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Economic Benefits of Supplemental Irrigation in Uganda

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Abstract

Rainfall variability and the recurrent droughts in the semi-arid regions of Sub-Saharan Africa have far reaching consequences. They have major effects on the socio-economic and environmental sustainability of rural communities. This study investigates the technical, economic, and financial feasibility of small-scale rain water harvesting, and supplemental irrigation (RWHSI) system to mitigate the negative impact of long droughts on crop production. The proposed system consists of limited farm grading to direct the harvested rain water to a lined earth-pond where several alternatives for pumping are proposed for supplemental irrigation schemes. The proposed scheme is mainly activated during the short period when the soil moisture is most critical for the crop yield. To reach an optimum size of the pond, the soil moisture during the critical growth period is simulated using FAO's water productivity model (AquaCrop). The pond size is optimized by applying AquaCrop for several years with the actual rainfall pattern and the possible supplemental irrigation applications. For each year with its possible drought periods, crop yield for each pond size is predicted, then used for the economic feasibility of the pond sizes. The optimum pond size is the one maximizing its benefit over its cost. The feasibility of the proposed RWHSI is investigated on maize production for the Soroti area in Uganda. For the rainfall pattern, soil conditions, and maize growth characteristics of Soroti, the proposed RWHSI is proved by simulations to be technically, and economically feasible. For a typical farm holding with a catchment area of one hectare, an 800 cubic-meters lined earth-pond can give up to 50% increase in the maize yield. After considering the construction and running costs of the supplemental irrigation system, the pay-back period is 6 years. The required investment cost for this RWHSI is low, and likely to be within the financial capacity of many farmers, while their selection of the pumping system will depend on their manpower and financial ability.

Keywords

Runoff Harvesting, Rain-Fed Irrigation, Rainwater Harvesting, Sub-Saharan Africa, Drought Mitigation

1. Introduction

Agricultural production accounts to almost 70% of the global fresh water extractions [1]. Meanwhile water is considered an essential element in both socio-economic and environmental development [2] [3] [4]. Pramod *et al.* and Rockstrom *et al.* [5] [6], reported that by 2050, the world will need an additional 5000 km^3/year of water for sustenance to meet the increasing food demands due to population explosion. Different researchers have suggested that supplemental irrigation to rain-fed agricultural settings could be a potential solution to the increasing food demands [1] [2]. A study conducted by Falkenmark *et al.* [7] reported that an approximate 80% of the world's cultivable land depends on rainfall. Yet rain-fed production produces up to 70% of the global food supply. However, there is a significant change in rainfall patterns, intensities and distribution [8]. The Food and Agriculture Organization (FAO) reported that almost three quarters of the fresh water resources in Sub-Saharan Africa (SSA) are used for agricultural purposes [9]. Estimates show that uncertain weather conditions as well as insufficient water for irrigation could cause the agricultural productivity in several countries to fall by up to 50% over the next decade, severely affecting their prospects of greater social and economic development [10]. FAO further reported that in SSA, there is an approximate 42 Million hectares of land that require irrigation [11]. Statistics have shown that 63% of Sub-Saharan population resides in rural areas and relies on rain-fed agriculture [12]. Almost 94% of agricultural land south of the Sahara Desert depends on rainfall for crop production [5] [13].

Agriculture, a main contributor to Uganda's economy made up almost a quarter of the gross domestic product (GDP) in 2013 [14]. The agricultural sector employs more than half of the country's population in addition to providing a foundation for the development of other economic spheres [15]. However, moisture stress to crops in Uganda has become the biggest challenge in the agricultural industry. Ronald Kalali an agricultural officer at Mobuku government prison, reported how drought drove their 300 acres of land to zero yields. "We were going to utilize all the rains because we planted in time but unfortunately we stopped receiving rains in March immediately after we had planted. We are expecting zero yields," [16]. When rainfall is small, not enough to support the full growth of a crop, full irrigation schemes are usually considered depending on streams or ground water resources. However, surface water resources may require large storage facilities such as dams and reservoirs to store water from the rainy to the dry season. Such facilities require high capital investments which reduce benefits from production and as well pose a great environmental concern. These findings were presented by McCartney & Smakhtin [17] who reported that large water reservoirs have negative social-environmental and economic constraint. They occupy large surface area reducing the area under crop production, causes environmental degradation, distortion of the soil structure and underground water movement hence leading to disastrous natural disasters like floods, earthquakes and drought [18].

On the other hand, when the annual rainfall is large, but its pattern includes several inter-seasonal droughts, crops are then subject to severe loss. This becomes worse if the drought is long and coincides with the period that critically affects the growth of the cultivated crop [19]. Supplemental irrigation could be the most effective solution to mitigate the negative effects of long droughts. Supplemental irrigation (SI) is defined as the application of limited amounts of water during critical crop growth stages to essentially rain-fed crops to improve and stabilize yields by maintaining a minimum amount of soil moisture in the root zone [20]. Even though SI is thought of as an effective and promising practice to mitigate drought effects, the system faces several challenges which may include:

- The difficulty to accurately plan the timing and amount of water to be applied to crops in advance.
- SI does not require a fixed schedule as it is with a full irrigation system since the system is dependent on rainfall variability.
- The practicability of storing and retaining water most especially precipitation till the when it is needed by crops despite of the huge seepage and evaporation losses [21].

This study attempts to investigate the possible solutions to such challenges most especially with the small-scale farming systems in the rain-fed agricultural zones. Findings from Pandey *et al.* [22] reported a higher increment in crop yields by developing smaller sized ponds for dry spell mitigation. Despite the many conducted studies on runoff harvesting, there are few published data specifically for supplemental irrigation of maize crops which happens to be the staple food for most of the sub-Saharan African countries [5]. Generally, there are has been lack of scientific consensus about both the trend and distribution of rainfall in developing countries. Kansiime *et al. and* McSweeeney *et al.* [23] [24] reported a 4.7% decrease per decade in rainfall over the past fifty years in Uganda. Geerts and Raes; Mango *et al.*; Vohland and Barry [25] [26] [27] previously reported that crop failures can be caused by short term agricultural droughts which can occur for just a few days and the yields can be greatly reduced. Findings from the United Nations Population Fund in collaboration with the Ugandan government [28] [29] reported an average yield reduction of 50% in maize during the growing seasons of 2006 and 2008 caused by long droughts. In many rain-fed agricultural zones, low crop yields are attributed due to low soil moisture, inappropriate management of soil and other poor field practices. Shortage of soil moisture due to drought and dry spells especially during the critical crop growth stages (flowering and grain filling) can lead to severe losses of crop harvests.

This research aims at increasing crop productivity through reducing crop failures during the moisture-critical growth stages. At a greater extent, these failures are due to low soil moisture content. This can be achieved by having an effective supplemental irrigation system that can easily be adopted and sustained by a small-scale farmer. The principle objective of this study is to develop a supplemental irrigation scheme for maize production under rain-fed agriculture. The study proposes a supplemental irrigation scheme that focuses on harvesting surface runoff during the intensive rainfall events and uses the stored water during the periods of water shortage in the growing season. The proposed scheme relies completely on rainfall. The study also employs FAO's water productivity model (Aquacrop) to simulate for the economic benefits of both rain-fed and supplemental irrigation system under crop production. The model is simulated using data from a study area in Soroti, Uganda. The simulated benefits along with the costs of establishing the scheme are used to make an economic analysis based on both the model results and the quantitative data that was collected in the study area.

2. Materials and Methods

2.1. Study Area and Data Description

Soroti is located in Eastern Uganda between geographical coordinates of 1.541˚ to 2.029˚ North and 33.39˚ to 38.82˚ East with an average elevation of 1125 m above MSL (**Figure 1**). Annual rainfall averages 1100 - 1200 mm distributed between two seasons of March to May (MAM) and September to November (SON) [30]. October to late February or early March and mid-June to late July are traditionally dry seasons for crop harvesting and land preparations. The MAM season is the main growing season however it has become variable with frequent dry spells causing famine [31]. Soroti area lies in the famous low-lying cattle corridor of Uganda. The cattle corridor is the most drought vulnerable region of the country [24] [31]. Rainfall trends over the past 25 years have shown a gradual decline. It's for example evident that regions practicing crop cultivation have had an average decline of around 8% when rainfall amounts between two periods, 1920 to 1969 and 2000 to 2009 are compared [32] [33]. Climatic data including daily temperature, daily rainfall and solar radiation was collected from the Uganda National Meteorological center in Kampala. Soil samples in addition to both primary and secondary data about the maize cropping system were taken from the study area in Soroti.

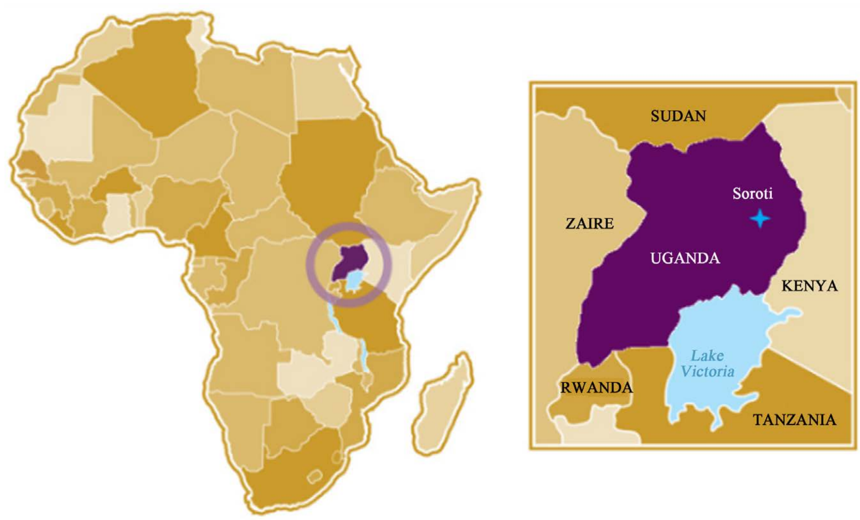

Figure 1. Map showing Soroti—The study area in Eastern Uganda.

Soil samples were taken from three sub-counties in Soroti district *i.e.* Ogweri, Arapai and Assuret in February 2017 and tested in the lab for their chemical and physical properties. This was a period just before the crops were actively growing and prior to manure applications. The samples were taken from 5 different sites whose soil types have been classified by [34] [35] as shown in **Figure 2**. Most of the soil in the study area is classified as plinthosols which are characterized by the presence of iron and aluminium oxides giving it more of a red colour [36]. These soils are very shallow and they often form hardpans with repeated wetting and drying which eventually lead to erosion [37].

The analysed samples were collected from the upper soil horizons (0-30 cm) and in the subsoil layers (30 cm to 60 cm) from each site under different soil types in the area. The soil physical and chemical characteristics were obtained from both field surveys and laboratory analysis. The soil samples were air-dried, pounded and sieved through 2 mm sieve to remove any debris then subjected to physical and chemical analysis following standard methods described by Okalebo *et al.* [38] for routine analysis. Soil pH was measured in a soil water solution ratio of 1:2.5; Organic matter by potassium dichromate wet acid oxidation method; total Nitrogen determined by Kjeldhal digestion; exchangeable bases from an ammonium acetate extract by flame photometry (K^+, Na^+) and atomic absorption spectrophotometer (Ca^{2+}, Mg^{2+}); and particle size distribution (texture) using the Bouyoucos (hydrometer) method [38]. Also, through continuous field visits, farm observations and consultation from the local farmers, the level of erosion hazard was classified and ranked into three at each sampling position (slight, average and high). Most of these parameters were required to run simulations for the AquaCrop model that is applied in this study (**Table 1**).

2.2. Proposed Supplemental Irrigation Concept

The system is developed to store water and use it for supplemental irrigation

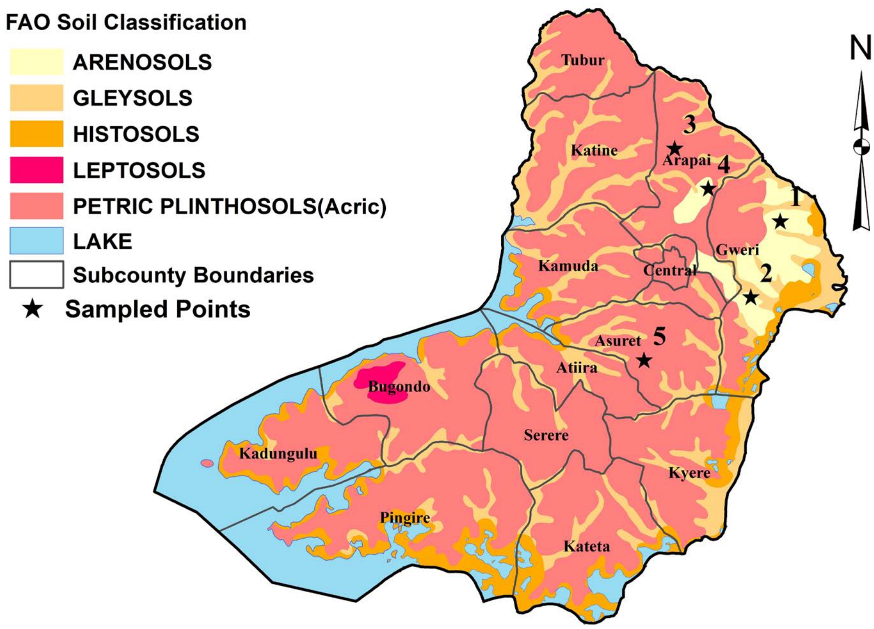

Figure 2. Soils types in Soroti district under FAO classification adopted from Atta-Krah *et al.* [34].

Table 1. Summary of the site characteristics of the studied soil.

Profile pits	Latitude	Longitude	Slope %	Altitude (mm)	Depth (cm)	Drainage	Erosion Hazard	Surface Stoniness
1	1.7782	33.7379	1 - 3	1037	90.0	Poorly drained	Average	Nil
2	1.6777	33.6185	1 - 3	1035	70.0	Poorly drained	Average	Nil
3	1.8620	33.6183	1 - 4	1035	90.0	Well drained	Slight	Nil
4	1.8050	33.6515	2 - 5	1038	80.0	Well drained	Slight	Nil
5	1.6120	3357640	2 - 5	1038	80.0	Well drained	Slight	Nil

during the most critical water sensitive stages of a maize crop. Irrigation is targeted primarily to be applied during the flowering and grain filling stages. **Figure 3** illustrates the concept of supplemental irrigation proposed in this study. When a rainfall event occurs, runoff water flows to the lower areas of the catchment by the effect of gravity. This runoff can be directed at certain points into a water storage pond with the aid of gullies, furrows or rills. The storage medium is composed of the sedimentation pond and a bigger water storage pond with a spill away channel in case of excessive storage. The sedimentation pond is mainly for the settling of sand, trash and other suspended materials from the runoff. Between the sedimentation and the storage pond is an underground inlet pipe that allows water into the storage pond. The bigger storage pond is well lined with a Polyvinyl chloride (PVC) to prevent the heavy losses of water through seepage. Furthermore, the extended part of the liner on the top sides of the pond is covered with a heap of soil to prevent direct contact of the liner with radiation from the sun.

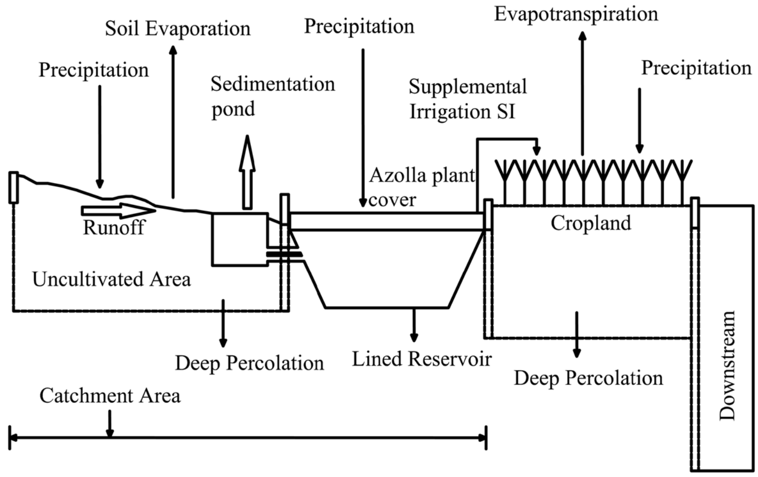

Figure 3. Supplemental irrigation system adopted and modified after pandey *et al.* [45].

The system also comprise of a surface water floating plant-Azolla as water cover primarily to control mosquito breeding on the surface of the pond [39]. Different authors have reported the great significance of Azolla in controlling mosquito breeding over water surfaces. Azolla mat suppresses mosquito breeding by inhibiting ovi-positioning of the female mosquitoes. It acts as a physical barrier for mosquitoes to lay their eggs on the surface of water [40] [41] [42]. The fern is a multi-purpose plant. It is a great source of proteins to livestock including cows, sheep, pigs and chicken. Azolla can replace conventional chicken meals with 5% - 15% and it is also used to control evaporation losses from surface water bodies [43] [44]. From the storage pond, water can be pumped using different alternatives of water lifting techniques to the cropped area. The examined techniques in this study include the traditional rope and bucket system, the treadle or pedal pump, diesel pump and the solar pump. In case of any pump, it should be a submersible pump since the water surface is covered with Azolla plant. The storage pond is established with a total depth of 2m with a slope of 1:1.

The system is suitable for the land use in the study area in addition to other areas with similar climatic conditions in Africa facing the same water shortage in agricultural production. This system can easily be constructed and afforded by an average farmer. The simply designed pond is developed to collect water that can serve and feed an average cultivated area of about 3 acres of land for supplemental irrigation. The pond can be designed with varying capacities for water storage.

2.3. Irrigation and Crop Growth Modelling

The FAO water productivity model—AquaCrop is used in this study to identify the necessary supplemental irrigation and avoid the losses in the Maize production during the dry spell. AquaCrop simulates the crop growth phases, soil water in the plant root zone and assess crop yield response. The model is used to simulate maize crop production under the conditions of rain-fed and supplemental irrigation. To run the simulations, the model requires both climatic and soil data as identified in section (2.1). Input data for the simulations was collected, validated and analyzed using the model and then the model results are used to develop a cost benefit analysis. The model functions by relating the interaction between the crop parameters, climatic conditions and the soil properties in addition to the practices of field management [46].

The first simulations were based on the existing farming practices in the study area which is rain-fed agriculture without considering any kind of supplemental irrigation. Crop yields are simulated depending on the soil characteristics, field practices and rainfall. A period of ten years from 2003-2012 is simulated and the crop yields were estimated. Then several simulations were conducted to test for optimization among the four alternative storage pond volumes for a hectare cropland *i.e.* 1000, 800, 600 and 400 m^3. Simulation of maize yields from the model under different irrigation levels are studied and analyzed to develop a cost benefit analysis. The results from the cost benefit are used to recommend the best irrigation system and pond size suitable for the study area. A supplemental irrigation system is established with a simple designed water collecting and storage facility to accommodate surface runoff for the periods of intensive rain events.

3. Results and Analysis

3.1. Rainfall Harvesting and Yield Increase

Results from the simulation without irrigation show that there is no clear trend of yields since 2003 till 2012. However, the yields only increased with an increase in the amount of rainfall received during the growing season as shown in **Table 2**. ET refers to the Evapotranspiration measured in kg yield/m^3; Potential yield is the maximum yield a crop can attain. The actual yield is the green biomass yield while the Dry yield is the harvested crop yields (grains in ton/ha).

Table 2. Rain-fed production analysis for the growing season (March-May).

Season	Seasonal Rainfall (mm)	ET (kg yield/m^3)	Potential Yield (ton/ha)	Actual Yield (ton/ha)	Dry Yield (ton/ha)
2003	795	1.42	13.67	13.3	6.808
2004	426	1.16	13.7	8.6	4.285
2005	608	1.38	13.8	12.2	5.986
2006	423	1.14	13.8	9.0	4.061
2007	510	1.56	13.9	11.7	6.321
2008	409	1.01	13.9	7.1	3.389
2009	360	1.13	14.0	7.9	3.915
2010	628	1.53	14.0	14.0	7.022
2011	423	1.47	14.1	12.6	6.252
2012	647	1.34	14.2	11.8	5.692

Figure 4 represents the Net irrigation water needs for maize analyzed for ten years using the model. The upper line graph shows the Net supplemental irrigation water needs (demand) to keep the soil moisture between the threshold for leaf expansion and the threshold for stomata closure *i.e.* at 75% Readily Available Water (RAW). The maximum values for net irrigation water needs are observed with years that had low amounts of rainfall during the seasons 2004, 2006, 2008 and 2009. The lower line graph represents the potential annual runoff (supply) that can be collected over a catchment area of one hectare calculated using the model. Although the study area is characterized with two growing seasons annually, MAM and SON, maize is always planted in the first season (MAM) which is most vulnerable to drought and it is the season that was simulated. Maize in most cases is intercropped with other crops such as soybean and groundnuts. Notably, such a diversified cropping pattern could lead to significant losses in yields in case of a drought within the growing season. For this reason, we assumed in this study that the annual water storage will only be used during this particular season alone for only one crop per year.

Setting the soil moisture level at 75% RAW creates limited tension or stress to the crop whereby it directs most of its available water needs to grain formation. This moderate level of water stress in the soil root zone induces more grain formation in many cereal crops. Regardless of having such a low moisture level with minimal stress to the crops, the net irrigation water demand is considerably still high compared to the potential annual runoff that can be collected. For this reason, the proposed supplemental system specifically applies irrigation water in only the critical growth stages of maize. So, unless the catchment area is bigger than one hectare, there is need for additional irrigation water supply e.g. underground water pumping or stream diversion.

Figure 5 compares three different scenarios *i.e.* the average seasonal maize water needs for the study area which is set at 580 mm, supplemental irrigation using surface runoff and the total seasonal rainfall received over the study area for each season. The values per unit area are calculated using the model. These

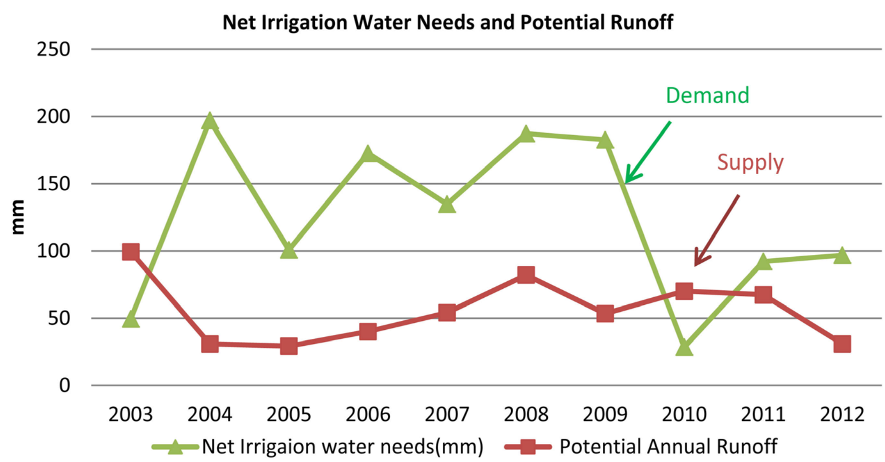

Figure 4. Irrigation demand vs. potential supply.

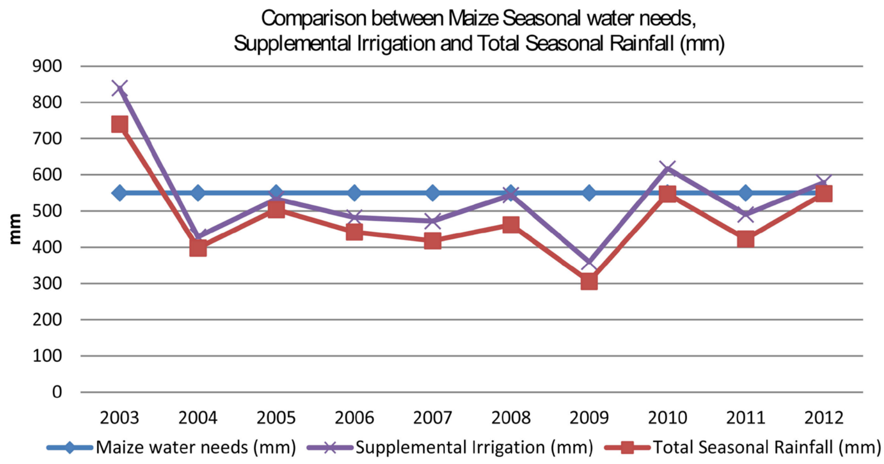

Figure 5. Reducing the Irrigation water gap.

results explain the significance of supplemental irrigation using runoff water as to reduce the water gap between what is needed and what is supplied as rainfall. Maize crops require an average seasonal water needs between 500 - 800 mm depending on the cultivar of the crop, soil characteristics and climatic condition [47]. In our case, the average seasonal rainfall received for the period of 10 years was even below 500 mm.

In a way to cope with the water shortage in rain-fed agriculture, **Figure 5** presents a simple economic solution of how the water gap in maize production can be reduced. Applying such a supplemental irrigation scheme specifically in the critical stages can reduce the moisture water demands by more than 50% and greatly increase crop yields. The maize seasonal water needs in the study area is set to be constant at 580 mm for all the growing seasons. It is observed that applying supplemental irrigation actually provides close to the needed seasonal water needs required by the maize crop to flourish and produce good yields.

The study found that the maximum amount of runoff that can be collected from a hectare catchment is 100 mm and the minimum at about 40mm. With these values, different alternative pond volumes are proposed to collect the all year around runoff for supplemental irrigation of maize for the critical stages. The pond capacities that are examined in this study are 1000, 800, 600 and 400 m^3 pond volumes. **Figure 6** shows the total yields in ton/ha with Rain-fed system and Supplemental Furrow Irrigation using different pond volumes over the critical growth stages of maize crops under a one-hectare land. Both the 800 and 1000 m^3 had relatively similar crop yields with supplemental irrigation. This means that large reservoirs do not necessarily increase per capita income from maize production under one-hectare cropland in particular.

3.2. Economic Feasibility of Supplemental Irrigation

A cost-benefit analysis of the four capacities (1000, 800, 600 and 400 m^3) has been carried out. **Table 3** gives an account of the costs of the construction of the

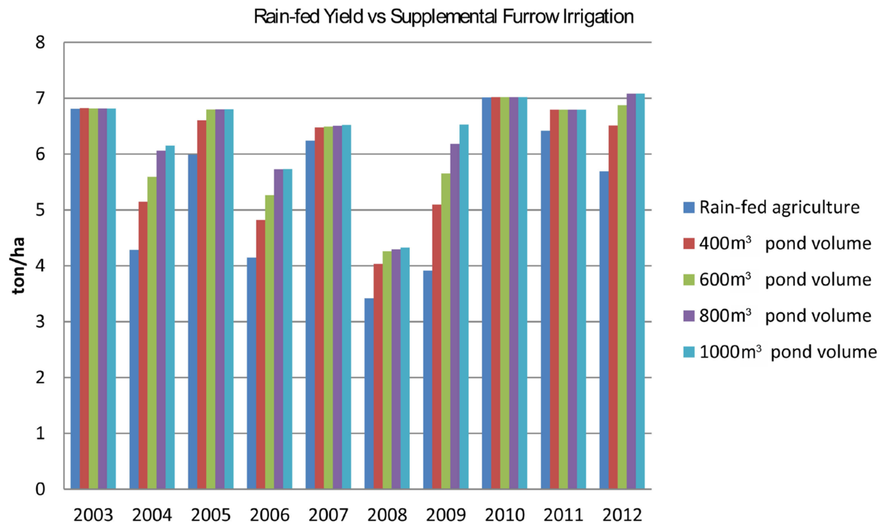

Figure 6. Rain-fed Yield (ton/ha) vs. supplemental furrow irrigation.

Table 3. Pond dimensions and construction costs.

Pond Volume (m^3)	Pond Dimensions (m)	Pond Liner Dimensions (m)	Unit Cost of Pond Liner (*UGX*)	Total Cost of Pond Liner (*UGX*)	Total Construction Costs (*UGX*)	Total Construction Costs *($ US)*
400	10 × 10 × 2	16 × 16	10,000	2,560,000	4,040,000	1138
600	20 × 15 × 2	26 × 21	10,000	5,460,000	7,655,000	2156
800	20 × 20 × 2	26 × 26	10,000	6,760,000	9,720,000	2738
1000	25 × 20 × 2	31 × 26	10,000	8,060,000	11,835,000	3334

pond and the pond liner (PVC) used in this study for all the four alternative pond capacities. All these costs are calculated based on a one-hectare piece of land for crop cultivation and irrigation. The costs are presented in **Ugandan Currency**, **UGX. ($1 US is equivalent to 3550 UGX**).

Table 4 presents the capital, maintenance and operational costs for the water lifting techniques for the four-different water lifting systems which are analyzed in this study.

The results in Figure 7 represents the simulated yields of supplemental irrigation using different pond capacities. The study used data for the past ten years to represent the hydrological conditions in the region. The system with the least value of yields is the rain-fed, closely followed by the supplemental irrigation system of 400, 600, 800 and 1000 m^3 respectively. These results are used to calculate the Average Annual Growth. There was a yield increase of between 25% to 50% in case of supplemental irrigation compared to rain-fed system alone. This increase is mainly attributed from the four dry years that were analyzed. These four seasons were previously considered as dry years by the Ugandan government since they had frequent dry spells and droughts that led to the failure of almost all the crops nationwide [48].

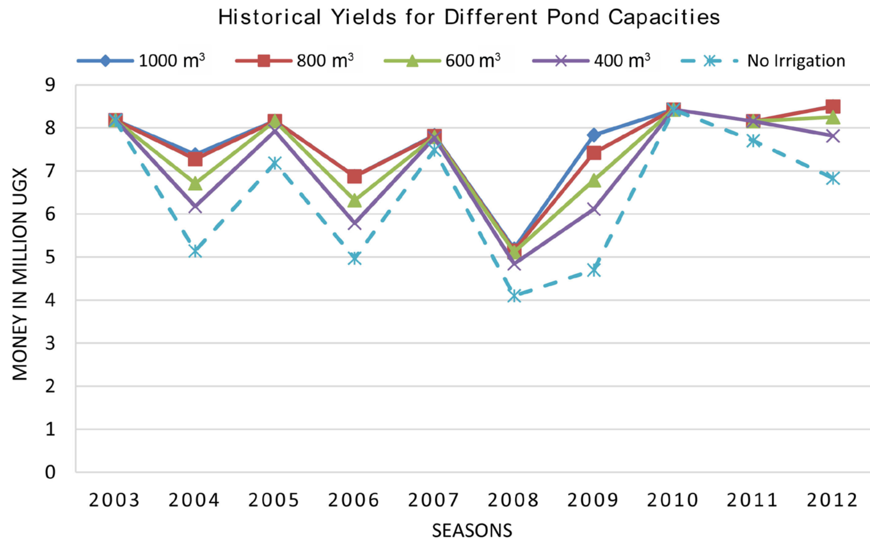

Figure 7. Historical seasonal monetary yields.

Table 4. Summarized costs for the water lifting techniques for supplemental irrigation.

Water-Lifting Technique	Flow rate (m^3/h)	Purchasing Price (*UGX*)	Annual Operation costs of the pump and maintenance of pond (*UGX*)	Life span in years
Rope and Bucket	2	120,000	5,040,000 ($1420)	1
Treadle Pump	6	720,500	730,000 ($205)	6
Solar Pump	8	5,060,000	260,000 ($73)	10
Diesel Pump	15	2,090,000	452,000 ($127)	20

This study findings conform to the few scientific studies that have been conducted regarding supplemental irrigation elsewhere in the world [49]. The authors reported about 60% increment in crop yields compared to rain-fed system. Other researchers who found relatively similar results when they experimented supplemental irrigation on other crops [5] [50] reported that dry seasons supported with supplemental irrigation had up-to 74% increase in yields. With this insufficiency in research concerning supplemental irrigation in mainly Sub-Saharan Africa, this prompted us to generate an economic analysis to investigate the feasibility of the proposed system. The calculated Annual Average growth for Irrigated agriculture is 2.86%. This value is used to forecast the future yield values for a period of 17 years. The period of forecast is selected to be 17 years because it was found most suitable for all the water lifting alternatives used in this study regarding their life span. The forecast period is from the current year 2017 till 2034. Figure 8 however, represents data for this projection since there was no data records from 2012 till 2017 which is the baseline year for the forecast, this study made forecasts for the missing years till 2017 to have a baseline from the current year (2017). The following equations are used to calculate the Annual average growth yield and the forecasted yield. Since there is a significant inflation of 5.50% in Uganda, this rate is also taken into consideration to increase the accuracy of the results [51].

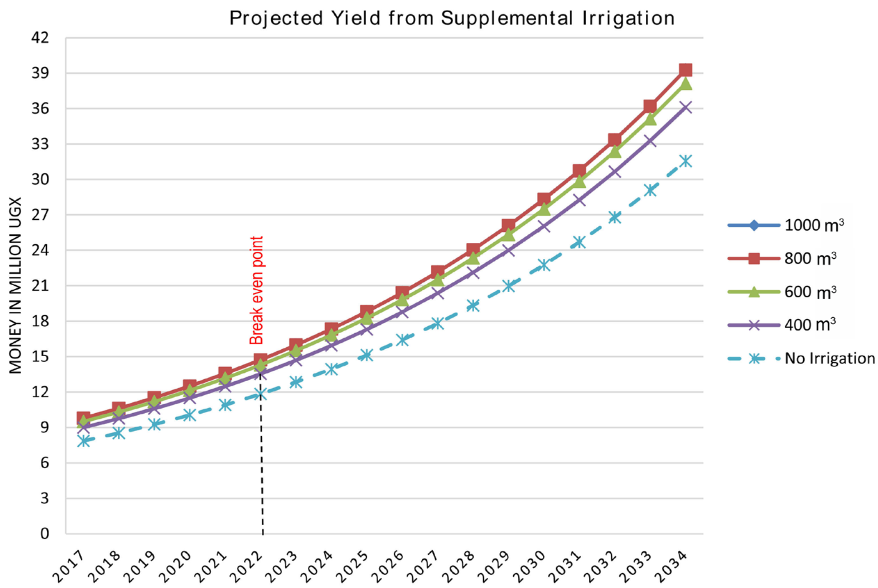

Figure 8. Forecasted monetary yield value.

$$\text{Average Annual Yield growth} = \frac{\text{Yield in current year} - \text{Yield in previos year}}{\text{Yield in previous year}} \times 100$$

$$\text{Forecasted yield value} = \text{Previous yield value} \times (1 + \text{Average annual yield}) \times (1 + \text{Inflation rate})$$

The values for these calculations are also presented in Ugandan currency ***UGX***.

After the calculation of the yield forecast, the study further calculates the discounted cash flow (DFC) for the alternative systems. Using an interest rate of 10% [51], the Net Present Values (NPV) for pond capacities are also calculated to better estimate the profitability of the project if farmers adopt and willingly invest their money in such a supplemental scheme. A similar concept of Net Present Value (NPV) for the water lifting techniques is also calculated. This is also forecasted for 17 years from the present year 2017.

3.3. Optimization of Supplemental Irrigation

Having calculated the NPV for both the pond volumes and the water lifting techniques, in addition to the benefits from the supplemental irrigation, the most profitable duo system *i.e.* (the optimum pond volume and the most profitable lifting technique) is estimated. **Figure 9** presents the most profitable supplemental irrigation for maize production in rain-fed systems. With the complete analysis of the economic benefits, the study finds that the most profitable system is the 800 m^3 pond along with the diesel pumping technique using furrow irrigation. Due to the high number of workers required for the rope and bucket system to carry out the manual irrigation activities, it makes the system unfeasible

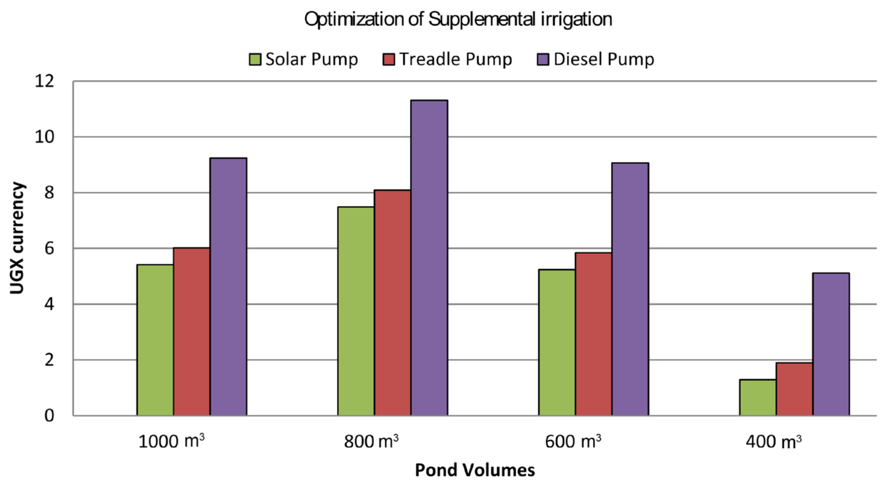

Figure 9. Profitability of different pond sizes with different lifting techniques.

to implement on such a large scale. For this reason, it was excluded in the economic analysis.

The treadle pump gives very good profits even more than the solar pump though still low compared to the diesel pump. Concerning the solar pump, its profitability is lower compared to the treadle and the diesel pump. This might be because of its high purchasing costs since it is still a new technology despite of being environmentally friendly. The diesel pump presents the highest profits amongst others maybe because of its durability (very long-life span if maintained well). However, it poses a great challenge to the environment since the system uses fossil fuels to operate. Furthermore, the study calculated the payback period or the break-even period for the selected system (800 m^3/diesel pump) to be 6.02 years. This period is calculated basing on both total costs and total revenue from the forecasted yields *i.e.* the point at which total costs will be equal to the total revenue and the farmer will start to earn profits out of his investment.

4. Conclusions

The study presents a simple sustainable economic solution for the problem of crop failures due to short droughts and dry spells during the crop growing seasons. As one of the most important staple foods in almost all regions of Sub-Saharan Africa, the production of Maize has greatly decreased due to water shortage. So, this study proposes that a farmer can sacrifice 5% of his cropland to construct a micro storage system that can collect surface runoff and use it primarily during the critical growth stages for a maize crop. The study suggests developing an earthen lined pond of 800 m^3 by volume along with a diesel pump to protect a one-hectare piece of cropland from intra-seasonal droughts.

Such a relatively cheap technology could greatly facilitate the up scaling of rainwater harvesting for small scale irrigation. This would thus boost farmers' yields and prevent crop loss due to insufficient or unevenly distributed rainfall. The study makes use of the crop water productivity model (AquaCrop) to estimate and predict the yield of supplemental irrigation using data from the study area in Eastern Uganda. The model is found very useful in relating climatic data more particularly rainfall patterns to crop yields. Such a model can be utilized for other locations anywhere in the world to estimate crop yields in relation to rainfall patterns for that specific location.

Lastly, additional research in the area of supplemental irrigation is very vital due to the fact that there are only few published data. In this study, we considered a few assumptions to generate the study's results. These results are based on the data from the study area, so the results are area specific. The crop under investigation is a maize crop which has different moisture critical stages, different water needs and as well different growth patterns compared to other crops. All these differences are possible areas of research which needs to be covered. The study gives no details of the pond balancing for the whole year; it only focused on irrigation in the moisture critical period during the growing season.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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