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The Economic Feasibility of Implementing Irrigation in Small, Limited Resource Farming Systems

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Authors' contributions

This work was carried out in collaboration between all authors. Author GFS was responsible for the initial idea and study design. Authors GFS and RW collected and compiled all information, and performed model simulations and preliminary analysis. Authors JH and WW worked with authors GFS and RW in data analysis and interpretation. Author RW wrote the first draft of the manuscript from his M.S. thesis. All authors contributed to the editing, revision, and final preparation of the manuscript. All authors have read and approve the final manuscript.

Research Article

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ABSTRACT

Small farms are particularly important for local food production in the Mississippi Delta, a region identified as having substantial food deserts. In order for small farms to survive, however, management strategies are needed that simultaneously yield high value fruits and vegetables and also enable farmers to remain economically solvent. The research reported here tested the economic and productive feasibility of implementing irrigation in sweet potato (*Ipomoea batatas* L. Lam) production in Mississippi US. Historical production

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records and management expenses were used to determine sweet potato production expenses and returns over a ten-year period from 2002 - 2011. Crop water use over this 10-year period was calculated from historical weather records. Yield improvements resulting from implementing irrigation were then used to determine potential increased return on investment. Irrigation costs increased yearly production expenses 3-4%, depending on pumping fuel costs. Costs associated with harvest and post-harvest processing of the greater yields added an additional 8 – 70% to production expenses, depending on yield increase. However, even very modest (10%) improvements in yield are sufficient to economically justify implementing irrigation, as the net return on investment increased by 5% or more. Irrigation is a relatively simple tool that farmers could use to enhance their management practices and maximize profits. However, access to startup capital and knowledge of irrigation management are still critically needed to assist small, limited resource farmers in adopting tools and skills that will improve the output and economic return of their production systems. The results from this research will be used to develop management tools for farmers to improve access to production information and assist in making crop management and business decisions.

Keywords: Economic return of irrigation; limited-resource production; vegetable production systems; irrigation expense.

ABBREVIATION

SLR: Small, limited resource

1. INTRODUCTION

The number of small, limited-resource (SLR) farms has declined as the US agricultural production system continues to specialize [1]. This intensification is having profound impacts on agriculture [2]. Ancillary changes are also being felt, particularly in rural communities that depend on agribusiness activities of farmers and are directly supported by farm produce [3]. Limited resource farmers are defined as those having less than 172,800 US$ in direct or indirect gross farm sales in the previous two years, and a total household income at or below the national poverty level in that time frame [4]. This limitation of economic resources hinders SLR farmers from realizing good production output and economic success, and contributes to the decline or disappearance of these farmers and ranchers [5].

While small farms have difficulty competing with larger farms that supply most of the national and international food markets [6], they are an important component of local and regional food markets. Particularly surprising is the occurrence of food deserts in areas known for their agricultural production capacity, such as the Mississippi Delta [7]. Food deserts are defined as areas in which residents have limited access to affordable and nutritious food. Some rural areas of the Mississippi Delta have been identified as “severe food deserts” [3,7].

Truck crops account for about 2 percent of Mississippi’s agricultural production value [8]. Although this is small in comparison to forestry, poultry, and large-scale row crop production in Mississippi, truck crops are an important part of the rural economy and provide seasonal opportunities for affordable nutrition [9]. Many of these truck crops are produced by SLR farmers. Improvements in small farm production could assuage problems of food inadequacy in at-risk rural communities. In order for small farms to survive, however, new strategies must be developed to produce high value fruit and vegetable crops that will reward limited-resource farmers and ranchers by both maximizing profits and minimizing costs [10].

SLR farm and ranch producers in Mississippi and nationwide face unique financial challenges that limit their ability to establish a credit rating that allows them to acquire capital. This lack of capital hinders their ability to purchase equipment, pay for expensive inputs, and harvest the crop in a timely manner, hence negatively impacting the production of a healthy, marketable crop. Farm programs have also been shown to benefit larger operations, rather than SLR farmers [11], further limiting the opportunity for these farmers to take advantage of technological advances through cost-sharing programs.

Lack of knowledge is another barrier that prevents SLR farmers from maximizing productive capacity [12]. Knowledge of how upgrades and alternative management technologies or practices can benefit limited-resource agricultural production is often not available. The focus of agricultural academic programs has consistently been geared towards supporting research and technological development for the predominant, large-scale production systems [13]. Limited-resource farmers have difficulty learning about and implementing the latest technology because of limited access to and knowledge of the most recent technologies, and uncertainty about the benefits of new technology. The probability of technology adoption, especially technologies that require substantial investments of human and financial capital, has been shown to be dependent on farm size [14]. Moreover, the number of professionals knowledgeable of small farm production systems are limited [15].

Small farms succeed in many of the key aspects required of sustainable production: greater efficiency and enhanced productivity with less negative environmental impact, reduction in rural poverty and maintenance of a vibrant rural economy, and improved food security [16]. In addition, small farms provide fresh, nutritious foods to rural communities and, more and more, to urban areas. To maintain the continued success of small farms, the farmers require access to human and fiscal capital, technologies appropriate for their operations, and knowledge of optimal business and production practices [6,16].

Sweet potato (*Ipomoea batatas* L. Lam) is a one of the major vegetable crops in the US, grown for both income and as a household food source [17]. Although many SLR farmers use sweet potatoes as a source of income, the production expenses associated with sweet potato production are high. To manage that risk, the farmer must insure the production of a crop of quantity as well as quality.

Mississippi has always been a major producer of sweet potatoes in the US, though the total area has varied over time [8]. In 2010, Mississippi was the third largest producer of sweet potatoes in the US, following North Carolina and California. Formerly, many US states were involved in sweet potato production, particularly in the South. Until the mid-1960’s, yields per hectare were very similar for all sweet potato production areas of the US [8]. Improvements in production practices and varieties have resulted in a doubling of per area yield in most areas. In contrast, yield per hectare in California has increased more than threefold during this period, indicating the potential for substantial yield improvements [8]. Many factors could account for this disparity in yield improvements, including differences in weather and total sunlight. Another major factor may be that nearly all vegetable production in California is irrigated, while less than 1% of vegetable production in Mississippi is irrigated [8]. Irrigation is one technological advance that has been shown to enhance yields and quality, and as such will play an increasingly important role in future agricultural production [18].

Irrigation is an important tool used to insure both adequate production and profitability, and has been shown to increase yield in most crops, including sweet potato [19,20]. Both yield and quality of sweet potatoes respond positively to irrigation [21,22], contributing to enhanced profitability. Irrigation has the potential to increase marketable yield from two to nearly six fold with irrigation [19,20]. Some studies have suggested that sweet potato production is most sensitive to early-season drought [21]. Brodie [23] found that sweet potatoes could benefit from an additional 12.7 – 22.9 cm of supplemental irrigation, depending on anticipated yield. However, sweet potato yield and quality can be compromised by late-season rains, which can delay harvest operations. Moreover, little is known about the rate and timing of irrigation requirements for optimal sweet potato production.

The research reported here is a theoretical study to determine if implementing irrigation is economically feasible for small, limited resource vegetable production systems. The results of the research will be used to develop extension guidelines to improve vegetable crop production for SLR farmers. Potential crop water use and yield enhancement are simulated using a sweet potato production system as a case study. The economic feasibility is determined from the simulation results using enterprise budgets to compare production expenses under irrigated and rain fed production for a ten hectare farm, based on typical resources and equipment available for production on that scale. Economic returns are calculated from the most commonly used method of irrigation (furrow) and for two power sources: electrical and diesel power driven engines. The results provide useful information to SLR farmers on the economics of incorporating irrigation into their production systems. The results also provide a foundation for future research on water management needs in vegetable production systems.

2. MATERIALS AND METHODS

2.1 Economic Assessment

All management inputs were used to determine costs of production [24]. Information on production, harvesting, processing and marketing methods, expenses, equipment used and labor required were compiled from three sources: interviews of SLR farmers (as defined by ERS) [25]; historical production records from the Alcorn State University Experiment Station and Demonstration Farm (ASU-ES) demonstration plots; and published records of standard agricultural management practices and inputs for sweet potato production [26,27]. The Mississippi State University Vegetable Planning Budgets (MSU-VPB) [28] were used for additional information as needed.

2.1.1 Plant growth and maintenance

For the simulation of crop production, agricultural practices were summarized for field preparation, crop production, fertilization, and weed and insect control for 10 and 20 ha fields, using a 96.5 cm row width [26,27,28]. The assumption was made that the farm has one 93.2 kW tractor capable of performing most operations (Table 1). Additional owned field equipment included a two-row planter, disk, hipper, row-pack, spray rig, and potato digger. Standard field preparation for the simulation included disking twice with a 4.3 m disk in the fall after harvest of the preceding crop, bed preparation using a 4-row disk bed hipper, rehipping in the spring prior to planting, then rolling using a 3.7 m roll pack to firm the beds (Table 1). For our case study, sweet potato (*Ipomoea batatas* L.) slips were purchased at an average price of 3.5 cents per slip and planted at the recommended rate of 29,700 slips per hectare using a 2-row transplanter. The planting operation requires one tractor driver plus six additional workers. In this case study, in-season weed and insect control was performed with a broadcast sprayer once with herbicide in the fall, and twice during the growing season. The simulation also included one application of insecticide in-season, and fertilizer application at the standard rate using a 6-row cyclone spin spreader.

Table 1. Summary of field operations and performance rates of equipment during typical sweet potato production for one production year (October – September)

Operation	Implement	Power Unit	Labor	Performance Rate, hr/ha
Tillage	Disk	Tractor[2]	Driver	0.346
Bed preparation	Disk bed hipper	Tractor	Driver	0.346
	Roll pack	Tractor	Driver	0.306
Spraying	Spray rig	Tractor	Driver	0.153
Fertilizer	Cyclone spreader	Tractor	Driver	0.208
Planting	Transplanter	Tractor	Driver + 6 hand-planting	3.286
Harvesting and processing for sale	2-row digger[1]	Tractor	Driver + 10 laborers	3.286
	Flatbed trailer	Tractor trailer	Driver	1.853
	Loading, storing[1]	Front end loader	Driver	1.853
	Curing[1]	Heated shed	Driver	8-10 days
	Washing/packing and processing[1]	Hand labor	6 - 18 laborers	3.114

[1] *based on producers' records*
[2] *based on 93.2 kW tractor*

2.1.2 Harvest and post-harvest processing

Post-harvest expenses were estimated based on standard procedures of harvesting, curing and processing for sale used by cooperating farmers. For economic analysis, we assume participation in the shared processing facility available to SLR farmers in the Delta, with each operator paying for all labor, materials, and supplies individually. For small scale sweet potato production, sweet potatoes are harvested with a two row harvester with eight workers riding the harvester and separating the marketable potatoes from the damaged or poor quality potatoes (culls, cuts and bites). Full crates are unloaded to a flat bed trailer using a frontend loader, and taken to the storage shed for curing. The harvest operation requires eight laborers riding the harvester, two laborers for operating the frontend loader and flat bed trailer, and one tractor driver. In the curing shed, the potato pallets are stacked on top of each other in bins, and the sweet potatoes cured by heating to 29 to 35 C for 5 to 7 days.

After the curing process, the sweet potatoes are cooled for 3 days at 10 to 18 C, and then prepared for shipping by washing to remove the soil and debris. Washing requires approximately 8-10 individuals to wash and grade the potatoes into US grades #1's, #2's, or Jumbos [29]. After fungicide treatment to control post-harvest decay [30], the sweet potatoes are boxed in 18 kg bushel boxes for shipment to market.

2.2 Economic Analysis

Most agricultural machinery is not used continuously throughout the year. Useful life, especially for power units, is based on hours used. Performance rate is a measure of the time spent per hectare on a given activity [31]. Performance rate, in hours per hectare, were based on production records from farmers and research at the ASU Experiment Station for each activity specified (Table 1).

2.2.1 Fixed costs

Fixed costs for power units were taken from MSU-VPB Appendix, and multiplied by the performance rate to get the fixed costs in dollars per hectare [28]. The implement fixed costs were taken from the MSU-VPB Appendix, listed in dollars per hectare [28]. Total fixed costs were calculated as the sum of the power unit and implement direct costs in dollars per hectare. Total costs were calculated as the sum of fixed costs, direct costs and supply expenses.

2.2.2 Direct costs

Fuel costs were determined based on an estimated fuel cost of $0.925 per liter for diesel fuel (average diesel costs of $1.057 per liter, less taxes of approximately 13% ($0.132)) and $0.1435 per kwh for electricity. Fuel use, in liters per hour, was based on size of the power unit, and taken from MSU-VPB Appendix [28]. For most field operations, the power unit used was the 93.2 kW tractor. The per-hectare fuel use was then calculated using Eq. (1) as the performance rate for that operation multiplied times the fuel use of the power unit. The fuel cost per hectare was calculated as given in Eq. (2) as the expense of fuel per liter times the fuel use per-hectare.

Fuel Expense:

Fuel use (liters/hectare)=performance rate (hours/hectare)*power unit fuel use (liter/hour) (1)

Fuel cost (dollars/hectare)=Fuel cost ($/liter)*Fuel use (liters/hectare) (2)

For planting and harvesting operations, performance rates summarized in Table 1 were estimated based on farmer input or MSU-VPB [28]. Although other fuel types, such as propane, can be used to power irrigation systems, we restrict our study here to those most commonly used in the Delta: electric and diesel.

Labor costs were based on the $10 per hour paid by ASU-ES for tractor drivers. Other operations were paid at a rate of $8/hr for labor. Per hectare labor costs were calculated as the performance rate in hours per hectare times the dollar per hour rate of pay.

Repairs and maintenance (R&M) for power units were taken from MSU-VPB [28]. The R&M per hectare expenses for power units were calculated as the listed R&M $/hr times the listed performance rate (hr/ha). Repairs and maintenance for implements were taken from MSU-VPB [28], in dollars per hectare.

Total direct costs for each operation were the sum of fuel costs, labor costs and repair and maintenance costs for both power unit and implement. Supply expenses for herbicides, insecticides, fertilizers and seeds or slips were taken from production records of receipts paid by ASU-ES. Harvest expenses were based on producer estimates of time and personnel used for harvesting. The number of people involved in the harvest could range from 8 to 16; we have chosen the average of 12 to perform the simulation calculations.

2.2.3 Irrigation expenses

Implementing irrigation involves start-up expenses to drill the well, install the pump, and install any ancillary equipment or power source needed to run the pump. We limit our discussion here to furrow irrigation through flexible plastic pipe, commonly called poly-pipe, which is the most common form of irrigation in the Mississippi Delta [8]. Two power sources are considered: electric and diesel. Total expenses to drill the well and install the pump are depreciated over the useful life [32]. Cost of the power source is also depreciated accordingly. Taxes are estimated based on the value times the assessed ratio of 15% times the millage rate for the state (0.098) according to MS tax rates [33]. Insurance is estimated at 0.5% of value [32].

In-year operating costs include setup, supplies, labor, repairs and maintenance, and fuel costs. The values used are based on ASU-ES rates, published estimates [32,34] or current prices. The number of irrigation applications required during a growing season was estimated based on crop water use calculations and total rainfall received during the growing season as described above.

2.3 Weather Data

Historical weather information was downloaded from the Delta Research and Extension Center Agricultural Weather Center [35]. After processing to remove erroneous readings [36], the historical weather data were used for calculation of crop water use as described below, and for summarizing historical yearly rainfall and other weather parameters.

2.4 Estimated water use and yield improvement with irrigation

The Mississippi Irrigation Scheduling Tool, MIST, is a web-based decision support tool designed to assist farmers in managing irrigation decisions [37]. MIST uses the standard Penman-Monteith equation to calculate a reference evapotranspiration (ET_R) from weather parameters [38]. Crop water use is then calculated by multiplying the ET_R by a crop specific coefficient. The model tracks soil water balance using a checkbook method that accounts for changes in crop water use, soil hydrology, rainfall, and irrigation [37]. To simulate sweet potato water use during the growing season, the MIST was parameterized by multiplying the ET_R by the published crop coefficient for sweet potato to give the crop evapotranspiration (ET_C) using daily weather data [37,38]. Daily weather data from the preceding ten years were used to calculate daily crop water use of sweet potatoes during the growing season in each year [35]. To facilitate year-to-year comparisons in the simulation, the planting date was set at 15 April, with harvest near 15 September, for all years. The total cumulative crop water use was then determined by summing the individual days of crop water use over the entire growing season.

It is difficult to develop a causal relationship between correlative responses such as total rainfall and total reported state yield of sweet potatoes due to annual variability in weather and other parameters that impact yield, and lack of specific production information, most importantly planting date. For example, a year with high rainfall may actually decrease yield if the rain is received close to crop maturity. Therefore, in order to estimate yield improvement with irrigation, we rely on published resultes. It has been shown that yield in vegetable crops responds linearly to increasing irrigation [39]. Moreover, sweet potatoes are most sensitive to water stress at transplanting [23]. The yield increase with irrigation will impact both the number and size of sweet potatoes, and quality of the crop due to production of more marketable potatoes and fewer culls [21]. In the simulation, the increased processing costs associated with improvements in crop yield and quality with irrigation are accounted for in the economic analysis to determine the overall increase on return to management with implementation of irrigation.

3. RESULTS AND DISCUSSION

3.1 Weather variability

Historical yields per acre were similar for all sweet potato production areas until around 1970 (Fig. 1) [8]. Improvements in production practices and varieties have increased production steadily since then. However, production in California since the 1970's has experienced a much greater increase than in Mississippi. The average annual sweet potato yield in Mississippi for the previous 10 years is 18.7 t/ha compared to 34.5 t/ha in California [8], an 84% increase over that of Mississippi.

Historical weather data for this prior ten year period shows substantial year-to-year variability in rainfall received in Mississippi during the growing season (Fig. 2). Total rainfall was less than total crop demand for eight of the ten years, though the deficit amount varied. Total rainfall received during the growing season only exceeded total crop demand for 2004 and 2009. Conversely, 2005 and 2010 were particularly dry years.

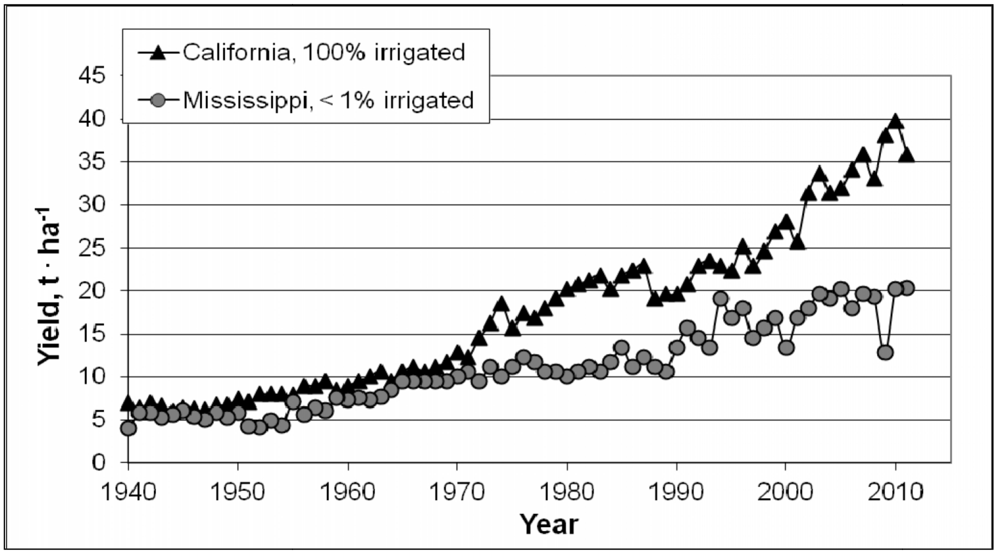


Fig. 1. Comparison of historical sweet potato yield between predominantly irrigated production in California and predominantly rain-fed production in Mississippi. (NASS, 2012)

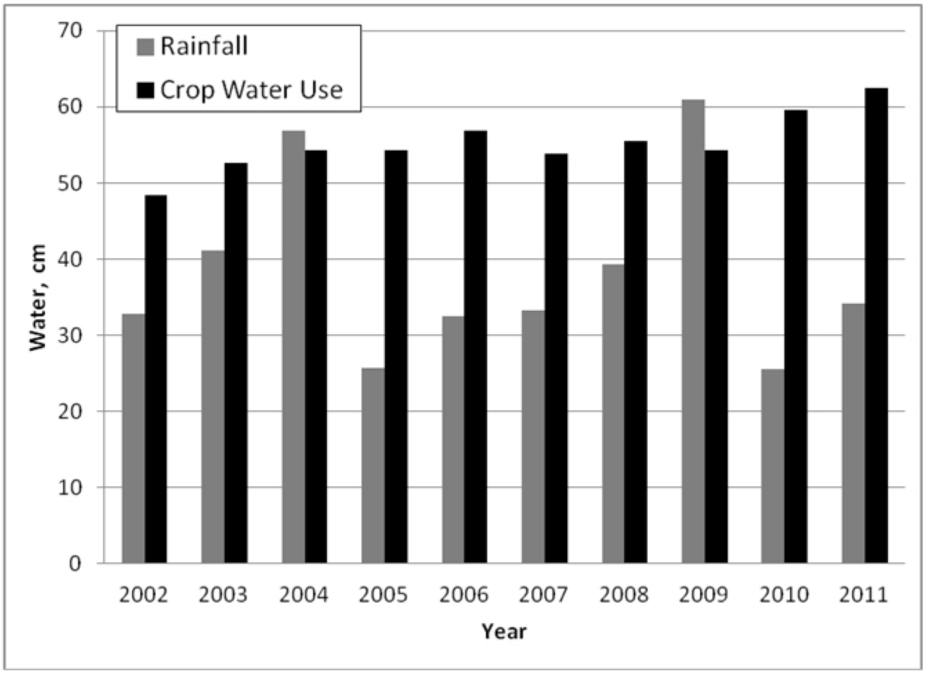


Fig. 2. Comparison of calculated sweet potato crop water use and measured useable rainfall during the growing season (15 April – 1 Sept.) for the previous 10 years. Crop water use was calculated using the Mississippi Irrigation Scheduling Tool

3.2 Crop Water Use

The daily crop water use for sweet potatoes was calculated for each day during the growing season for each of the ten preceding years using MIST. A typical crop water use curve is shown in Fig. 3 for the 2011 growing season. This is similar to the cumulative and daily water use quadratic functions developed by Smittle et al. [21] for sweet potatoes. During the fastest growing period, sweet potatoes can use as much as 0.89 cm of water per day.

To explore differences between crop water use from one year to the next, the daily crop water use curves were summed day by day over the entire growing season. For 2009, cumulative rainfall exceeded crop water use throughout the growing period (Fig. 4a). Although there was a period from mid-May till mid-June during which very little rain was received, significant rain was received in early May, and also in July. The amount of total incoming precipitation exceeded the water use of sweet potato in 2009. Conversely, the following year was a dry year (Fig. 4b). Rain early in the growing season maintained sufficient water to keep up with crop water use only during the initial growing period. Beginning in June and during the remainder of the growing season, rainfall amounts were significantly below that needed to support crop growth and keep pace with crop water use.

The total water use in each year was then compared to total rainfall received during that growing season to estimate the water deficit that would be replaced with irrigation (Fig. 2). Total crop water use by sweet potatoes was fairly consistent at 55.24 cm of water use per growing season for each of the ten years. Total rainfall exceeded crop water use in only two of the ten years (2004 and 2009). During the remaining years, the crops experienced water deficit ranging from 11.46 cm in 2003 to 33.98 cm in 2010. This is similar to the range of 12.7 – 22.9 cm that Brodie [23] found for supplemental irrigation requirements of sweet potatoes in Virginia. On average over the 10 year period, crops experienced a water deficit of 17 cm, with three of the ten years experiencing deficits in excess of 25.4 cm of water.

For estimating irrigation expenses, we use an average replacement requirement of 15 cm of water. Although this is slightly less than the average water deficit, it will allow three equal volume furrow irrigations during the growing season, pumping 5 cm-ha^{-1} of water per irrigation. During drier years requiring more frequent irrigation, in-season irrigation operating expenses would increase.

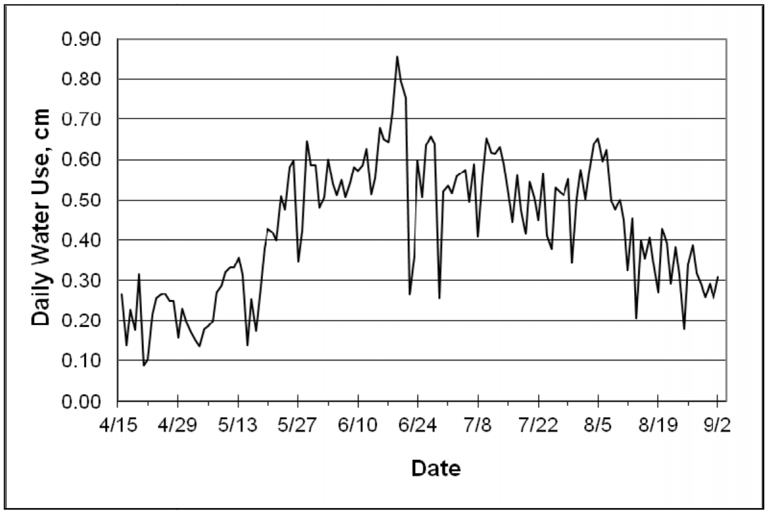
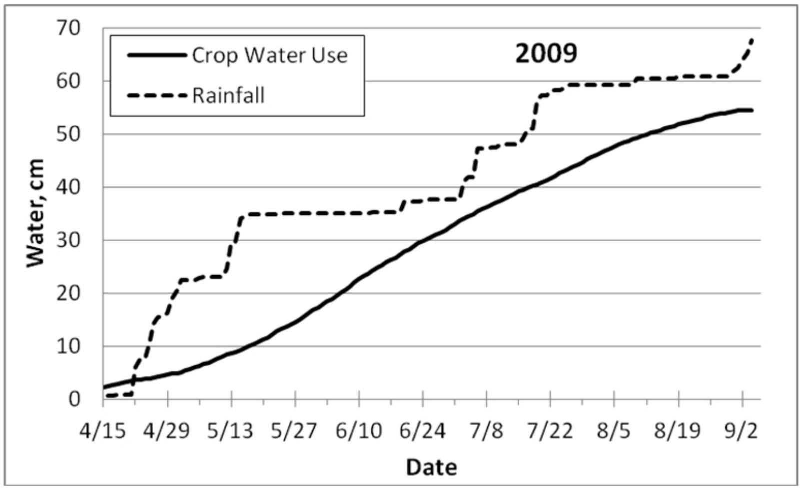


Fig. 3. Example calculation of daily crop water use for sweet potatoes in Mississippi during one growing season (2011), calculating using the Mississipi Irrigation Scheduling Tool (MIST) and published crop coefficients.



4a

4b

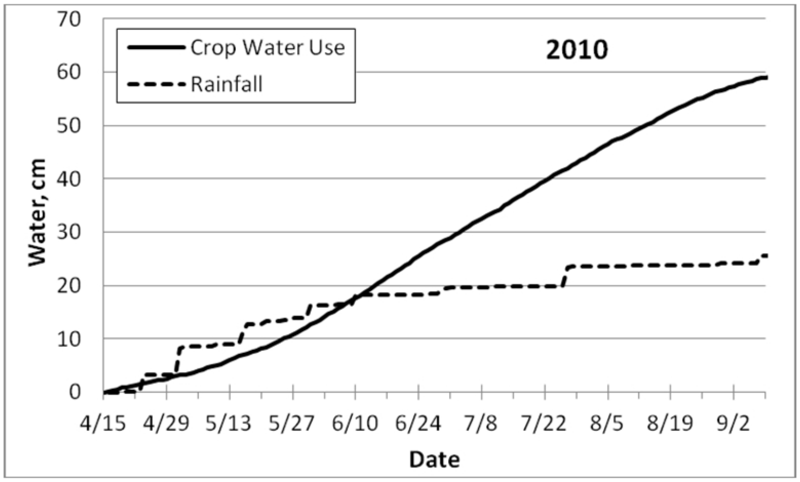


Fig. 4. Cumulative crop water use and rainfall during the growing season for a wet year (2009, 4a) and a dry year (2010, 4b). Daily recorded rainfall and calculated crop water use values from MIST were summed to obtain cumulative values for each growing season (15 April – 1 Sept.)

3.3 Economic Assessment

3.3.1 Rain-fed production expenses

Initial expenses to plant the sweet potatoes account for twenty percent of the production costs, primarily due to seed costs and labor expenses (Table 2). Within-season maintenance costs associated with fertilization, weed and insect control, and other field operations are comparatively low. Harvest and post-harvest operations are the most expensive component of sweet potato production primarily due to the labor required. Overall, processing costs associated with washing, grading, and packing the sweet potatoes account for more than 40% of the production budget. Harvesting operations and storage (curing) of the potatoes take an additional 20% of the budget, while marketing accounts for twelve percent of the budget. Total operating expenses for rain-fed sweet potato production were calculated to be $6,635 per hectare (Table 2 – Rain fed).

From harvest records, average yield in Mississippi was 18.7 t/ha over the past ten years[8]. Of that yield, approximately 7.5 t/ha of #1 and #2 quality potatoes are produced, 5.6 t/ha of jumbos, with the remaining 5.6 t/ha being poor quality culls, cuts and bites. The #1's, #2's and jumbos are processed for marketing, while the culls, cuts and bites are sold at a discount. At a price per unit of $0.442 averaged over all grades, overall revenues from crop sales would be $8,265 per hectare (Table 2 – Rain fed). Given total operating and ownership expenses of $6,860, this would return $1,406 per hectare to management (Table 2 – Rain fed).

3.3.2 Irrigated production expenses

Development of irrigation capacity requires digging a well and installing a pump and power source to pump the water to the fields. The price of digging a standard well that will service a 10-ha field is $6,000 for a 25.4 cm well, 37 m deep (Table 3). This will serve for either an electric or diesel pump. The electric power unit and gear head will cost an additional $6,000, while the diesel power unit will cost $8,000. These costs are depreciated over the useful life, which is 20 years for the well, and 10 years for both power sources. Yearly property tax would be $44 for the well, and $44 and $59 for the electric and diesel power units, respectively, based on the average value over the useful life of the equipment at Mississippi tax and millage rates. Annual insurance expense would be $15 - $20, depending on power source, and interest on the investment would add an additional $255 per year for the well, and $255 to $340 per year depending on power unit. Repairs and maintenance, estimated at 1% [32], would cost between $60 and $80 per year. The total annual expenses to dig the well were determined to be $659.00 (amortized over the useful life). The electric power unit would cost $974.00, while the diesel power unit would cost $1,299.00, a difference of $325.00 per year. These installation expenses would be charged to production every year, regardless of frequency or extent of use.

Total annual per hectare expenses associated with installing the irrigation system are summarized in Table 4A. The expenses for irrigating a 10 and a 20 hectare field are calculated as well as the expenses for two power sources, diesel and electric. Initial drilling and installation expenses are approximately $32 per hectare less for electric than for diesel. This cost difference drops in half when the production area doubles.

Within-season operating expenses would include installation and setup of flexible poly-pipe tubing to carry the water to the field, and removal of poly-pipe from the field prior to harvest (Table 4B). The per-hectare labor and fuel costs for this operation are minor ($7.22 for installation and $2.79 for removal); the poly-pipe costs $250 per 411 m roll, which would serve 10 hectares.

Labor costs associated with irrigation operations in-season are based on three irrigations per year, to replace the calculated average yearly water deficit of water (Table 4B). The duration of each irrigation event is dependent on the area being irrigated and the pump capacity. Irrigating 10 hectares with the 15 kW pump would require approximately 28 hours. Of this time, approximately 2 hours of labor would be required to turn the pump on and off and check the system, for an additional $4.80 labor cost per hectare.

By far the greatest within-season expense for irrigation is the energy cost to supply power to the pump (Table 4B). Of these, electric power is currently much less expensive than diesel. This will change depending on the base price of fuel and power. Total annual operating expenses are also $27.81 per hectare less expensive for electric ($63.89) than for diesel ($91.70) at current energy prices. However, the within-season operating expenses on an area basis do not change since irrigating a greater area would require longer pumping time and increase the total energy expense. The operating expenses will also change each year, depending on the irrigation demand. During dry years when greater irrigation would be required, the energy expenses to pump water would increase.

The total annual budget to install and operate furrow irrigation is least expensive using an electric pump on 20 hectares ($145.54/ha; Table 4C). The cost to irrigate 20 ha with a diesel system is $44.06 more expensive per hectare than for a comparable system powered by electricity. Decreasing the farm size doubles the installation costs, but not the within-season operating costs. For the simulation example, expenses to install and operate a diesel system would be $60 more per hectare than for an electric pump on a 10 hectare production system.

Table 2. Comparison of enterprise budgets of sweet potato production for rain fed and irrigated production systems, for different potential yields and two power sources

Description	Units	Price per unit	Quantity	Value or cost per hectare	Quantity	Value or cost per hectare	Quantity	Value or cost per hectare	Quantity	Value or cost per hectare
1. Revenue			**Rain fed**		**Irrigated (electric)**		**Irrigated (diesel)**		**Irrigated (electric)**	
Potato sales					10% yield increase		10% yield increase		84% yield increase	
#1 and #2	tonne		7.5		8.2		8.2		13.7	
Culls, cuts and bites	tonne		5.6		6.2		6.2		10.4	
Jumbos	tonne		5.6		6.2		6.2		10.4	
Total Sales		0.442	18.7	$8,265	20.6	$9,105	20.6	$9,105	34.5	$15,249
2. Operating Expenses										
Seed cost	1000	$35	29.7	$1,040	29.7	$1,040	29.7	$1,040	29.7	$1,040
Pesticides	ha	$125.00	1	$125	1	$125	1	$125	1	$125
Fertilizer	bag	$15.00	9.9	$149	9.9	$149	9.9	$149	9.9	$149
Fuel and repairs	ha	$328.00	1	$328	1.1	$361	1.1	$361	1.8	$590
Drying/curing	tonne	$44.00	12.6	$554	14.4	$634	13.81	$634	24.2	$1,065
Clean, grade, pack	box	$2.00	692	$1,384	761	$1,522	761	$1,522	1273	$2,546
Boxes	ha	$1.43	692	$990	761	$1,088	761	$1,088	1273	$1,820
Hauling	ha	$102.42	4.9	$502	5.4	$553	5.4	$553	9.1	$932
Hired labor	hour	$10.00	74.7	$747	82.1	$821	82.1	$821	137.4	$1,374
Broker	ha	$1.00	815	$815	815	$815	815	$815	815	$815
Total operating expenses				$6,634		$7,108		$7,108		$10,456
3. Irrigation Expense					Electric-powered		Diesel-powered		Electric-powered	
Total operating expenses, in season per ha					$63.89		$91.70		$63.89	
Total set up costs, per ha					$163.3		$195.80		$163.30	
Yearly setup and operating expenses				$0.00		$227		$288		$227
4. Gross Margin				$1,630		$1,770		$1,709		$4,566
5. Ownership Expenses										
General overhead				$225		$225		$225		$225
6. Total Expenses				$6,860		$7,560		$7,621		$10,908
7. Return to Management				$1,406		$1,545		$1,484		$4,341

Table 3. Expenses associated with purchase and installation of electric and diesel powered irrigation systems

	Price	**Years of useful life**	**Depreciation (Price/years)**	**Property tax[1] (15% x 0.098 millage)**	**Insurance[1] (0.5%)**	**Interest[1] (8.5%)**	**Repairs and maintenance (1%)**	**Cost per year**
Dig well, 25.4 cm pipe, 37 m deep	$6,000.00	20	$300.00	$44.00	$ 0.00	$255.00	$60.00	$ 659.00
Electric power unit, pump and gear head	$6,000.00	10	$600.00	$44.00	$15.00	$255.00	$60.00	$ 974.00
Diesel power unit, pump and gear head	$8,000.00	10	$800.00	$59.00	$20.00	$340.00	$80.00	$1,299.00

[1] *Based on the average value over the useful life of the equipment.*

Table 4. Total yearly within-season expenses for installation and operation of electric and diesel powered irrigation systems.

A. Total annual installation cost per hectare		
	10 ha	20 ha
Electric	$163.30	$81.65
Diesel	$195.80	$97.90
B. Total annual operating cost per hectare		
Setup and install irrigation tubing[1]	$7.22	$7.22
Irrigation tubing (poly pipe)	$25.00	$25.00
Pick-up, haul and remove pipe[2]	$2.79	$2.79
Labor, in-season[3]	$4.80	$4.80
Energy[4]		
Electric ($0.1435/kwh)	$24.08	$24.08
Diesel ($0.925/l)	$51.89	$51.89
Total		
Electric	$63.89	$63.89
Diesel	$91.70	$91.70
C. Total annual irrigation installation and operating expenses per hectare		
Electric	$227.19	$145.54
Diesel	$287.50	$189.60

[1] *Diesel fuel: $1.07; Labor: $4.40; R&M: $0.17; Ownership costs: $1.58*
[2] *Diesel fuel: $0.52; Labor: $1.41; R&M: $0.07; Ownership costs: $0.79*
[3] *2 hrs per irrigation per 10 ha, 3 irrigations per year, $8 per hr*
[4] *2.79 hours per irrigation per hectare, based on pump capacity*

3.4 Economic Return

Anticipated benefits from irrigation were considered for a range of potential yield improvement levels (Table 2). For each yield level, the distribution of potatoes harvested was held consistent between marketable #1, #2, and jumbo and damaged culls, cuts and bites. The increased expenses of harvesting and processing were accounted for in the economic analysis (Table 2 – irrigated). For a yield increase of 10%, total yield was increased to 20.6 t/ha, for a gross return of $9,105/ha, an increase of $840/ha above rain-fed production (Table 2 – irrigated 10% yield increase). Operating expenses associated with crop production (seed, pesticide, and fertilizer) would remain the same. Harvesting and processing costs increased, however, due to the increase harvest, for a total operating budget of $7108/ha. Installation and operation of irrigation costs for an electric-powered system would be $227/ha, giving total operating and ownership expenses of $7560/ha for an electric irrigation system. This is a $700 increase in expense over rain-fed production. A diesel-powered irrigation system would require $7,621 in total expenses, for a net return to management of $1,484. Overall, for a 10% yield increase, implementing irrigation would result in a net increased return on investment of $78 per hectare above rain-fed production for a diesel irrigation system, or $139 per hectare for an electric system.

To determine the minimum yield required for irrigation to be economically feasible, we considered the net return to management for a range of yield increases from 1% to 84% (Fig. 5). For minor yield increases (less than 10%), the choice of power source for the well engine (electric or diesel) impacted the net return, as did the total area of production (Fig. 5). With only a 5% increase in yield, an electric irrigation engine operating over 20 ha was economically feasible. All irrigation methods became economically feasible only for yield increases greater than ten percent, though electric power source and larger area of production led to better returns. If yield increased 84% from 18.7 t/ha to 34.5 t/ha, comparable to the ten year average yield harvested in California, the choice of power source and production area had less importance (Fig. 5).

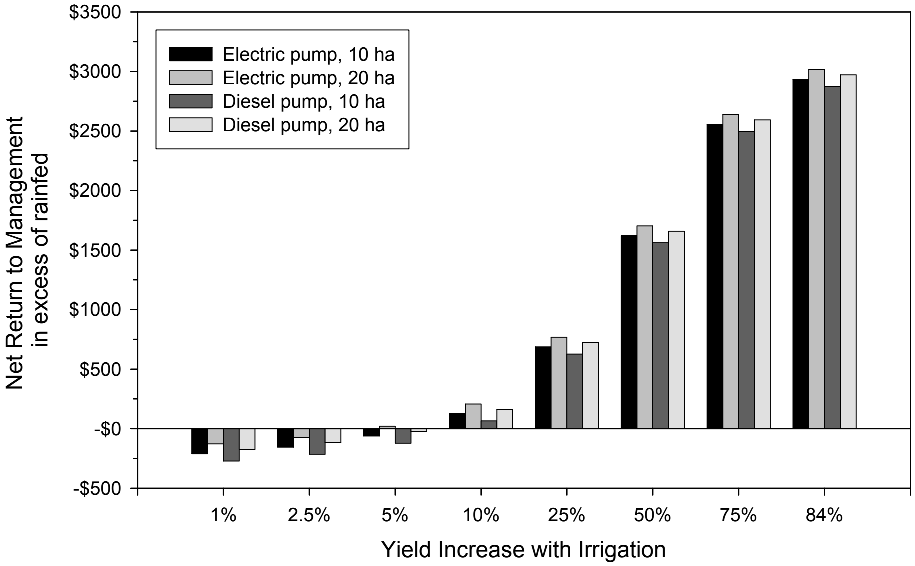


Fig. 5. Net return to management above rain fed production for different levels of yield enhancement using irrigation.

Although installing and operating an irrigation system did add additional expenses to the production, the largest portion of the increased expenses resulted from the additional processing costs associated with the increased yield (Table 2.2). Irrigation expenses accounted for between 32 – 42% of the additional expenses, depending on power source. However, the greater yield resulted in increased expenses associated with harvest and processing operations. Because the hauling, curing, and processing expenses are based on volume of material, these costs increase with greater harvest amount. At 10% yield increase, the additional 12.5 t/ha yield of #1's, #2's and jumbos with irrigation would increase the drying and curing, based on $44/t, an additional $550/ha. The 69 additional boxes would increase cleaning, grading and boxing operation by $138/ha and the cost of boxes by an additional $98 per hectare. Total production, processing and marketing expenses would increase to $7,108/ha, exclusive of the additional expenses associated with irrigation. Irrigation expenses for a diesel system would add an additional $288/ha, or $227/ha for an electric system. Total expenses for production would be $7,560/ha for an electric irrigation system, and $7,621/ha for a diesel-powered irrigation system.

Irrigation can be economically feasible for small, limited-resource vegetable production systems, provided they realize a minimum yield increase of ten percent above rain-fed production (Fig. 5). Startup expenses for installation of the irrigation system will accrue yearly, but remain constant throughout the life of the equipment. Once implemented, these expenses must be paid yearly regardless of use. Operating expenses for irrigation applications during the growing season will vary from year to year depending on the weather patterns during the growing season. Adequate rainfall was received in the Mississippi Delta in only two years out of ten (Fig. 2), and even during these two years, there were dry periods during which irrigation could have increased yield (Fig. 4). Provided yields could be increased an average of 10%, the anticipate return to management from implementing irrigation would cover the expenses of installation in years during which irrigation was not required.

For SLR farmers, electric-powered irrigation systems provided greater return on investment. One limitation of electric systems however, is that electric power requires proximity to a power line. The electric company will install approximately 305 m of poles and lines from the power source without extra charges. Running electric service beyond this distance could require potentially substantial economic investment. This would make use of electric power not feasible unless the pump is in the vicinity of power lines or poles. Diesel powered well pumps are more flexible because they can be placed in areas where no power lines are available. However, as shown here, diesel powered well pumps can be more expensive because of both the initial overhead cost of the system and the expense of fuel to power the pump (Table 4).

Larger farms will have greater return on irrigation investment because of greater economies of scale and the spreading of the initial installation and purchasing costs over more area. However, a significant increase in planted area could require a larger pump or multiple pumps, reducing returns.

4. CONCLUSIONS

Improvements in production practices and natural resource management are required to attain sustainable production and meet the escalating demands for high quality, locally produced food. Irrigation is one technology that is reasonably inexpensive to implement and manage. However, implementing irrigation must be done in concert with management practices that improve the efficiency of use of this limited natural resource, requiring knowledge of good water management practices.

In order to remain economically viable, limited-resource farmers will need to adopt highly productive management practices and tools. Enabling SLR farmers to adopt technology that demands substantial investments in human and financial capital requires addressing these two major issues. A directed cost sharing program would allow SLR farmers to supplement some of the cost of implementing technological advances, and provide the farmers with the necessary tools to successfully continue to farm.

Human capital is required to instruct farmers on how to use the technology to obtain the potential yield boost that makes implementing the technology economically feasible. Having the knowledge required to manage irrigation is important to prevent overwatering or flooding of the crop, which is particularly problematic for root crops such as sweet potatoes. Moreover, random, high-intensity rain events can confound good irrigation management in humid areas such as the Delta. Poor management could result in excessive costs for electric or diesel power, negatively impacting economic return. In order to manage risks and improve production, the farmer must know the potential of irrigation, how to install, use and maintain a system, proper timing and amount of irrigation needed by the crop, and how to monitor the operation closely. These areas, and development of extension tools to transfer this knowledge to producers, are future areas of work.

It is hoped that this study, which clearly demonstrates the potential impact on return on investment for small farming systems through improvement in one management practice, will provide the basis for new financial support, and research and outreach programs. Whether the initial impetus comes from state or federal agencies, the development of decision support tools tailored for small, limited-resource farmers has the potential to enhance economic opportunities, impacting not only the farmers, but their communities.

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DISCLAIMER

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COMPETING INTERESTS

The authors have declared that no competing interests exist.

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