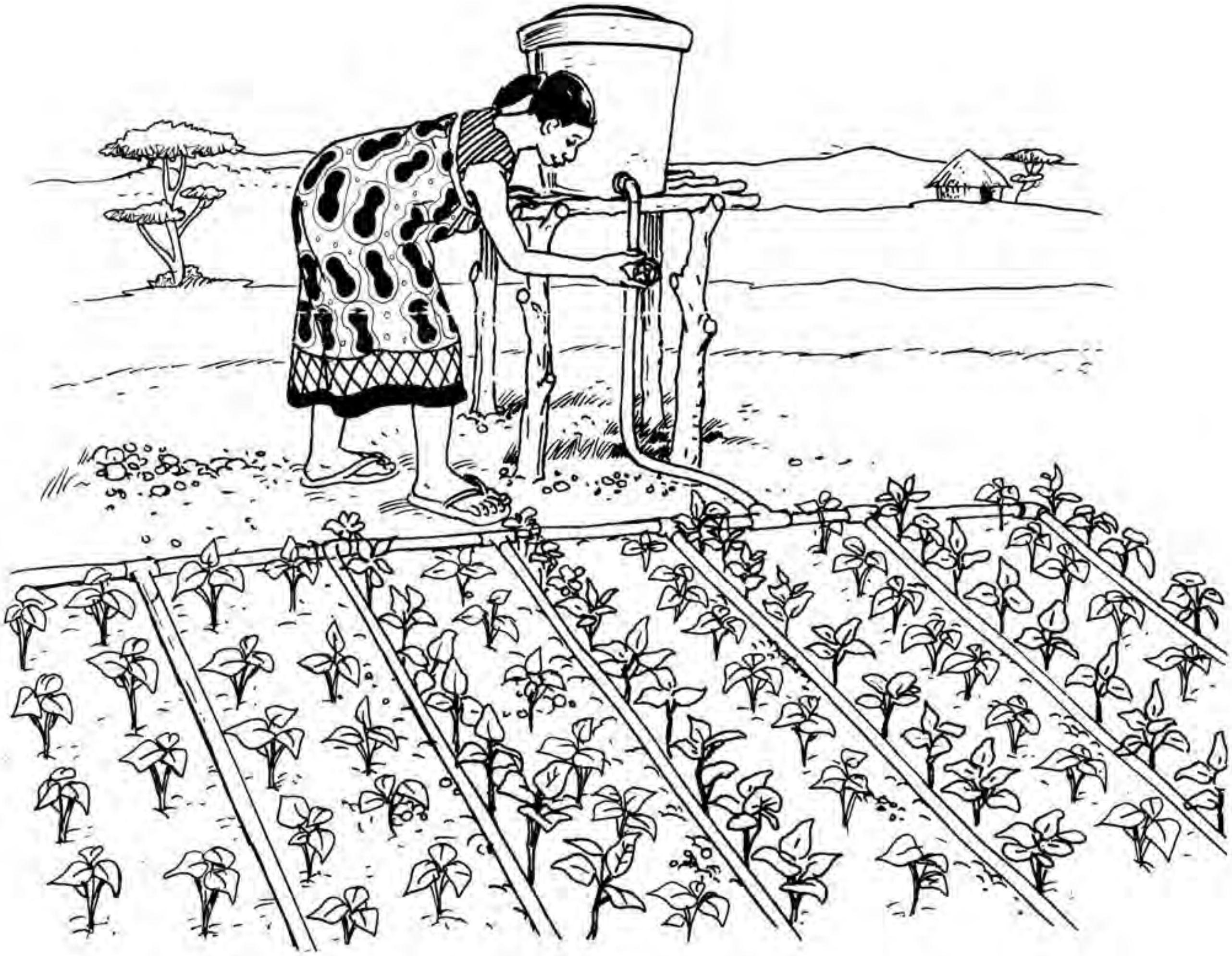
Low-cost Drip Irrigation Systems for Smallholder Farmers in Tanzania



Agriculture in Tanzania continues to be the largest sector in the economy with its output largely dependent on smallholder rainfed production. Its performance therefore has a significant effect on people's income and poverty levels. Tanzania covers an area of about 94.5 million ha, of which 44 million ha are classified as suitable for agriculture, of this, 23% (10.1 million ha) are cultivated. The country has substantial water resources and an irrigation potential of 1 million ha, of which 20% (200,000 ha) is under irrigation (URT, 2004).

Irrigation in Tanzania is very important as it helps in satisfying subsistence requirements in many parts of the country. It increases food security at the household level, generates local surpluses of main staples, particularly rice, in order to achieve food security in the country. It also helps ensure the production of much needed dietary supplements such as vegetables, fruits, and pulses. Conventional irrigation such as surface irrigation has been challenged because of its very low water use efficiency. Given the fact that water resources are diminishing, there is a need for innovations that are diminishing, "water-smart" innovations that can ensure better yields and increase water use efficiency and water productivity are needed.

Addressing rural poverty requires a focus on smallholders who make up majority of the rural poor. Improving irrigation productivity on large farms alone will not solve the continuing problems of rural poverty, which are getting worse in sub-Saharan Africa. Increasing agricultural productivity and income of majority of farmers who cultivate less than 2 ha in developing countries is a relatively untapped opportunity for finding practical solutions to rural poverty and household food security. Surface irrigation methods are utilized for more than 80% of the world's irrigated land, yet its field-level application efficiency is often only 40–50%. In contrast, drip irrigation may have field-level application efficiencies of 70–90% as surface runoff and deep percolation losses are minimized (Heermann *et al.*, 1990; Postel, 2000). Thus, drip irrigation may allow more crops per unit water to be grown and permit crop cultivation in areas where water is too insufficient to irrigate using surface irrigation methods.

While the drip irrigation system has higher water use efficiency of 70–90% (Postel *et al.,* 2001; Postel, 2000), the conventional drip irrigation (CDI) systems available commercially are unaffordable to majority of smallholder farmers (Polak *et al.*, 1997; Narayanamoorthy, 2003), Drip irrigation is a knowledge-intensive, technology-oriented operation, designed for larger landholdings (e.g., >4 ha), with capital cost ranging from $1500 to $2500 per hectare (Phene, 1995; Postel *et al.,* 2001). These CDIs are unavailable to many Tanzanian smallholder farmers who live in rural areas, have small landholdings, and limited financial resources (Postel *et al.,* 2001). Low-cost drip irrigation (LCDI) is an irrigation method that is suited for small fields and maintains the water-saving advantages, hence gaining the advantage of being a water-smart technology through its affordability, simplicity, easy maintenance and operation, and big water saving. The LCDI presents an opportunity to substantially improve the economy and food security of smallholder farmers.

Opening smallholders' access to affordable small-plot irrigation is a critical first step to wealth creation for the rural poor, particularly women. Low-cost drip irrigation systems not only open doors to a path out of poverty; they are also a path to saving water and doubling irrigation productivity on small farms as a water-smart agricultural strategy. For smallholder farmers, LCDI provides a means of maximizing returns on their crop land by increasing economic biomass production per unit of water and increasing cropping intensity by also growing crops during the dry season. The LCDI was therefore designed using locally available components, with preference given to local manufacturing that only requires relatively unsophisticated facilities, but not at the expense of performance and functionality. The system is simple and easily understood, and can be operated and maintained by average users, compared with conventional systems that are sophisticated and require expertise.

Low-cost drip irrigation system

Improving access to and adopting water-conserving practices can help irrigation systems cope with water scarcity. Water-conserving technologies can maintain cropping intensity and can provide opportunities to diversify, leading to production of high-value crops and reducing reliance on rainfed field crops. Technologies for achieving higher water productivity include existing LCDI technologies such as the "bucket and drip" system at prices that smallholder farmers can afford (Carruthers *et al.,* 1997). Drip irrigation systems are normally used for high-value cash crops (vegetables and fruits). These systems are common in some parts of Africa. For example, the Chapin bucket kits are being used in Kenya, Tanzania, Malawi, Zambia and Uganda (Phene, 1995; Narayanamoorthy, 2003).

The conventional pipes used for most of the outstanding schemes of drip irrigation are made mainly of polyvinylchloride (PVC) and occasionally asbestos-cement, while emission devices include point- and line-source emitters that operate either above or below the ground surface at discharge rates of 2 to 8 liters per hour (James, 1993; Yanbo and Fipps, 2003). These pipes and emitters are very efficient and adequate but are being imported and are thus beyond the reach of a rural farmer (Onilude, 2005), thus, the search for and use of a substitute technology. Therefore, fabrication and installation of LCDIs using locally available materials that are in the vicinity of smallholder farmers have become inevitable. To facilitate acceptability and adoption, LCDIs should be made simple for most smallholder farmers. LDCI can either be the bucket type or drum type.

The LCDI using drum irrigation systems operate under a low pressure head of water (0.5–5 m). Mounting the drums on block supports raised at least 1 m above the planting surface is recommended (Fig. 1). The higher the drum is placed, the greater the area that can be irrigated. An area of up to 1,000 m^2 can be covered by a drum system. The main advantage of drum systems is the bigger area that can be covered compared to the bucket system. The drum irrigation systems present an economic advantage because of the number of plants per drum system. A drum system covering five beds, each 1 m wide and 15 m long, can be used to grow 250 plants (tomato, eggplant, and similar plants requiring a spacing of 60 cm along plant rows); 500 plants (spinach, cabbage, kale, pepper and similar plants requiring a spacing of 30 cm along plant rows); or 1,500 plants (onion, carrot, and similar plants requiring a spacing of 10 cm). The drum system also offers water storage and control through a control valve, making it possible to fill the drum for irrigating at another time. The standard drum kit system comprises a drum, a control valve, a manifold, and drip lines. The drum should be filled with the valve in the closed position. To irrigate, it is important to open the valve fully. This allows the water to be distributed quickly through the drip lines and results in good water distribution.

Objectives

The main objective of the study was to evaluate the effectiveness of LCDI compared with CDI in terms of being a simple, cost-effective, and water-smart irrigation technology. The specific objectives were the following:

a) Evaluate water use and water productivity of LCDI compared with CDI

b) Evaluate crop growth performance and yield under LCDI

c) Evaluate the costs and benefits of LCDI compared with CDI system

Materials and methods

Study area

The study was conducted at Mkindo village (latitude 6°16’ and 6°18’ south and longitude 37°32’and 37°36’ east) located in Mvomero District, Morogoro Region in Tanzania. Its altitude ranges between 345 and 365 m above mean sea level. The study area is about 85 km from Morogoro municipality. The average annual temperature in Mkindo is 24.4°C with a minimum of 15.1°C in July and a maximum of 32.1°C in February. The rainfall pattern is bimodal, characterized by two rainfall peaks with short rains from October to December with a mean value of 140 mm, and long rains from March to May) with a mean value of 500 mm. The groundwater table rises at a range of 80–140 cm from the ground surface during the wet season. Soil type on the experimental site was predominantly clay loam.

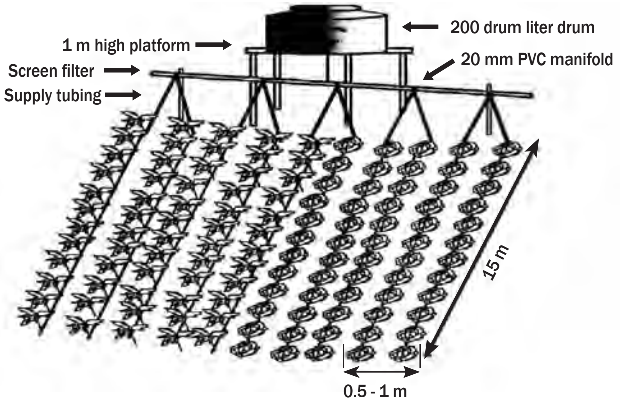


Fig. 1. *Drum-type LCDI (Source: KARI Kenya).*

The experiment was done in randomized complete block design. The study involved pressure heads of 0.8 m (T1), 1.0 (T2), and 1.2 m (T3) of the LCDI with one punched hole, compared with the conventional drip irrigation (CDI) system at 1.0 m pressure head of the supply tank (T4). Calibrated tensiometers were used to monitor the soil moisture status. The discharge of the emitters was determined before planting to know hydraulic performance parameters that include Christiansen’s uniformity coefficient (CUC), distribution uniformity (DU), and emission uniformity (EU). Irrigation water was measured at each irrigation event to determine irrigation water productivity (IWP). At harvest, aboveground biomass and grain yield were measured. Data were analyzed using the Genstat computer package.

Farmer field schools

Farmer field school (FFS) plots (4 m by 7) m were prepared and the LCDI systems were installed in collaboration with farmers. Farmers chose tomato as the test crop. Field visits were organized to monitor and evaluate progress. Regular on-site discussions were held with farmers on the practicability and limitations of the system. The performance of the low-drip irrigation system was also compared with typical farmers’ practice of hand watering using water in the FFS plots. Three plots per each irrigation method was assessed and okra was the test crop used for both methods. The methods were

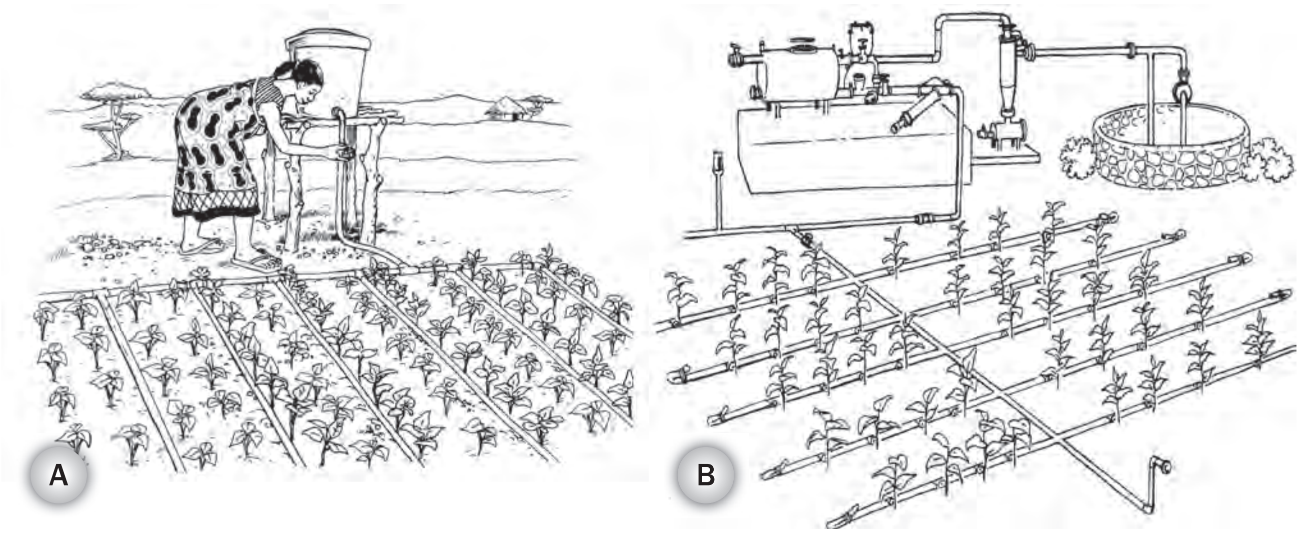


Fig. 2. *(a) Low-cost drip irrigation system and (b) conventional drip irrigation system in Mkindo village, Morogoro region.*

evaluated in terms of technical performance (water savings, labor savings, and yield increase), suitability, and marketability (perceived benefits and price). Water use was measured (in liters) by the number of buckets of known volume each time water was applied (Fig. 2).

Results and discussion

Water use and water productivity

The results on performance parameters for LCDI and CDI are presented in Table 1. No significant differences in terms of EU, CUC, CV and DU for treatments T1 to T4 ($p<0.05$) were noted. A comparison of average results from LCDI and CDI also indicated no significant differences in system performance. This means that the locally fabricated LCDI performed as well as the industrially manufactured irrigation system (T4). As to discharge, however, CDI had a significantly lower discharge than to LCDI due to better control provided by industrial emitters.

Yield and crop water use are presented in Table 2. For LCDI, the treatment with a pressure head of 0.8 m (T1) did not show any significant difference in yield compared with other treatments. However, it had the lowest water use and it gave higher water productivity than did other LCDI treatments. T1 is regarded as the best treatment in terms of water saving.

Average seasonal irrigation water use across constant-head, low-cost drip irrigation treatments was 5.9 m^3 for CDI (T4) and 11.13 m^3 for T3. Seasonal irrigation water use did not vary appreciably among these treatments but it increased with increase in pressure head. Optimum water use for LCDI was at a pressure head of 0.8 m (T1), which gave a water productivity of 1.023 kg/m^3. Statistics show a significant difference between T4 (CDI) and the other treatments ($p<0.05$) on the water used. This is due to variation in emission devices.

Table 1. *Performance parameters of different treatments of a constant-head low-cost drip irrigation system.*

Irrigation type	Treatment	EU (%)	CUC (%)	CV (%)	DU (%)	Discharge (L/h)
LCDI	T1	90.034a	61.292a	38.708a	99.508a	1.5345b
	T2	89.644a	76.013a	23.987a	99.695a	1.8472b
	T3	83.782a	73.814a	26.185a	99.667a	1.9372b
LCDI (avg)		87.820a	70.373a	29.627a	99.623a	1.773b
CDI	T4	87.528a	80.012a	19.988a	99.746a	0.6128a

Means followed by the same letters are statistically non-significant at the 5% probability level.

Table 2. Yield, water use, and irrigation water productivity under constant-head condition.

Irrigation type	Treatment	Yield (t/ha)	Water used (m^3/ha)	Water productivity (kg/m^3)
LCDI	T1	11.13a	10,850b	1.023ab
-	T2	11.10a	11,000b	1.009ab
-	T3	8.92a	11,550b	0.774a
LCDI (Ave)	-	10.38a	11,130b	0.935ab
CDI	T4	10.46a	5,900a	1.778b

Means followed by the same letters are statistically non-significant at the 5% probability level.

Nevertheless, the hydraulic performance did not significantly differ among the treatments ($p>0.05$) as stated earlier (Table 1).

Economic comparison

The gross returns of the two systems (LCDI and CDI) are presented in Table 3. There was no significant difference in terms of income gained from the two systems. A comparison of the production costs for LCDI and CDI is presented in Table 4. The investment cost for LCDI was less by 24.1% compared with that of CDI. Installation cost of LCDI was also 44% less than that of CDI because the latter needs expertise on installation while the former does not. Irrigation activities (filling water in the tanks) in LCDI were higher by 16.7% compared with CDI. This is because, in LCDI, many tanks have to be filled during irrigation. Cost of other activities in both irrigation systems did not vary. Generally, cost associated with LCDI was less by 24.1% that of CDI (Table 4).

Gross returns from soya bean cultivation under CDI were slightly higher than those under LCDI (Table 4). However, this gross amount cannot be treated as effective (real) profit under LCDI and CDI, because it does not take into account the capital cost of the drip set, its depreciation, and the interest accruing on fixed capital.

In the FFS demonstration plot trials, the benefits of LCDI—increased yield, decreased water usage, decreased labor usage, improved water and labor productivity—were observed. Net income from drip-irrigated crops was only 8% higher than hand-watered plots (farmers' practice), while yields were 61% higher, man-hour savings were 33%, and water savings were 33%. Considering total production cost per hectare, LCDI's is 24.1% less than CDI's. The water and time savings realized from LCDI compared with can-watering indicates that LCDI is more water-smart than conventional practice. Also, if female farmers were involved, the labor and time saved will enable them to do other activities for the well-being of their households. The lower total cost also shows that farmers adopting LCDI can save money without compromising crop yield.

Table 5 indicates that irrigation water productivity under LCDI was high (3.27 kg/m^3) compared with hand watering (1.37 kg/m^3). LCDI was thus more economical than hand watering (labor saving). Nevertheless, this comparison is limited to capital cost, seasonal investment input, and returns. There is a need to consider the lifespan of the two systems and determine the net present value and net profit, including depreciation and interest accrued on fixed capital. The longevity (duration of service) of the drip-set is an important variable to assess net present value, which, in turn, is a determinant of per–hectare profit.

Table 3. *Comparison of soya bean production per hectare under LCDI and CDI.*

S.N Description	Unit	Under LCDI	Under CDI
Crop productivity	kg	10,384	10,463
Average harvest crop price	Tsh/kg	3,000.00	3,000.00
Total gross returns	Tsh	3,115,200.00	3,138,900.00

Table 4. Per-hectare costs (Tsh) associated with LCDI and CDI.

Description	LCDI	CDI	Gain over CDI	
			Amount	Percentage
Material purchase	10,990,000	14,666,800	3,676,800	25.07
Drip installation	150,000	270,000	120,000	44.44
Cultivation	75,000	75,000	-	0.00
Seed sowing	40,000	40,000	-	0.00
Pesticide application	30,000	30,000	-	0.00
Weeding and intercultural practices	360,000	360,000	-	0.00
Irrigation	140,000	120,000	(20,000)	-16.67
Harvesting	120,000	120,000	-	0.00
Total	11,905,000	15,681,800	3,776,800	24.10

Table 5. Yield, water use and water use efficiency of low-cost drip system and hand watering under farmer-managed conditions.

Irrigation method	Yield (t/ha)	Water use (m^3/ha)	Irrigation water productivity (kg/m^3)	Man-hours used
Low-cost drip system	13.214	4,035.71	3.27	149
Hand watering	8.214	6,000.00	1.37	224

Conclusions and recommendations

A low-cost drip irrigation system was introduced in Mkindo village and tested for its affordability, acceptability, and performance under farmer-managed environment. During season one, the treatment with one punched hole per emitter and the supply tank raised to 1 m elevation head (T1) was recommended for use among other treatments because it used less water. Further it was shown statistically that there were no significant differences in water productivity with T3 (higher WP). During season two, the treatment with supply tank at a pressure head of 0.8 m was found to be the best as it used less water than did other LCDI systems. Its WP had not significantly differed from that of CDI system.

An economic analysis of the LCDI system revealed better performance in terms of in payback period than CDI. However, further economic analysis using other crops should be done to get a more solid basis for recommending possible changes in the LCDI technology.

Farmers' testimonials

- *LCDI is simple to install, I don't need to hire an expert.*
- *We are getting the same yields just like commercial family drip systems, but these are much cheaper and affordable.*
- *I used to irrigate with watering cans and was taking quite some time. With LCDI I am spending less time irrigating my fields.*
- *The system can easily be installed and dismantled at the end of cropping season.*

Farmers reported high levels of satisfaction with the low-cost drip system and they were willing to pay for the equipment. With relative abundance of water in some areas in Mkindo, however, it is a challenge to motivate farmers to use it. It is better to promote drip irrigation among farmers for whom water is a key constraint—i.e., water is scarce and costly to pump. When integrated with improved crop management practices, low-cost drip irrigation can be a water-smart technology compared with conventional drip irrigation.

The labor and time saved through LCDI can give female farmers opportunity to engage in other activities for the well-being of their households. The lower total cost of LCDI indicates that farmers adopting this system can use 24.1% less money than when they use CDI while at the same time not compromising yield. There is therefore a need for government to promote LCDI.

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