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NEW LOW-COST IRRIGATION TECHNOLOGIES FOR SMALL FARMS

NOUVELLES TECHNIQUES D'IRRIGATION PEU COUTEUSES POUR PETITES EXPLOITATIONS AGRICOLES

Jack Keller[1], J.N. Ray[2], Andrew Keller[3], Xiaopeng Luo[4], and Robert Yoder[5]

"An 'appropriate technology' is usually characterized as small scale, energy efficient, environmentally sound, labor-intensive, and controlled by the local community. It must be simple enough to be maintained by the people who use it. In short, it must match the user and the need in complexity and scale and must be designed to foster self-reliance, cooperation, and responsibility." (Amadei, 2004)

ABSTRACT

New efficient low-cost *affordable small-scale irrigation technologies* (ASITs) designed for farmers with land holdings of a hectare or less have recently been developed. They are being delivered to resource poor smallholders using a business development approach. This allows them to efficiently irrigate and grow high value crops and significantly boost their farming income. At the same time they also increase crop production per unit of both applied water and the water consumed by evaporative demands or losses to salt sinks (or water quality degradation).

Efforts to improve the on-farm performance of traditional surface irrigation of small fields have not succeeded because of the difficulties associated with trying to precision-level them. This has led to the use of pressurized irrigation systems, like drip and sprinkle. But simply downsizing the modern systems used in developed countries has usually resulted in systems that are technically and economically impractical for smallholders. To develop a successful ASIT the authors propose: a) beginning with the fundamental aspects of a system such as drip; and then b) working in an environment similar to that of the smallholders to create a version of it that is practical for and attractive to them.

The paper covers the evolution of the developments leading to the *KB Drip* irrigation system, which can be operated efficiently at a pressure head as low as 1 meter,

[1] PhD, CEO, Keller-Bliesner Engineering LLC (also Professor Emeritus of Agricultural and Irrigation Engineering, Utah State University and Board member IDE-US and International) 78 East Center Street, Logan, UT 84321-4619; PH (435) 753-5651; FAX (435) 753-3619; email: jkeller@kelbli.com
[2] Sr. Manager Technology Development, International Development Enterprises-India (IDE-India)
[3] Vice President, Keller-Bliesner Engineering and IDE Professional Associate
[4] Country Director, IDE-China
[5] Technology Program Manager, IDE-International

and only costs about US $0.04 per square-meter ($m^2$) for a crop that is planted in rows, such as tomatoes. Other ASITs that are touched on include: 1) a new overhead sprinkle irrigation system that will cost about US $0.04 per m^2, and provides good uniformity when operating at a 10-meter pressure head with sprinklers spaced on a 8- x 12-meter spacing/grid; 2) an innovative surface irrigation system in which the water is supplied from a pipe system directly to the mini-basins formed when using FAO's conservation-tillage practices for row corps; and 3) 10,000-liter tanks that cost less than US $50 to installed, and can efficiently store water over long periods for drinking or irrigation.

RESUME ET CONCLUSIONS

De nouvelles *techniques d'irrigation efficaces à petite échelle et peu coûteuses* (ASITs, *affordable small-scale irrigation technologies*) ont été récemment développées pour les petits exploitant agricoles possédant une ferme d'un hectare ou moins. Ces techniques sont proposées aux petits exploitants pauvres selon une approche de développement de marché. Elles leur permettent une irrigation efficace, de produire des récoltes de haute valeur et d'accroître de façon significative les revenus de l'exploitation. En même temps, elles augmentent également la production par unité d'eau d'arrosage et d'eau perdue par évaporation ou par les océans (ou dégradation de la qualité de l'eau). Cependant, ceci peut conduire à une surconsommation des ressources aquifères (spécialement des nappes phréatiques) si la demande est déjà trop forte. Ceci est principalement dû au fait que les petits exploitants utilisent l'eau qu'ils conservent pour agrandir les zones d'irrigation. Par conséquent, il est recommandé que les gouvernements et les organisations comme CIID adressent ce point critique.

Les efforts pour améliorer les performances de l'irrigation de surface traditionnelle n'ont pas réussi à cause des difficultés à contrôler la précision de ces systèmes. Ceci a conduit à l'utilisation de systèmes d'irrigation pressurisé tels que le goutteur et l'asperseur. La simple réduction de la taille des systèmes modernes d'irrigation utilisés dans les pays développés a produit des systèmes qui ne sont pas techniquement et économiquement utilisables pour les petits exploitants. Plusieurs exemples de ce problème sont présentés accompagnés de solutions possibles. Les auteurs recommandent de développer un système ASIT performant: a) en commençant avec les aspects fondamentaux du système telle q'une irrigation par goutteur, qui est constituée par un tuyau percé d'un système de trous permettant à l'eau de s'écouler lentement et de façon contrôlée, de travailler b) dans un environnement semblable à celui des petits exploitants pour créer une version d'un système d'irrigation qui est pratique et attractive pour eux

Ce papier présente l'évolution du développement des systèmes d'irrigation par écoulement spécialement conçus pour les petits exploitants. Le détail des coûts associés à chaque étape du développement est présenté sur la base d'un kit d'irrigation par goutteurs capable d'irriguer 100 mètre-carré d'un jardin potager. La nouvelle version du système de goutteur ASIT est un produit développé en Inde, appelé *KB drip*. Ces systèmes d'irrigation par goutteur peuvent opérer efficacement sous des pressions aussi faibles qu'à 1-mètre, et ils ne coûtent que $0,04 (US dollar) par mètre-carré, pour des champs de taille allant jusqu'à 1-hectare avec une récolte plantés en rangées espacés de 0,9-mètres, telles que les tomates. Les rampes latérales de *KB drip* conçues pour des productions maraîchères comprennent des tuyaux de plastiques plats de 16-mm de diamètre et de 125-micron d'épaisseur fait de 80% LLDPE/20%LDPE comportant des microtubes émetteurs de 1,2-mm de diamètre interne par 0,20- mètre de longueur. Pour la production horticole un tuyau de 250-micron est utilisé avec généralement des microtubes de 1,5 mm de diamètre interne et de 1- à 1,5- mètre de longueur.

Suivent les descriptions de trois autres systèmes ASIT. **1)** Un système d'irrigation par aspersion qui est dans son stade de développement final mais qui n'a pas encore été testé dans les champs et sur le marché. Le coût anticipé pour un petit exploitant sera d'environ $ 0,04 (US dollar) par mètre carré pour des champs allant jusqu'à 1-hectare. Le système est conçu pour fournir une bonne uniformité d'arrosage lorsqu'il opère à une pression de 10 mètres avec des jets formant une grille de 8- x 12- mètre. **2)** un système d'irrigation innovant (qui a juste passé le stade de la conception) conçu pour fournir de l'eau à partir d'un système de tuyaux directement dans des mini-bassins pour des cultures en rangée qui sont plantées utilisant la méthode de labour recommandée par la FAO. **3)** des citernes qui peuvent contenir efficacement 10000 litres d'eau sur une longue période, mais coûtent moins de $50 (US dollars) à l'installation sont en stage de test dans les champs. Elles comprennent un tuyau de plastique d'une fine paroi de 1-mètre x 1- mètre de surface et de 10- mètre de long situé dans une tranchée de taille similaire. Le tube, fabriqué à partir de feuilles de plastique laminées se comporte comme une peau imperméable sur une large « saucisse» et peut retenir l'eau collectée durant la saison des pluies pour être utilisée comme eau potable ou eau d'irrigation durant la saison sèche.

1. INTRODUCTION

Considerable effort has been spent to improve the performance of surface irrigation systems designed to serve small fields of 500 to 10,000 square-meter (m^2). However, it has not proven practical to achieve high efficiencies using traditional surface irrigation methods because it is almost impossible to do precision land leveling on small plots and have accurate control of the inflow rates. This has led to the use of pressurized irrigation systems, because the area irrigated from a given volume of applied water can be greatly increased (often by 2 to 4 times) by converting from traditional surface to drip or sprinkle (and possibly some new concepts with mini-furrow) irrigation. Of even greater importance from a basin-wide water resources perspective, the production per unit of water applied by drip irrigation (and to a lesser extent by sprinkle irrigation) and depleted by evaporation (E) and evapotranspiration (ET) or lost to salt sinks or salt loading is often increased by 30 to 50%.

Polak, et al. (1997) recognized that it is not sufficient to merely scale-down "state of the art" irrigation 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). 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) operating at very low pressure heads. Compromises are made in operational convenience, manufacturing tolerances, and application uniformity to achieve these advantages. But the availability of *affordable small-scale irrigation technologies* (ASITs) unlocks the potential benefits of modern pressurized irrigation systems for literally millions of resource-poor farmers (even where water supplies were considered insufficient or too costly to acquire for traditional irrigation methods); see Kay (2001) and IDE (2005).

International Development Enterprises (IDE) has taken up the challenge of developing and intensifying the use of ASITs in developing countries through a process it calls PRISM (Poverty Reduction through Irrigation and Smallholder Markets). IDE envisions the smallholder as a micro-entrepreneur who transforms natural resources (land and water), human resources (labor and know-how), and purchased inputs, such as ASITs into high value agricultural products that can be marketed at economically rewarding prices. IDE uses the PRISM methodology to assist in the creation of pro-poor rural market systems based on: a) exploring and identifying market opportunities, and b) good water control. Since water is an essential input in all agriculture production systems, ASITs play an important role in integrating smallholders into the market system and improving their livelihoods; see Heierli (2000) and Postel, et al. (2001).

1.1 Too Much of a Good Thing?

Conversion to efficient irrigation technologies can create a problem because they reduce the amount of applied water required for a given piece of land without a commensurate reduction in crop evapotranspiration plus evaporation ($ET_c + E$) from it. However, there are usually significant yield increases (of from 10% up to 100 % depending on the crop and irrigation technologies involved). Thus if one uses the metric "kilograms of crop per cubic-meter of (ET + E)", there is usually significant real water savings. But if the metric is "cubic-meters of (ET + E) per square-meter of land" there will probably be no savings.

In water-short areas, smallholders often take advantage of the "applied water savings" and increase their irrigated land area instead of reducing groundwater withdrawals. And that creates a commons problem! In already stressed groundwater areas, improved irrigation technologies enable smallholders to exploit and consume limited groundwater resources even faster; see Keller and Keller (2005).

The authors do not believe this very real problematic side of ASITs should slow down the development of them, because they benefit society in general as well as the smallholders who use them. For example, some of the benefits of the ASITs, in addition to the improved livelihood of smallholders, are: significant increases (perhaps 20 to 75%) in the kilograms of crop produced per cubic-meter of (ET + E); reduced water losses to salt sinks; and decreased water logging, pollution, and leaching of fertilizers that contaminate public water supplies.

There is an urgent need for the community of irrigation professionals, which ICID represents so well, to assist with tackling the socio/political issues related to over exploitation of groundwater resources in many areas throughout the World. This need will intensify as the uptake of ASITs accelerates. This is already happening in India and elsewhere. For example, in India, many farmers have already replaced the ditches they used to convey water from their wells to their irrigated plots with cheap pipelines (made of recycled plastic) to reduce water losses. Now they are taking the next step and converting from traditional surface to low-cost drip irrigation at an accelerating rate. Soon they may also be converting to low-cost, low-pressure sprinkle irrigation as well.

2. ANSWER TO AN INTERESTING QUESTION

Why is it so difficult to develop appropriate technologies for smallholders? The general answer may lay just beneath the surface of a statement like Donald Rumsfeld's "You go to war with the Army you have" as Schwartz (2005) points out in his editorial concerning why he believes the U.S. Military is making blunders in Iraq that it cannot correct. Schwartz believes that this is because it illustrates a familiar pattern of organizational problem-solving, that is - organizations usually proceed with whatever their strengths are and try to fit the problem to these strengths, rather than developing new or different strengths to fit the problem. He gives some examples of how this sort of organizational *idée fixe* has led to failures in business- and military-history. Here are some similar examples of efforts to develop and promote *affordable small-scale irrigation technologies* (ASITs) that have failed as commercially sustainable enterprises:

- The Chapin Watermatics: *Bucket and Drum Drip Irrigation Kits*. These were the first drip kits promoted for smallholder use. They were developed around Chapin's regular dip tape that is sold in developed countries. The problem with these kits for smallholders is that they are too costly. For example Stillhardt, et al. (2003), reported that the ex factory (USA) cost for the piping system alone was about US $225/1000 m^2 in 2001. Furthermore, since the emitters are integral with the drip tape they cannot be cleaned or replaced when they become clogged, and the irrigation water must be carefully filtered to avoid clogging.

- The International Development Enterprise: *IDE 1990s Vintage Bucket and Drum Kits.* The ex factory (India) cost of these systems was somewhat lower at US $140/1000 m^2 in 2001 according to Stillhardt. Furthermore, the irrigation water does not need to be very carefully filtered to avoid clogging the emitters, and they can be removed and replaced if they do get clogged. These systems used standard drip irrigation tubing, and to reduce costs each lateral was placed between two crop rows and equipped with 0.75-meter long microtube emitters to reach the rows to either side. But the smllholders did not like having the laterals and microtubes between the rows because they were in-the-way for normal cultural practices

- The Netafin: *Family Drip System.* This is a very elegant system, but it is even costlier than the Chapin kits, e.g. US $240/1000 m^2 ex factory (Israel) in 2001 according to Stillhardt, et al. (2003). Furthermore, the laterals have in-line emitters that also require careful filtration and cannot be cleaned when they become clogged.

- The Premier Irrigation Equipment or Jain Irrigation Systems: *Overhead Sprinkler Systems for Small Fields.* These are hand-move systems that are similar to conventional commercial sprinkle systems used through the world. To hold down costs, 75-mm PVC plastic (instead of aluminum) lateral pipe is used. Conventional sprinklers are used along the laterals and moved to provide a 12- x 12-meter sprinkler spacing. The main system limitations are cost and operating pressures requirements. The present smallholder cost in India is about US $900 for a system designed to serve 4,000 m^2 even after receiving a 25% subsidy form the Government; and the pressure head at the sprinklers needs to be about 20 meters to obtain reasonable application uniformities.

- The Underhill International: *Tote-A-Way Small Farm Sprinkler System.* This is a very elegant system that is assembled using high-quality components selected from 10 different commercial irrigation equipment manufacturers. It utilizes durable plastic hoses and mini-fixed-nozzle sprinklers mounted on top of movable risers; and fits in a box that can be conveniently stored or carried from one field to another. The system operates efficiently with a pressure head of only 10-meters at the sprinklers when they are moved to form a square 6- by to 6-meter pattern. The system's main limitations are cost and to a lesser extent moving the system in field crops like small and coarse grains and many varieties of pulses. The cost of the pipe system alone was roughly US $100/1000 m^2 ex-works USA in 2001, which would result in a cost of over $250/1000 m^2 for an Indian smallholder.

2.1 The IDE Team

The authors of this paper are key players in International Development Enterprise's team that is engaged in developing ASITs that are "high efficiency" water application systems and truly "appropriate technologies" for smallholders in countries like India and Ethiopia. The authors will be referred to hereafter as the Team. The individual authors-members have distinctive attributes that collectively encompass a set of talents uniquely suited for developing ASITs. For example, the senior author has been involved with the drip, sprinkle, and piped furrow irrigation throughout their entire development -- from the conceptual stages to the sophisticated systems available today. Another author has many years of experience working with local craftspeople that employ their talents in the simple facilities that are common in relatively small regional towns in India to fabricate or manufacture the hardware needed. Other authors bring the technical skills needed for: evaluations of land and water resources; understanding the local economic and social conditions; and developing appropriate software that is needed by the various participants in the ASITs supply chain and the farmers that purchase and use ASITs.

3. DEVELOPING LOW-COST SYSTEMS

Developing ASITs requires a relentless pursuit of cost reduction, while also improving the functionality and robustness of the equipment. Furthermore, the Team has found that the development work can best be accomplished in settings that are similar to the support systems and environment where smallholders will use them. Ideally, prototypes should be developed and made at facilities that are typical in rural trade centers, not in highly professional workshops that have elaborate tools. Of course this may not be possible for all system components. But components that require sophisticated facilities to develop and manufacture should be held to a minimum of strategic parts, and normally not be major components of the system in terms of cost, volume or weight.

Another interesting point the Team has learned is that beginning with the current modern equipment configurations designed for a given irrigation method, is usually not a very good starting point for developing an ASIT. It has usually been better to review the entire evolutionary path of the technology. Then select a more opportune place to start, which is usually nearer to its modern beginning than to where the technology has evolved to now. But this does not preclude picking and working with ideas and available materials from anywhere along the evolutionary path. The techniques and strategies used for field-testing during the beginning stages have also proven to be very useful. The Team uses this strategy and tries to take full advantage of the lifelong experiences of its members and that of any others they can find.

The *IDEal Treadle Pump* is an example of a very successful ASIT (see Shah, et al., 2000). Global sales of (them or similar) treadle pumps exceed 2.5-million and the market is still growing. Various models of both simple and pressure treadle pumps are being made in many small workshops throughout the developing world. The original treadle pump was invented in Bangladesh, where there are millions of smallholders with access to shallow groundwater. Simple hand tools were used to develop the initial treadle pumps and they were designed so they could be fabricated in small workshops throughout the country. Thus the treadle pump was "developed and promoted using the knowledge and tools at hand", but these were fully compatible with the smallholder's working and marketing environment in Bangladesh.

4. DRIP IRRIGATION

To illustrate the stages in the development of a successful ASIT, the Team will focus on the progressive improvements of the drip systems. The latest system configuration is called *KB Drip* [6], which is a very affordable high-efficiency drip irrigation system. In India the entire pipe distribution system costs smallholders less than $0.04/m^2 ($40/1000 m^2) installed. Besides being affordable they have the following other attributes that are desired by smallholders: 1) under low operating pressure heads (1.0 to 2.0 m) the discharge rate from the emitters is 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 small fields that are relatively level, the application Coefficient of Variation Uniformity (*CvU*) is in the neighborhood of C_vU = 90%, which is comparable to conventional drip systems.

4.1 Relentless Pursuit of Low-Cost

Standard commercial weights and sizes of plastic drip irrigation tubing were used for the laterals and supply lines of the initial drip systems promoted by IDE in India. However, relatively low quality pipe and fitting could be used because the required operating pressure was very low. This made it possible for manufacturers with simple inexpensive plastic molds and machinery to compete in the drip irrigation equipment market, which resulted in considerably lower tubing and fitting prices. Additionally, to lower system costs further, long microtubes were used as the emitters so each lateral could serve two crop rows, as shown in Figure 1.

During the 1990s the Indian Government was providing a 50 percent subsidy to entice farmers to purchasing drip systems and conserve water. But even with this subsidy, these original IDE drip systems were cheaper. Also the systems could be purchased without the paperwork and long waiting periods associated with the Government subsidy program. So several of the larger smallholders bought this original

[6] *KB* stands for the Hindi words "Krishak Bandhu", which means "farmer's friend".

type of IDE system to irrigate fields of up to one or two hectares. But most of the sales were the very small drip systems that are referred to as bucket kits, which have a 20-liter bucket and enough tubing to irrigate a 20- to 30-square-meters (m^2) garden. Although some 100-m^2 drip kits like the one shown in Figure 1 were also sold to smallholders.

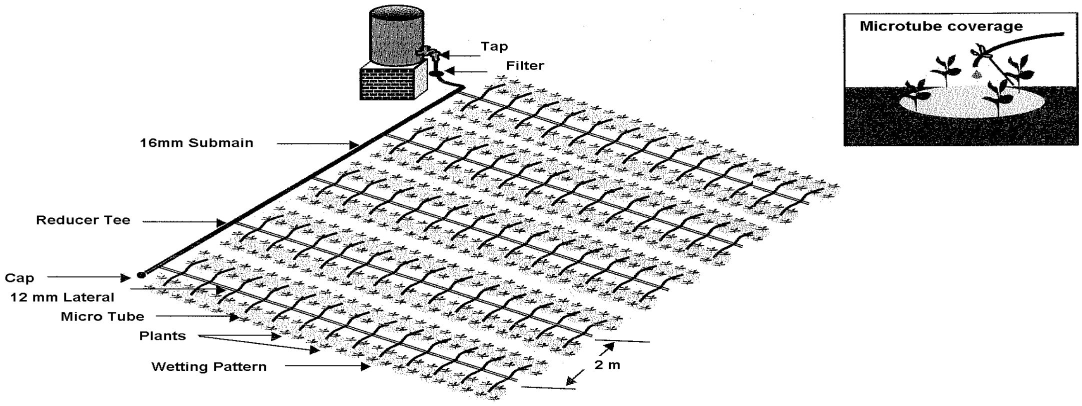

Figure 1: Schematic of a 1990s vintage IDE low-cost drip irrigation system. (Diagramme d'un système d'irrigation bon marché, IDE par goutteur des années 1990.)

Table 1 shows the list of components for an original IDE 100-m^2 drum kit like the one shown in Figure 1. The unit and total costs of the components is given in Indian Rupees[7] (INR) based on January 2005 prices for plastics and materials. The table also shows the typical costs for the labor to assemble the system, the transportation cost for delivering it from the manufacturer to the dealer, the IDE overhead, and the standard dealer profit margin suggested by IDE in India.. It is interesting to note that the drum makes up almost half the total cost of the system, i.e. the pipe system costs the farmer INR 750 and the plastic drum costs INR 600.

These original IDE drip systems worked very well and clogging of the microtubes, which have a 1.2-mm internal diameter (ID), was seldom a problem. Although farmers liked these systems and quit a few were sold, they were still too costly for many smallholders and the better-off farmers soon tired of cultivating around and dealing with all of the microtubes between the rows where the laterals were laid. So many of them simply bought a second set of laterals to avoid this difficulty, which raised the wholesale cost of the piping system by:

10 + 203 (Tees and 12-mm pipe) – [44 + 54 (short microtubes w/o pegs)] = INR 115

So the additional cost to farmer was:

1.15 [(1 + 0.03 +0.10) x (INR 115, cost of tubing and fittings)] = INR 150

Thus the addition of the extra laterals brings the total smallholder cost of the pipe system to INR 900, and the total costs for a 100-m^2 drip kit to INR1500 (which is INR 15/m^2) when the drum is included. Only a few farmers were willing to pay this much, although the net return from double cropping 100-m^2 of high value vegetable crops typically ranges between INR 2,500 and 5,000 per year.

[7] At the current exchange rate \$ 1.00 US = INR 42.50.

Table 1. Cost to farmer of IDE-India's Original 100-m² Drip Kit with standard 200-liter plastic drum. (Coût pour un exploitant agricole d'un kit de goutteur IDE-India de100-m2 incluant un tonneau en plastique de 200-L.)

COMPONENTS	UNITS	UNIT	RATE INR	COST INR
DRUM TO PIPE CONNECTOR WITH TAP	1	Nos	9	9
IN-LINE SCREEN FILTER	1	Nos	52	52
16-mm REGULAR LATERAL PIPE	9.4	Meter	5	47
12-mm REGULAR LATERAL PIPE	45	Meter	4.5	203
TEE (16-mm X 12-mm)	5	Nos	1.9	10
MICROTUBE EMITTER	117	Meter	0.75	88
MICROTUBE PEG TO HOLD ENDS IN PLACE	155	Nos	0.35	54
16-mm JOINER	1	Nos	1	1
12-mm JOINER	4	Nos	0.9	4
TAP HOLE PUNCH FOR DRUM CONNECTOR	1	Nos	4.5	5
CORRUGATED BOX	1	Nos	25	25
USER MANUAL	1	Nos	3	3
A= TOTAL WHOLESALE PIPE SYSTEM COST				**499**
B= LABOUR COST FOR ASSEMBLING				80
C= TRANSPORTATION CHARGES@3% OF 'A'				15
D= OVERHEAD @10% OF (A+B)				58
SUB TOTAL (A+B+C+D)				652
DEALER PROFIT MARGIN @15% OF(A+B+C+D)				98
TOTAL PIPE SYSTEM COST TO FARMER				**750**
STANDARD 200-Liter PLASTIC DRUM				600
TOTAL 100-m² DRIP KIT SYSTEM COST TO FARMER				**1350**

4.2 Breakthrough with *KB Drip*

Less than 3 years ago there was a major ASIT drip system price breakthrough. This was when the Team first recognized the potential of using thin-wall layflat tubing with short microtube emitters for the drip system laterals. The Team quickly captured this concept and began trying various configurations of it in smallholders' fields. After less than a year of field-testing and consultation with the smallholders and IDE field staff, the Team developed specifications for the plastic composition, sizes, wall thicknesses, and tolerances of the layflat tubing for laterals used to irrigate both vegetable and horticultural crops. Specifications were simultaneously established for the lengths and the IDs of the microtubes used for the emitters installed along them.

This new drip system lateral tubing is called *KB Drip.* This new product, which only cost INR 0.75/meter, was used to replace the regular lateral pipe, which cost INR 4.5/meter for 12-mm and 5.0/meter for 16-mm pipe (see Table 1). This brought the 100-m^2 drip kit's total pipe system cost to the farmers down from INR 900 to INR 370 for a system with a lateral for every row. But the 200-liter drum, drum connection, and screen water filter, which together cost the farmer about INR 680 (see Table 1) were still necessary, and the total cost of the 100-m^2 drip kit to the farmer only dropped to INR 970.

The next cost cutting breakthrough came when the Team realized the possibility of replacing the standard 200-liter plastic drum with a collapsible laminated plastic sackcloth tank that costs INR 150. Then supporting it with a simple iron frame (that costs another INR 150) placed on top of a 1-meter high earth mound, Rather than cutting a hole in the tank and installing a tap, water is simply siphoned out of it. The cartridge for the screen filter is installed on the inlet-end of the siphon pipe so it is exposed and easy to inspect and clean. This also eliminates the need for the filter housing, which reduce the farmer cost by another INR 40. The total cost to the farmer of this latest configuration of a 100-m^2 drip kit drip is only INR 618 (see Table 2).

Table 2. Cost to Farmer of 100m² *KB Drip* Kit with Collapsible 200-liter Sackcloth Tank with Iron Support Stand. (Coût pour un exploitant agricole d'un kit, KB Drip de100-m2 comprenant un réservoir en tissu de 200-L avec un support en fer.)

COMPONENTS	UNITS	UNIT	RATE	COST
			INR	INR
16-mm flexible hose	0.5	Meter	13.5	7
SCREEN FILTER CARTRIDGE	1	Nos	20	20
16-mm REGULAR LATERAL PIPE	0.75	Meter	5	4
KB Drip TAPE(125 MICRON)	100	Meter	0.75	75
TEE(16-mm x 16-mm)	6	Nos	2.5	15
MICROTUBE EMITTER	25	Meter	0.75	19
KB Drip TAPE JOINER	4	Nos	2	8
FILTER CARTRIDGE HOSE CONNECTOR	1	Nos	4	4
16-mm VALVE COCK	1	Nos	7	7
CORRUGATED BOX	1	Nos	15	15
USER MANUAL	1	Nos	3	3
A= TOTAL WHOLESALE PIPE SYSTEM COST				**176**
B= LABOUR COST FOR ASSEMBLING				70
C= TRANSPORTATION CHARGES@3% OF 'A'				5
D= OVERHEAD @10% OF 'A+B'				25
SUB TOTAL (A+B+C+D)				276
DEALER PROFIT MARGIN @15% OF(A+B+C+D)				41
TOTAL PIPE SYSTEM COST TO FARMER				**318**
IRON TANK SUPPORT STAND				150
COLLAPSIBLE 200-liter SACKCLOTH TANK				150
TOTAL100-m² DRIP KIT SYSTEM COST TO FARMER				**618**

A common irrigated vegetable crop such as tomatoes typically produces a net return of over INR 20/m^{2}of field area. Therefore, the cost of the drip kit would be more than covered during the first crop cycle. In fact the net return after paying for the system would be: (100 x 20) – 618 = INR 1382 (or about US $32).

In addition to these 100-m^2 *KB-Drip* Kits, IDE-India produces a *Family Nutrition Kit* for kitchen gardens. It is provided with a 20- or 40-liter sackcloth water bag and enough *KB Drip* tubing and microtubes to cover a 20- or 40- m^2 garden plot. To set up the kit a simple tripod is made out of sticks and the water bag hung about 1-metrer above the ground. Then the tubing is set up and the bag filled. A cartridge from a screen filter is put on the inlet end of the tubing and this is used to siphon water out of water bag so it is filtered, then distributed through the emitters. These nutrition kits sell for INR 100 to 200 complete with seed and instructions. This is an easily afforded addition for even the poorest of households that provides a means for efficiently irrigating a kitchen garden with only a couple of buckets of water day. The garden can produce plenty of fresh vegetables for the family's consumption and usually there are some left over to sell.

4.3 Features of and Progress with *KB Drip*

Customized *KB Drip* irrigation systems can be operated efficiently at a pressure head as low as 1-meter. They only costs about US $\$0.04/m^2$ for field sizes up to 1-hectare with a crop that is planted in 0.9-meter rows, such as tomatoes. *KB Drip* lateral pipelines designed for such a vegetable crop consists of 125-micron thick 80%LLDPE/20%LDPE layflat 16-mm diameter plastic tubing with 1.2-mm ID x 0.20-meter long microtubes emitters. For horticultural crops 250-micron tubing is used and the microtubes are usually 1.5-mm ID x 1- to 1.5-meter long. Inexpensive standard 16-mm barbed plastic pipefittings are used with the *KB Drip* layflat tubing, and a simple ring-lock is used to secure the tubing on fittings.

To date, more than 500,000 ASIT drip irrigation systems have been distributed through market channels in India, other areas in Asia, and Africa. During the early development stages, some members of the Team recommended relaxing official micro-irrigation performance standards (such as those proposed by the American Society of Agricultural Engineers) for systems designed for smallholders, to facilitate achieving this outcome. They proposed the following performance standards based on the use of a term referred to as the Coefficient of Variation Uniformity (*CvU*), in which $CvU = 100(1.0 - v)$, as the measure of application uniformity for smallholder drip irrigation systems (see Keller and Keller, 2003):

- *CvU* above 88% is excellent;
- *CvU* between 88% and 80% is good;
- *CvU* between 80% and 72% is fair; and
- *CvU* between 72% and as low as 62% is marginally acceptable.

4.4 *KB Drip* Design Tools

Many people in the supply chain for *KB Drip* systems have limited knowledge of pipeline hydraulics and how to apply the typical equations engineers use for designing irrigation systems. In view of this the Team has developed pre-engineered design tables that are intuitive and convenient to use, and held workshops to demonstrate how to apply them (see Keller and Keller, 2003). These design tools make it easy to train inexperienced field personnel as well as assemblers and dealers so they can provide adequate design services for their customers.

5. OTHER PRESSURIZED ASIT*s*

Other pressurized ASITs that the Team is working on are: **1)** a shift-able overhead sprinkler systems that operates at roughly 10 meters of pressure head with a targeted farmer cost of about $\$0.05/m^2$ of coverage; and **2)** An innovative surface irrigation system (that is just beyond the conceptual stage) designed to supply water from a pipe system directly to the mini-basins for row crops that are planted using FAO's conservation-minimum-tillage method. The target cost for this mini-basin irrigation system is between US \$0.02 and 0.04/m^2 of crop area.

5.1 Overhead Sprinkle Irrigation

The Team is nearing the end of the design phase of a new ASIT overhead sprinkle irrigation system. Although sprinkle irrigation will not be as efficient as *KB Drip* and it will require considerably more pressure to operate, it is better suited than drip irrigation under the following conditions:

- For irrigating close spaced crops such as carrots, beets, and onions and non-rowed crops such as small grains and forage crops;
- For fields where the elevations differences within the irrigated area are much greater than half of the average operating pressure head of a drip system; or
- Where the water contains relatively large quantities of suspended mineral or organic matter.

The small-scale sprinkle systems that IDE and others have promoted in the past are (as mentioned earlier) too expensive for most smallholders and also cumbersome or tedious to move. In view of this the Team is doing to following to reduce cost and improve their functionality:

- Holding operating pressures at the sprinkler heads to between 8 and 12 meters of pressure head.
- Using simple low-cost locally manufactured (in India) system components.
- Using thin-walled (250-micron) by 20-mm or 25-mm diameter layflat tubing for the sprinkler laterals.
- Designing the systems so that only the sprinklers along with their tripod-risers (not the laterals or long hoses) need to be shifted.
- Reducing the length of lateral tubing required by using a 12-meter wide lateral spacing and pulling the laterals back and forth (longitudinally) across the main supply line when convenient.
- Using locally manufactured standard impact-sprinkler bodies fitted with special nozzles and other modifications that greatly improve their water distribution uniformity, when operated at 8 to 12 meters of pressure head and spaced on a 6- to 9-meter x 12-meter grid (so each sprinkler position serves a 72- to 108-m^2 area).
- Allowing lateral pipe friction losses to range between 20 and 30% of the average sprinkler operating pressure head to minimize the lateral pipe sizes required.

The cost to smallholders is targeted to be between US \$0.04 and \$0.05/m^2 for fields of up to 1-hectare. It is anticipated that this new overhead sprinkle irrigation system configuration will have wide appeal for farmers in India and elsewhere. But this will not be known for certain until the system has been tested in farmers fields and then market-tested.

6. BAGGING WATER FOR IRRIGATION AND DRINKING

For many smallholders, access to water for drinking and irrigation follows a feast or famine pattern. During the rainy season water is abundant, but there are acute water shortages during dry season. Developing cost-effective storage to hold water captured from runoff or taken from small ponds, intermittent streams, or perennial wells, to use for drinking and/or irrigation during the dry season has been a major challenge.

A recent innovation (being developed with the Team's assistance) that appears promising is to store water in large low-cost plastic bag-like tanks. The first level of experimentation has already been completed and the tanks are now being tested in pilot studies in India and in Africa. Each tank stores roughly 10,000 liters (10 m^3) of water that is completely enclosed to eliminate evaporation losses. The installed cost of a tank is roughly US $40 to US $50 and its life expectancy is 5 years.

The storage tanks are constructed by first digging a 1.0-meter deep by 10-meter long trench with a top width of 1.2-meters and a bottom width of 0.8-meters, then placing a sausage-like three-layer-laminated tube-like tank in it. The tanks are like casings for large sausages. They are being fabricated by using a three layer laminated wall, with a LDPE 100-micron sackcloth inner layer sandwiched between a black LDPE 50- to 100-micron outside layer and a black LDPE 150- to 200-micron inside layer. The sackcloth (which is like the material used for fertilizer bags) provides strength, the outer layer provides protection from mechanical damage and ultraviolet rays, and the inner layer provides the water-tightness.

The edges of two 2-meter wide laminated sheets are heat welded together to form a tube. Each end of the tube 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. A sloped cover made from reed mats is then placed over the trench to provide additional protection from the sun and mechanical damage.

6.1 Techniques Used to Harvest Rain

Several techniques are being used and evaluated for harvesting rainwater. These include:

- Installing the water tank at a low point where runoff collects during the rainy season and having a settling pond followed by a sand filter bed to keep silt and debris out of the tank.
- Putting a rain-gutter along the edge of a roof and diverting the runoff into the tank.
- Collecting the runoff from a large thin plastic sheet placed on the ground uphill from the tank.

6.2 Use of Stored Water for Irrigation

The expectation (or hypothesis) is that by maximizing the storage and conservation of in-situ soil moisture for later dry season use, the 10-m^3 of water stored in the tank could be applied through a *KB Drip* system to irrigate up to 100 m^2 of a high value vegetable crop during the dry season to sell when prices are highest. However, the Team believes that a 10-m^3 tank will need to be refilled at least once and probably twice to provide sufficient water for a 100-m^2 vegetable plot during the dry season. Thus the tanks will provide an essential link for the smallholder to become involved in the water transporters' markets that already exist in India. They may also be able to use their bullock cart to transport their own water.

7. SUMMARY AND CONCLUSIONS

New efficient low-cost *affordable small-scale irrigation technologies* (ASITs) designed for farmers with land holdings of a hectare or less have recently been developed. ASITs are being delivered to resource poor smallholders using a general marketing and business development approach. This allows these smallholders to efficiently irrigate and grow high value crops and significantly boost their farming income. At the same time they also increase crop production per unit of both applied water and the water consumed by evaporative demands or losses to salt sinks (or water quality degradation). However, this can lead to serious overtaxing of water resources (especially groundwater) because smallholders typically use the increased application efficiency to expand their irrigated area instead of reducing surface or groundwater withdrawals. Rather than curtailing the development of ASITs, it is recommended that governments and professional organizations like ICID address this critical water resource sustainability issue by other means, such as administrating and regulating water rights.

Efforts to improve the on-farm performance of traditional smallholder surface irrigation have not succeeded because of the difficulties associated with trying to precision-level small fields. This has led to the use of pressurized irrigation systems, like drip and sprinkle. But simply downsizing modern commercial systems used in developed countries has usually resulted in systems that are technically and economically impractical for smallholders. Several examples of this are presented along with a suggested remedy. The authors recommend that a successful ASIT is best developed by: a) beginning with the fundamental aspects of a system such as drip irrigation, which is simply a pipe with a controlled set of slow leaks; and then b) working in an environment similar to that of the smallholders to create a version of it that is practical for and attractive to them.

The paper covers the evolution of the development of drip irrigation systems specially designed for smallholders. Detailed breakdowns of the costs associated with each stage of the development are presented based on a drip irrigation kit designed to serve a 100 square-meter vegetable garden. The newest version of the drip ASIT is the product developed in India called *KB Drip.* These drip irrigation systems can be operated efficiently at a pressure head as low as 1 meter, and they only cost about US $0.04 per square-meter for field sizes up to 1 hectare with a vegetable crop that is planted in rows spaced 0.9 meters apart, such as tomatoes. *KB Drip* lateral pipelines designed for such a crop consist of 125-micron thick layflat 16-mm diameter plastic (80%LLDPE/20%LDPE) tubing with 1.2-mm ID x 0.20-meter long microtubes used for the emitters. For horticultural crops 250-micron tubing is used and the microtubes are usually 1.5-mm ID x 1 to 1.5 meters long.

Following are brief descriptions of three other ASITs that are also touched on in this paper: **1)** A sprinkle irrigation system that is in the final development stages, but has not yet been field or market tested. Its anticipated cost to smallholder is targeted to be about

US $0.04 per square-meter for fields up to 1 hectare. The system is being designed to provide good uniformity when operating at a 10-meter pressure head with the sprinklers spaced on an 8 x 12-meter grid. **2)** An innovative surface irrigation system (that is just past the conceptual stage) designed to supply water from a pipe system directly to the mini-basins for row crops that are planted using FAO's conservation-minimum-tillage method. **3)** Tanks that can efficiently store 10,000 liters of water over long periods, but cost less than US $50 to install are in the field-testing stage. The tank is constructed by placing a thin-wa1led 1-meter x 1-meter cross-section plastic tube that is 10 meters long in a similar sized trench. The tube is fabricated out of a laminated plastic sheet that functions like the impervious skin of a large sausage so it can store water collected during the rainy season for either drinking or irrigation in the dry season.

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