Irrigation Technologies for Small Holders

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Several important new irrigation innovations have been developed and commercialized during in the past few decades. These include: automated canal and piped water delivery systems; laser land leveling for surface irrigation applications; set and automated sprinkle irrigation; micro-irrigation including surface and sub-surface drip systems; and sophisticated control systems for managing these technologies. With these new technologies it is technically practical to uniformly irrigate a field so all areas receive approximately 90% or more than the average amount of applied water per unit area. Furthermore, with subsurface drip irrigation and accurate scheduling almost all of the water applied to the plants is transpired (so the E component of the applied water ET is minimized).

Practically all of this new technological development and commercialization has been directed toward relatively large and fairly sophisticated systems for use in regions populated by well-resourced farmers. However, the majority of the world's farmers are resource poor smallholders who have not been able to afford to participate in this revolution in irrigation technologies. Their purchasing decisions are exceptionally price-sensitive, thus reducing costs to levels smallholders can afford is key to making modern irrigation technologies accessible to them. But the private sector and most development agencies have neglected the special irrigation technology needs of stallholders.

This neglect of smallholders within the mainstream irrigation technology sector has resulted in a wide gap between the performance of systems used by most smallholders and what is practical with modern irrigation technologies. It is not sufficient to merely scale-down technologies that are appropriate for larger commercial farms. Systems must be re-engineered to match smallholders' unique characteristics (e.g., small landholdings, low capital availability, low risk tolerance, and relatively low opportunity cost of family labor). Technological features that are important to smallholders include: 1) low investment cost; 2) suitable for various plot/field sizes at about the same cost per unit of area served; 3) rapid return on investment; 4) simple inexpensive maintenance; and 5) operation at very low pressure head.

Fortunately, re-engineering is indeed taking place and some new innovations have been developed that show great promise for providing smallholders with improved irrigation technologies that are appropriate, affordable and highly efficient. Furthermore, an effective "venture donor capital[2]" business development approach has proven to be a successful low cost means for delivering them to large dispersed

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[1] The references for this paper are included in the Discussion Paper, Keller, Andrew and David Seckler.2004. *Limits to Increasing the Productivity of Water in Crop Production.*

[2] This is similar to the way a venture capitalist would work to develop a product, market test and then commercialize it except the donor forgoes any profit potential.

populations of farmers with land holdings from 100 m^2 to 20,000 m^2 (see Heierli, 2000 and Postel, et. al., 2001). A number of NGOs are successfully using this marketing approach throughout the world.

Examples of three of these improved irrigation technologies that are suitable for smallholders are covered in the following sections. These are low-cost drip irrigation for efficient water application, treadle pumps for water lifting, and large low-cost plastic water tanks to store water collected during the rainy season for use in the dry season. We have chosen these three technologies because they represent examples of the water supply, water conveyance and water application components of irrigation systems. The treadle pump was the first new irrigation technology to be successfully and widely distributed using a business development approach. Low-cost drip irrigation is in the "market takeoff stage" and holds great promise both in terms of significantly increasing food production per unit of water consumed and reducing rural poverty. Low-cost water storage tanks, while still in the development stage, appear promising for bringing the benefits of supplemental irrigation to smallholders who have no other access to irrigation water.

Low-Cost Drip Irrigation

Drip irrigation has the potential to be the most efficient irrigation technology when evaluated in terms of either crop production per unit of water consumed by ET or per unit of water applied. This is because the water can be uniformly delivered to each plant through a closed pipe system. Thus converting from traditional surface irrigation to drip irrigation can significantly increase the area of land that can be fully irrigated with a given volume of water. In Table 1[3], which shows results from various research stations in India, in most cases the production of different crops per unit of water supplied is increased by 100 to 200 %. But of even greater importance, the production per unit land area (which is a rough proxy for ET) is increased by 20 to 50 %. This increase in production per unit of land results from the more precise timing, higher uniformity and accurate amount of water applied made possible by using drip irrigation. Thus more favorable soil moisture conditions can be maintained throughout the cropping season.

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[3] There appear to be some discrepancies in the last column of Table 1 that we assume are caused by either inaccurate data transfers or calculation errors somewhere along the line.

Standard commercial drip systems are simply not appropriate or affordable for most smallholders. Some of the reasons are: 1) they cost from $1,500 to $2,500 per hectare ($0.15 to $0.25/m²); 2) to eliminate dripper clogging expensive and complicated water filtration systems are required, thus a 2-hectare system is about the smallest practical size; 3) the required operating pressure head at the pump is typically between 20 m and 30 m to overcome losses in the filter and pipe distribution network and provide sufficient pressure for the drippers; and 4) without very careful maintenance, the drippers clog.

Table 1: Water Productivity Gains from Shifting to Drip from Conventional Surface Irrigation in India [a].

Crop	*Change in yield (%)*	*Change in Water Use (%)*	*Water Productivity Gain (%)* [b]
Banana	+52	-45	+173
Cabbage	+2	-60	+150
Cotton	+27	-3	+169
Cotton	+25	-60	+255
Grapes	+23	-48	+134
Potato	+46	~0	+46
Sugarcane	+6	-60	+163
Sugarcane	+20	-30	+70
Sugarcane	+29	-47	+91
Sugarcane	+33	-65	+205
Sweet potato	+39	-60	+243
Tomato	+5	-27	+49
Tomato	+50	-39	+145

Source: Postel, et al. (2001)

(a) Results from various Indian research institutes.

(b) Measured as crop yield per unit of water supplied.

R. Chapin, of Chapin Watermatics, was among the first to recognize the need to promote a low-cost version of drip irrigation among low-income households. In 1974, at the invitation of an NGO (Catholic Relief Services), Chapin introduced small (20 to 30 m^2) drip irrigation systems in Senegal to help subsistence farmers produce vegetables where there was little or no rain. In the mid 1990s, IDE developed and began promoting a variety of drip irrigation kits that were appropriate for small land holdings. Figure 3 shows a typical 1990s vintage drip system for irrigating a 100-m² plot with water supplied from a 200-liter water storage tank supported 1-meter above the ground. Although these systems had most of the attributes necessary for smallholders, the plastic fittings and tubing cost about $0.15 per m^2, which is at the high end of affordability.

Recently Keller-Bliesner Engineering assisted IDE-India with re-engineering and commercializing drip irrigation systems so they are appropriate and affordable for smallholders. These drip systems are low-cost, require a minimum of filtration, are available in small packages, operate at low inlet pressure, and are easy to understand and maintain by smallholders. Although no effort is made at keeping others from copying these systems, they are promoted as *KB Drip*[4] systems, which is a registered brand name. Manufacturers and dealers, who subscribe to using the *KB Drip* brand name, must agree to adhere to specified standards[5] that are periodically checked.

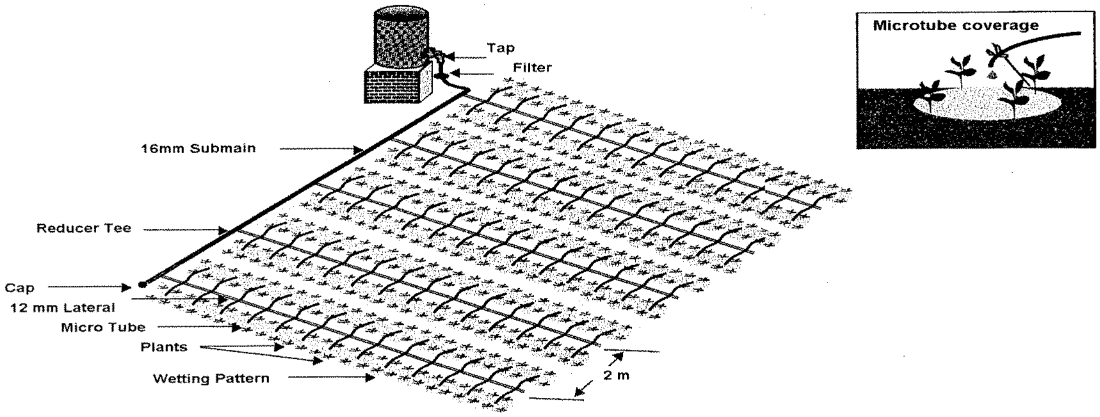

Figure 3. Schematic of a 1990s vintage low-cost micro-tube drip irrigation system.

These low-cost drip systems are very affordable, with an installed cost in India of between \$0.03 and \$0.05/m² for the laterals with drippers plus the sub-main, depending on field size, lateral spacing and layout. The affordable design is made possible because:

1. The systems operate at inlet pressure heads of from 1 to 3 m, so lightweight tubing and inexpensive fittings can be used and leaks are easily repaired.
2. The major system components are plain tubing and simple fittings and the microtube drippers and fittings are installed in the field.
3. The plain tubing and simple fittings can be manufactured by utilizing inexpensive manually controlled extruders and simple molds; therefore, the entry cost for manufactures is very low, which assures a competitive marketing environment.

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[4] KB stands for the Hindi words "Karishak Bandhu", which means "farmer's friend".

[5] For row crops, lay-flat tubing with an inside diameter (ID) of 16 mm and a wall thickness of 0.125 mm manufactured from a mixture of 80 % linear low density polyethylene (LLDPE), 20 % low density polyethylene (LDPE), and carbon-black is used for the laterals. It is strong and resists stress cracking, ultraviolet deterioration, and internal algae buildup and lasts for two or more years, which is long enough for four or more crop seasons. The typical dripper (emitter) is a 20-centimeter long black plastic microtube with an inside diameter of 1.2 mm, so only minimum filtration is necessary to eliminate clogging. The lay-flat laterals are supplied from larger diameter sub-mains that are also flat when empty and manufactured from LLDPE and LDPE.

4. The systems are lightweight and the lateral and sub-main tubing is packaged in tight rolls; therefore, transportation and handling costs are low.
5. The system components are simple and easy to assemble without sophisticated tools; therefore, farmers can either install their own systems at the rate of 1,000 to 2,000 m^2 of field per day, or have them installed by $2.00/day assemblers.

Besides being affordable the *KB Drip* systems (or other low-cost drip systems with similar specifications) have the following other attributes required for smallholders: 1) under low operating pressure heads (1.0 to 2.0 m) the discharge rate from the microtube drippers is about ideal for individual vegetable plants such as tomatoes; 2) dripper clogging is minimal even with little or no filtration when using water from dug wells; and 3) on relatively level small fields the application uniformity is comparable to that achieved by conventional drip systems used in developed countries. For example, the Design Emission Uniformity (EU) is 85 % for a 50-meter long lateral (the longest recommended length) with a pressure head of 1.0 m at its inlet and microtube drippers spaced 0.6 m apart. For shorter lateral lengths EU values as high as 96 % can be achieved. This compares favorably with conventional irrigation systems, which are typically designed to produce EU values of 85 % or higher (Keller and Keller 2003).

These low-cost drip systems only cost about fifth as much as standard commercial drip systems and less than a third as much as the earlier drip systems that were designed for smallholders. The availability of these low-cost drip irrigation systems in small affordable packages unlocks their potential benefits for literally millions of resource-poor farmers. In addition, it opens the potential benefits of irrigation even where water supplies were considered insufficient or too costly to acquire for traditional irrigation methods to be practical. To date, more than 200,000 low-cost drip irrigation systems have been distributed through market channels in India, Nepal and other areas in Asia.

Following are findings reported by Keller and Keller (2003) that are based on interviews with over 25 farmers who had installed *KB Drip* systems in the semi-arid region of the Western Maharashtra, India where the average land holding is less than one hectare. Most of the farmers had previous experience producing vegetable crops (such as tomatoes, eggplant, okra, squash, etc.) using traditional surface irrigation supplied from hand-dug-open wells fitted with electric or diesel-powered pumps. During the dry season their open dug wells only produce from 5 to 20 m^3 of water per day, and the sizes of their vegetable plots ranged from roughly 200 m^2 to 2,000 m^2.

- All of the farmers interviewed said the conversion to drip irrigation was very cost-effective. They reported yield increases of roughly 50 to 100 % and decreases in water use of from 40 to 80 % compared to their experience with traditional surface irrigation systems. The very low efficiencies resulted from high conveyance losses in earth channels and poor application uniformity on their unleveled fields, which are exacerbated by only having enough water to pump for an hour or less per day.

- The net returns from double-cropped vegetable areas were roughly \$0.50/m^2 greater under the *KB Drip* systems than under their traditional surface irrigation systems. In most cases water was the limiting resource and they have been able to double or even triple the irrigated area by converting from surface to drip irrigation[6] and generate increased net returns of \$1.00/m^2 from the additional irrigated land.
- Based on field observations and farmer experiences, the practical life of the *KB Drip* lateral tubing is expected to be about four growing seasons, which is about two years with double cropping.
- Farmers found the drip systems much easier and less time consuming to operate than traditional surface irrigation systems, particularly where water supplies were limited.
- Micro-tube clogging was not a problem with any of these drip systems, even though some of them that were being supplied directly from open wells did not have simple in-line screen filters. The few micro-tube emitters that clogged were simply replaced if flushing did not unclog them (three 20-centimeter long micro-tubes cost about \$0.01).

The Treadle Pump

A treadle pump is a simple low-cost manual (foot-operated) pump that can lift water from shallow groundwater sources or surface water bodies. The typical pump consists of two vertical cylinders fitted with pistons that are interconnected using a pulley (or lever) system so when using a stepping motion, as one treadle is pushed down the other treadle is moved up. Basic treadle pumps can lift water from depths of up to seven meters with a flow rate ranging from about 30 to 80 liters per minute (lpm) depending on the rigor of the operator, water depth, and cylinder diameter. Pressure treadle pumps can not only lift water, but also provide pressure heads of up to 20 m at the pump outlet.

Treadle pumps are suitable for agricultural use by smallholders because:

- They are inexpensive, for example, in Southeast Asia, the retail cost of a basic pump ranges from US \$12 to \$15 including the wood or bamboo treadles and support structure (see Figure 4). However, in Africa the typical cost ranges from \$55 to \$95 because pressure pumps are usually required and they generally have steel treadles and supports so they are compact and portable to facilitate moving to a secure location when not in use. The cost of a borehole well (when necessary) varies according to local geological conditions, but typically ranges from \$20 to \$80 in alluvial soils.
- The design and construction of the pumps is simple, so local craftsmen can manufacture them using readily available tools and materials; and they can be

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[6] However, by increasing the irrigated area the total water consumed by Crop ET would be proportionately increased. Therefore, from a basin-wide water resource perspective this would not increase the production per unit of water consumed if the so called "losses" from the less efficient traditional surface irrigation were being reused. The losses are only "real losses" if the water is discharged to salt sinks, becomes too saline for further use, or is consumed by undesirable evaporation and transpiration.

maintained and repaired easily by the users. Parts requiring periodic replacement such as plastic piston seals, which are common to many popular hand pumps, are usually available in local markets. The foot valve at the bottom of each cylinder is made from rubber that can be replaced using a discarded bicycle tire inner tube.

- Because they have two pistons, water is kept in motion during the up- and down-strokes resulting in a continuous flow and efficient use of manual energy.
- Leg muscles are used in a natural walking motion making it possible for an operator to pump for several hours per day delivering enough water to drip irrigate roughly 2,000 m^2 of vegetable cropped area.

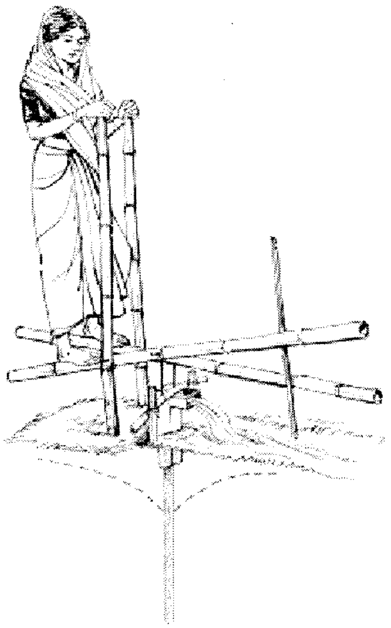

Figure 4. Woman operating a basic treadle pump (with a bamboo support structure and treadles and metal cylinders and pistons) that is supplied from a borehole.

Keller and Roberts (2003) presented the following brief history of treadle pumps:

> *"The treadle pump was developed in Bangladesh by a non-governmental development organization (NGO), Rangpur-Dinajpur Rural Services (RDRS), and popularized by another NGO, International Development Enterprises (IDE). Beginning in 1986, IDE-Bangladesh facilitated a market network of approximately 65 manufacturers, 700 dealers, and 5000 installers and stimulated demand for the pumps through mass media campaigns in rural areas (Hiereli 2000). To date, approximately 1.5 million treadle pumps have been distributed through market channels in Bangladesh and another half million have been distributed through similar programs in other Asian countries."*

Shah et al (2000) studied the socioeconomic impact of the treadle pump in eastern India, Nepal, and Bangladesh. The research indicated that treadle pumps enabled smallholders to intensively manage water and other inputs on "priority plots" within their land holdings, which significantly increased their agricultural production and income. The average additional net income to land and labor was found to be more than $100 per year per smallholder, and a significant percentage them were making an extra $500 or more per year. The extra income enabled some treadle pump owners to graduate to a higher level of mechanization by purchasing engine driven pumps for irrigation.

If one million (that's only half of the roughly 2,000,000 treadle pumps that the various NGOs claim to have been sold) are currently generating the average net annual income of $100, the total contribution of treadle pump irrigation to rural economies is $100 million per year. Treadle pump sales have leveled off in Bangladesh and practically every smallholder there now has access to their own supply or purchased irrigation water. However, Shah et al (2000) point out that theoretically there is potential for future expansion of the treadle pump technology in India and Nepal that could reach 9 to 10 million more smallholders. He also pointed out that with treadle pumps, the cost of new irrigation development in these areas is only $100 to $120 with the poorest farmers being the beneficiaries. In view of this success several NGOs are actively involved in the promotion of treadle pumps throughout Asia (including China) and Sub-Saharan Africa using the venture donor capital business development approach.

Bagging Water for Irrigation

Cost effective storage of the runoff water from small catchments or water from perennial wells or streams to use for irrigation during the dry season has been a major challenge. A recent innovation developed by IDE that looks promising is to store water in low-cost plastic lined tanks. The first level of experimentation has already been completed and the tanks are now being tested in a pilot study in India. Each tank stores 10 cubic meters (m^3) of water that is completely enclosed to eliminate evaporation losses. They cost roughly $40 and have a life expectancy of 5 years.

The tanks are constructed by first digging a 1.00 deep by 10.00 m long trench with a top width of 1.2 m and a bottom width of 0.8 m, then placing a sausage-like tube with two skins in it. The inner skin (or bladder) is a seamless extruded black LLDPE/LDPE 200-micron thick plastic tube. The outer skin is made from high-density polyethylene (HDPE) woven sackcloth (like the material used for fertilizer bags) to protect the bladder. Each end of the bladder is gathered and tied around a 63 mm (2.5 inch) PVC pipe elbow to provide an inlet and outlet that is held above the soil surface (and potential water level) to avoid leakage. The pieces of HDPE sackcloth used for the outer skin must be stitched together to make a tube that is slightly smaller in diameter than the bladder. Thus the bladder is the leak free membrane and the sackcloth provides a protective skin for it, while the earth bottom, sidewalls and end-walls provide the structural support. A sloped roof made from reed mats is then placed over the trench to provide additional protection.

The technique used to harvest rainfall is to install the water tank at a low point in the farmer's field or some other nearby depression where runoff collects during the rainy season. A settling pond followed by a sand filter bed is then constructed at a sufficient elevation uphill from the inlet to the water tank so the system will be gravity-fed. The settling pond being tested is a simple pit and dike system, and the sand filter is constructed by laying a slotted tube on the bottom of a 1- by 1-meter shallow pit and covering it with a gravel layer followed by a layer of sand. The slotted tube is then plumbed so the water entering it is conveyed to the water tank inlet.

Part of the pilot study is focused on rainwater harvesting during the monsoon season and storing the water so it is available for drip irrigating a cotton crop that is planted a few weeks prior to the next monsoon season. Cotton planted and irrigated 6 to 8 weeks prior to the monsoon will already be 30 or so centimeters tall when the rains begin. Thus able to take fuller advantage of the rainfall and potentially produce 30 to 50% higher yields than cotton that germinates after the monsoon starts.

The expectation (or hypothesis) is that by using a *KB Drip* system and very careful water management, each 10-m^3 tank of water will provide pre-monsoon irrigation for 1,000 m^2 of cotton. To test this the systems will be laid out with the laterals spaced 1.2-meters apart and a microtube dripper installed every 0.9 m along it. Then 4 m^3 of pre-planting water will be applied six weeks prior to the expected beginning of the monsoon season. Immediately after applying the water one or two cotton seeds will be planted at each dripper location and the surrounding wetted areas will be cultivated to create a "loose-soil mulch" to reduce evaporative losses. Two weeks after planting the seeds, another 2 m^3 of water will be applied, followed by applications of 2 m^3 every two weeks thereafter.

Another part of the pilot study is focused on irrigating plots of up to 100 m^2 of very high value vegetable or herbal crops from the water stored in each 10-m^3 water tank. To take fullest advantage of the monsoon rain, a deep layer of compost will be incorporated into the top 0.3 to 0.5 m of soil to maximize the rain infiltration and soil water storage and provide ideal soil conditions for the crop. After the rains stop, the plots will be covered with conventional plastic-sheet-mulch to conserve the stored moisture. At the appropriate planting time slits will be cut in the plastic mulch to accommodate planting either seed or seedlings (transplanted from nurseries grown with water from the storage tanks). A *KB Drip* system will then be laid out on top of the plastic mulch with a dripper provided for each plant. Irrigations applications will be carefully scheduled to take maximum advantage of the water stored in both the soil and the tank.