Smart Agricultural Resources Optimization System: The case for sensor-based automatic irrigation management

Abstract

To be finished after discussion of results

Introduction

Small scale agriculture has been found to suffer from several technical inefficiencies (Seyoum, 1998). This is due to several causes ranging from lack of technical knowledge by smallholder farmers, to lack of equipment to improve practices. These technical inefficiencies affect different facets of agricultural production. In particular they have an impact on the quantities of inputs such as water that are utilized in production (Speelman, 2008). Technical inefficiency leads to the wastage of limited and crucial resources needed for agriculture such as water. It has been estimated that small-scale irrigation schemes can have up to 49% inefficiencies attributable to technical limitations (Speelman, 2008). This is of significance given the importance such resources have in contributing to livelihoods and development in farming communities. It is also a pertinent issue given the pressure exerted on such resources by growing populations and climate change. Studies have shown that the productivity of rice systems for instance can be raised by increasing the technical efficiency of smallholder farmers (Idiong, 2007). The pressure on resources and the potential for increasing productivity make a strong case for enhancing technical efficiencies in smallholder agriculture.

Various solutions have been designed to increase the efficiency with which agricultural resources are utilized. Some of these solutions have focused on reducing water released by irrigation systems for instance. Various techniques have been applied to achieve this. Among the methods applied is the use of technology to limit water release. The solution we propose lies along this framework where we use instrumentation and control to optimize how resources are used in agricultural production. This Concept Note uses the example of water as a limited resource whose technical efficiency can be improved through the use of climate-smart technologically based solution. Our solution is designed to meet the needs of smallholder farmers in developing countries, whose lack of technical knowledge leads to inefficiencies. This is particularly around small-scale irrigation where the amount of water used could be significantly reduced if decisions on when to irrigate were made based on technical knowledge. Since it is not practical to equip farmers with all the technical knowledge needed to make these decisions, our solution relies on technology to assist a farmer improve their technical efficiency. It uses micro-controllers, which are small computer processors that can receive data and perform logical computations. It also uses sensors that can detect various conditions in the immediate environment to determine if irrigation is needed. The solution has been designed around the needs of smallholder farmers in developing countries. This concept paper describes a climate-smart technological solution designed to improve technical efficiencies among smallholder farmers.

The objective of this solution is to increase the technical efficiency of agricultural resource utilization. It aims to reduce the water wasted in small-scale irrigation, while helping monitor the health of the soil to provide information for decision making to various stakeholders.

Methodology

The solution is built around a field-deployable kit that monitors the weather, soil moisture and other environmental parameters to determine when irrigation should be done and how much water needs to be released. All this is based on data collected by the kit from the environment where it is located. The kit has sensors that measure a variety of environmental conditions and relay the data to an onboard micro-controller. The controller evaluates this data to determine if it is necessary to irrigate the land, while also monitoring other aspects of soil health. In this way the kit is able to regulate the amount of water used in crop production to a very high degree of efficiency, since it can be programmed with all the technical knowledge necessary to make informed decisions. The kit can be configured to automatically open irrigation systems when it detects crops need watering, thus allowing the mechanization of task. This not only allows higher levels of efficiency to be achieved, but it also has the dual advantage of freeing the farmer from the task of watering plants on a continual basis. This means more time for the farmer to engage in other activities but it also means plants get water whenever they need it with no delays or over irrigation due to human error. The kit loges the amount of water dispersed during each irrigation cycle and this information is made available to the farmer through their mobile handset. By connecting to a back-end system where the soil health data is uploaded, the kit will send back data that can be used to inform land management decisions. This information will be useful for detecting land degradation before soil fertility is compromised, allowing appropriate interventions to be identified and targeted. The solution will provide a service that farmers can connect to trough their mobile phones to get this land management information from the back-end system. In this way farmers will be able to increase the efficiency in which they use other agricultural inputs by basing their land management decisions on technical data. The combination of the kit and the back-end is what we have named the System for Agricultural Resource Optimization (SARO).

Expected outcomes

We expect this solution will increase the technical efficiencies of small-scale irrigation and will be particularly useful in places where water efficiency is a strategic issue. It will also enhance land management by providing farmers with strategic climate-smart information on the health of their soils. The combined effect of this is expected to be an increase in productivity and more strategic resource management.

Beneficiaries

This solution is primarily targeted at small holder farmers whose technical knowledge on soil and water issues is not high. The solution is meant to bridge this knowledge divide thus allowing the farmers to increase their technical efficiencies. By basing resource use decisions on actual climate-smart data and knowledge, the kit will remove much of the guesswork and risk exposure to vagaries of rainfall variability involved in small-scale irrigation allowing with better adaptation to climate change. The land management data logged to the back-end of the system will allow farmers to query and receive information about the state of the soil and water resources from the convenience of their mobile handsets. The system will also provide other stakeholders with a platform to monitor land health and resource use information thus mitigating any unintended environmental consequences. This will provide policy makers with information from field scale to landscape scale allowing better decision making across the board.

Preliminary Cost Benefit Assessments

Below is a list of other supplementary benefits being monitored at two field sites in Kenya and Tanzania.

Attribute per ha	**Unit (amount)**	**Cost**	**Comment on Benefit**
Labor savings *(Alternative livelihood options resulting from labor savings)*	Man hours/annum	800,000 Tz Shs; about 400 USD per annum.	60% labor savings; based on about 280 days of full time labor; SAROS saves the farmer about 168 days; based on minimum wage fee earnings of 1000 Tzs/day would amount to about 885 USD per annum.
Water savings	Liters/annum (over 4 seasons)	1,040,000 litres saved from SAROS; at a cost of about 500 Tz Shillings per liter= 250K USD	This has cost implications in that farmers spend less and more water could be available for other uses (domestic and other food production needs)

Benefit of farming in water scarce area (Value of out of season crop)	$/annum		
Crop yield differences (Vs not irrigated)	Ton/Acre		

Emerging Findings:

We provide a draft of emerging finding below:

Table 6: Costs associated with SAROS irrigation in and outside screen houses and used in the subsequent economic analysis

Attribute per ha	**Unit (amount)**	**Cost (US$)**	**Comment on Benefit**
Labor savings *(Alternative livelihood options resulting from labor savings)*	Man hours/annum. Other labor beyond irrigation includes: -Weeding and land preparation -Routine field maintenance -Land preparation -Screenhouse setup -Reservoir refilling	800,000 Tshs; about 400 USD per annum.	60% labor savings; based on about 280 days of full-time labor; SAROS saves the farmer about 168 days; based on minimum wage fee earnings of 1,000 Tzs/day would amount to about 885 USD per annum.
Water savings compared to normal irrigation with watering can	Liters/annum (over 1 season)	540,000 litres saved from SAROS; if water were to cost about 500 Tshs per liter= 135K USD	This has cost implications in that farmers spend less and more water could be available for other uses (domestic and other food production needs)
Benefit of farming in water scarce area (Value of out of season crop)	$/annum	See Table 7	See Table 7
Crop yield differences (Vs conventional irrigated)	Ton/Acre	See Table 7	See Table 7
Production inputs* Seedlings, Pesticides, Fertilizers, and Water	$/annum	-Seedlings (40) Pesticides (120) -Fertilizers (60)	Costs of water are not included here; these are already accounted for.

		-Water (Accounted for above) Weeding (30)	
Setup and establishment: -Eucalyptus poles -AZ shed netting -Nails -Door locks	$ (initial one time expenditure)	-Eucalyptus poles; locally sourced (10) -AZ shed netting (100) -Nails (3) -Door locks (5)	
Irrigation components	$ (initial one time expenditure)	-SAROS Unit (70) Drip lines, laterals, Nozzles (40) Electrical wiring (30) Silicon sealant (10) Reservoir (35) Solenoid (10) Mini Solar panel (15)	

*costs on production inputs as shown here are for all 16 sites totalling 0.38 ha.

Productivity and economics of the water saving technologies in and outside of screen houses

Productivity and economics assessment was done on a sample of 15 plants per vegetable crop inside and outside the screen house. Application of drip irrigation with SAROS increased yield and water productivity of sweet pepper and tomato vegetables both inside and outside of screen houses. As illustrated in Table 6; the yield for sweet pepper in Gallapo was 4.8 and 10.6 kg/m^2 for both inside and outside respectively while that for Seloto was 10.4 and 22.7 kg/m^2 for both inside and outside respectively. Yield for tomato in Gallapo was 35.4 and 78.1 kg/m^2 for both inside and outside respectively while that for Seloto was 90.4 and 60.9 kg/m^2 for both inside and outside respectively The higher yields under the drip irrigation system are consistent with the increased water productivity of both vegetable crops under drip irrigation than conventional irrigation involving the use of watering cans (Table 7). On the overall, for inside, outside and conventional yields, the average water productivity of sweet pepper for Seloto was 7.7 kg m-3 and 3.7 kg m-3 for the Gallapo area and the average water productivity of tomato for Seloto was 38 kg m-3 and 27 kg m-3 for the Gallapo area. There was a clear difference in yields between inside and outside the screen houses Higher yields in outside than inside could be attributed to a technical fault of the SAROS at the beginning of the experiment where the outside benefited from rainfall while no-irrigation was taking placed inside. Nevertheless, higher marketable produce was still observed inside the screen house following a greater pest and disease damage for crop grown outside screen houses as reported by the World Vegetable Center.

The size of the screen house was 12 m x 20 m and the estimated costs of the production components have been laid out in Table 6. The gross expenditures included as overall costs are US$ 708 for the complete screen house set up, production and irrigation components, US$ 590 for outside production and US$260 for the conventional irrigation (i.e., excluding costs of setup of screen house, irrigation components and pesticide costs). The gross returns were computed by multiplying average market rate price with the yield of respective vegetables during the crop harvesting period. The market rate for sweet pepper was about $0.95 per kg and $1.136 per kg. For both vegetable crops, gross returns are better under SARO irrigation (both inside and outside of screen houses) relative to the conventional irrigation practice(Table 8). The Gross Economic Water Productivity was computed as the product of the water use efficiency or productivity (kgm^{-3}) and the market price of the produce ($\$kg^{-1}$) (Table 8). It should be noted that the gross returns are insufficient to offset the high capital investment within a first season i.e., the net returns and the associated cost benefit ratio are negative. With the labor dividends associated with the use of the SAROS as well as the water savings as demonstrated, farmers will likely break even in the second year. Fortunately, this activity is ongoing as a loose end and benefits over an extra season are part of the evaluation, taking into cognizance that a SAROS kit can serve a much larger land area than currently applied. Overall, tomato cultivation under drip irrigation resulted in better economic outcomes compared to sweet pepper.

Table 7: Yield and Water Productivity of vegetable cultivation under drip irrigation with the SAROS both inside and outside a screen mesh housing compared to conventional vegetable growing in Seloto (N=1009 observations) and Gallapo (N=2749 observations)

		Yield per unit area (kgm^{-2})			**Water use efficiency (kgm^{-3}); Productivity**			**% Increase from Conventional**	
		Inside	**Outside**	**Conventional**	**Inside**	**Outside**	**Conventional**	**Inside**	**Outside**
Sweet Pepper	**Seloto**	10.4	22.7	8.4	5.8	12.7	4.7	23.3	169.3
	Gallapo	4.8	10.6	4.4	2.7	6.0	2.4	9.7	143.2
Tomato	**Seloto**	90.4	60.9	52.1	50.6	34.0	29.1	73.6	16.9
	Gallapo	35.4	78.1	32.5	19.8	43.6	18.2	9.0	140.2

*Conventional practice: Vegetable growing with the normal watering can as irrigation device; main costs are labor associated

Table 8. The Economics of vegetable cultivation under drip irrigation with the SAROS both inside and outside a screen mesh housing compared to conventional vegetable growing in Seloto and Gallapo

		Gross return ($\$m^{-2}$)			Net return ($\$m^{-2}$)			Gross Economic Water Productivity ($\$m^{-3}$)		
		Inside	**Outside**	**Conventional**	**Inside**	**Outside**	**Conventional**	**Inside**	**Outside**	**Conventional**
Sweet Pepper	**Seloto**	9.9	21.5	8	-698.1	-568.5	-252	5.5	12	4.5
	Gallapo	4.6	10.1	4.2	-703.4	-579.9	-255.8	2.5	5.7	2.3
Tomato	**Seloto**	102.7	69.2	59.2	-605.3	-520.8	-200.8	57.5	38.7	33.1
	Gallapo	40.2	88.7	36.9	-667.8	-501.3	-223.1	22.5	49.6	20.7

References

Seyoum, E. T., Battese, G. E., & Fleming, E. M. (1998). Technical efficiency and productivity of maize producers in eastern Ethiopia: a study of farmers within and outside the Sasakawa-Global 2000 project. *Agricultural economics*, *19*(3), 341-348.

Speelman, S., D'Haese, M., Buysse, J., & D'Haese, L. (2008). A measure for the efficiency of water use and its determinants, a case study of small-scale irrigation schemes in North-West Province, South Africa. *Agricultural systems*, *98*(1), 31-39.

Idiong, I. C. (2007). Estimation of farm level technical efficiency in smallscale swamp rice production in cross river state of Nigeria: a stochastic frontier approach. *World Journal of Agricultural Sciences*, *3*(5), 653-658.