


## Article

# Evaluating the Effect of Farmers' Participation in Irrigation Management on Farm Productivity and Profitability in the Mubuku Irrigation Scheme, Uganda

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**Abstract:** Irrigation remains a critical input into farming and, therefore, it remains a proxy for food security and poverty alleviation in developing countries. Despite their role in economic growth and the received investment, irrigation schemes are still underperforming. Among many irrigation schemes, transferring more management responsibilities to farmers proved to be a viable path toward improving performance. However, the large diversity of implementation strategies makes evaluation difficult, while its well-demonstrated benefits have paramount importance to convince reluctant smallholders to take additional roles. In order to address this gap, we analyze the effects of participation on farming outcomes (yield, revenue, net profit) by estimating the treatment effect. We present the case study of a Mubuku small-scale irrigation scheme, Uganda. We provide a framework to construct the Farmers Participation Index while distinguishing farmers into participating and not participating groups. The effects of participation are investigated through econometric methods including nonparametric and semiparametric estimation methods such as a difference in means, a regression adjustment, propensity score matching, and entropy balancing. The analysis reveals a positive and significant treatment effect of participation on farming outcomes. The obtained results endorse the efforts of governmental programs to foster responsibility transfer and the farmers' role in irrigation management. A strong causal relationship between management and profitability provides incentives for farmers to engage in participation.

**Keywords:** responsibility transfer; small-scale irrigation; Farmers Participation Index; farming outcomes; treatment effect

## 1. Introduction

Exploiting the potential of irrigation is particularly important in import-dependent, food-insecure developing countries, where the majority of the population is employed in agriculture. Despite their role in economic growth and the received investment, irrigation programs and established schemes are still underperforming in exploiting their potential [1–5]. Among many irrigation programs, transferring more management responsibilities to farmers proved to be a viable path toward improving scheme performance [6–8]. In order to reclaim the lost profit with respect to a tight budgetary situation,

governments started to pay attention to the importance of farmers' involvement in management in the 1980s [9]. Farmer participation in irrigation system management as a community-based design of development programs has grown into a key operational strategy since then [10]. According to dissimilar conditions of involved institutions, such strategies might be labelled differently: responsibility transfer, participatory irrigation management (PIM), turnover, irrigation management transfer (IMT), etc. Their primary objective is to reduce the role of government in irrigation management and transfer the responsibility to farmers [11]. In order to avoid conceptual interference, we apply the definition of Participatory Irrigation Management in this study, which refers to partial involvement of water users in irrigation management along with the government [12]. How did farmer participation evolve over time? Management transfer from the government agency to local communities was accelerated by governmental intentions to reduce the pressure on government expenses, to ensure sustainable financing and to tackle rapid deterioration of hydraulic structures [13]. This participative approach has rapidly gained recognition. Establishment of Water User Associations (WUA) spread worldwide to take responsibility of the three major domains of irrigation management, which includes water management, maintenance, and financial management [14]. In general, WUAs are groups of farmers operating in well-defined areas and are organized as a non-profit organization for partial or full irrigation management [15]. Beyond resource-efficient management, participation strategies line up with many further merits such as improving productivity and durability of irrigation systems, more in-system equity among farmers, and increased farming outcomes, such as yield and income [16]. Based on extensive experience in developing countries, Vermillion and Sagardoy declared that farmer participation in physical and financial management, as well as in decision-making is a cornerstone of improving performance [17]. However, there is no "one-size-fits-all" mechanism for farmers' involvement into irrigation management. Its implementation and the subsequent performance vary significantly among countries in accordance with the surrounding external and internal factors [13]. Technical conditions, governance, socio-economic environment, and resource endowments can be considered external factors. In addition, organizational structure, capacity, membership criteria, and operational mechanisms are the internal ones.

The number of studies evaluating the effect of farmer participation is ample. Brewer and Raju developed a typology for a variety of irrigation management transfers in India [18]. Based on seven dimensions, they defined four types of transfer policies and activities, whereas the Water User Association (WUA) and farmers have shared responsibilities in irrigation management. They found that implemented management transfers differ from each other in many ways. While farmers are involved marginally in some regions and full operation and maintenance (O&M) activities are transferred to WUAs, other regions assign O&M activities below the outlet level merely to farmers. Despite their diverse implementations, participants perceive positive effects of the programs on sustainability and productivity. Zinzani investigated the institutional changes in Central-Asia after transitioning, whereas collapse of the Soviet Union left the irrigation systems without clearly defined management roles. The dismantling and division of large-scale systems into small units led to institutional and organizational vacuum between the government and WUA in Kazakhstan. Due to weak technical skills and fragile financial strength of WUAs and farmers, governmental intervention is still required to distribute water for farmers not involved in any WUA [14]. Ndlovu et al. (2015) illustrated the identified shortcomings of management transfers to local communities in Zimbabwe such as poorly developed management skills and lack of technical support. Nevertheless, authors found that farmer participation in irrigation embraces the potential to enhance productivity [19]. The synthesis report prepared by Vermillion (1997) summarizes the measured impacts of management transfer in several countries. Sixteen case studies in total are presented to evaluate the effect on productivity and profitability. Regarding profitability, seven cases found somewhat increase, three cases showed decline after management transfer, and six cases acquired no data about changes. Furthermore, a positive effect on productivity was identified in 14 cases [20]. Transferring management to local communities is a case-specific task, which involves incurring costs and organizational or policy changes. It potentially

affects livelihoods. Therefore, its implementation requires careful planning and monitoring. Only those programs are acceptable, which ensure that benefits to farmers outweigh costs [13].

The widely varying implementation strategies makes the evaluation difficult. Furthermore, the paucity of data limits the ability to draw generalized lessons about the impacts, while well-demonstrated benefits of PIM is of paramount importance to convince reluctant farmers to take additional roles [21]. This is particularly the case in smallholder schemes of developing countries, where farmers are poorly resourced and their access to relevant information is cumbersome [22–24]. However, more than 80% of farmers are smallholders in Sub-Saharan Africa, so plugging the gap is crucial [25]. For this purpose, we seek answers to the following questions: How can causality between farmer participation in management and direct benefits be demonstrated? Is the measured effect robust enough to endorse farmers' involvement in governmental programs?

The relationship between farmer participation and agricultural productivity is less direct. We attempt to bridge this gap. In our research design, we provide a framework for measuring the degree of farmers' participation in management to complement the experimental literature on the effectiveness of Participatory Irrigation Management. In the current context, farmers are engaged to contribute to physical, financial, institutional, and decisional processes, while expecting that the additional benefits exceed the investment costs [26]. In other words, farmers' decisions to take additional management roles depends on how it supports their individual interests such as income, wealth, well-being, or any other social status-related factor [27]. This approach allows us to measure the degree of farmer participation in management and to estimate its direct effects on farming outcomes in the same time frame. Through the case study of the Mubuku irrigation scheme in a remote area of Uganda, the study estimates the effect of farmer participation on farming outcomes using empirical procedure. Another essential contribution of the paper is that the research is carried out in a data-scarce environment, where agricultural statistics are not available. After identifying locally available irrigation management practices, the Farmers Participatory Index (FPI) is constructed to categorize farmers into participating and non-participating groups. In the second step, the causal effect of FPI on farm revenue, profitability, and productivity is investigated by estimating the average treatment effect (ATE). The effects are investigated by four econometric methods, including two nonparametric and semiparametric estimation methods known as a difference in means, a regression adjustment, propensity score matching, and entropy balancing.

## 2. Materials and Methods

### 2.1. Study Area

The research covers a one-and-a-half-year period in 2017–2018 from establishing a dataset to analyze. The pilot area is the Mubuku irrigation scheme in Kasese district, in a remote area of Uganda. Kasese is promoted as a high priority area due to its excellent climatic conditions for agriculture. The sub-catchment plan of River Mubuku sets poverty alleviation to the core of the planned development programs. Improving food security and typical low-income levels is envisioned through more effective natural resource use and better farming practices for sustainable land and water management [28].

Ugandan National Water Policy regulates the establishment of User Associations of irrigators and herders to act as service providers based on performance contract. The monitoring and evaluation, as well as necessary back-up and supervision of irrigation activities remain the responsibilities of the government. While the government ensures gradual transfer of ownership of the irrigation facilities, associations are expected to collect funds in order to cover the operation and maintenance works. The Mubuku settlement scheme is not an exception to the adoption of the national policy. Its main objective is to provide decent livelihood in the area through the provision of agricultural facilities. The small-scale irrigation scheme consists of 540 hectare agricultural land cultivated by 167 farmers. According to the cropping pattern, rice, maize, and onion are produced primarily in two irrigation seasons per

annum. The three crops are produced in rotation in both humid and dry seasons. Furthermore tomato, beans, and mango are cropped randomly in small plot sizes. They occupy a significantly smaller production area compared to the three main crops. Crop selection is not restricted, although a governmental maize program provides several provisions for farmers such as delivering inputs, extension services, post-harvest technology (including drying and storing), and a guaranteed minimum farm gate price. The production is commercial, despite the fact that market conditions are often unpredictable. Farmers have little market power to influence farmgate prices and become exposed to fluctuations. Furthermore, sale is physically limited to Kasese district in the absence of transportation, post-harvest technologies, or warehouses. These market uncertainties are clearly strong incentives for farmers to prefer to grow low-profitability, but fixed-price maize. The system of gravity-fed surface irrigation such as Mubuku is of high importance in Sub-Saharan Africa [29]. Their broad application is due to low initial investment need and easy maintenance. However, surface irrigation through open canals has the lowest conveyance and application efficiency of 60% [30]. This low efficiency calls for local actions to reduce water loss, which are preferably inexpensive and can be performed by farmers. In Mubuku, irrigation is scheduled in dictated rotation, which allows the irrigation of one block of farm (around 0.8 hectare) every four days. Rigid irrigation turns force farmers to improve their on-farm water management to its maximum potential. The Scheme has recently undergone a project led by Food and Agriculture Organization of United Nations (FAO) to improve agricultural water management through enhanced water use efficiency and crop water productivity [31]. According to the findings of the project, improving irrigation with “hard-path” approaches such as re-engineering solutions are not enough. Complementary “soft-path” measures could increase the irrigation efficiency and improve farming outcomes. These management practices must ensure that farmers can maximize the benefits of farming while keeping production costs low [32].

## 2.2. Study Design and Data

Farmers Participatory Index (FPI) is constructed in two steps. In the first step, management activities available for farmers are identified and selected. In the second step, farmers are ranked according to their engagement in these practices. The chapter provides insight into the process of implementing FPI.

In order to identify farmers’ participatory management activities, qualitative methodology was carried out in the Scheme. FAO-developed Mapping System and Services for Canal Operation Techniques (MASSCOTE) is applied to assess the performance of irrigation management in the Phase II of the Mubuku Irrigation Scheme. The overall goal of the MASSCOTE approach is to maximize irrigation efficiency by providing equally accessible and high-quality water delivery service [33]. As the first step of MASSCOTE, a Rapid Appraisal Procedure (RAP) is carried out to establish a baseline assessment of performance (Rapid Appraisal Procedure is developed in a set of Excel spreadsheets, and is available as part of the FAO Irrigation and Drainage Paper 63: Modernizing irrigation management—the MASSCOTE approach). The RAP consists of a systemic set of procedures for diagnosing the deficiencies and potentials of the irrigation system. It allows us to identify and prioritize both infrastructural and management improvement strategies. Likewise, RAP is suitable to map the operation and management practices at an institutional level and a farmers’ level. The appraisal evolves various steps: (i.) assessment of key performance indicators regarding irrigation efficiency, management, conditions, and operation of the system and an overall water delivery service, (ii.) analysis of operation and maintenance (O&M) mechanisms, (iii.) identification of the bottlenecks of management, and (iv.) recommendations drawn for improvement. The RAP elaborates the analysis of the irrigation system through multilayer management. Each layer provides water service to the successive layer, from the water source to the final deliveries to farms [34]. The appraisal results in a set of composite indicators known as external and internal indicators. Each composite indicator is computed from sub-indicators with assigned weights. Weights are defined according to the contribution of indicators to an efficient and high-quality water service. This sequential

approach not only results in the identification of O&M activities, but also enables the distinction of management responsibilities over the previously mentioned major domains such as water management, maintenance, and financial management. The same surveys of RAP are conducted at multiple levels in Mubuku: (i) managers of local WUA, called Abasaija Kweyamba Mubuku Farming Cooperative at the management level, (ii) division leaders at the secondary canal level, and (iii) upstream and downstream farmers per each Division at the farm level. The appraisal is also decomposed along the shared management responsibilities. The current management scheme distributes the responsibilities between the Cooperative and farmers. Although the scheme has been established for decades, the management transfer from public authorities to farmers remains imperfect, and asymmetries included responsibility distribution. The Cooperative is responsible for the major maintenance works at the main canal level and the secondary canal level, such as repairing canal banks and maintaining the inspection roads and hydraulic structures. In addition, the Cooperative schedules the irrigation turns from the main canal level to the secondary canal level. Farmers are responsible for distributing water among each other below the secondary level. The elected Division leader arranges the irrigation turns among the farms, and requests an additional water supply in case of need. The farmers are responsible to maintain and operate the hydraulic structures from the tertiary level. The majority of farmers have no effective mean to carry out major maintenance work, which leads to a significant decrease in water use efficiency at the tertiary level. For water services, farmers are required to pay fees. The fee collection efficiency is about 85% when data recording. The degree of farmers' participation in the operation, maintenance, and management varies according to their facilities, expertise, knowledge, and financial background. In order to measure the farmers' participation, Farmers Participatory Index is established.

Based on the RAP results, performance-improving variables as management activities were selected to define involvement in management. Table 1 shows the compiled list limited to the 14 management activities, which can be pursued in a small-scale canal system. In accordance with the three major domains, these activities are grouped as follows.

The current definition of FPI is composed of these variables. In Mubuku, possibilities of farmer participation in irrigation management are limited to these activities, but the degree of their engagement varies. Further criteria for selecting activities include equal access for all farmers. Since unequal water distribution among farmers causes continuous conflicts, activities which discriminate downstream farmers are eliminated [35]. Based on the RAP definition, the assigned weights to variables correspond to their potential positive effect on system performance, such as irrigation-efficient management at the scheme level. In order to set standard weights for practices and align them to the overall objective of Mubuku scheme, a literature review is undertaken, which is followed by validation through the local expert pool [36–40]. While considering the weights according to RAP, the most important piece of criteria was the direct effect on improved water delivery service. Budgetary issues, when farmers contribute to the overall O&M, receive the lowest weight. Activities on capacity-building, overall management arrangement, direct investments, and interventions in irrigation structures receive medium weight. High weights are assigned to maintenance and water control activities. In order to be consistent with sustainability and socioeconomic objectives of the settlement scheme, equal access to water distribution is of the highest importance. Where there is equal access to water resources, the impact of improved irrigation management is more likely to reduce poverty. Therefore, the water allocation arrangements, and, more specifically, the adjustment of the water rate to crop demand and re-distribution of the water supply among farmers receive the highest weight.

In the second step, simple random sampling was carried out involving all farmers in Mubuku. Furthermore, 122 farmers out of a total of 167 farmers are sampled. Other farmers either declined to answer or were not available at the time of the survey. The surveyed farmers follow the typical cropping pattern: maize, rice, and onion. The semi-structured survey records (i) farmers' characteristics in the first block, (ii) pursued management activities in the second block, and (iii) farm economics data in the third block. In order to achieve the highest degree of comparability, farmers who produced



maize in the growing season are preferably involved. Although tomato, beans, and mango are also produced in the Scheme, the size of the production plots is marginal, and their production practices and profitability are not available. The survey is conducted after the harvesting period of the first season from June to July 2018. In order to validate the farm economics data, a local extension service is surveyed to obtain control values. In order to calculate FPI, the second block of the survey is investigated (pursued management activities). This block involves a dichotomous scale (“Yes” or “No”) for about 14 management practices. Each farmer provided a binary response according to pursued management activities. Farmers are scored by considering these activities and their corresponding weights. Engagement in management activities is considered voluntarily assuming that the farmers pursue them only if additional cost results in higher benefits. The Farmers Participatory Index (FPI) categorizes farmers into two groups. Farmers achieving higher scores than  $FPI = 0.5$  are pooled into the participating group while others are pooled into the non-participating group. Table 2 presents the aggregated scores of participating and non-participating groups.

**Table 1.** Identified management activities based on the RAP method.

Irrigation Management Domains	Identified Management Activities (Variables) of Farmers	Corresponding RAP Indicators
Water management	1. Measure water discharge. 2. Observation of irrigation demand of crop and consequent adjustments of the flow rate. 3. Visiting other schemes to follow good practices. 4. Cooperation with other farmers to re-distribute the water supply. 5. Regular participation in irrigation training organized by the WUA or other institutes. 6. Regular participation in an extension service related to irrigation. 7. Attending meeting in irrigation turn planning. 8. Other water-management techniques applied in the scheme.	“Service and Social Order,” “Main canal appraisal,” “Second level canal appraisal,” “Third level canal appraisal,” “Final deliveries,” “Field Irrigation Efficiency,” “Command area Irrigation Efficiency”
Maintenance	9 Weeding, bushing, reshaping tertiary/quaternary canals on a regular basis. 10. Regular manual work on the irrigation structure. 11. Consultation with WUA officers for maintenance. 12. Private investment on the irrigation structure on a yearly basis.	“Main canal appraisal,” “Second level canal appraisal,” “Third level canal appraisal,” “Final deliveries,” “Budget, Employees, WUAs”
Financial management	13. Contribution (in-kind or cash) to canal maintenance—above the regular water fee. 14. Regular payment of water fee.	“Budget, Employees, WUAs”

**Table 2.** Summary table of Farmers Participation Index survey in the Mubuku irrigation scheme, N = 122 (2018).

Variables	Average Scores of Farmers-Participation Index			
	Standardized Weights	Participating Farmers	Non-Participating Farmers	All Farmers
1. Contribution (in-kind or cash) to canal maintenance—above the regular water fee	0.01	0.005	0.0021	0.0035
2. Regular payment of water fee	0.01	0.005	0.0027	0.0037
3. Visiting other schemes to follow good practices	0.02	0.008	0.0074	0.0075
4. Regular participation in extension services related to irrigation	0.03	0.020	0.0097	0.0145
5. Consultation with WUA officers for maintenance	0.03	0.022	0.0121	0.0170
6. Regular participation in irrigation training organized by the WUA or other institutes	0.05	0.034	0.0081	0.0209
7. Attending meeting in irrigation turn planning	0.05	0.039	0.0331	0.0361
8. Private investment in the water irrigation structure on a yearly basis	0.05	0.028	0.0258	0.0266

Table 2. Cont.

Variables	Average Scores of Farmers-Participation Index			
	Standardized Weights	Participating Farmers	Non-Participating Farmers	All Farmers
9. Other water-management techniques applied in the scheme (tillage techniques, etc.)	0.05	0.003	0.0000	0.0016
10. Regular manual work on irrigation structures	0.1	0.077	0.0177	0.0467
11. Weeding, bushing, reshaping tertiary/quaternary canals on a regular basis	0.1	0.090	0.0677	0.0787
12. Measure water discharge	0.1	0.005	0.0016	0.0033
13. Observe irrigation demand of crop and consequent adjustments of the water rate	0.2	0.127	0.0065	0.0656
14. Cooperation with other farmers to re-distribute the water supply	0.2	0.193	0.1613	0.1770
Overall FPI	1	0.65	0.35	0.50

Through the computing of FPI, 60 farmers are categorized into the participating group and 62 farmers are categorized into the non-participating group from the total sample of 122 farmers. The non-participating group corresponds to the control group, and the participating group corresponds to the treatment group in the study. In order to compare these two groups, socio-economic and farming characteristics are observed. Smallholders in the Mubuku scheme are under-resourced in terms of mechanics, access to production inputs (quality seeds), or production equipment. The climatic and environmental conditions are homogenous across the scheme. Therefore, the number of optional characteristics is limited. The following variables are recorded: educational background, gender, age, number of people living in the household, information held on irrigation, frequent experience of water shortage, waterlogging and/or failing production, and access to information systems. A difference in means is used to compare treatment and control groups by characteristics such as:

$$t = \frac{\overline{X}_A - \overline{X}_B}{\sqrt{\frac{S_A^2}{n_A} - \frac{S_B^2}{n_B}}} \quad (1)$$

where  $\overline{X}_A$  and  $\overline{X}_B$  are the means of each group,  $S_A$  and  $S_B$  are the sample standard deviations of the groups, and the  $n_A$  and  $n_B$  are the numbers of populations per group.

As Table 3 reports, the major difference of the characteristics between the two groups lies in their educational background. According to the two-sample non-parametric test, the difference in means for both the education level and participation in irrigation training are statistically significant. Meanwhile, the gender and age categories are balanced between the two groups. However, it is noteworthy that both groups experience water supply shortcomings despite their sufficient water sources. Farmers' single income derives from agriculture in Mubuku, even though they lack a long experience in agriculture. Each household has around 3.4 hectares land to produce food for both household consumption and the market. The large number of household members reflects the pro-poor role of agriculture in the area. Increasing yield and income through improved agricultural practices is the primary mean of combating poverty and food insecurity in Mubuku.

**Table 3.** Difference in means of observable characteristics between treatment and control groups.

Characteristics	Total Sample	Control	Treatment	Difference	p Value
Education level <sup>1</sup>	1.361	1.194	1.533	−0.339	0.011 *
Gender <sup>2</sup>	0.730	0.726	0.733	−0.007	0.926
Age <sup>3</sup>	4.582	4.597	4.567	0.030	0.819
Number of household members	7.975	7.339	8.633	−1.294	0.055
Attended irrigation training <sup>4</sup>	0.648	0.548	0.750	−0.201	0.019 *
Frequent experience of water shortage or waterlogging <sup>4</sup>	0.393	0.435	0.350	0.085	0.338
Frequent experience of failing production <sup>4</sup>	0.484	0.500	0.467	0.091	0.715
Access to information system <sup>4</sup>	0.811	0.790	0.833	−0.043	0.547
<b>Outcome Variables</b>					
Average revenue <sup>5</sup>	3134	2901	3375	−474	0.0003 ***
Average profit <sup>6</sup>	1270	1047	1501	−453	0.0000 ***
Productivity <sup>7</sup>	2.04	1.90	2.19	−0.29	0.014 *

Note: Null hypothesis (H0) = there is no significant difference between the two samples. \* corresponds to  $p \leq 0.05$ , where 0.05 is the significance level of the probability value. \*\*\* corresponds to  $p \leq 0.001$ , where 0.001 is the significance level of the probability value. <sup>1</sup> Education level: 1 = “primary,” 2 = “secondary,” 3 = “advanced,” 4 = “university.” <sup>2</sup> Gender: 1 = “male,” 0 = “female.” <sup>3</sup> Age: 1 = 15–25, 2 = 26–35, 3 = 36–45, 4 = 46–55, 5 = above 55. <sup>4</sup> Attended irrigation training. Frequent experience of water shortages or waterlogging. Frequent experience of failing production. Access to the information system: 0 = “No,” 1 = “Yes.” <sup>5</sup> Average revenue: thousand Ugandan shilling per acre. <sup>6</sup> Average profit: thousand Ugandan shilling per acre. <sup>7</sup> Productivity: tons per acre.

Table 3 includes the outcome variables: average revenue (thousand Ugandan shilling per acre), average profit (thousand Ugandan shilling per acre), and productivity (tons per acre). The study investigates the impact of the participation on these variables. Net profit and productivity are calculated from recorded yield, production cost per unit, and production revenues per unit. Assuming that farmers’ goal is to reach the highest profit possible and the irrigation scheme allows them to select their crops, then revenue and net profit are applicable outcome variables even in a multi-cropping system. Unlike production revenue, net profit is a residual income for consumption and off-farm expenditures. Accordingly, net profit is more adequate in rural development programmes where agriculture plays a crucial role in increasing household income. The issue of revenue and net profit variables is their complexity and dependency on other production conditions. Fluctuating market results in uncertainties in establishing a direct relationship between irrigation water as production input and profitability. The evaluation requires a supplementary variable to overcome the contingency on the demand side. Therefore, productivity is introduced to complement the monetary variables. The productivity outcome variable (N = 95) is limited to maize producing farmers. Yield is measured after post-harvest weighing as being healed and dried maize seeds are for direct consumption. Since the maize programme ensures equal opportunity for all farmers with guaranteed input supply and trigger price, this variable is independent from market uncertainties. The subsidies of the maize programme encourage farmers to raise the efficiency of inputs, and to put additional effort in the production. The values of outcome variables are validated by control surveys to eliminate outliers. The control surveys are compiled with a local extension service and investigated the cost-benefit analysis of each crop. The survey details the costs of production per variable costs and fixed costs. In addition, the control survey includes the market price during the research period. The results of control surveys can be found in Appendix A. The values differ significantly from the control surveys, are marked as outliers, and are removed. Simple difference in means of the outcome variables is reported in Column 5. The difference of means is statistically significant for each variable, whereas the participating group reaches higher average values. However, alternative methods are introduced, to avoid the possible biased estimate obtained by simple difference in means. Therefore, the study further investigates the estimates of outcome variables’ differences through more sophisticated statistical approaches to account for the groups’ characteristics. In other words, we estimate the level of difference of average revenue, average profit, and productivity between the participating and non-participating groups.



### 2.3. Estimation Method

The effect of farmers' participation in management is measured on three farming outcomes: farm revenue, profitability (Ugandan shilling per acre, UGX) (Exchange rate in the time of surveying: 1 USD = 3732.26 UGX), and productivity (tons per acre). The study investigates how these outcomes vary according to the binary treatment of participating or non-participating groups in management. As mentioned before, participating and non-participating groups correspond to treated and control groups, respectively. Beyond the difference in means, three alternative econometric methods are used to estimate the effect, which include a regression adjustment, propensity score matching, and entropy balancing.

Regression specification is calculated as:

$$Y_i = \beta_0 + \beta_1 T_i + \beta_2 X_1 + \varepsilon_i, \quad (2)$$

where  $Y_i$  measures various outcomes, e.g., profitability or productivity of farming for individual  $i$ .  $\beta$  is the effect of predictor,  $T_i$  is the binary indicator of the treatment variable, as part of participation in management, and  $X_1$  is the vector of characteristics covariates such as education level, gender, age, number of household members, attendance in irrigation training, frequent experience of water shortage, frequent experience of failing production, and access to the information system.

As another alternative strategy, the study attempts to establish counterfactual analysis by replicating the characteristics of the participating (treatment) group for the non-participating (control) group [41]. A vast number of literature deals with establishing a causal effect relationship between factors mostly in an experimental and a quasi-experimental design. Matching is a widely used non-experimental method of evaluation that can be applied to measure the effect of participating in a program [42]. This approach is particularly useful for research studies in remote areas, where sampling can be done only once [43]. The concept is to find one or more non-participating farmer(s) with a similar conditional treatment probability for each participating farmer by obtaining a propensity score. In other words, the performed evaluations are based on the comparison between one group of units that received certain "treatment" (treated) and the other group of units, which did not receive such "treatment" (control). These matches are chosen according to the similarity in observed characteristics of each group member. Many evaluations and studies of different programmes aimed at measuring the effect and the degree of the effect on the outcome assume that "the treatment received by one unit does not affect other units' outcome" [44,45]. In other words, estimation of the effect of farmer participation on the outcome variables of revenue, profitability, and productivity aims at answering the following question: What would have happened to non-participating farmers if they had participated in management? Methods using effective matching on critical variables are generally robust enough to minimize statistical bias, imbalance, or inefficient group identification [46]. Therefore, they prove to be more appropriate in comparing two groups. Average treatment is estimated by the equation below.

$$ATT = E(Y_{i1} - Y_{i0} | T = 1), \quad (3)$$

where  $T$  is the binary treatment variable (participation),  $i1 = 1, \dots$ , and  $Y_{i1}$  indicates the outcome that received treatment ( $T = 1$  indicates the participation, 0 otherwise). Generally, the treatment effect is defined as the average difference in outcome variables of treated and weighted non-treated matched characteristics.

$$\hat{\Delta}_{\text{match}} = \frac{1}{N_1} \sum_{i:T_i=1} \left( Y_i - \sum_{i:T_j=0} W_{ij} Y_j \right), \quad (4)$$

where  $N_1$  is the number of treated observations, and  $W_{ij}$  is the weight of outcome of nontreated observation  $j$  after matching the treated observation unit  $i$ .

The classic evaluating problem is to find  $E(Y_{10}|T = 1)$  when only  $E(Y_{10}|T = 0)$  is available. Rosenbaum and Rubin worked out the propensity score matching as the most widely-used matching approach [47]. The propensity score is defined as the probability of treatment, or as the probability of participation in management. The model is estimated by explaining the treatment/participation by several observable characteristics (set of characteristics  $X = x_1$ ), and the prediction of this estimation is used to create a propensity score ranging from 0 to 1. The choice of variables is at a critical stage of estimating propensity scores by the logit or probit model [48]. In the study, participating farmers are matched to non-participating farmers with some similar characteristics by using the following equation.

$$t(X) = Tr\{D = 1|X\} = E\{D|X\} \quad (5)$$

where  $D$  is the indicator of exposure to treatment (participation), and  $X$  is the multidimensional vector of characteristics. Propensity scores are derived from the standard probit model as shown below.

$$Tr\{D_i|X_i\} = \frac{e^{\lambda h(X_i)}}{1 + e^{\lambda h(X_i)}} \quad (6)$$

where  $h(X_i)$  is the function of covariates with linear and higher order terms. The comparison of estimated propensity scores increases the reliability of the estimation strategy by assessing the similarity between treated and control groups. Matching the treated unit to the nearest control unit in terms of propensity scores ensures the highest comparability between groups.

Lastly, entropy balancing is introduced as a methodology to achieve a balancing property, which involves a reweighting process to incorporate a covariate balance into the weight function [49]. This function is applied in the sample unit. Entropy balancing is necessary when covariates are significantly different between treatment and control groups. Weights for the control group are defined to seek exact balance between covariates, and to minimize loss function  $H(\omega)$ . In the first step, weights are assigned to the control observations by the reweighting scheme to match their characteristics to treated observations. The balancing scheme, which consists of reweighting a set of units, enables similar statistical pre-moments of covariates (e.g., skewness, mean, variances, etc.). After reaching moment-independent covariates, the counterfactual mean can be defined as:

$$E[\hat{Y}(0)|T = 1] = \frac{\sum_{(i|T=0)} Y_i \omega_i}{\sum_{(i|T=0)} \omega_i} \quad (7)$$

where  $\omega_1$  is the weight assigned to the control observation based on the  $H(\omega)$  reweighting scheme minimizing the distance between the distribution of estimated control weights and the distribution of the base weights. The weights are adjusted as much as needed to eliminate balance constraints, while keeping the maximum possible information in reweighted data as shown below.

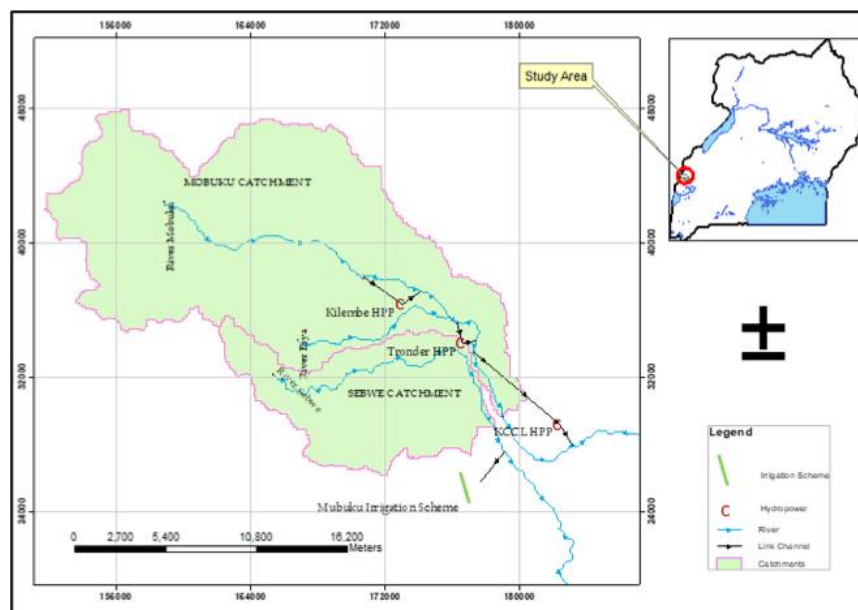
$$\min_{\omega} H(\omega) = \sum_{(i|T=0)} \omega_i \log \frac{\omega_i}{q_i} \quad (8)$$

The key advantage of entropy balancing is the simplicity of balancing the property of covariates. As the entropy distance metric shows, estimated weights of observations remain as close as possible to the base weights to minimize loss of information.

### 3. Results

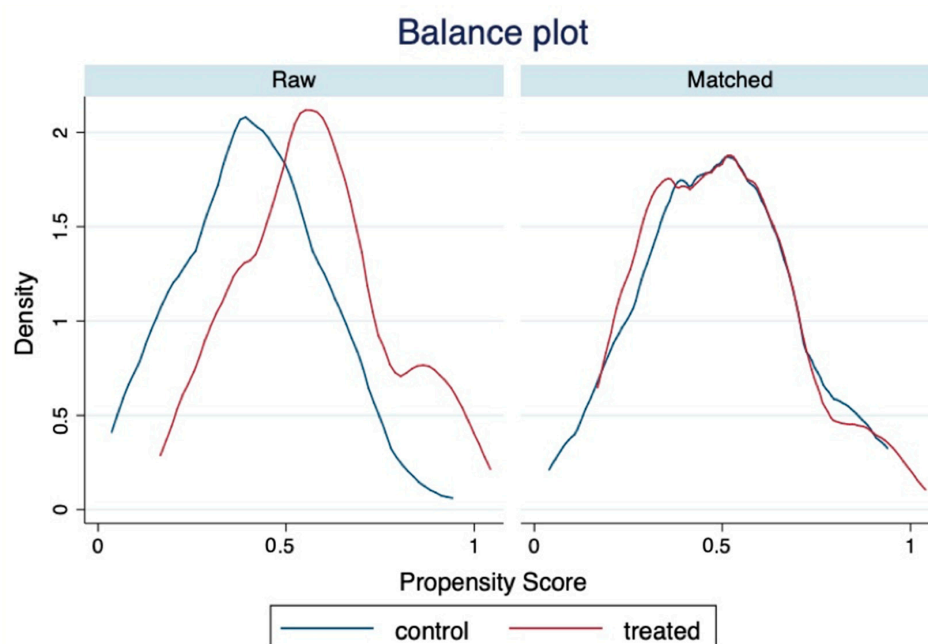
A total of 122 farmers are included in the estimation of the revenue and profitability outcome variables, and 95 maize-growing farmers are analyzed for the productivity variable. Propensity score matching is derived from the probit model whereas FPI is the treatment variable. The farmers' observed characteristics are the treatment independents, and revenue, profitability, and productivity are the

outcome variables. Matching estimators hold the assumption that characteristics are comparable in both treatment states. Figure 1 provides balance plot before and after matching.



**Figure 1.** Mubuku irrigation scheme in Sebwe-catchment (source: Food and Agriculture Organization, “Strengthening agricultural water efficiency and productivity on the African global level” project documents).

Prior to matching, some non-overlapping areas are observed, but, after matching, decent overlap is created in the propensity score distribution as Figure 2 displays. In order to reach an unbiased estimate of the average causal effect, characteristics must be fully balanced across different treatment states. Table 4 presents balancing *t*-tests of the matched sample, which indicates improvement in almost all characteristics after matching.



**Figure 2.** Balance plot of the propensity score before and after matching (created by `psmtest`, `tbalance density` command in STATA).

**Table 4.** Balancing *t*-test after propensity score matching.

Variable	Mean			t-Test	
	Treated	Control	% Bias	<i>t</i>	<i>p</i> > <i>t</i>
Education level	1.370	1.444	−10.0	−0.54	0.591
Gender	0.740	0.666	16.5	0.84	0.404
Age	4.5926	4.425	22.9	1.03	0.303
Attended irrigation training/course	0.722	0.740	−3.9	−0.22	0.830
Frequent experience of water shortage or waterlogging	0.333	0.296	7.6	0.41	0.682
Number of household members	8.111	7.611	13.5	0.91	0.364
Access to information system on production and water use	0.814	0.833	−4.7	−0.25	0.803

Table 5 summarizes the treatment effects for the outcomes of revenue, profitability, and productivity. Columns 2, 3, 4, and 5 report the mean differences, estimates by regression adjustment, propensity score matching, and entropy balancing, respectively. Column 2 shows the mean differences in outcome variables across the control and treatment groups. The estimates based on regression adjustment, propensity score matching, and entropy balancing are reported in Columns 3, 4, and 5, respectively. The table shows the increase of outcome variables that could be achieved if all farmers engaged themselves in the identified irrigation management practices.

**Table 5.** Treatment effects for the outcomes of revenue, profitability, and productivity.

Outcomes	Mean Difference	Regression Adjustment	Propensity Score Matching nn(1)	Entropy Balancing
Average yield of production <sup>1</sup>	0.294	0.396	0.332	0.372
st. error	0.118	0.143	0.166	0.155
t stat	2.49	2.76	1.99	2.39
Average revenue per acre <sup>2</sup>	474.40	437.63	584.29	408.75
st. error	126.75	140.43	179.25	148.73
t stat	3.74	3.12	3.26	2.75
Average profit per acre <sup>3</sup>	453.95	523.74	427.47	463.01
st. error	103.53	112.92	150.99	120.02
t stat	4.38	4.64	2.83	3.86

<sup>1</sup> Average yield of production: tons per acre. <sup>2</sup> Average revenue per acre: thousand Ugandan shilling per acre.

<sup>3</sup> Average profit per acre: thousand Ugandan shilling per acre.

Our estimation suggests that farmers' involvement in management has a positive and significant effect on all outcome variables according to each alternative method (regression adjustment, propensity score matching, and entropy balancing). According to maize's growth results, farmers can reach higher yield with an average of 0.396, 0.33, and 0.372 tons per acre estimated by regression adjustment, propensity score matching, and entropy balancing, respectively. As farmers cultivate 3.4 acre land in multi-cropping, farmers' participation in irrigation management can result in higher yield with an average of 2.2 tons per household on a yearly basis. This significant achievement in improving yields can contribute to the overarching goals of achieving food security and reaching export markets. The governmental maize programme sets the objectives to strengthen the role of maize in the daily diet, and to supply export markets to countries suffering from a chronic maize deficit, such as in South-Sudan. As a key part of Uganda's development strategy, maize production is a potential sector to increase its share in regional and global markets.

The positive effect of farmer participation on farm economics gained statistical evidence. Based on the results of propensity score matching, farmers pursuing the identified activities can reach more revenue with around 580,000 Ugandan shilling and more profit with 427,000 Ugandan shilling per acre. Beyond propensity score matching, regression adjustment and entropy balancing also resulted in a statistically evident and positive effect on farmer participation. The selection of irrigation management practices may play an important role in improving farming outcomes while avoiding high additional costs. In the current design, we recommend only inexpensive and accessible practices obtained by RAP assessment, which do not require large investments or operating costs. The positive treatment effect

proves that simple practices strengthen the pro-poor impact of irrigation by demonstrating measurable revenues for farmers.

#### 4. Discussion

Evaluating the effects of farmers' participation in irrigation management is a key issue of development programmes to address food insecurity and low-income of smallholders. This paper focuses on a case study of practical implementation of Participatory Irrigation Management. So far, national policies transmitted PIM into strategies such as farmers' institutionalized contribution through WUAs, and not as individually measured efforts. Although, responsibility transfer of PIM directly involves farmers in irrigation management practices. This approach allows us to measure the direct effect of farmers' participatory approach on their farming outcomes. Our study complements the existing research by closing the gap in investigating PIM strategies and prove the legitimacy of responsibility transfer to farmers. The estimation of the effect of farmer-centered development can be performed by constructing the Farmers-Participatory Index. Categorizing farmers based on FPI allows their comparison in terms of farming outcomes. As a result, causality between farmer participation and direct benefits can be demonstrated. However, it is important to note that available practices vary according to the features of the scheme and require careful selection. Many small-scale schemes in Africa are under-resourced, which leads to shortfalls in O&M and investment feasibility. Therefore, this study builds on soft measures of PIM, which can be done by farmers without high investment needs. As many other schemes in Sub-Saharan Africa, the Mubuku irrigation scheme is under pressure to deliver maximum benefits for farmers, who rely on agriculture to ensure food for their families and a decent income. Irrigation management practices can be introduced only if they do not jeopardize farmers' financial situation, and their effects are measurable. The study applies four econometric methods including two alternative strategies to provide a robust analysis. The applied methodologies help overcome many uncertainties, which often violated the evaluations of agricultural development programmes such as the non-experimental nature of data, a nonlinear causal relationship, and data scarcity. Estimating the average treatment effect by regression adjustment, propensity score matching, and entropy balancing delivers more reliable results to measure the impact of PIM. Due to the lack of credible information, many farmers still refuse to take additional responsibilities in management. This analysis reveals positive and significant treatment effects of participation on farming outcomes such as on revenue and net profit. The results endorse the efforts of governmental programmes to promote farmers' involvement in irrigation management as an effective tool of delivering pro-poor outcomes. PIM strategies need to be further fostered in national strategies to complete responsibility transfer and find a sufficient level for farmers' active role in management. By creating a strong causal relationship between improved irrigation management practices and farm profitability, it provides incentives for farmers to engage in irrigation management.

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## Appendix A

**Table A1.** Cost-benefit analysis of maize production (in UGX) in Mubuku, 2018.

Costs				
Cost	Unity	Quantity	Unit Price	Total Price
Seed	ha	1	-	-
NPK	bags	6	120,000	720,000
Urée	bags	6	120,000	720,000
DAP	bags	6	100,000	600,000
Herbicide total	l	2	20,000	40,000
Herbicide selective				-
Insecticide system				-
Insecticide contact	containers	4	7000	28,000
Fungicide for seeds				-
Fungicide for growth	containers	6	7000	42,000
Cleaning	ha	1	140,000	140,000
Nursery	not used			-
Labour	ha	1	200,000	200,000
Harrowing	ridge	200	500	100,000
Transplanting	not used			-
Pesticide application	containers	6	8000	48,000
Tilling	ha	1	140,000	140,000
Guarding	ha	1	100,000	100,000
Harvesting	ridge	200	500	100,000
Transportation	sacs	60	2000	120,000
Irrigation cost	service	1	30,000	30,000
Sorting	sacs	60	200	12,000
Bagging	sacs	60	400	24,000
Water/farmers' contribution	annual	1	62,500	62,500
Rent	annual	1	600,000	600,000
Total cost				3,826,500
Risk rate				
Total Cost				3,826,500
Total revenue	kg	4500	1700	7,650,000
Profit (UGX)				3,823,500
Profit (USD)				1013

**Table A2.** Cost-benefit analysis of rice production (in UGX) in Mubuku, 2018.

Costs				
Cost	Unity	Quantity	Unit Price	Total Price
Seed	ha	1	400,000	400,000
NPK	bags	6	120,000	720,000
Urée	bags	6	120,000	720,000
DAP	bags	6	100,000	600,000
Herbicide total	l	2	20,000	40,000
Herbicide selective	not used			-
Fungicide for seeds				-
Fungicide for growth	containers	6	7000	42,000
Cleaning	ha	1	140,000	140,000
Nursery	not used			-
Labour	ha	1	200,000	200,000
Harrowing	ridge	200	500	100,000
Transplanting	not used			-
Pesticide application	bags	6	120,000	720,000
Tilling	ha	1	140,000	140,000
Guarding	ha	1	100,000	100,000
Harvesting	ridge	200	500	100,000
Transportation	sacs	40	2000	80,000
Irrigation cost	service	1	30,000	30,000
Threshing	sacs	40	1000	40,000
Drying	sacs	40	2500	100,000
Water/farmers' contribution	annual	1	62,500	62,500

Table A2. Cont.

Costs				
Cost	Unity	Quantity	Unit Price	Total Price
Rent	annual	1	600,000	600,000
Total cost				4,934,500
Risk rate				
Total Cost				4,934,500
Total revenue weak market position	bags	26	250,000	6,500,000
Total revenue strong market position	bags	26	300,000	7,800,000
Profit weak market position				1,565,500
Profit good market position				2,865,500
Profit weak market (USD)				415
Profit strong market (USD)				759

Table A3. Cost-benefit analysis of onion production (in UGX) in Mubuku, 2018.

Costs				
Cost	Unity	Quantity	Unit Price	Total Price
Seed	ha	1	500,000	500,000
NPK	bags	8	120,000	960,000
DAP	bags	8	100,000	800,000
Herbicide total	manual			
Herbicide selective				-
Insecticide system	not used			-
Insecticide contact				
Fungicide for seeds				-
Fungicide for growth	kg	4	15,000	60,000
Weeding	weeks	7	240,000	1,680,000
Nursery	ha	1	300,000	300,000
Labour	ha	1	200,000	200,000
Harrowing	ridge	200	2200	440,000
Transplanting	weeks	1	500,000	500,000
Pesticide application	containers	6	8000	48,000
Tilling	ha	1	140,000	140,000
Guarding	ha	1	100,000	100,000
Harvesting	ridge	200	2200	440,000
Transportation	sacs	60	2000	120,000
Irrigation cost	service	1	30,000	30,000
Water/farmers' contribution	annual	1	62,500	62,500
Rent	annual	1	600,000	600,000
Total cost				6,980,500
Risk rate				
Total Cost				6,980,500
Total revenue strong market position	ridges	200	70,000	14,000,000
Total revenue weak market position	ridges	200	5000	1,000,000
Profit strong market position				7,019,500
Profit weak market position				-5,980,500
Profit high market (USD)				1860
Profit low market (USD)				-1585

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