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Full Length Research Paper

Improving agricultural productivity by promoting low-cost irrigation technologies in Sub-Saharan Africa

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The performance of small scale irrigation technologies such as Californian (PVC pipe layout) and drip irrigation systems with the traditional bucket method is compared in six Sub-Saharan African countries. The results of field trials conducted on farmer fields reveal that water and economic productivities of Californian and drip systems were two to three times higher than the bucket method. However, smallholder farmers preferred Californian irrigation system over drip system due to its low installation and operation and maintenance costs. The average installation cost of drip system was US$ 2000-4000 per ha compared to US$ 600-1000 per ha for the Californian system. However, despite these advantages, adoption of these irrigation technologies remain a challenge for resource poor farmers. This study suggests policy level changes to facilitate farmers financially and technically for the adoption of these technologies to increase their agricultural productivity and farm incomes. To cut down the costs, local manufacturing of equipment through active participation of private sector and introduction of solar driven and wind driven pumps at affordable prices could be a step in the right direction. Farmers' training on improving water use efficiency and maintenance of these systems is also found to be crucial to increase agricultural production, increase incomes and reduce rural poverty.

Keyword: small-scale irrigation, water use efficiency, rural poverty, food security, Sub-Saharan Africa

INTRODUCTION

Agriculture sector is the backbone of African economies, which provides more than 60 percent of all employment. However, during the last decade, agricultural production has not kept pace with the increasing population. Consequently, currently more than 400 million people are malnourished in Africa, out of which 218 million are living in Sub Saharan Africa, an increase of approximately 42 million people since 1990-92 (FAO, 2015). This region is still challenged with rapid population growth which affects the ability of countries to assure stable supply of, and access to food. Despite concerted efforts over the last two decades, rate of poverty reduction in SSA has been far lower than other regions of the world. The number of poor people in SSA, living with less than US$ 1.25 a day, has declined by 23 percent between 1993 and 2011 compared to world average of 59 percent during the same period (World Bank, 2015). Therefore, development of the agricultural sector in this region is central to combating

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hunger, reducing poverty, and achieving economic growth. However, this cannot be achieved without ensuring a substantial development of surface water and groundwater resources.

The irrigation in many SSA countries is dependent on groundwater or run-off-river pumping systems. Transportation of water from main sources to farmer fields is usually done through long unlined channels, which wastes huge amount of water as percolation losses. Therefore, introducing low cast and efficient water delivery systems and irrigation technologies that enable farmers to irrigate their small plots and improve water use efficiency can boost crop harvests, farm incomes and nutritional health in deepest pockets of hunger in SSA (Svendsen et al., 2009). The irrigation technologies such as drip and sprinkler systems have the potential to increase productivity of small-scale irrigation in SSA region.

Sub Saharan Africa (SSA) is water-abundant but uses only 2 percent of its total renewable water resources due to lack of water infrastructure (World Bank 2015). Water resources at the regional level do not technically limit irrigation expansion. However, it is restricted due to high investment costs and management complexities. Food production in the region is almost entirely rain-fed with irrigation currently playing a minor role (Tafesse, 2003). The impact of climate change on crop yields and the social and economic repercussions is another major concern especially in light of the region's high dependence on rain fed agriculture.

Except in few countries of northern Africa, such as Tunisia and Morocco, the potential for irrigation development has not been effectively tapped in Africa. Though SSA has a rich and varied water endowment, only 4 percent (6 million ha) of the region's total cultivated area is irrigated compared to 37 percent in Asia and 14 percent in Latin America (Amjath-Babu et al., 2016)). Thus Africa is far from achieving its irrigation potential, which is estimated at 42.5 million hectares. According to recent studies, development of small-scale irrigation could expand irrigation by some 30 million hectares in SSA (a four-fold increase over the current area), generate annual net revenues of US$22 billion, and improve food security and incomes for some 185 million people (IWMI, 2005; IFPRI, 2012).Therefore, scaling up the use of small-scale irrigation systems (with special emphasize on cheaper and sustainable access to energy) should rise to the top of African development priorities. With targeted investments and policies to expand small-scale irrigation, the problems of hunger, poverty and malnutrition can be addressed.

The smallholder farmers in SSA have the potential to improve irrigation water management and increase their agricultural productivity if they are provided with the low cost irrigation delivery systems and water efficient irrigation technologies (Svendsen et al., 2009; IFPRI, 2012). This requires identification, testing and dissemination of appropriate irrigation technologies to transition from existing low productive and uncertain rainfed production systems to a more reliable and productive irrigated agricultural systems. This transition can also help in protecting rangelands and forest from conversion to cropped agriculture (IFPRI, 2012; Vanlauwe et al., 2014).

Realizing the gravity of the problem, a study was initiated in six SSA countries to evaluate the performance of Californian water delivery system and drip irrigation system with the commonly used bucket method of irrigation with respect to the water saving characteristics and attainable crop yields. The Californian system consists of a network of PVC pipelines buried in the soil to transport water from the source to farmer fields. The above-ground outflow terminals are provided at regular intervals for irrigation. The paper also deliberates on the challenges faced by the farmers and suggest policy recommendations to facilitate large scale adoption of these systems in the target countries and the entire region.

Description of the Study area

The study was carried out in six SSA countries, which include Burkina Faso, The Gambia, Niger, Mauritania, Mali, and Senegal (Figure 1). The predominant agricultural systems in these countries are characterized as rainfed and extensive pastoral systems (Tittonell and Giller, 2012). The productivity of these systems is well below their potential due to non-availability of irrigation water and extremely low use of fertilizer (SSA has only one percent share in world fertilizer market) (FAO, 2008). Future water availability in these countries is at risk due to severe drought conditions as a result of climate change; groundwater extraction is exceeding the natural recharge; and over-pumping from the rivers. The surface water availability is only 4 to 6 percent of the total renewable water resources due to lack of water infrastructure and poor management practices (Table 1). Groundwater is mainly used for domestic purposes and has helped farmers to expand their irrigated areas.

Agriculture is the most important economic activity in these countries and more than 70 percent of the population is engaged in this sector to earn their livelihood. Furthermore, agriculture sector is playing a significant role in the socio-economic development by providing employment, food and fiber, and income generation activities for rural communities. Principal agricultural sub-sectors comprise livestock, horticulture and annual field crops. Livestock is the most important sub-sector of the rural economy and vast majority of the population lives in the areas where rainfall levels were relatively high to sustain cattle herding. The agriculture remains largely subsistence farming and 90 percent of the cultivation is done by smallholder resource poor farmers who has limited access to land and water resources.

Figure 1: Map of 6 SSA countries targeted for this study

Table 1: Annual renewable water resources and water withdrawal in selected SSA countries

Country	Annual Renewable Water Resources (Million M^3)		Annual Water withdrawal (Million M^3)	
	Internal	Total	Irrigation	Total
Burkina Faso	1,2500	1,2500	690	800
Gambia	3,000	8,000	21.3	31.8
Mali	60,000	100,000	5,900	6,546
Mauritania	400	114,000	1,500	1,698
Niger	3,500	33,650	2,080	2,186
Senegal	25,800	38,800	2,065	2,221

(Source: FAO 2015. The total renewable resources include trans-boundary water resources)

The agricultural production is dominated by traditional rainfed cereals with large inter-annual productivity gaps, which results in persistent food insecurity and poverty in rural households. Among the dry season crops, on average, vegetables occupy more than two-third of the area with a dominance of onion, tomato, peppers and potato. The vegetables are grown in small plots by smallholder farmers on an individual basis although communal gardening is also being practiced and encouraged. These small plots are irrigated with groundwater through shallow hand dug wells. Groundwater over-exploitation has become a serious problem in many agricultural areas of these countries where groundwater levels have gone out of the reach of small farmers (Villholth, 2013). Extraction of groundwater from deeper levels necessitates provision of motorized pumps, which are beyond the financial capacity of most of the smallholder farmers.

The crop yields in these countries are extremely low due to the use of non-optimal fertilizer rates, non-availability of good quality crop seed and poor soil and plant nutrient management practices. According to recent estimate, about 50 percent farmers in SSA only apply inorganic fertilizer, 35 percent use organic fertilizers, 5 percent use microelement whereas 10 percent do not use fertilizer (Vanlauwe et al., 2014). Lack of local and regional seed production facilities for different crops and their trouble-free availability to farmers is also a major concern for farmers. Therefore, in addition to the development of water infrastructure and introduction of new irrigation technologies, production and distribution of good quality seeds are also equally important to attain significant improvements in crop yields.

The major problem of the irrigated agriculture in these countries is low water use efficiency. The water is lifted from the river or pumped from groundwater using small

Figure 2: Californian irrigation system

motorized pumps. The pumped water is stored in water tanks usually have a capacity of 2000 litres and then transported to the fields through small earthen channels. These channels waste significant amount of water as percolation losses. The water loss is much higher in sandy soils. Farmers use bucket method for irrigating small vegetable fields especially those owned by women. Water distribution within the field is done through gravity run furrow irrigation method.

The traditional furrow irrigation method is associated with excessive runoff and causes erosion and nutrient loss. The capacity of small water lifting pumps is low and are not suitable for lifting water in low flow periods. This situation deprives small farmers of their crops during the below average rainfall years and aggravate food insecurity problems. Due to varying topography and poor land leveling of farmer fields, irrigation efficiencies are low resulting in poor crop yields and increased soil salinization. The accessibility to water efficient irrigation technologies is very limited due to multiple factors ranging from poor financial resources of farmers to non-availability of equipment in local markets.

MATERIALS AND METHODS

Field trials were conducted on farmer fields in six countries during 2013-15 and tomato and onion crops were cultivated using drip, Californian and bucket method of irrigation. The purpose of these field trials was to compare the performance of these irrigation systems under the local conditions with regard to water saving and crop production. During the field trials, data regarding irrigation water application, attained crop yields, costs of operation and maintenance and market prices of vegetables was collected. These data were used to estimate irrigation water used for different crops under drip, Californian and bucket irrigation systems. The data was also used to determine water productivity (kgm^{-3}) and economic productivity (kgm^{-3}) of tomato and onion crops under different irrigation systems.

In each country, farmer field days were organized each year of the project to demonstrate the performance of these irrigation technologies to larger community of farmers. During the last year of the project, a socio-economic survey was also conducted to get farmers' feedback on the feasibility of these technologies for their local conditions. The brainstorming sessions were also held with government officials, policy makers and farmer groups to devise strategy to scale up these technologies in other parts of the six implementing countries and the entire region. A brief description of three irrigation systems is given below.

Californian irrigation system

The Californian system is a network of PVC pipelines buried in the soil to deliver water from the source to farmer fields. The PVC pipes are buried under the ground and above-ground terminals are supplied at regular intervals for irrigation (Figure 2). Water is lifted from the surface steams or groundwater source and distributed in the fields through furrows with crops planted on ridges. Californian system reduces water conveyance losses and ensure uniform water delivery in varying topography areas. The possibility of connecting flexible pipes to irrigation terminals makes it easier to irrigate elevated portions of the fields. This system is most suitable for growing vegetables on small farms. This system has the following advantages:

- Reduced infiltration losses during the water delivery especially in sandy soils
- Well adapted and most suitable for fields with varied topography
- Minimizes water loss during irrigation and water is adequately distributed between several irrigation terminals
- Covers less area compared to surface channels.

- Easy and low cost installation, use and maintenance - all materials are available locally
- Easy extension and opportunity to expand the irrigated area.

Drip irrigation system

The drip irrigation system distributes water to individual plants through a network of tubes or pipes in a controlled low flow rate. This system reduces water losses especially in coarse soils and control weeds. The drip system is suitable for vegetables and fruits. Despite established efficiency, adoption of drip system in SSA is limited due to high initial costs, lack of farmer skills and poor maintenance services. Clogging of drippers especially while irrigating with poor quality water and risk of damages during land cultivation and animal walk are serious disadvantages.

Bucket irrigation method

This traditional water lifting equipment is produced by local artisans using native materials. The major advantage of this technology is its low cost. In most SSA countries, women manually draw water from the wells with buckets and ropes to fill storage tanks and then use buckets and/or watering cans to fetch from the reservoirs to irrigate their plots.The major disadvantage of this method is its low flow rate capacity and resulting small size of irrigated plots which, in turn, limit production and incomes. This technique is very laborious and time consuming, allowing for a flow rate of about 1000 liters per hour when water is 4.5 meters from ground level.

RESULTS AND DISCUSSIONS

Californian system vs Bucket method

Table 2 shows comparison of Californian irrigation system with the bucket method for onion crop in Burkina Faso, Mali, and Senegal and for tomato in Mauritania. For the onion crop, the average yield obtained under Californian system in Burkina Faso was only 3 percent higher than the bucket method however, the amount of water applied was 13 percent lower. In Mali, however, the Californian system produced 28 percent higher yield and used 52 percent less water compared to bucket method whereas, in Senegal, applied water under Californian system was 25 percent lower and yield was 24 percent higher than the bucket method. The differences in water application and yields of the same crop in different countries are related to dissimilarities in soil characteristics, seed varieties and management practices of farmers. The tomato crop in Mauritania performed much better than the onion crop, using 38 percent less water and producing 57 percent higher yield under the Californian system compared to bucket method.

The increase in water productivity of onion under the Californian system ranged from a lowest of 14 percent in Burkina Faso to a highest of 53 percent in Mali. The economic productivity "*The prices of onion and tomatoes vary from US$ 0.3 to 1.0 per kg in these countries .However, for the calculation of economic productivities, an average onion price of US$ 0.5 per kg is assumed." The price of tomato is taken as US$ 0.5 per kg.* trails similar trend. In general, except for Burkina Faso, water and economic productivities of onion under the Californian system were two times higher than the bucket method. Under the Californian system, maximum gains in water and economic productivities were obtained for tomato in Mauritania due to higher yields. These results indicate that the Californian system not only saves irrigation water but also produce higher yields.

Drip system vs Bucket method

The comparison of the performance of drip system and bucket method for tomato and onion crops in Burkina Faso, The Gambia, Niger and Mali is given in Table 3. Under drip system, tomato was grown in Burkina Faso, The Gambia and Mali whereas onion in Niger. For tomato crop, maximum water saving under drip system was obtained in Burkina Faso followed by Mali and The Gambia. The drip system used 38 percent, 26 percent and 10 percent less water than the bucket method in Burkina Faso, Mali and The Gambia, respectively. The tomato yields under drip system were 38 percent, 24 percent and 10 percent higher than bucket method in Mali, The Gambia and Burkina Faso, respectively. For onion crop in Niger, drip system used 10 percent less water and produced 25 percent higher yield than the bucket method.

The increase in water productivity of onion crop under drip system ranged from 31 percent in The Gambia to 51 percent in Mali with an average value of 39 percent for all countries. The economic productivity follows the similar trend. The water and economic productivities of onion crop under drip system in Niger were 31 percent higher than the bucket method. The onion yield in Niger was much lower than the potential due to the use of poor quality seed and low nitrogen application rates. This stresses the need for the use of good quality seed and appropriate fertilizer amounts to ensure higher crop yields and farm incomes for smallholder farmers.

Combined analysis of Tables 3 and 4 suggest that, on average, Californian system uses 32 percent less water and produce 28 percent high yields compared to the bucket method. In comparison, the drip system used 21 percent less water and produced 24 percent higher yields compared to bucket method. On average, the economic

Table 2: Comparison of water applied, crop yield, water productivity and economic productivity under Californian and bucket irrigation methods.

Parameters	Burkina Faso (Crop = Onion)			Mali (Crop = Onion)			Mauritania (Crop = Tomato)			Senegal (Crop = Onion)		
	Californian system	Bucket method	Diff. (%age)	Californian system	Bucket method	Diff. (%age)	Californian system	Bucket method	Diff. (%age)	Californian system	Bucket method	Diff. (%age)
Water applied (m^3/ha)	9863	11190	13↓	4100	6240	52↓	4250	5850	38↓	6720	9400	25↓
Crop yield (kg/ha)	15850	15375	03↑	22630	16250	28↑	32900	14200	57↑	21400	16200	24↑
Water productivity (kg/m^3)	1.60	1.37	14↑	5.51	2.60	53↑	7.70	2.42	69↑	3.18	1.92	40↑
Economic productivity ($/$m^3$)	0.80	0.69	14↑	2.76	1.30	53↑	3.87	1.21	69↑	1.60	0.86	46↑

Table 3: Comparison of water applied, crop yield, water productivity and economic productivity under drip and bucket irrigation methods.

Parameters	Burkina Faso (Crop = Tomato)			The Gambia (Crop = Tomato)			Niger (Crop = Onion)			Mali (Crop = Tomato)		
	Drip system	Bucket method	Diff. (%age)	Drip system	Bucket method	Diff. (%age)	Drip system	Bucket method	Diff. (%age)	Drip system	Bucket method	Diff. (%age)
Water applied (m^3/ha)	3820	5270	38↓	7840	8650	10↓	6260	6880	10↓	6300	7920	26↓
Crop yield (kg/ha)	18650	16780	10↑	23470	17735	24↑	2400	1800	25↑	48811	30304	38↑
Water productivity (kg/m^3)	4.90	3.18	35↑	2.99	2.05	31↑	0.38	0.26	32↑	7.74	3.82	51↑
Economic productivity ($/$m^3$)	2.44	1.59	35↑	1.50	1.03	31↑	0.20	0.13	33↑	3.87	1.91	51↑

and water productivities of Californian and drip systems were two to three times higher than the bucket method. Farmers showed great interest in drip irrigation system because of its advantages such as uniform distribution of water to plants, better use of fertilizer and increased crop yields. However, higher installation and the subsequent operational and maintenance costs of drip systems were a matter of serious concern for them.

In addition to water saving and better crop yields, the installation, operation and maintenance cost of drip system was three to four times higher than the Californian system. Therefore, farmers preferred Californian system over drip system.Lack of capital was reported as the major problem in the adoption of these systems. Therefore, there is a strong need to make concerted efforts to support farmers both financially and technically to adopt these technologies to increase their agricultural production and maximize economic returns.

Constraints and limitations for the adoption of small-scale irrigation technologies

A comprehensive survey was conducted in all countries to document farmer perceptions about the performance of Californian and drip irrigation systems and apprehend problems encountered by them in the adoption of these technologies and to prepare policy recommendations for the national governments to overcome these obstacles.

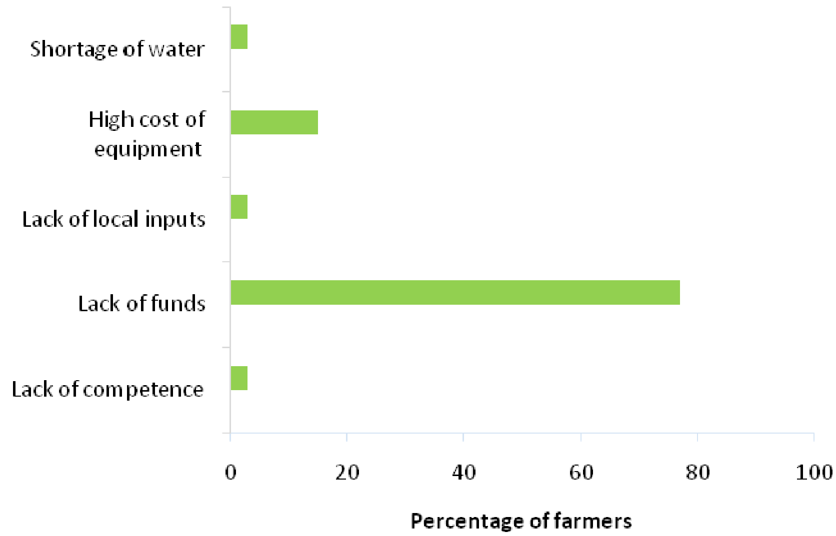

Figure 3: Challenges in the adoption of irrigation technologies

In total, 300 farmers (50 from each country) were selected for this survey. These include farmers directly involved in the field trials and those who attended farmer field days organized under this project for the demonstration of these technologies. The survey was conducted on a pre-tested questionnaire. Group discussions were also held with the farmer associations, extension workers and policy makers to get their feedback and suggestions for scaling up these technologies within countries and on a regional scale.

The survey results confirm that the farmers were convinced that the profitability of growing crops using these irrigation technologies can be increased provided costs are reduced. For these systems, fuel and maintenance costs were found to be the leading cost elements, which makes up 25 to 30 percent of the total production costs. On average, 66 percent farmers preferred Californian system whereas the rest 34 percent favored drip system. The farmers' preference was based on the lower installation and maintenance cost of the Californian system. The installation cost of the Californian system ranges from US$ 600-1000 per ha compared to US$ 1500-4000 per ha for the drip system. Farmers found Californian system more suited to poorly leveled agricultural fields and coarser soil types as it reduces percolation losses to the minimum and makes more water available for crops.

Despite these advantages, Californian system is not affordable for most of the smallholder farmers. Figure 3 shows that about 77 percent respondents consider lack of financial resources as the major reason for low or no adoption of these irrigation technologies. High equipment (engines and pumps) and operational costs (fuel and maintenance), lack of technical knowledge and non-availability of required material for these technologies in local markets were reported as major challenges by smallholder farmers. For drip irrigation, clogging of emitters and damaging of pipes by animals were also noted as major problems.

Propositions for scaling up irrigation technologies

Since more than 70 percent farmers in SSA are involved in subsistence farming (cultivating less than 2 ha), it would be prudent to promote Californian and drip irrigation systems because of their social and economic acceptance by the farming communities. However, scaling up of these technologies would require provision of financial and technical assistance from government, NGOs and/or other development partners. Small farmers do not have collateral to safeguard loans from government banks. NGOs in few countries (i.e. Kenya) have helped small farmers with credit facilities, but they do not have enough capital to expand and administer such loans on commercial basis. Therefore, national governments should formulate policies to extend credit facilities to small farmers as the installation and operational costs of these irrigation systems are beyond the reach of many farming communities in SSA. In addition to national governments, international donors can also play an important role by allocating grants or soft loans (Amjath-Babu et al., 2016). Use of climate adaptation funds to support smallholder farmers of SSA may also be justifiable, because such investments could reduce the degree of risk and vulnerability farmers face in light of climate change (Kadigi et al., 2012).

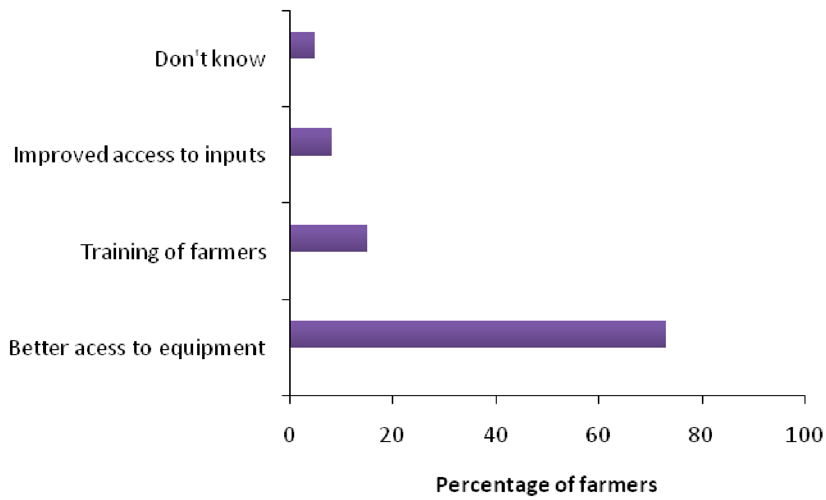

Figure 4: Farmer suggestions for scaling up irrigation technologies

Figure 4 shows that more than 70 percent farmers think that better access to equipment would accelerate the adoption of these technologies. For this to happen, reduction in the installation costs of these technologies and making maintenance costs affordable would be inevitable. This objective can be achieved through the involvement of private sector in the local manufacturing of pumps and equipment used in these irrigation systems. Manufacturers of low-cost equipment face a host of problems. Their knowledge and capacity for technology development and application is limited and government policies are more focused on crop and livestock research and little attention is given to support agricultural engineering (FAO, 2011).

Improving pump manufacturing capacity and availability of imported equipment and spares at affordable costs can help increase crop productivity while providing resilience against erratic rainfall patterns of SSA. For this purpose, national governments nee to formulate policies to facilitate private equipment manufacturers, importers of spares and providers of maintenance services. The Asian countries (i.e. India, Pakistan and Bangladesh) have revolutionized their irrigated agriculture through increased access to irrigation technologies (such as cheap Chinese pumps) and physical and economical access to energy (Qureshi et al., 2010). In these countries, electricity and diesel supply for agricultural purposes is supplied at discount rates and import of irrigation pumps are heavily subsidized. These agricultural policies have increased agricultural production of these countries making them self-sufficient in food despite growing concerns that indiscriminate use of energy for irrigation is causing environmental problems (Qureshi et al., 2015). The SSA countries may also follow these models, at least for the coming 5 to 10 years to revitalize agriculture. To cut down operational costs, the potential of solar powered and wind driven pumps need to be explored. These energy sources can also energize household lamps and fans. These developments can bring revolution in the lives of rural communities especially the children as they will have better environment for education with potential human health benefits.

The study results indicate that in most of the irrigated areas of SSA, irrigation water application has no relevance with the actual crop water requirements. Farmers' perception about a good irrigation is the depth of irrigation applied to the field regardless of soil moisture deficiency and the age and conditions of the crop. As a result, the applied amount of irrigation is usually much higher than the required amount of water for a particular crop(Burney and Naylor, 2012). Due to diminishing water resources in SSA, farmers need to be educated on improved water management and conservation strategies. Farmers should be trained in calculating crop water requirements and developing irrigation schedules for different crops. Improving water use efficiency using micro-irrigation techniques can also improve returns to investment in groundwater irrigation, especially in high value crops. The relationship between knowledgeable technicians, extension workers and smallholder farmers also need to be strengthened.

In most of the SSA countries, farm products are generally sold in the local markets where buyers come from the nearby big towns and neighboring countries(i.e. Ghana, Ivory Coast, Togo and Benin). Prices are negotiated directly in the fields or in the local market and the products are immediately removed. This system does not benefit farmers because they are forced to sell their product at low price due to limited access to big markets and lack of storage facilities. Lack of market information restrict farmers to transport their produce to distant areas due to the fear of market saturation. Improving road infrastructure can enhance market access, which may lead to increased farm gate prices by lowering transactions costs. Smallholder farmers also need help to fortify processing activities to reduce post-harvest losses and earn better price in the market (Hodges et al., 2011).In countries such as Mali and Senegal, few farmers have contracts with exporters, which allows them to earn competitive profits.

Farmers may also be encouraged to form cooperatives or farmer associations/groups to jointly afford installation of expensive equipment for shared benefits. In addition, farmer groups may also be able to acquire bank loans and establish links with sources of genuine farm inputs and markets. This will reduce poverty at the community and household levels and contribute positively to overall national economy. However, this process needs strong motivation because experience in Kenya has shown that farmers often pool their resources to pay for conveyance systems but are extremely reluctant to share irrigation pumps (FAO, 2008).

The crop yields in smallholder farms of SSA are far lower than regional and international standards. In addition to lower water availability, poor soil fertility, low fertilizer application rates and use of poor quality seed are the major contributing factors. During the survey, it was realized that smallholder farmers of SSA are in desperate need of good quality seed to enhance their agricultural productivity. Low soil fertility problem can partially be solved by micro-dosing of fertilizers with sufficient farm yard manure and organic matter. Farmer also need to be educated in integrated nutrient management, which involves timely application of nitrogen as per crop demand and irrigation schedules (Godfray and Garnett, 2014).

The provision to better quality seed can narrow down potential and existing yield gaps and reduce post-harvest losses with minimal spoilage during storage; unlike the local varieties which mature late, produce low yields and do not withstand stress during handling and long distance transportation. Better quality produce therefore earns good market price. This shows that economic viability of improved irrigation systems is directly linked with the provision of good quality seed to the farmers. It is, therefore, recommended that national governments should give due attention to the production of good quality seed and its distribution to farmers at affordable prices.

CONCLUSIONS AND RECOMMENDATIONS

The water and economic productivities of Californian and drip irrigation systems are two to three times higher than the traditional bucket method of irrigation. Farmers prefer Californian system over drip system due to its low installation, operation and maintenance costs. The cost of installing Californian system ranges from US$ 600-1000 per ha compared to US$ 2000-4000 per ha for drip irrigation system in these countries. Furthermore, Californian system is also more suited to poorly leveled agricultural fields and coarse soil types.

Despite these advantages, adoption of this technology in SSA is constrained by multiple factors. These include high cost of equipment, lack of local expertise and above all lack of financial resources of farmers. Farmers suggest that better access to credit facilities through government and private institutions can help a great deal in the adoption of these technologies by smallholder farmers. For long-term sustainability, however, reduction in capital (pumps and other equipment)and operational costs (fuel and maintenance of pumps) by encouraging local manufacturing and possibility of introducing solar driven and wind driven pumps need to be explored. Farmers also need to be trained in the maintenance of these systems to cut down maintenance costs.

To increase profitability of farmers, provision of good seeds, access to competitive markets and establishment of processing facilities is recommended. These facilities will increase shelf life of produce which will give them true economic returns. Through increased farm incomes, farmers will also be able to invest on these technologies from their own resources. Till that time, government interventions to provide needed financial support for scaling up these technologies to larger farming communities would be inevitable.

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