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Key Points:
- GIS and regression analyses were used to evaluate the effect of several water proxies on irrigated production in two smallholder schemes
- Head and tail-end locations had negative effects on rice yields, while proximity to the main canal increased both yields and incomes
- The varied effects of farm location, water satisfaction, and supply scheduling reinforce the need to consider multidimensional water proxies

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Exploring the Head Versus Tail-End Dichotomy on Yield and Farm Incomes in Smallholder Irrigation Schemes in Tanzania

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Abstract Variations in water supply and their impact on farm production in smallholder irrigation schemes are often associated with the location of irrigators at either the head or tail-end, with tail-enders usually considered to be at a severe disadvantage. However, it is rare that the impact of multidimensional proxies of water (capturing adequacy, timing, and location) on farm production and income have been evaluated in conjunction with other relevant variables. Using GIS analysis, this study combines irrigation household surveys, irrigation area characteristics, and cadastral data from two smallholder irrigation schemes in southern Tanzania. The results indicate that location at both the head-end and tail-end had a negative significant impact on farm yields, but not farm incomes. Also, being further downstream the secondary canals (but not necessarily away from the system's intake) had a significant negative effect on both yields and incomes. Surprisingly, increased tomato production drove a decline in incomes, thus raising the importance of crop selection and productivity barriers linked to markets and knowledge. In absence of actual quantitative measures of water supply, this study concludes that using a multidimensional water proxy can uncover important effects that would otherwise remain overlooked by the widespread head versus tail-end dichotomy, commonly used in the study of water distribution within smallholder irrigation systems.

Plain Language Summary In most low-technology, smallholder irrigation schemes, no accurate measures of physical water supply are available. Thus, a common alternative in the literature is to use head-end and tail-end locations within the schemes as proxies for “good” or “bad” irrigation water supply. However, other aspects of water supply (e.g., location along the distributary canals and irrigation scheduling) may also have an impact on irrigated production. Thus, this study proposes a multidimensional approach where various water-related factors are evaluated in conjunction with socioeconomic and farm variables to understand their effects on crop yields and incomes. Based on two smallholder irrigation schemes in southern Tanzania, this study found that various water factors are critical for crop yields, but less so for incomes from irrigated crops. The results of this study suggest that water supply within smallholder schemes is better understood through its multiple aspects, rather than limited to the unidimensional head versus tail-end dichotomy.

1. Introduction

On a global scale, and in sub-Saharan Africa (SSA) in particular, poverty is most prevalent in rural areas where agriculture is the main source of livelihoods. Irrigation development is a key strategy for rural poverty reduction, although growing water demands and reduced supply reliability, due to climate change, pose major challenges for future livelihoods and food security (Petra & Stefan, 2002). In developing countries, the most common form of irrigation is smallholder systems, which are characterized by rudimentary infrastructure. Within such systems, water is very rarely evenly distributed, chiefly under water scarcity circumstances, when supply to tail-end plots is typically restricted to avoid conveyance losses along the canals (D'Exelle et al., 2012; Lal Kalu et al., 1995).

It is widely understood that gravity-fed, low-technology irrigation systems present considerable differences in water supply between head and tail-ends (Hussain & Hanjra, 2003; Maskey et al., 1994; Ostrom & Gardner, 1993; Senaratna Sellamuttu et al., 2014). Typically, farms located closer to the intake withdraw larger volumes of water, with greater frequency and reliability, compared to those further downstream.

Such advantages can be crucial for successful cultivation of irrigated crops; hence, it is a common assumption that water-underprovided irrigators are less productive than their water-advantaged counterparts (Ostrom, 1993). Furthermore, theory (Bhattarai et al., 2002) and empirical evidence (Manero, 2018) suggest that such heterogeneities in irrigation water supply may aggravate economic inequalities within irrigation communities.

Tanzania provides a representative case study of the issues facing many countries in SSA. Poverty remains prevalent, especially in rural areas where one third of the population lives below the national poverty line (World Bank, 2019). Agriculture provides livelihoods for three quarters of Tanzania's 56 million habitants and is the second largest contributor to GDP (28%), with cropping being the number one agricultural activity (The United Republic of Tanzania, 2013b). Over 42% of the country's area is dedicated to agriculture, although only less than 0.4% is equipped for irrigation—predominantly under smallholder farms, that is, those with less than two hectares of cropland (FAO, 2016; Hazell et al., 2007). It is estimated that the irrigated area could be expanded up to 2.1 million hectares (FAO, 2016) across high-potential areas, including the Great Ruaha subbasin, where this study is based. Following legislative reforms in the early 2000s, Tanzania has developed a number of water and irrigation policies calling for improved water management (van Koppen et al., 2007). However, at the local level, important questions remain regarding the adequacy of existing infrastructure, the equity of water distribution, and the (advantageous or disadvantageous) effect that water and other factors have on irrigated crop profitability.

This study seeks to examine the impact of water on irrigated crop productivity by studying the associations between water supply, location, irrigated crops yields, and farm incomes in two smallholder irrigation schemes in southern Tanzania (namely, Magozi and Kiwere). Importantly, low-technology irrigation systems often lack objective records of water delivery. Hence, in absence of volumetric water measurements, various proxy indicators can be found in the literature, that is, frequency of irrigation (Maskey et al., 1994; Saldias et al., 2013), water depth (Anwar & Ul Haq, 2013), irrigation costs (Koirala et al., 2016), presence/absence of flooded land (Ahmed et al., 2014; Hirooka et al., 2016; Kamoshita et al., 2010), plot location (Bardhan & Dayton-Johnson, 2002; Bhatta et al., 2006; Hussain et al., 2004; Ostrom & Benjamin, 1993), and irrigators' water perceptions (Pasaribu & Routray, 2005; Starkloff, 2001; Williams & Carrico, 2017). Selecting only one variable as a proxy for water supply may ignore the varied effects of multiple aspects related to irrigation water supply. To overcome this gap, this study uses a combination of water proxies and GIS location data at the level of individual farm plots to evaluate their effects on irrigated yields and incomes. To the authors' knowledge, this is the first study employing this multidimensional approach. Using spatial (GIS) and survey data, collected in 2014 and 2015, this study develops and tests the following water proxy measures: (a) irrigators' perceptions of adequacy and equity of water supply, (b) timing of water deliveries, and (c) farm proximity to the main canal and the system's intake.

2. Literature Review

The importance of small-scale irrigation to boost agricultural production and rural incomes in developing countries is widely recognized (Kandulu & Connor, 2017), yet barriers against its further development still need to be better understood (Bjornlund et al., 2017). Most empirical and theoretical studies on gravity-fed, low-technology irrigation systems find agreement on two main outcomes (Bardhan & Dayton-Johnson, 2007; Hanjra et al., 2009). First, water is inequitably distributed between head and tail sections, with farms located further away from the water source being the most disadvantaged. Second, such water asymmetries may translate into other types of inequality including crop yields, incomes, wealth, willingness to cooperate, and infrastructure maintenance.

In an extended empirical review across South and South-East Asia, Hussain (2005) concluded that productivity and wealth were most often unevenly distributed between canal reaches. Anwar and Ul Haq (2013) provide evidence of considerable disparities in water depths thorough calculations of Gini and Theil indices within the Hakra Branch Canal (*warabandi* system in Punjab, Pakistan). Using empirical data from *warabandi* irrigation systems in India and Pakistan, Sharma and Oad (1990) and Khepar et al. (2000) show that tail-enders received less water than head-enders due to seepage losses. In addition to head versus tail-end contrasts, Maskey et al. (1994) note significant differences between upper and lower sections of canal reaches (i.e., within branch and distributary canals) regarding frequency of water supply and wheat yields in Nepali

Table 1
Key Factors Affecting Yields and Farm Incomes in Irrigated Agriculture

Category	Definition	Key Factors for Irrigated Agriculture
Human	Skills, ability, and physical capability of people to pursue livelihood strategies	Household size, education, marital status, gender, training
Social	Social resources upon which people draw to pursue livelihood strategies	Participation in community organizations, type of irrigation organization, cooperation/conflict
Financial	Capital base that supports the pursuit of any livelihood strategy	Area, incomes, expenses, asset ownership, livestock ownership, off-farm activities, farm inputs
Natural	Factors relative to natural resources (e.g., water, air, soil) from which benefits are derived and that exist in a particular location	Precipitation, temperature, soil conditions, water quality, agro-climatic zone
Physical	Factors relative to infrastructure supporting livelihood strategies	Water access (volumes, frequency, reliability, etc.), farm location (distance to main canal, to canal intake), proximity to markets

Source: Authors' adaptation from Scoones (1998), Emery and Flora (2006), and studies cited in Appendix A.

irrigation schemes. Similarly, following a detailed examination of water supply in a south Indian irrigation scheme, Mollinga (2003) concludes that important differences exist along the distributary canals, and that rotation scheduling helps to transfer water toward downstream areas.

Lipton et al. (2003) provided a framework for the analysis of irrigation and poverty in developing areas. Their approach considers that irrigation may affect the poor differently depending on their position along the distribution system and access to water. Drawing from experience in India and Pakistan, Bhattarai et al. (2002, p. 19) strongly argue that inequitable water distribution between head, middle, and tail reaches of large-scale irrigation systems “is one of the major factors contributing to income inequality in irrigated agriculture.” The authors reason this is the case because of disparities in crop yield, crop selection, water volumes, reliability of supply, infrastructure, water quality, interpersonal conflict, governmental services, incomes, and wealth accumulation. Crop underproduction by tail-enders and yield heterogeneities have also been noted as consequences of unequal irrigation water access (Ostrom, 1993). Ostrom (1993) and Lam (1996) argue that water asymmetries are caused by improper overuse by head-end irrigators, thus resulting in tail-enders not having predictable and adequate water flow.

Appendix A provides an overview of the studies on linking water access and farm outcomes. Most of the explanatory variables used in models of irrigated yields and incomes fall into five main categories: human, social, financial, natural, and physical (Table 1). This classification mirrors the Sustainable Livelihoods (Scoones, 1998), Capitals and Capabilities (Bebbington, 1999), and Community Capitals (Emery & Flora, 2006; Gutierrez-Montes et al., 2009) frameworks.

3. Methods

3.1. Hypotheses

This study seeks to evaluate the effect of various perception-based and physical measures of water supply on irrigated crop productivity. In particular, this study seeks to test the association between water supply, plot location, irrigated incomes, and yields, while holding as many other relevant influences constant. Based on previous findings from the literature, the following hypotheses were formulated:

H1.1 : Irrigated crop yields are positively associated with the adequacy of water supply;

H1.2 : Irrigated crop yields are positively associated with the proximity of the farm to the system's intake.

H2.1 : Irrigated crop income is positively associated with the adequacy of water supply;

H2.2 : Irrigated crop income is positively associated with the proximity of the farm to the system's intake.

For the hypothesis testing H1.1 and H1.2, only the main crop of the irrigation areas (namely, paddy rice yields) are modeled. For income regressions (H2.1 and H2.2), a range of income from all crops is considered (see section 4.2).

3.2. Regression Methods

A variety of regression methods were tested, with OLS multiple regression chosen as the best fitting and most robust to identify the partial effect of water (and other factors) on incomes and yields, while holding the rest of explanatory variables constant. Thus, the model was

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \dots + \beta_k X_{ki} + u_i, \quad i = 1, \dots, n \tag{1}$$

where $Y_i$is the ith observation on the dependent variable (two dependent variables were tested: irrigated crop yields or irrigated crop incomes) and X_{ki} are the ith observations on each of the k regressors and u_i the error term.

Independent variables were selected based on previous literature (Appendix A) and fieldwork observations. In a second step, an iterative backward elimination procedure (restricted model) was conducted until only significant variables remained in the model (in this case $\alpha = 0.10$; Lai & Ing, 2010). To check for robustness, the models were tested using an alternative variable elimination method, that is, general-to-specific algorithm (Clarke, 2014). The regression modeling results were consistent with those obtained through the backward elimination process and are not reported here.

Given the variety of specifications in the literature with no common application, various specifications of linear, linear-log, log linear, and log-log forms were tested. In addition, sensitivity analyses were conducted on plot location defined based on (a) linear distance to intake and (b) trichotomous variable—head/middle/tail. Best fitting and most robust models are depicted.

Pairwise correlations and variance inflation factors were tested with the independent variables to make sure there was no serious multicollinearity, that is, no correlation factors above 0.7, nor variance inflation factors above 5 (see Appendix B for more details). Outliers were identified using summary statistics and graphical methods. Thus, two observations were dropped from the sample as income figures appeared abnormally high, could not be confirmed by in-country research staff, and significantly impacted model performance. Appendix C provides a full description of the variables used, their sources, and descriptive statistics.

4. Data

4.1. Case Study Area: Southern Tanzania

The Kiwere and Magozi irrigation schemes were originally selected for a larger research project based on "their potential to improve or address agronomic practices, institutional capacity, market barriers, farming practices, and other factors, such as site accessibility, research cost, crop diversity, and the district authority's willingness to collaborate" (Mdemu et al., 2017, p. 2). Both schemes are located in the southern-highland area, within the Iringa region. Farming is the main economic activity in Iringa, employing almost 80% of its 941,000 inhabitants (The United Republic of Tanzania, 2013a), and making it one of the five largest food-producing regions of the country (Swai, 2005).

Water for the Kiwere and Magozi schemes is abstracted from the Little Ruaha River, within the Rufiji River Basin (Figure 1), where 78% of consumptive uses is driven by irrigation (WREM International, 2015). The Rufiji Basin covers an area equivalent to 20% of Tanzanian's mainland (183,791 km^2), comprising four river catchments: Great Ruaha, Kilombero, Luwegu, and Lower Rufiji. The Great Ruaha—where the Little Ruaha is located—is the largest subcatchment (85,554 km^2), accounting for 80% of the Rufiji Basin's consumptive water uses.

Water within the Kiwere and Magozi schemes is distributed through a network of open channels—only a third of which are concrete or stone-lined. This type of schemes is very common in mainland Tanzania, where almost all irrigation water comes from surface sources, while only 0.2% of all irrigated areas use groundwater, in particular by large commercial farms (FAO, 2016). Eighty-five percent of Tanzania's irrigated area is under traditional irrigation schemes (Table 2), directly managed by smallholder farmers. Two thirds of the area under traditional irrigation schemes is equipped with improved infrastructure, resulting from external intervention (e.g., government or donor agencies). These schemes—as it is the case of Kiwere and Magozi—are referred to improved traditional irrigation schemes.

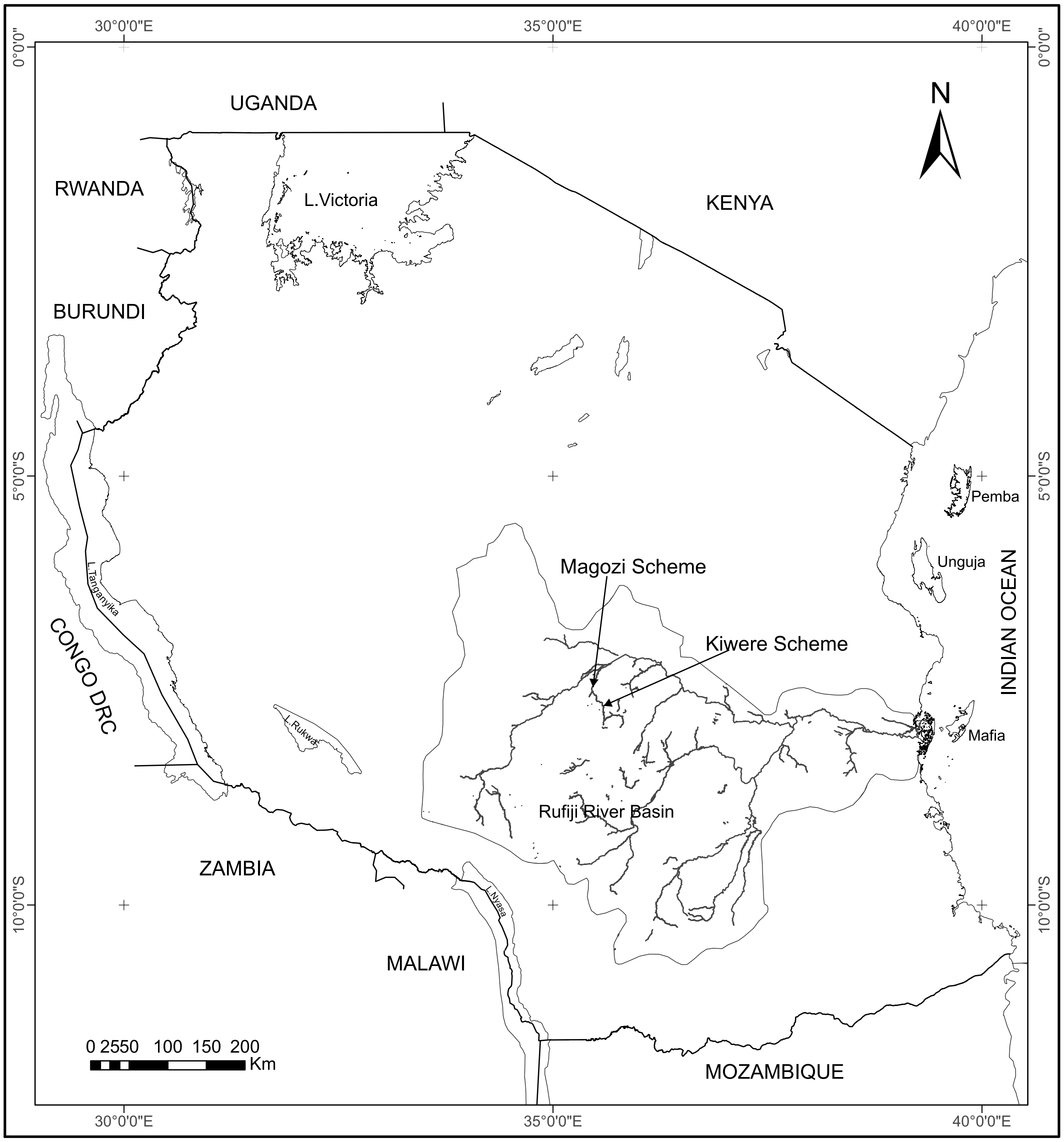

Figure 1. Map showing the location of the Magozi and Kiwere irrigation schemes in Tanzania. Source: produced by Ardhi University in 2018.

Table 2
Land Use in Tanzania in 2013

	Area ('000 ha)	%
Nonagricultural land	55,080	58.14
Meadows and pastures	24,000	25.34
Dryland agriculture	15,286	16.14
Traditional irrigation without external intervention	117	0.12
Improved traditional irrigation	191	0.20
Large-scale irrigation	55	0.06
Total area	94,730	100.00

Source: Authors' calculations from FAO (2016).

The Kiwere and Magozi schemes vary in size, number of members, and type of crops (Table 3). In both schemes, irrigated agriculture is critical for the livelihoods of the local communities, as it is the single largest source of income, well above other sources such as dryland crops, livestock, and off-farm activities (Manero, 2017).

In Kiwere, over 13 different horticultural and staple crops are grown, with tomatoes accounting for over 56% of the total output (in kg in 2014). Produce variety is favored by two key factors. First, the scheme is easily accessible along 20 km of graveled road from the regional capital, Iringa. Such proximity facilitates access to inputs (notably seeds and chemicals), extension services, and suppliers to regional and national markets. Second, the scheme is irrigated all year-round, thus allowing cultivation of crops across all seasons, and multiple crops per year. Kiwere irrigators have a daily water-sharing roster, whereby the tail-end

Table 3
Characteristics of the Irrigation Schemes in 2014

	Magozi	Kiwere
Total area (ha)	939	189
Number of plots	760	248
Average plot size (ha)	1.24	0.76
Number of registered households	578	199
Average household landholding (ha)	1.62	0.95
Main crops	Rice	Tomatoes, maize, onion, sunflower, rice, eggplant, other vegetables, and fruits

Source: Mdemu et al. (2017).

plots are scheduled to receive water in the mornings, while head-enders have their turn in the afternoons.

Magozi lies 50 km away from Iringa, along the same road as Kiwere, although its access is hindered by the poor quality of the road, chiefly over the last 20 km. The scheme is supplied from the Little Ruaha River, upstream from Kiwere. However, Magozi's water withdrawal license is limited to the rainy season, that is, December to May, when the river flows are deemed high enough to satisfy all catchment demands. Without easy access to markets and only seasonal water provision, rice is a preferred crop in Magozi, as it needs little inputs and is only harvested once a year. The by-laws of the Magozi scheme dictate that all members have right to use irrigation water. However, the informal arrangement is such that plots located closer to the system's intake and to the main canal are the first to withdraw water early in the season, that is, December to February. By contrast, plots located further downstream need to await until March or April for water to become available, as upstream plots are drained for harvesting. In dry years, when the river levels are too low to supply enough water for the entire Magozi scheme, some areas remain fallow or become unproductive.

As part of this study, fieldwork conducted in 2015 included direct observations of the irrigation infrastructure and farms, as well as qualitative discussions with 130 irrigators. In Magozi, it was observed that plots at the head-end of the scheme had typically more water than those in the middle, while parts of the tail-end had been unirrigated (Figure 2). Year 2015 was a particularly dry year, and thus, little water had reached the tail sections. A similar situation to that of Magozi is noted by Lankford (2004), in traditional irrigation systems in the southern Tanzanian district of Usangu, where head-enders transplant rice in December–January, while tail-enders work as farm labor, as they wait for water to reach them in March. In years with low levels of rainfall, only a reduced number of head-end plots are irrigated, whereas the tail-end of the scheme is left uncultivated.

4.2. Survey Data

The data used in this study originate from two sources: (a) irrigation household surveys conducted in 2014 and 2015 and (b) schemes' cadastral information (collected in 2015). The households selected for participating in the surveys were identified using a stratified sampling approach based on the Irrigators' Organizations member registry. Households were categorized based on their wealth/farm size, gender of the household head, and village location and then randomly sampled. Geographic stratified sampling was carried out based on place of residence, as irrigators tend to live nearby the areas of the scheme they cultivate, thus providing an indication of the likely location of their plots (head, middle, or tail). Population samples could be not stratified by exact plot location given that cadastral information was not available in 2014, when the first survey was carried out. The areas under irrigation are subdivided into plots, each of which is cultivated by one family, with some families cultivating more than one farm plot. Given the association between farm plots and households, the data collection process was designed using households as the basic unit.

The first survey was conducted between May and July 2014 and comprised 100 households in Kiwere and 100 in Magozi. Information was collected on the family structure, farm characteristics, agricultural practices, revenues and expenses, and farmer attitudes. The second survey, carried out between May and July 2015, was based on the same population sample, yet only 70 households in Kiwere and 58 in Magozi could be reinterviewed due to farmer unavailability at time of the second survey. Nonparametric tests (Appendix B) showed no statistically significant differences between “dropped-out” and “retained” households, thus concluding that there is no indication of attrition bias between the 2014 population and the 2015 subset. All variables used related to household characteristics and farming practices were obtained from the 2014 and 2015 household surveys. Variables based on geographic data, that is, plot size and location, were obtained from cadastral sources, as detailed in section 4.3.

No quantitative, objective measures of water supply were available, given the lack of any type flow measuring instruments or systematic records of water deliveries. To overcome this limitation, qualitative proxies were used based on irrigators' perceptions. As part of the 2014 and 2015 surveys, interviewees were asked

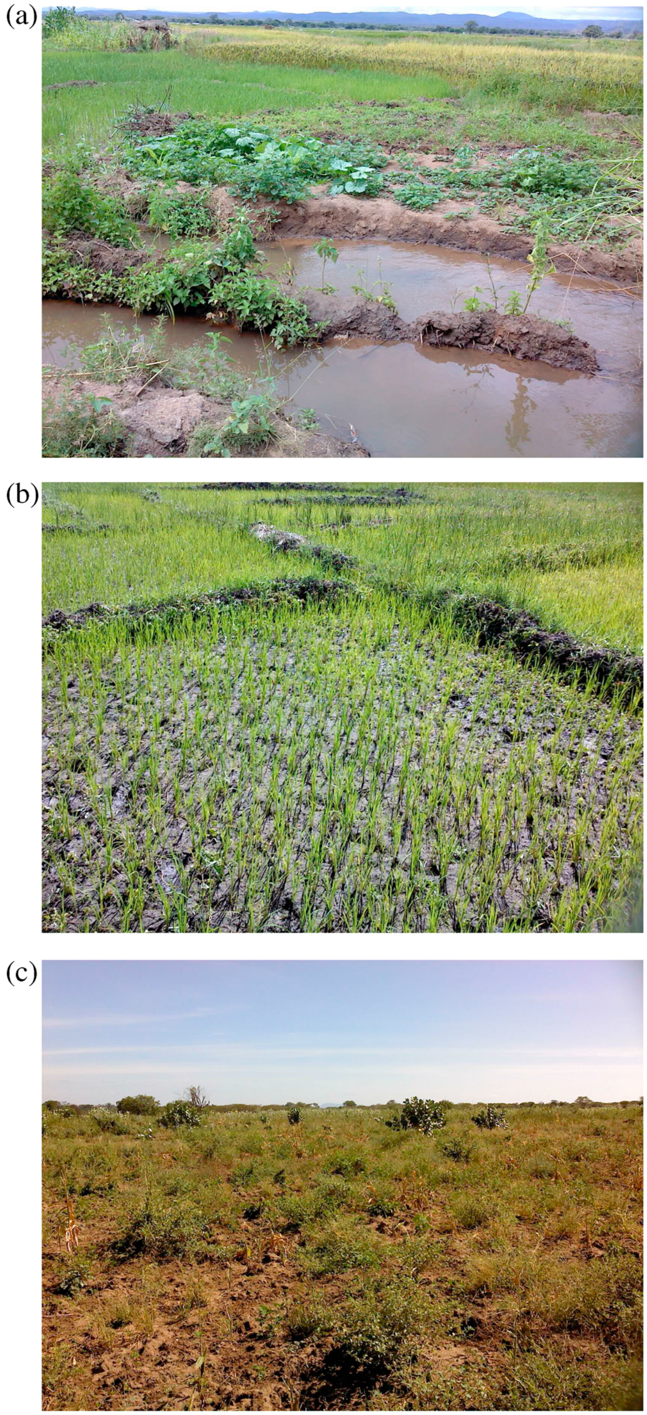

Figure 2. Paddy fields at the Magozi scheme. (a) Overflowing canal and irrigated plot at the head-end. (b) Cultivated plot in the middle section. (c) Uncultivated plot at the tail-end. Source: authors' own images.

to describe the times when they typically receive water. Qualitative answerers were then classified into defined slots, that is, start versus end of the irrigation season in Magozi. Also, during the household surveys, participants were prompted to think about various water adequacy aspects (e.g., volumes, timeliness, and reliability), and then asked *How satisfied are you with your water supply?* Responses were recorded on a five-point Likert scale, where 1 = very dissatisfied and 5 = very satisfied. This method was adapted from a growing body of literature utilizing irrigators' perspectives as indicators of irrigation performance (Oates, Hisberg, et al., 2017; Svendsen & Small, 1990; Yakubov, 2012). Abernethy et al. (2001) build an *index of satisfaction*, ranging from −7 to +7, based on Sri Lankan irrigators' opinions on reliability and sufficiency of irrigation water supply to their fields. In a study of water users organizations in Pakistan, Starkloff (2001, p. 31) ask respondents "about their level of satisfaction with the prevailing system of water distribution" and analyze irrigators' perceptions based on farm location. Similarly, Pasaribu and Routray (2005) investigate irrigators' water supply perceptions and use various tests to explore asymmetries in irrigation schemes in Indonesia. More recently, Williams and Carrico (2017) use self-reported levels of satisfaction with irrigation water to differentiate between water-stressed and water-secure irrigators in Sri Lanka.

The dependent variable in the first model was paddy rice yields in Magozi over the two years. Accordingly, the yield model was run with clustered standard errors to account for pairs of values (2014 and 2015) corresponding to the same household. Modeling crop yields in Kiwere would require converting production of the various crops into a crop yield equivalent, based on conversions across crop market prices (Dayton-Johnson, 1999; Uddin et al., 2009; Vidyavathi et al., 2012). However, in the context of this study, such approach had serious limitations. First, crop market prices in the Iringa area fluctuate widely over time, so the conversion rates would vary within one irrigation season and interannually. Second, there is no historic information on crop prices in Iringa that would allow an accurate estimation of crop equivalences at the time of production.

In the second model, the dependent variable was irrigated farm gross income for Magozi and Kiwere in 2014 (such data were not available in 2015). The models were run with robust standard errors to mitigate any potential effect of heteroscedasticity.

4.3. Spatial Data

Spatial information of farm plots was obtained from the cadastral data (plot code, name of custodial landowner, plot size, and plot specific location) contained in digital maps of the irrigation schemes. Geospatial surveys were conducted by a team of researchers from Ardhi University (Dar es Salaam, Tanzania), during the 2014 dry season (May–December). Names on the list of registered landowners and their corresponding plot codes were matched against names of household members provided in the surveys. In this way, cadastral (spatial) data were linked survey (quantitative) data, which could then be explored and manipulated through GIS analysis. Figure 3 depicts the spatial distribution of rice yields in Magozi, and Figure 4 depicts incomes in Kiwere and Magozi.

Plot location was defined using two distinct measures: (a) distance between a farm plot and its off-take on the main canal (sometimes referred to as "transversal distance") and (b) distance between farm off-take on the main canal and the system intake (see the example in Figure 5). In the first instance, both

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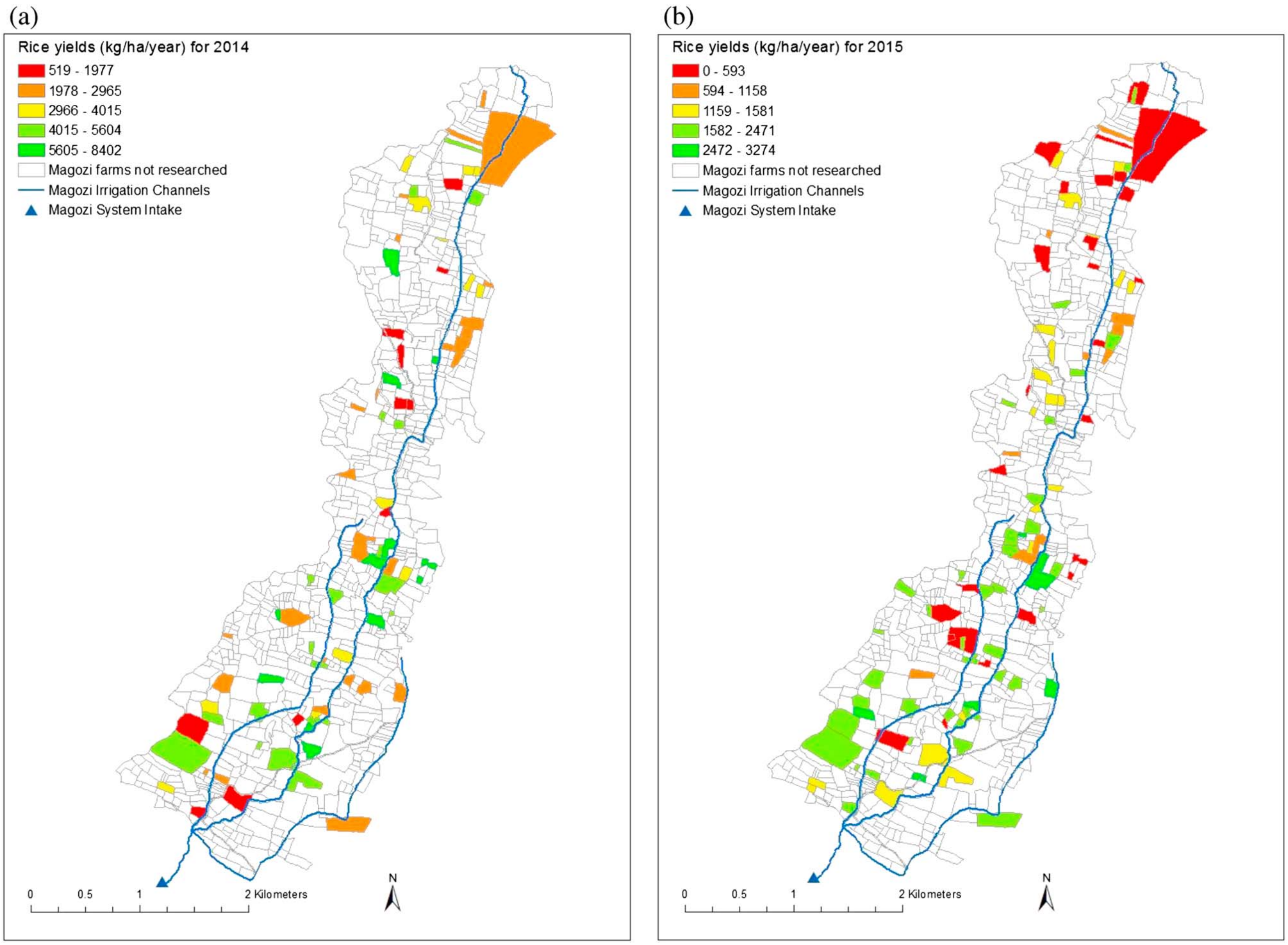

Figure 3. Spatial representation of rice yields in the Magozi scheme in (a) 2014 and (b) 2015. Source: figures elaborated by the authors using ArcMap 10.3.1.

distances were calculated as continuous variables (in km). Second, the distance to the system's intake along the main canal was divided into three equal parts, thus defining a trichotomous variable: head, middle, or end.

Most households in this study only cultivate one farm plot, while a small portion (36% in Magozi and 29% in Kiwere) own/rent two, three, or in rare cases, up to seven plots, across the irrigation schemes. Households with multiple plots typically have them close to each other, as they often acquire land from nearby family or neighbors. Moreover, working across distant plots would require irrigators to walk long distances—an impractical and physically demanding task. In Magozi, the average distance between multiple plots cultivated by the same household is 1 km, which equals to just over one tenth of the total scheme length. In Kiwere, the average distance among multiple plots is 526 m, or 8% of the scheme length.

Because the survey data are associated to households and not plots, an adjustment was needed whereby households cultivating multiple plots had their distances calculated as an area-weighted average across all their plots. Further details on the averaging method can be found in Manero (2018). Weighted average distances expressed in km could only be used when analyzing each scheme separately. This is because the Kiwere and Magozi schemes differ significantly in size (6.8 and 9.4 km, respectively, in the main canal length), and therefore, the same distance would not reflect the same proximity to the intake. Thus, in the income model where both schemes are combined, relative distance was expressed as the ratio of the distance between farm plot and system's intake over the total system's length (and likewise for the transversal distance along secondary canals).

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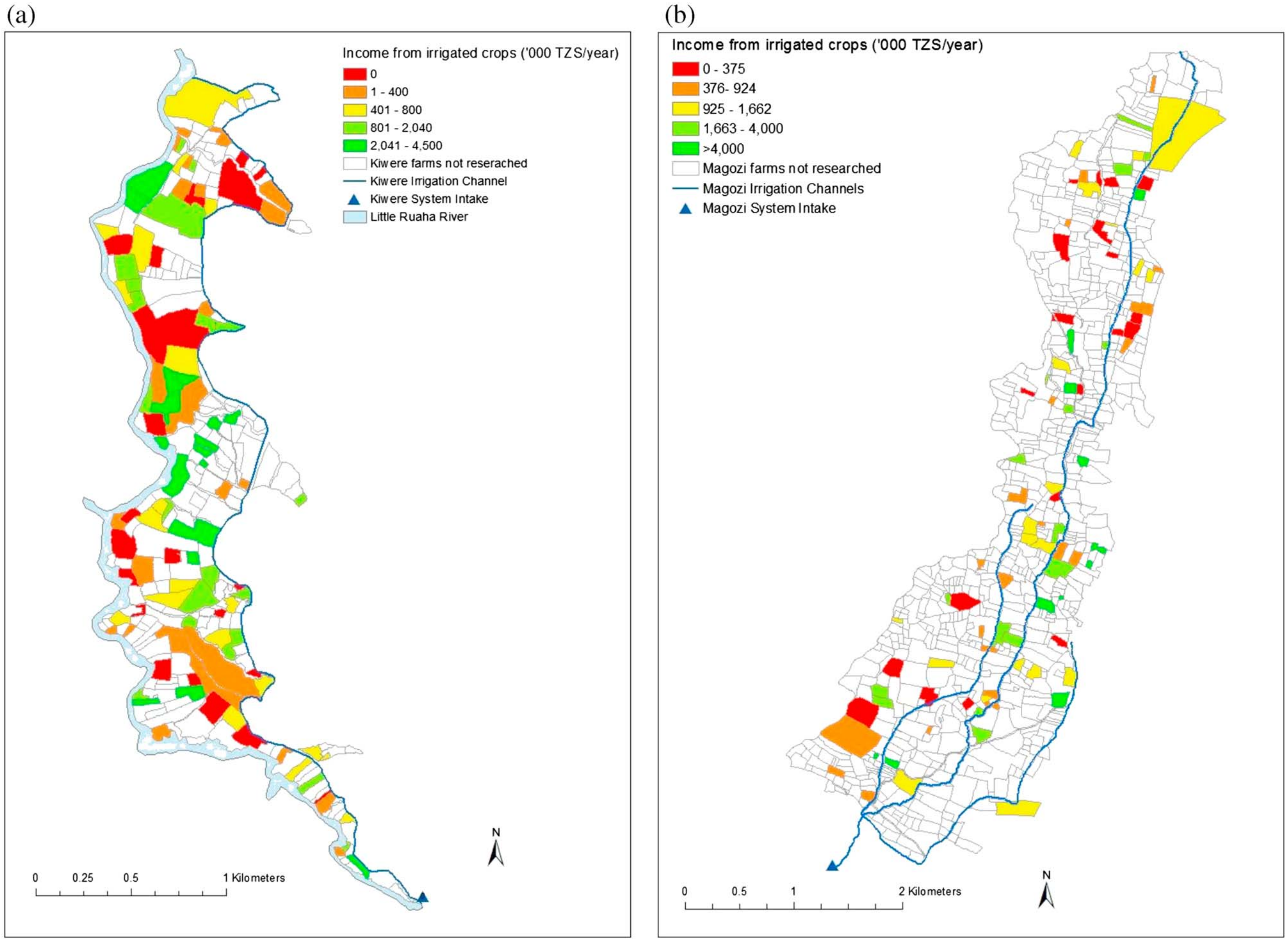

Figure 4. Spatial representation of irrigated crop incomes in 2014 in (a) Kiwere and (b) Magozi. Source: figures elaborated by the authors using ArcMap 10.3.1.

5. Results and Discussion

5.1. Model Results

The OLS regression results for the rice paddy yield and irrigated crop income models are presented in Tables 4 and 5. Models 1 and 2 represent the yield models (theoretical and restricted) using proximity to intake as a continuous variable. Similarly, Models 3 and 4 illustrate regressions using plot location as a trichotomous (dummy) variable. The regression on incomes was also tested using distance (Model 5) and dummy (Model 6) variables for location, but both theoretical models resulted in the same restricted model (Model 7). All the models have significant *F*-statistics and relatively high-adjusted *R*-squared for survey data.

5.2. Water Supply Variables

The first hypothesis (H1.1. Irrigated crop yields are positively associated with the adequacy of water supply) is supported by the results of Models 2 and 4, indicating that irrigators' water satisfaction has a statistically significant and positive effects on paddy rice yields. The implication of this result is that, in the absence of quantitative, objective measures of water supply, irrigators' perceptions could be considered as a valid proxy. Conversely, there was no statistically significant evidence found (Model 7) to support Hypothesis 2.1 that irrigated gross income was positively associated with water supply adequacy (measured by irrigators' satisfaction with water supply). This suggests that perceptions of supply adequacy are not significant for irrigated gross incomes when other more relevant human, physical, and financial factors are controlled for. This also highlights the fact that production (yields) in irrigated production do not necessarily translate into improved irrigation farm income.

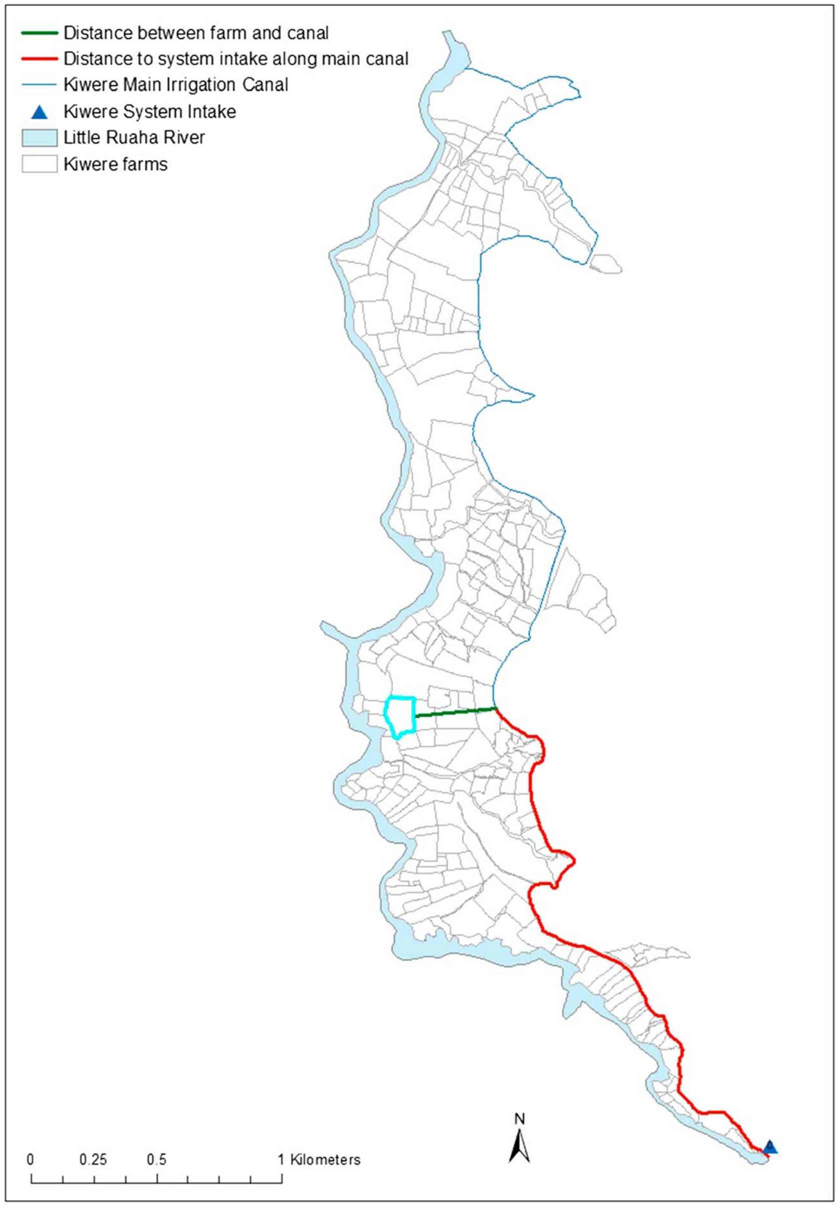

Figure 5. Example of distance calculations in the Kiwere scheme using cadastral data. Source: figure elaborated by the authors using ArcMap 10.3.1.

Proximity to the system's intake (Hypothesis 2.2) expressed as a continuous variable was not statistically significant for yields (Model 2) or incomes (Model 7). Plot location as dummies were not significant for incomes (Model 7), but they were found to be good predictors of paddy yields (Model 4). Interestingly, the results suggest that head-end had a negative effect on yields, corroborating that proximity to the intake does not necessarily constitute a location advantage. A similar example of poor-performing head-enders can be found in Hussain's (2005) observations in South and East Asia, noting that it was in the middle reaches—but not at the head—where productivity was the highest and poverty the lowest. As explained by Gorantiwar and Smout (2005, p. 13), this can be due to the fact that "the farmers at the head of the system generally apply more water than needed for potential yield and excess water will not improve the productivity but will reduce it." The interpretation of the model results was that head-end location was associated with a 24% decrease in paddy yields compared to the middle section, while the effect of tail-end is even more remarkable, that is, −62%. On the mean, these figures would be equivalent to 624 and 1,647 kg/ha, respectively.

Table 4
OLS Log-Linear Model Results of Rice Paddy Yield in the Magozi Scheme, 2014–2015

	Location as Linear Distance to Intake		Location as Dummies	
Variables	Theoretical Model (1)	Restricted Model[a](2)	Theoretical Model (3)	Restricted Model[a](4)
Farm and farmer characteristics				
Female	−0.23 (0.22)	-	−0.27 (0.20)	−0.29** (0.13)
Age	−0.03** (0.01)	−0.03** (0.01)	−0.03** (0.01)	−0.03*** (0.01)
Education	0.42 (0.33)	0.46** (0.19)	0.34 (0.32)	-
Household size	0.21** (0.09)	0.17** (0.07)	0.19** (0.08)	0.13* (0.07)
Irrigated area	−0.06 (0.10)	-	−0.00 (0.00)	-
Farm tools	−0.17 (0.47)	-	−0.19 (0.47)	-
Herbicide, pesticide, fungicide	0.00 (0.00)	-	0.00 (0.00)	-
Soil fertility	−0.69** (0.27)	−0.69** (0.26)	−0.66** (0.25)	−0.53** (0.25)
2015 year	−0.63*** (0.23)	−0.70*** (0.22)	−0.61** (0.24)	−0.70*** (0.21)
Location and water perception characteristics				
Equity of distribution	0.10 (0.10)	-	0.09 (0.10)	-
Satisfaction water supply	0.31** (0.15)	0.31** (0.13)	0.33** (0.15)	0.31** (0.13)
Timing of water (END)	−0.72** (0.31)	−0.71** (0.35)	−0.46* (0.26)	-
Distance to main canal	−1.30 (1.18)	−1.23* (0.69)	−0.96 (1.15)	-
Distance to intake	−0.02 (0.07)	-	N/A	N/A
Head location	N/A	N/A	−0.28 (0.21)	−0.27** (0.13)
Tail location	N/A	N/A	−0.68** (0.32)	−0.98*** (0.32)
Constant	7.10*** (0.95)	7.14*** (0.71)	7.29*** (0.85)	7.88*** (0.59)
Observations	98	98	98	105
Adjusted R^2	0.34	0.37	0.35	0.37
F-statistic	4.89***	5.85***	4.87***	6.20***

Note: N/A variables are not included in the model. - Variables are not statistically significant at the 0.10 level and dropped from the restricted model. Standard errors in parenthesis.
*$p < 0.10$. **$p < 0.05$. ***$p < 0.01$. [a]The restricted models are those where regressors whose coefficients were not significantly different from zero at the 0.10 significance level in previous regressions have been removed one by one in subsequent regressions, until all the remaining coefficients were significant at least at the 0.10 level.

Even on a small, half-hectare plot, such gains would provide enough rice to meet the staple-food demand of between five and 13 people (Muthayya et al., 2014), thus contributing to the food security of the entire household.

Although the results for tail versus head location were mixed in the models, it was found that proximity to the main irrigation canal (distance between plot and farm off-take) had a statistically significant and negative effect on both yields (Model 2) and incomes (Model 7). In fact, during fieldwork investigations, it was observed that only small amounts of water were effectively being diverted into secondary canals, which, in turn, often became blocked up with sediment and weeds. The economic interpretation is that, given an average squared plot of 100 m by side (area = 1 ha), it is expected that farms directly adjacent to the main canal would obtain, on average, 12% higher yields than their immediate downstream neighbors. In terms of incomes, being the irrigator closest to the main canal, or the one at the end of the secondary canal can result in a difference of almost TZS 640,000 per year—roughly half the schemes' average household gross income. To put these figures into perspective, in Kiwere or Magozi, this amount would suffice to buy a solar energy system and a basic set of domestic appliances, including a lamp, radio, and mobile phone charger.

Importantly, timing of water supply (end of the irrigation season) has a statistically significant and negative effect on yields (Models 2 and 4). The interpretation is twofold. First, cultivating rice at the end of the irrigation season (April–May) hinders grain growth. Knowing that their water supply is likely to be delayed, certain farmers plan to sow their fields later in the season. This shift results in the rice becoming maladapted to optimum growth periods in terms of temperature. As noted by Sekiya et al. (2017), the highland areas in Tanzania experience notable seasonal climatic variations, leading to temperatures below 10 °C in the cool months (May to September). Low temperatures result in reduced paddy yields due to cold-induced

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Table 5
OLS Regression Linear Model Results of Irrigated Gross Income in Kiwere and Magozi Schemes in 2014

Independent Variables	Theoretical Model With Linear Distance (5)	Theoretical Model With Location as Dummies (6)	Restricted Model[a] (7)
Farm and farmer characteristics			
Female	−334.99 (331.58)	−366.3 (328.31)	-
Age	−18.44* (10.51)	−20.02* (10.77)	-
Education	−632.93* (366.88)	−679.36* (364.33)	-
Household size	35.5 (80.89)	43.7 (76.08)	-
Scheme (1 = Magozi)	−85.41 (568.71)	−99.98 (583.19)	-
Rice production	316.01* (169.2)	316.87* (171.95)	307.37** (129.19)
Maize production	−18.26 (17.8)	−18.26 (18.18)	-
Tomato production	−12.82*** (4.27)	−12.12*** (4.11)	−11.89** (4.74)
Onion production	136.48** (57.12)	123.06** (56.14)	141.48** (65.61)
Other irrigated. crops	1,316.37** (559.06)	1,378.35** (583.52)	1,068.24* (611.96)
Irrigated area	512.37** (249.57)	507.62** (246.23)	499.99** (208.14)
Off-farm income	−258.17 (304.14)	−243.67 (304.65)	-
Fertilizer input	0.00 (0.02)	0.01 (0.02)	-
Herbicide, pesticide, fungicide	1.04 (0.76)	1.05 (0.74)	1.18** (0.59)
Soil fertility	401.3 (410.95)	428.38 (404.94)	-
Location and water perception characteristics			
Equity of distribution	175.28 (186.74)	163.67 (185.72)	-
Satisfaction water supply	166.23 (229.75)	182.85 (235.52)	-
Distance to main canal	−70.16 (616.48)	−362.19 (513)	−619.14* (354.56)
Distance to intake	−482.5 (545.66)	N/A	-
Head location	N/A	245.78 (346.12)	-
Tail location	N/A	66.51 (414.91)	-
Constant	371.83 (1413.87)	233.02 (1312.84)	222.13 (319.16)
Observations	117	117	125
Adjusted R-squared	0.44	0.44	0.47
F-Statistic	2.98***	3.30***	2.75**

Notes: N/A variables are not included in the model. - Variables are not statistically significant at the 0.10 level and dropped from the restricted model. Standard errors in parenthesis. *$p < 0.10$.
**$p < 0.05$. ***$p < 0.01$. [a]The restricted model is where regressors whose coefficients were not significantly different from zero at the 0.10 significance level in previous regressions have been removed one by one in subsequent regressions, until all the remaining coefficients were significant at least at the 0.10 level.

sterility (Sandra et al., 2007; Sekiya et al., 2015, 2017). During one of the on-farm interviews, one irrigator explained:

"Better water scheduling would be helpful. Now at the start of the irrigation season, some farmers are not receiving enough water, so they have to work as labor. Then, later in the season, the right time for cultivating has been missed and the rice is not so good" (female irrigator, head-end, Magozi).

Further, water allocation rules in the Magozi scheme are seldom followed, meaning that irrigators who are allocated water at the start of the season would continue to withdraw water uninterruptedly, thus impeding flows toward other parts of the system. Noteworthy, while overirrigation is a common practice in water-intensive cropping systems (Ostrom & Gardner, 1993), it can be detrimental for plant growth, given leaching of nutrients and poor aeration of the soil (Stirzaker et al., 2017).

The negative effect of the year dummy can be linked to a 40% rainfall reduction in 2015, as compared to 2014 (The United Republic of Tanzania, 2016), which irrigators reported as a key reason for lower paddy production. Such interannual variations suggest that access to irrigation alone is not an effective strategy to protect growers from climatic uncertainty. It should be noted that timing of irrigation could not be used in the income model because water scheduling in both schemes is organized on different time lapses and thus cannot be compared. In Kiwere the roster alternates on a daily basis (morning/afternoon), while in Magozi, water allocations are planned on a seasonal basis (December–May). Unfortunately, there were no data available on soil type and texture to see if this was a factor influencing waterlogging issues or presence in head-end locations.

5.3. Other Variables of Interest

Other influences on higher paddy rice yield (Models 2 and 4) included the household head being male, younger, more educated and part of a larger household. As in many rice-growing areas (FAO, 2004), gender-specific tasks are common in Magozi. While seeding and weeding are the traditional domain of women, men are typically responsible for harvesting and marketing the crops. The positive and statistically significant influence of household size may indicate the important contribution of children or elderly to family livelihood activities, as noted by Wan (2004).

Most variables related to financial capital were found to be statically significant for irrigated crop gross incomes (Model 7). Production of "other irrigated" crops (sweet potatoes, eggplant, sugar beans, peppers, and sunflower) was associated with higher incomes. While only six households reported irrigating crops other than rice, onions, maize, and tomatoes, these results suggest that diversifying their portfolio into high-value produce may lead to an increase in their incomes. Perhaps surprisingly, higher production of tomatoes was associated with lower incomes, contrary to the effect of other horticultural products. During fieldwork in 2015, it was observed that market oversupply and poor quality due to pests and diseases in the Iringa region can cause a dramatic drop in farm-gate prices. Consistently, studies in Iringa (MUVI-SIDO, 2009) and Morogoro (Mutayoba & Ngaruko, 2018) regions find that tomato plants are affected by a number of diseases, such as late blight, cutworms, *Tuta absoluta* larvae, and nematodes, which causes root rot. Tomatoes account for the largest vegetable production in Tanzania, yet their profitability is hindered by their proneness to pests and diseases, as well as damage in the transportation process, chiefly in areas with poor road infrastructure (SAGCOT, 2015). At the time of the survey, a tomato-processing plant was planned to open in Iringa (Mdemu et al., 2017). With a daily capacity to process 200 t of tomatoes, the plant was expected to buy part of the local supply, thus reducing issues with short shelf life (SAGCOT, 2015). However, the prospects of better marketing for Kiwere tomatoes have not been realized to date for several reasons. First, the factory sources tomatoes from a large area, beyond the Iringa region, which results in supply always exceeding demand. Second, peak production of raw tomatoes in the Kiwere scheme coincides with peak supply in other tomato-producing areas, thus contributing to oversupply. Third, the Iringa plant processes tomatoes into paste/pulp, which is then transported 700 km north to the city of Arusha, for final processing and packaging. This implies that demand for raw tomatoes in Iringa fluctuates with the requirements for semiprocessed products at the Arusha factory.

In SSA, prices of perishables, such as tomatoes, are often dictated by supply rather than demand. Thus, increased production from multiple smallholder schemes, serving the same markets, typically leads to a price drop and, consequentially, lower farm incomes. Results in Kiwere and Magozi are typical to other tomato-producing areas in SSA, as shown by Gilbert et al. (2017) in Malawi. The negative impact of poor tomato quality and oversupply highlight the importance of adequate pest control and crop selection. These issues are linked to key profitability barriers identified by Bjornlund et al. (2017), including access to knowledge, inputs, market channels, and the value chain. In Kiwere, a broader variety of crops could be cultivated, provided farmers acquired the necessary knowledge and reliable access to the value chain. In Magozi, the choice of irrigated crops is limited to rice, given the seasonal water supply regime and the method of irrigation (flooding). Lack of proximity to markets also hampers the viability of commercializing, high-value, perishable crops such as fruits or vegetables.

As expected from the literature, irrigated area was statistically significant and positively associated with irrigated gross incomes. The model results suggest that for every additional hectare, irrigated gross incomes would increase by over 1 million TZS (USD 450) per year. With a standard farm rental price of around 62,000 TZS/ha/year, the return-on-investment would be 16-fold, thus suggesting that land rental is an effective strategy to increase incomes (albeit we could only measure gross income). While the schemes are at the limit of their water capacity, high economic returns could be an argument in favor of farmer investment in infrastructure repairs and upgrades, which would help reducing water losses and enhancing the system's operability. Currently, a large portion of the canals and control structures are defective and contributing to high water loses through evaporation, seepage, and overflowing.

Given the growing problem of water scarcity in the Great Ruaha subbasin (Mdemu & Francis, 2013), strategies to improve the productivity and profitability of water use are more desirable than increasing allocations for irrigation or subsidizing construction of new irrigation infrastructure (Grafton et al., 2018). In Kiwere and Magozi, reduced water losses and improved infrastructure operability could translate into more water being available for sections of the schemes currently suffering from water deficit. It is important to note that, in many rural, developing areas, disparities in irrigation water and landholdings remain a critical issue affecting equitable distribution of agricultural benefits across gender and socioeconomic groups (Bjornlund et al., 2019; Hussain & Hanjra, 2003; Lipton et al., 2003). Notably, in Kiwere and Magozi, the largest 20% irrigators cultivate almost half of the available land, while the bottom quintile only holds a mere 5.5% of the total. Importantly, less than 15% of the irrigated land in Kiwere and Magozi is cultivated by female-led households, which raises questions about the impact of irrigation land development for gender equity.

Promoting rural growth and fighting poverty through irrigation development is one of the key pillars of Tanzania's Agriculture Sector Development Programme—an initiative that recently launched its second investment plan, costing US$5.9 billion between 2017/2018 and 2027/2028 (The Citizen, 2018). While the area with high potential for irrigation is estimated at more than 2×10^6 ha (Oates, Mosello, et al., 2017), experts believe that viable expansions are modest at best (Coulson, 2015) and that optimal irrigation development strategies lie within small-scale farms producing high-value crops during the dry season (Mdee et al., 2014). Pointedly, the results of this study suggest that none of these initiatives is, on its own, a silver bullet for increased crop production or incomes. This is because disparities in water supply, as well as poor understanding of cropping and marketing mechanisms, may lead to a decline in irrigation-derived benefits. Therefore, we would advocate more emphasis on farmer behavior change, extension, and market development (e.g., as discussed in Wheeler et al., 2017), as part of several pathways for translating irrigation development into actual improvement of livelihoods and well-being of rural communities.

6. Conclusions

In rural areas of Tanzania, as in many SSA countries, irrigation is promoted as a key strategy for increased food security and livelihoods, although a number of factors hinder the achievement of its full potential and the equitable distribution of its benefits. Within smallholder, low-technology irrigation schemes, it is commonly understood that plots located closer to the intake benefit from greater, more frequent, and reliable water supply, which in turn, favors crop yields and their derived income. While previous studies typically use only one proxy for water supply, this study uses a combination of quantitative (survey), qualitative (in-depth interviews), and GIS (spatial) data to define and test for multiple aspects of water supply, including adequacy, timing, proximity to intake, proximity to main canal, and head/middle/tail location. Based on two smallholder schemes in Tanzania, multiple regression methods were employed to test the hypotheses that crop yields (in Magozi) and incomes from irrigated crops (in Kiwere and Magozi) were positively associated with adequacy of water supply and proximity to the system's intake, while controlling for several human, social, financial, natural, and physical variables.

The results of the rice yield model confirmed the hypothesis that farms at the tail-end are the worst-off, but unexpectedly showed that head-end was also associated with lower (−24%) yields compared to the middle section. Moreover, proximity to the main canal (as a continuous variable) was found to be not statistically significant. These results call for the reconsideration of the common assumption that location advantages decline following the scheme's hydraulic gradient (from head-end to tail-end), which has, so far, dominated the literature on water distribution and equity in smallholder irrigation systems. Conversely, water-induced advantages may be clustered in the middle section, and also derived from other factors. In fact, timing of water supply at the start of the irrigation season and satisfaction with water supply had a statistically significant, positive effect on rice paddy yields, while proximity to the main canal was a significant driver of both yields and incomes. Importantly, crop production and irrigated area had statistically significant effects on incomes, but their direction was surprisingly mixed. In particular, higher output of tomatoes (the most common crop in Kiwere) was associated with lower incomes. This result suggests that inadequate crop selection may be a major profitability barrier linked to poor access to markets and knowledge.

This study concludes that, to understand water supply and distribution within smallholder irrigation systems, a multidimensional water proxy can unveil critical influences on crops and yields. Otherwise, these would, most likely, remain overlooked by widespread unidimensional approaches, such as the head versus end dichotomy.

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Appendix A: Literature Summary on Regression Analyses on Yields and Incomes

Source and Study Area	Dependent Variable	Independent Variables and Model Types
Reardon et al. (1992), Burkina Faso	Net household income	Share of noncropping income, asset vector (livestock, land, foodstock, savings, outmigration, cultivated cotton land), household size, household structure, prices (nonfood, food), dummy near main road OLS multiple linear regression
Battese and Coelli (1992), India	Value of rice output	Total irrigated land, total unirrigated land, human labor, bullock labor, input costs, stochastic frontier production function
Ostrom and Gardner (1993), Nepal	Water availability difference	Length of canal, labor input, headworks dummy, lining dummy, Terai (marsh, grassland, and savannah) dummy, farmer managed dummy, regression type not specified
Makombe and Sampath (1998), Zimbabwe	Maize yield	Area, fertilizer, water, water × fertilizer, labor/human capital, OLS multiple linear regression
Becker and Johnson (1999), Cote D'Ivoire	Rice yield, weed mass, fertilizer efficiency	Water control dummy, seeding method, seeding density, age of transplants, herbicide, time of weeding, *N* rate, *N* timing, *P* application, dummy OLS, multiple regression
Canagarajah et al. (2001), Ghana	Nonfarm income	Female head of household, female, age, age squared, dependency ratio, attended primary school, attended high school, central region, eastern region, western region, OLS, multiple linear regression
Sadras and Bongiovanni (2004), Argentina	Maize yield	Nitrogen, area, season, yield inequality, correlation analyses
Wan (2004), China	Per capita disposable income	Household size, the dependency ratio, per capita capital input, average level of education of household members, per capita possession of cultivable land, and proportion of labor force employed in rural industrial enterprises. Multiple linear regression
Hussain et al. (2004), India and Pakistan	Wheat yield	Dummy for middle location of farmers on the distributary, dummy for tail location on the distributary, dummy for improved varieties, sowing week, quantity of NPK fertilizers, quantity of irrigation water applied measured at field outlet, total number of irrigations, time gap between presowing and postsowing irrigation, percentage of groundwater times electrical conductivity, dummy for season multiple linear regression
Pasaribu and Routray (2005), Indonesia	Paddy production	Plot size, seed use per area, labor expenditure per area, fertilizer use per area, pesticide use per area, irrigation intensity, age of head, education level, frequency of canal maintenance, OLS, multiple linear regression
Safa (2005), Yemen	Farm income	Family size; age of respondent, land size, number of animals, education, coffee production, agroforestry dummy, multiple linear regression (OLS and weighted least squares)
Bhatta et al. (2006), Nepal	Satisfaction with irrigation management	Age, education, land, distance from main canal, leakage, equity distribution, logit regression
Kato et al. (2006), Japan	Rice Yield	Water regime: flooded lowland, rainfed upland, irrigated upland, water deficit upland, correlation analysis
Tittonell et al. (2007), Kenya	Maize yield	Soil type, fertility rating, area, slope, percentage of clay and silt, soil organic carbon, total soil nitrogen, delay in planting, plant density, diammonium phosphate, calcium ammonium nitrate, compost, residue, labor, multiple linear regression
Tittonell et al. (2008), Kenya	Maize yield	General (site, wealth ranking, fertility ranking); management (distance between homestead and sampling point), plant population density, weed level, striga level, nutrient intensity score); soil and landscape (soil wet chemistry, slope, soil spectral data), classification and regression tree (CART)
Zhang et al. (2010), Iowa, USA	Corn yield	Vegetation index, precipitation, temperature, water-holding capacity, OLS, multiple linear regression, and spatial lag
Kurukulasuriya et al. (2011), 11 African countries	Irrigation choice and net revenue	Temp winter, Temp spring, Temp summer, Temp fall, Precip winter, Precip spring, Precip summer, Precip fall, plot area, log (household size), electricity, Eutric Gleysols, Chromic Vertisols, Orthic Luvisols, Chromic Luvisols, Dystric Nitosols, inverse mills ratio; flow winter, flow spring, flow summer probit, and multiple linear regression (OLS and corrected)
Auffhammer et al. (2012), India	ln (Rice yield)	Weather (rainfall, drought dummy, extreme rainfall, minimum temperature, solar radiation); nonweather (area, area with high yield varieties, fertilizer, labor), multiple linear regression

Table
(continued)

Source and Study Area	Dependent Variable	Independent Variables and Model Types
Sarker et al. (2012), Bangladesh	Rice yield	Maximum temperature, minimum temperature, total rainfall, OLS, multiple linear regression, and quantile regression
Barnwal and Kotani (2013), India	Rice yield	Year, area, irrigation (% sown area), fertilizer, drought (dummy), rain intensity, temperature, precipitation, temperature standard deviation, precipitation standard deviation, agroclimatic zone, Temp × agroclimatic zone, precipitation × agroclimatic zone quantile regression
Ahmed et al. (2014), Nigeria	Rice yield	ln (fertilizer, pesticide, herbicide, labor, education, other area), dummy (irrigation used, land hired, seed source, age, other job, farmers organization, training, rice major crop, livestock, flooding), OLS, multiple log-log regression (Cobb-Dougl`as production function)
Collins et al. (2014), Cambodia	Rice yield	Distance to water source, correlation analysis
Koirala et al. (2016), Philippines	Rice yield	Area, output value, seed cost, fuel cost, fertilizer, labor, capital, irrigation cost, male age, male education, female age, female education, household size, stochastic production frontier models
Hirooka et al. (2016), Cambodia	Leaf area index	Seeding date, planting method, water score, C in soil, C/N ratio in soil, N fertilizer (excluded weed due to inadequate data), analysis of covariance
Silva et al. (2017), Philippines	Rice yield	Cultivated land, farm size, rice yield, variety type, input use, seeds, nitrogen, phosphorus potassium, irrigation water, fertilizers, insecticide, herbicide, no. of operations, land preparation, crop establishment, total labor, crop establishment, harvest and threshing, stochastic frontier analysis (and yield gap)

Appendix B: Additional Statistical Tests on Survey Data

Table B1
Variance Inflation Factors (VIFs) in Paddy Yield Models in Magozi

	VIFs	
Variable	Model (2): location as linear distance to intake	Model (4): location as dummies
Female	-	1.14
Age	1.55	1.68
Education	1.22	-
Household size	1.63	1.78
Soil fertility	1.09	1.10
2015 year	1.78	1.75
Satisfaction water supply	1.86	1.91
Timing of water (END)	1.11	-
Distance to main canal (km)	1.10	-
Head location	-	1.51
Tail location	-	1.61
Mean VIF	1.42	1.56

- Variable is not part of the model

Table B2
Variance Inflation Factors (VIFs) in Irrigated Income Model in Kiwere and Magozi

Variables	VIFs Model (7)
Rice production	1.83
Tomato production	3.21
Onion production	3.09
Other irrigated crops	1.03
Irrigated area	1.92
Herbicide, pesticide, fungicide	1.11
Distance to main canal	1.05
Mean VIF	1.89

Table B3
Nonparametric Test on Paddy Yields by Retained and Dropped-Out Observations

	n		Median Annual Irrigated Income ('000 TZS)		Wilcoxon Rank-Sum Test		Kolmogorov-Smirnov Test	
Scheme	Retained	Dropped-Out	Retained	Dropped-Out	Z	p	D	p
Magozi	58	42	2,965	3,212	0.748	0.454	0.145	0.661

Table B4
Nonparametric Test on Irrigated Income by Retained and Dropped-Out Observations

	n		Median Annual Irrigated Income ('000 TZS)		Wilcoxon Rank-Sum Test		Kolmogorov-Smirnov Test	
Scheme	Retained	Dropped-Out	Retained	Dropped-Out	Z	p	D	p
Kiwere	70	30	500	425	−0.237	0.813	0.096	0.978
Magozi	58	42	1,000	840	−0.835	0.404	0.154	0.556

Appendix C: Full Variable Description

Variable	Definition	Model	N	Mean	Standard Deviation	Minimum	Maximum
Rice paddy yields	Paddy yield in kg/ha/year	Yield	170	2,828	1,846	0	10,383
	Ln (paddy yield in kg/ha/year)	Yield	170	7.24	1.96	0	9.25
Irrigated income	Gross annual gross income from irrigated crops ('000 TZS)	Income	198	1,292	1,994	0	19,001
Female (dummy)	Gender of household head 0 = male, 1 = female	Income	200	0.13	0.34	0	1
		Yield	248	0.19	0.39	0	1
Age	Age of the of household head (years)	Income	196	43.54	13.26	18	91
		Yield	200	42.76	13.08	18	77
Education of household head (dummy)	0 = no education or some primary, 1 = completed primary education or beyond	Income	196	0.79	0.40	0	1
		Yield	198	0.81	0.39	0	1
Household size	Number of people living in household	Income	200	5.71	2.17	1	10
		Yield	200	5.46	2.01	1	10
Scheme (dummy)	0 = Kiwere, 1 = Magozi	Income	200	0.50	0.50	0	1
Rice production	Annual rice production ('000 kg)	Income	200	1.99	4.00	0	30.15
Maize production	Annual maize production ('000 kg)	Income	200	2.10	5.09	0	48.00
Tomato production	Annual tomato production ('000 kg)	Income	200	3.07	26.11	0	360.00
Onion production	Annual onion production ('000 kg)	Income	200	0.31	2.06	0	24.00
Production of other irrigated crops (dummy)	0 = no other irrigated crops produced, 1 = other irrigated crops produced	Income	200	0.07	0.25	0	1
Irrigated area	Area under irrigation (ha)	Income	200	1.01	0.90	0	4.86
		Yield	174	1.05	0.98	0	6.07
Off-farm income (dummy)	0 = household has no off-farm income, 1 = household has some off-farm income	Income	200	0.70	0.46	0	1

Table
(continued)

Variable	Definition	Model	N	Mean	Standard Deviation	Minimum	Maximum
Farm tools (dummy)	0 = ownership of only hand tools, 1 = ownership of animal or motor-driven farming tools	Yield	200	0.19	0.39	0	1
Soil fertility (dummy)	0 = infertile or moderately fertile, 1 = very fertile	Income	199	0.27	0.45	0	1
		Yield	200	0.45	0.5	0	1
2015 year (dummy)	0 = 2014, 1 = 2015	Yield	236	0.50	0.50	0	1
Perception of equity of water distribution	Agreement with the statement "water is equitably distributed among the irrigators in your irrigation system": 1 = totally disagree, 2 = disagree, 3 = neutral/do not know, 4 = agree, 5 = strongly agree	Income	197	3.29	1.13	1	5
		Yield	175	2.74	1.04	1	5
Satisfaction with water supply	1 = very dissatisfied, 2 = dissatisfied, 3 = neutral/do not know, 4 = =satisfied, 5 = very satisfied	Income	197	3.49	1.01	1	5
		Yield	176	3.14	1.12	1	5
Timing of water supply (dummy)	1 = only receive water at the end of the irrigation season, 0 = otherwise	Yield	152	0.29	0.46	0	1
Distance to main canal	Average weighted distance between farm plot and irrigation canal (km)	Yield	144	0.108	0.135	0	0.573
	Average weighted distance between farm plot and main canal (% relative to maximum distance)	Income	0.20	0.25	0	1	150
Distance to intake	Average weighted distance between farm off-take and system intake (km)	Yield	144	3.916	2.587	0.196	9.380
	Average weighted distance between off-take and system intake (% relative to maximum distance)	Income	150	0.42	0.26	0	1
Head location (dummy)	Conversion from relative distance where 0 = middle/tail, 1 = head	Yield	44	0.44	0.50	0	1
		Income	150	0.41	0.49	0	1
Tail location (dummy)	Conversion from relative distance where 0 = head/middle, 1 = tail	Yield	44	0.24	0.43	0	1
		Income	150	0.23	0.42	0	1
Herbicide, pesticide, and fungicide input	Annual expenses per ha (TZS)	Yield	194	14,706	15,146	0	84,016
	Annual expenses ('000 TZS)	Income	200	88	215	0	1,610
Fertilizer input	Annual expenses ('000 TZS)	Income	200	450	2,865	0	40,400

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