that the fractional probit was the best.

Variables	Tobit Regression		Fractional Probit		Fractional Logit	
	Coefficient	Robust Std. Err	Coefficient	Robust Std. Err	Coefficient	Robust Std. Err
Scheme land prop to total land	0.307***	0.058	0.874***	0.194	1.407***	0.310
Scheme land prop to total land squared	−0.091***	0.009	−0.258***	0.029	−0.417***	0.047
Farmer Scheme Experience	0.011	0.008	0.043*	0.024	0.070*	0.039
Level of Education	−0.002**	0.001	−0.008**	0.004	−0.013**	0.006
Gender of household head	0.027*	0.014	0.078*	0.042	0.126*	0.068
Extension Services	−0.043***	0.015	−0.090**	0.044	−0.135*	0.071
Access - Farm Credit	−0.010	0.009	−0.027	0.028	−0.044	0.045
Distance to Input Market	−0.013	0.010	−0.042	0.031	−0.066	0.050
Seed used is improved	0.029	0.021	0.084	0.063	0.141	0.103
Radio - Mkt Info Source	−0.056***	0.016	−0.192***	0.050	−0.304***	0.083
Other crops - Cereals	0.017	0.012	0.064*	0.034	0.102*	0.056
Other crops - Legumes	0.009	0.013	0.040	0.036	0.064	0.059
Other crops - Roots	0.034***	0.012	0.104***	0.035	0.172***	0.056
Other crops - Perennials	0.050***	0.016	0.151***	0.047	0.245***	0.075
Irrigation Cost	0.474***	0.172	1.509***	0.504	2.515***	0.823
Irrigation Cost squared	−0.019**	0.007	−0.060***	0.022	−0.101***	0.035
Rear Livestock	0.018	0.014	0.090*	0.046	0.145*	0.076
Constant	−2.346**	0.994	−9.217	2.887	−15.324	4.729
Number of Observations	385		385		385	
Prob > F/chi^2	0.000		0.000		0.000	
Pseudo R^2	50.982		0.1265		0.1252	
Log pseudolikelihood	397.316		−232.817		−233.170	
AIC	−758.632		499.634		500.341	
BIC	−687.473		566.839		567.546	

Note: ***, ** & * imply significance at $p < 0.01$, $p < 0.05$ and $p < 0.1$ respectively; Source: field survey.

References

[1] P. Ayella, A. Ishii, M. Satoh, A comparative analysis of two paddy irrigation schemes under contrasting water management of participatory and top-down systems in Uganda, Paddy Water Environ. 17 (3) (2019) 497–505, https://doi.org/10.1007/s10333-019-00745-y.

[2] J. Wanyama, E. Bwambale, P. Nakawuka, Comparative performance assessment of pilot irrigation schemes in Uganda, Heliyon 10 (10) (2024) e31600, https://doi.org/10.1016/j.heliyon.2024.e31600.

[3] Z. Ahmed, D. Gui, Z. Qi, Y. Liu, Poverty reduction through water interventions: a review of approaches in sub-Saharan Africa and South Asia, Irrig. Drain. 71 (3) (2022) 539–558, https://doi.org/10.1002/ird.2680.

[4] J. Wanyama, H. Ssegane, I. Kisekka, A.J. Komakech, N. Banadda, A. Zziwa, T. O. Ebong, C. Mutumba, N. Kiggundu, R.K. Kayizi, D.B. Mucunguzi, Irrigation development in Uganda: constraints, lessons learned, and future perspectives, J. Irrig. Drain. Eng. 143 (5) (2017) 04017003, https://doi.org/10.1061/(ASCE)IR.1943-4774.0001159.

[5] N. Mango, C. Makate, L. Mapemba, M. Sopo, The role of crop diversification in improving household food security in central Malawi, Agric. Food Secur. 7 (1) (2018) 7, https://doi.org/10.1186/s40066-018-0160-x.

[6] W. Tesfaye, N. Tirivayi, Crop diversity, household welfare and consumption smoothing under risk: evidence from rural Uganda, World Dev. 125 (2020) 104686, https://doi.org/10.1016/j.worlddev.2019.104686.

[7] T. Hien, Relationship between crop diversification and farm efficiency: does farm size matter? Eur. Rev. Agric. Econ. 52 (3) (2025) 334–377, https://doi.org/10.1093/erae/jbaf016.

[8] A. Mzyece, J.N. Ng'ombe, Crop diversification improves technical efficiency and reduces income variability in Northern Ghana, J. Agric. Food Res. 5 (2021) 100162, https://doi.org/10.1016/j.jafr.2021.100162.

[9] K. Ogundari, Crop diversification and technical efficiency in food crop production: a study of peasant farmers in Nigeria, Int. J. Soc. Econ. 40 (3) (2013) 267–287, https://doi.org/10.1108/03068291311291536.

[10] D.M. Okello, J. Bonabana-Wabbi, B. Mugonola, Farm level allocative efficiency of rice production in Gulu and Amuru districts, Northern Uganda, Agric. Food Econ. 7 (1) (2019) 19, https://doi.org/10.1186/s40100-019-0140-x.

[11] X. Wang, J. Cheng, J. Zhang, F. Chen, Influences of crop diversification on yield, resource use efficiency, and environmental footprint in farmland landscapes in intensive farming, Sci. Total Environ. 945 (2024) 174009, https://doi.org/10.1016/j.scitotenv.2024.174009.

[12] B.K. Barmon, E.R. Prince, A. Sultana, Crop diversification and its impact on income diversification and crop income in Bangladesh, Agroecol. Sustain. Food Syst. 49 (2) (2025) 269–295, https://doi.org/10.1080/21683565.2024.2416010.

[13] M.R. Bellon, B.H. Kotu, C. Azzarri, F. Caracciolo, To diversify or not to diversify, that is the question. Pursuing agricultural development for smallholder farmers in marginal areas of Ghana, World Dev. 125 (2020) 104682, https://doi.org/10.1016/j.worlddev.2019.104682.

[14] M.S. Islam, H. Jahan, N.S. Ema, M.R. Ahmed, Determinants of crop diversification and its impact on farmers' income: a case study in Rangpur District, Bangladesh, JSFA Rep. 4 (10) (2024) 352–361, https://doi.org/10.1002/jsf2.216.

[15] E. Kemboi, K. Muendo, C. Kiprotich, Crop diversification analysis amongst smallholder farmers in Kenya (empirical evidence from Kamariny ward, Elgeyo Marakwet County), Cogent Food Agric. 6 (1) (2020) 1834669, https://doi.org/10.1080/23311932.2020.1834669.

[16] Y. Kijima, Farmers' risk preferences and rice production: experimental and panel data evidence from Uganda, PloS one 14 (7) (2019) e0219202, https://doi.org/10.1371/journal.pone.0219202.

[17] T.P. Higginbottom, R. Adhikari, R. Dimova, S. Redicker, T. Foster, Performance of large-scale irrigation projects in sub-Saharan Africa, Nat. Sustain. 4 (6) (2021) 501–508, https://doi.org/10.1038/s41893-020-00670-7.

[18] D. Feliciano, A review on the contribution of crop diversification to Sustainable Development Goal 1 "No poverty" in different world regions, Sustain. Dev. 27 (4) (2019) 795–808, https://doi.org/10.1002/sd.1923.

[19] A. Kurdyś-Kujawska, A. Strzelecka, D. Zawadzka, The impact of crop diversification on the economic efficiency of small farms in Poland, Agriculture 11 (3) (2021) 250, https://doi.org/10.3390/agriculture11030250.

[20] T.B. Mihrete, F.B. Mihretu, Crop diversification for ensuring sustainable agriculture, risk management and food security, Glob. Chall. 9 (2) (2025) 2400267, https://doi.org/10.1002/gch2.202400267.

[21] R. Paut, R. Sabatier, M. Tchamitchian, Reducing risk through crop diversification: an application of portfolio theory to diversified horticultural systems, Agric. Syst. 168 (2019) 123–130, https://doi.org/10.1016/j.agsy.2018.11.002.

[22] K. De Roest, P. Ferrari, K. Knickel, Specialisation and economies of scale or diversification and economies of scope? Assessing different agricultural development pathways, J. Rural Stud. 59 (2018) 222–231, https://doi.org/10.1016/j.jrurstud.2017.04.013.

[23] S. Asfaw, A. Scognamillo, G. Di Caprera, N. Sitko, A. Ignaciuk, Heterogeneous impact of livelihood diversification on household welfare: cross-country evidence from Sub-Saharan Africa, World Dev. 117 (2019) 278–295, https://doi.org/10.1016/j.worlddev.2019.01.017.

[24] G. Dagunga, M. Ayamga, G. Danso-Abbeam, To what extent should farm households diversify? Implications on multidimensional poverty in Ghana, World Dev. Perspect. 20 (2020) 100264, https://doi.org/10.1016/j.wdp.2020.100264.

[25] M.K. Kansiime, P. van Asten, K. Sneyers, Farm diversity and resource use efficiency: targeting agricultural policy interventions in East Africa farming systems, NJAS-Wagening. J. Life Sci. 85 (2018) 32–41, https://doi.org/10.1016/j.njas.2017.12.001.

[26] C. Makate, R. Wang, M. Makate, N. Mango, Crop diversification and livelihoods of smallholder farmers in Zimbabwe: adaptive management for environmental change, SpringerPlus 5 (1) (2016) 1135, https://doi.org/10.1186/s40064-016-2802-4.

[27] A. Mzyece, J.N. Ng'ombe, Does crop diversification involve a trade-off between technical efficiency and income stability for rural farmers? Evidence from Zambia, Agronomy 10 (12) (2020) 1875, https://doi.org/10.3390/agronomy10121875.

[28] B. Tadesse, F. Bakala, L.W. Mariam, Assessment of postharvest loss along potato value chain: the case of Sheka Zone, southwest Ethiopia, Agric. Food Secur. 7 (1) (2018) 18, https://doi.org/10.1186/s40066-018-0158-4.

[29] G. Danso-Abbeam, G. Dagunga, D.S. Ehiakpor, A.A. Ogundeji, E.D. Setsoafia, J. A. Awuni, Crop–livestock diversification in the mixed farming systems: implication on food security in Northern Ghana, Agric. Food Secur. 10 (1) (2021) 35, https://doi.org/10.1186/s40066-021-00319-4.

[30] A.B. Dessie, T.M. Abate, T.M. Mekie, Y.M. Liyew, Crop diversification analysis on red pepper dominated smallholder farming system: evidence from northwest Ethiopia, Ecol. Process 8 (1) (2019) 50, https://doi.org/10.1186/s13717-019-0203-7.

[31] A.D. Jones, A. Shrinivas, R. Bezner-Kerr, Farm production diversity is associated with greater household dietary diversity in Malawi: findings from nationally representative data, Food Policy 46 (2014) 1–12, https://doi.org/10.1016/j.foodpol.2014.02.001.

[32] W. Mekuria, K. Mekonnen, Determinants of crop–livestock diversification in the mixed farming systems: evidence from central highlands of Ethiopia, Agric. Food Secur. 7 (1) (2018) 60, https://doi.org/10.1186/s40066-018-0212-2.

[33] A. Mzyece, V. Amanor-Boadu, J.N. Ng'ombe, Strategic value of crop diversification among farmers: new insights and measurement, World Dev. Sustain. 3 (2023) 100090, https://doi.org/10.1016/j.wds.2023.100090.

[34] J.L. Parré, A.L.S. Chagas, M.P. Arends-Kuenning, The effect of farm size and farmland use on agricultural diversification: a spatial analysis of Brazilian municipalities, Agric. Food Econ. 12 (1) (2024) 27, https://doi.org/10.1186/s40100-024-00323-9.

[35] G. Agitew, Z. Berhanie, S. Gebremedhin, Diversified production of smallholders in Northwest Ethiopia: implications for nutrition-sensitive agriculture, World Dev. Sustain. 8 (2026) 100273, https://doi.org/10.1016/j.wds.2026.100273.

[36] M.J. Chegere, J. Stage, Agricultural production diversity, dietary diversity and nutritional status: panel data evidence from Tanzania, World Dev. 129 (2020) 104856, https://doi.org/10.1016/j.worlddev.2019.104856.

[37] M.R. Kabir, O. Halima, N. Rahman, S. Ghosh, M.S. Islam, H. Rahman, Linking farm production diversity to household dietary diversity controlling market access and agricultural technology usage: evidence from Noakhali district, Bangladesh. Heliyon 8 (1) (2022) e08755, https://doi.org/10.1016/j.heliyon.2022.e08755.

[38] S. Khandoker, A. Singh, S.K. Srivastava, Leveraging farm production diversity for dietary diversity: evidence from national level panel data, Agric. Food Econ. 10 (1) (2022) 15, https://doi.org/10.1186/s40100-022-00221-y.

[39] M. Saaka, S.M. Osman, I. Hoeschle-Zeledon, Relationship between agricultural biodiversity and dietary diversity of children aged 6-36 months in rural areas of Northern Ghana, Food Nutr. Res. 61 (2017) 1391668, https://doi.org/10.1080/16546628.2017.1391668.

[40] K.T. Sibhatu, V.V. Krishna, M. Qaim, Production diversity and dietary diversity in smallholder farm households, Proc. Natl. Acad. Sci. 112 (34) (2015) 10657–10662, https://doi.org/10.1073/pnas.1510982112.

[41] D. Tobin, K. Jones, B.C. Thiede, Does crop diversity at the village level influence child nutrition security? Evidence from 11 sub-Saharan African countries, Popul. Env. 41 (2) (2019) 74–97, https://doi.org/10.1007/s11111-019-00327-4.

[42] F. Atube, O.B. Christopher, R.L. Labeja, D.M. Okello, C.N. Okumu, Determinants of finger millet farmers' choice of adaptation strategies to climate change in northern Uganda, Discov. Agric. 3 (1) (2025) 105, https://doi.org/10.1007/s44279-025-00277-6.

[43] P.S. Birthal, J. Hazrana, Crop diversification and resilience of agriculture to climatic shocks: evidence from India, Agric. Syst. 173 (2019) 345–354, https://doi.org/10.1016/j.agsy.2019.03.005.

[44] K.T. Erekalo, T.A. Yadda, Climate-smart agriculture in Ethiopia: adoption of multiple crop production practices as a sustainable adaptation and mitigation strategies, World Dev. Sustain. 3 (2023) 100099, https://doi.org/10.1016/j.wds.2023.100099.

[45] S. Bhat, D. Kumar, V. Paramesh, P. Kumar, N. Ravishankar, S. Kumar, P. Kashyap, V. Arunachalam, Enhancing farm profitability and sustainability through integrated farming systems: a case study of coastal Karnataka, India, Farming Syst. 1 (3) (2023) 100052, https://doi.org/10.1016/j.farsys.2023.100052.

[46] P. Ayella, A. Ishii, M. Satoh, Effects of irrigation water sufficiency on water fee collection rate in uganda's large-scale paddy irrigation schemes, Water 14 (10)) (2022) 1611, https://doi.org/10.3390/w14101611.

[47] A.M. Adam, Sample size determination in survey research, J. Sci. Res. Rep. 26 (5) (2020) 90–97, https://doi.org/10.9734/jsrr/2020/v26i530263.

[48] S. Alibu, M. Obura, J. Ekebu, D. Nampamya, J. Lamo, G. Asea, T.S. Park, Modest ag-extension and access to seeds of aromatic rice can boost returns of smallholder farmers in Uganda, a case study, Agriculture 12 (8) (2022) 1172, https://doi.org/10.3390/agriculture12081172.

[49] P. Fatch, C. Masangano, T. Hilger, I. Jordan, I. Mambo, J.F.M. Kamoto, A. Kalimbira, E.A Nuppenau, Holistic agricultural diversity index as a measure of agricultural diversity: a cross-sectional study of smallholder farmers in Lilongwe district of Malawi, Agric. Syst. 187 (2021) 102991, https://doi.org/10.1016/j.agsy.2020.102991.

[50] E.K. Morris, T. Caruso, F. Buscot, M. Fischer, C. Hancock, T.S. Maier, T. Meiners, C. Müller, E. Obermaier, D. Prati, M.C. Rillig, Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories, Ecol. Evol. 4 (18) (2014) 3514–3524, https://doi.org/10.1002/ece3.1155.

[51] L.E. Papke, J.M. Wooldridge, Econometric methods for fractional response variables with an application to 401 (k) plan participation rates, J. Appl. Econom. 11 (6) (1996) 619–632, https://doi.org/10.1002/(SICI)1099-1255(199611)11:6%3C619::AID-JAE418%3E3.0.CO;2-1.

[52] G.O. Adjimoti, G.T.M Kwadzo, Crop diversification and household food security status: evidence from rural Benin, Agric. Food Secur. 7 (1) (2018) 82. https://link.springer.com/article/10.1186/s40066-018-0233-x.

[53] S. Ruzzante, R. Labarta, A. Bilton, Adoption of agricultural technology in the developing world: a meta-analysis of the empirical literature, World Dev. 146 (2021) 105599, https://doi.org/10.1016/j.worlddev.2021.105599.

[54] G. Danso-Abbeam, D.S. Ehiakpor, R. Aidoo, Agricultural extension and its effects on farm productivity and income: insight from Northern Ghana, Agric. Food Secur. 7 (1) (2018) 74, https://doi.org/10.1186/s40066-018-0225-x.
[55] D. Mojo, C. Fischer, T. Degefa, The determinants and economic impacts of membership in coffee farmer cooperatives: recent evidence from rural Ethiopia, J. Rural Stud. 50 (2017) 84–94, https://doi.org/10.1016/j.jrurstud.2016.12.010.
[56] E.A. Donkor, E. Garnevska, M.I. Siddique, E. Donkor, Determinants of rice farmer participation in the direct marketing channel in Ghana, Sustainability 13 (9) (2021) 5047, https://doi.org/10.3390/su13095047.
[57] FAO, Cropping Systems Diversification to Enhance Productivity and Adaptation to Climate Change in Zambia, FAO, Rome, 2019.
[58] A.C. Sánchez, H.N. Kamau, F. Grazioli, S.K. Jones, Financial profitability of diversified farming systems: a global meta-analysis, Ecol. Econ. 201 (2022) 107595, https://doi.org/10.1016/j.ecolecon.2022.107595.
[59] R. Nandi, T. Jackson, A. Jannat, A. Ghosh, B. Mitra, K.R. Chakma, P. Timsina, A. Chaudhary, W. Rahman, E. Karki, G. Rana, T.J. Krupnik, P. Pokhrel, Status and drivers of crop diversification in the Eastern Gangetic Plains of South Asia: across borders and communities, J. Agric. Food Res. 20 (2025) 101776, https://doi.org/10.1016/j.jafr.2025.101776.
[60] U. Malaiarasan, R. Paramasivam, K.T. Felix, Crop diversification: determinants and effects under paddy-dominated cropping system, Paddy Water Environ. 19 (3) (2021) 417–432, https://doi.org/10.1007/s10333-021-00843-w.
[61] H.A. Awiti, E.O. Gido, G.A. Obare, Smallholder farmers climate-smart crop diversification cost structure: empirical evidence from western Kenya, Front. Sustain. Food Syst. 6 (2022) 842987, https://doi.org/10.3389/fsufs.2022.842987.
[62] A. Hepelwa, Potential of fragmented landholding on crop diversification and credit worthiness to smallholder farmers in Tanzania, Afr. J. Econ. Rev. 9 (4) (2021) 238–252.
[63] S.A. Emran, T.J. Krupnik, S. Aravindakshan, V. Kumar, C.M. Pittelkow, Impact of cropping system diversification on productivity and resource use efficiencies of smallholder farmers in south-central Bangladesh: a multi-criteria analysis, Agron. Sustain. Dev. 42 (4) (2022) 78, https://doi.org/10.1007/s13593-022-00795-3.
[64] L.J.S. Baiyegunhi, F. Akinbosoye, L.O. Bello, Welfare impact of improved maize varieties adoption and crop diversification practices among smallholder maize farmers in Ogun State, Nigeria, Heliyon 8 (5) (2022) e09338, https://doi.org/10.1016/j.heliyon.2022.e09338.
[65] J.H. Ainembabazi, J. Mugisha, The role of farming experience on the adoption of agricultural technologies: evidence from smallholder farmers in Uganda, J. Dev. Stud. 50 (5) (2014) 666–679, https://doi.org/10.1080/00220388.2013.874556.
[66] A. Abdul-Rahaman, A. Abdulai, Do farmer groups impact on farm yield and efficiency of smallholder farmers? Evid. Rice Farmers North. Ghana. Food Policy 81 (2018) 95–105, https://doi.org/10.1016/j.foodpol.2018.10.007.
[67] M. Aliber, Forms of agricultural support and the "culture of dependency and entitlement, Agrekon 58 (2) (2019) 141–153, https://doi.org/10.1080/03031853.2019.1575249.
[68] A. Namyenya, M. Zeller, P.B. Rwamigisa, R. Birner, Analysing the performance of agricultural extension managers: a case study from Uganda, j. Agric. Educ. Ext. 28 (3) (2022) 363–389, https://doi.org/10.1080/1389224X.2021.1932539.
[69] I. Akite, D.M. Okello, A. Kasharu, B. Mugonola, Smallholder farmers' contextual ingredients of process, functional and product upgrading strategies for improved competitiveness in Uganda's rice markets, J. Int. Food Agribus. Mark. 36 (4) (2024) 763–787, https://doi.org/10.1080/08974438.2023.2206817.
[70] M.J. Nystrand, Disentangling inequality and exploitation in the rice value chain in Northern Uganda, J. Agrar. Change 2026 (2026) e70090, https://doi.org/10.1111/joac.70090.
[71] A.J. Ma-Azu, A. Abdul-Rahaman, A. Zakaria, C.Y. Lamptey, Market channel participation amongst smallholder rice farmers in the northern region of Ghana, J. Agribus. Dev. Emerg. Econ. 14 (3) (2024) 622–636, https://doi.org/10.1108/JADEE-08-2022-0167.