Low-Pressure, Low-Cost Sprinkle Irrigation for Smallholders

By
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Abstract

This paper describes an affordable low-pressure sprinkle irrigation system, called *IDEal Rain*, developed in India by International Development Enterprises. It is ideally suited for millions of very small farms worldwide (it can even be powered using a manually operated treadle pump). A 0.4-hectare (1-acre) fixed system cost about $225 (and it can easily be shifted to serve another plot). Simple extruded plastic lay-flat tubing is used for the mains and laterals. Conventional impact sprinklers with specially designed nozzles are used at operating pressures of only 7- to 10-meter (10- to 15-psi). Only the sprinklers along with their unique tripods are shifted between sprinkler sets to provide an 8-meter by 10- or 12-meter (26-ft by 33-ft x 40-ft) sprinkler spacing. The system's water application efficacy is roughly 70 to 75%, which is more than three times as efficient as the classical surface irrigation systems typically used on small farms in developing countries.

Introduction

Efficient *affordable small-scale irrigation technologies* (ASITs) designed for farmers with land holdings of a hectare (2.5 acres) or less are needed for improving water use efficiency and the incomes of farmers in developing countries. To be most effective, based on the International Development Enterprises (IDE) experience, they should be delivered to resource poor farmers using a business development approach, but at minimum cost with little or no markup for property rights. This allows smallholders to purchase efficient irrigation technologies to irrigate and grow more intensive and 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, we have succeeded by: a) beginning with the fundamental aspects of a system such as drip or sprinkle; 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 need for developing improved water management strategies for small plots in developing countries stems form the fact that: most small holder farmers do not have access to a means for efficiently capturing and applying the available water to their small plots. We will focus on the

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general framework for developing ASITs and discusses the challenges encountered during the evolution of the developments leading to *IDEal Rain*, which is a new low-pressure overhead sprinkle irrigation system that only costs about US $225 for a fixed pipe system serving a 1-acre field. It provides good uniformity when operating at a 10-meter pressure head (15-psi) with sprinklers spaced on an 8- x 12-meter (26- x 40-foot) grid for close spaced crops such as alfalfa, or at a 7-m (10-psi) pressure head with sprinklers spaced on a 8- x 10-m (26- x 33-ft) grid.

Developing Technologies for Small Holder Farmers

In this section we will cover two key points. The first point is related to organization problem solving in general and the second on the general thinking processes involved in developing appropriate technologies for farmers with small land holdings.

Organizational Problem Solving

Why is it so difficult to develop appropriate technologies for small holder farmers? The general answer may lie just beneath the surface of a statement like Donald Rumsfeld's "You go to war with the Army you have", which is why the U.S. Military made serious blunders in Iraq that it cannot correct. 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 as pointed our by Schwartz (2005)[3]. Schwartz's editorial provides some examples of how this sort of organizational *idée fixe* has led to failures in business- and military-history. We also have similar examples of efforts to develop and promote *affordable small-scale irrigation technologies* (ASITs) that have failed as sustainable enterprises for small holder farmers, such as:

- The Netafin: *Family Drip System.* This is a very elegant system, which is a scaled down version of their commercial drip irrigation systems, and it cost US $240/1000 m^2 ex factory (Israel) in 2001. Furthermore, the laterals have in-line emitters that 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 sprinkle irrigation systems that are similar to conventional commercial hand-move systems used through the world. The main system limitations are cost and operating pressures requirements. The 2005 smallholder cost in India was about US $600 for a system designed to serve 1-acre (4,000 m^2) even after receiving a 25% subsidy form the Government ($150/1,000 m^2). The systems need a minimum pressure head of 20 meters (30 psi) at the sprinklers for reasonable application uniformities. This usually requires a higher pressure well pump or a booster pump when converting a shallow well irrigation installation from surface to sprinkle irrigation.

The problem is there is a technology **gap** between contemporary irrigation system design and small farm needs.

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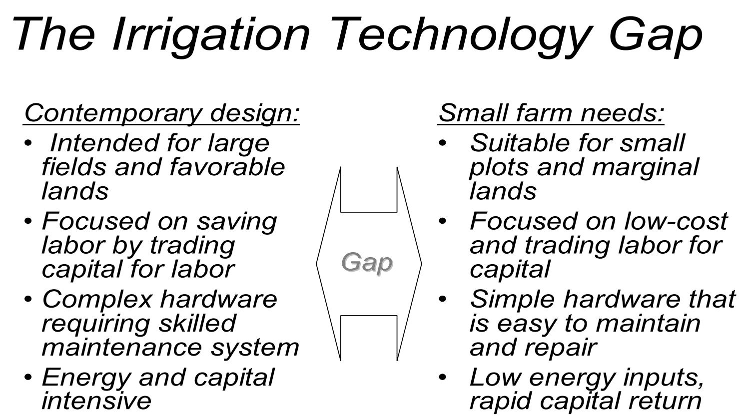
[3] "Going to War with the Army You Have". TomDispatch.com, Posted March 5, 2005 at 11:25 am. http://www.tomdispatch.com/index.mhtml.



Challenge of Developing Low-Cost Systems

Developing ASITs requires focusing on affordability, while also improving the functionality and robustness of the equipment. We have found that the development work can best be accomplished in settings that have similar support systems and environmental conditions to 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.

We believe all creative work requires some kind of meditation. Paraphrasing Pirsig (1974)[4], the first author expresses the meditative process he follows this way: "*When I approach a design and am stuck, I know this stuckness and a blank mind precede inventiveness. I don't try to avoid stuckness because I have found that the harder I try to hold on to it, the faster my mind will naturally freely move toward finding a good design. So I just concentrate on what I want to accomplish - live with it for a while. Study it like I study a line when fishing and before long, I will get a little nibble, a system design idea asking in a timid way if I am interested……*"

Another interesting point that we have 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 technology's evolutionary path. The techniques and strategies used for field-testing during past development stages have also proven to be very useful. We use this strategy and try to take full advantage of ours and colleagues' lifelong experiences and any other historic or new information we can find.

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[4] R.M., Pirsig, *Zen and the Art of Motorcycle Maintenance* (New York: Bantam Books, 1974)

Affordable Low-Pressure Sprinkle System Development

We have already developed generic user friendly low-cost drip irrigation systems for small holder farmers and these are being widely promoted and marketed in India and in other developing countries (see Keller and Keller, 2003)[5]. However, drip is not very well suited for irrigation of forage, grain and other closed spaced crops, and the small-scale sprinkle systems promoted in developing countries (as mentioned earlier) are too expensive, cumbersome, and energy consuming for most resource poor farmers with small plots. In view of these limitations, we decided to start anew and design a sprinkle irrigation system that would be affordable and appropriate for millions of these resource poor farmers in Asian, African, and the Americas.

As a result of our efforts to date the *IDEal Rain* sprinkle irrigation system has been developed. This system is suitable for both larger fields as well as for small plots. (The system can even be operated with a manually powered pressure treadle pump.) It is capable of providing water application efficacies in the neighborhood of 75%, which is more than three times as efficient as the classical surface irrigation systems typically used on small farms in developing countries. We began by establishing the following design criteria to reduce cost and improve system functionality:

- Having an operating pressure head of between 7 and 10 meters (10 and 15 pounds per square inch, psi) at the sprinklers.
- Using thin-walled (500-micron or 20 mill) by 25-mm (1-inch) diameter layflat tubing for the sprinkler laterals with only one sprinkler operating on the lateral at a given time.
- Designing the system 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 10- to 12-meter (33- to 40-feet) wide lateral spacing and pulling the laterals back and forth (longitudinally) across the main supply line where convenient.
- Using simple low-cost locally manufactured (in India) system components, including standard impact-sprinkler bodies and developing special nozzles and other modifications to obtain good water distribution uniformity at low operating pressures.
- The cost to smallholders was targeted to be between 2.0 and 2.5 Indian Rupees (US \$0.05 and \$0.06/m^2) for fields of up to 1-hectare (2.5-acres or 10,000 m^2).

Using an intuitive strategy for new nozzle designs along with a breakthrough with a unique new tripod design, we succeeded in meeting our design criteria objectives. We have found from our field tests that this new overhead sprinkle irrigation system configuration performs well even when supplied by a treadle pump and has wide appeal. In the following sections we will describe the development and features of the system components and the complete system.

Sprinkler Selection

Designing viable sprinkle systems for irrigating field or vegetable crops on small farms required selecting or developing sprinklers that when operated at low pressures produce large

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[5] Keller, Jack, and A.A. Keller. Affordable Drip Irrigation for Small Farms in Developing Countries. Proceeding of the 2003 Irrigation Association Conference. Paper No. IA 03-0415. pp: 14-25. Nov. 2003.

wetted diameters with uniform water distribution and small drops. To meet our sprinkler spacing and pressure head targets we needed a uniform water applications with small drops over a wetted area with a diameter of 12 to 16 meters when operating at between 7 and 10 meters of head pressure (0.7 to 1.0 Kg per square centimeter or 10 to 15 pounds per square inch, psi).

We tested sprinklers form various manufacturers and were unable to find one that could meet the above objectives. Some sprinklers that produced good application uniformities did not produce a sufficiently large wetted diameter while others produced large diameters, but poor distribution uniformities and large drops. As a result of observations made during these tests, we decided that:

- Impact sprinklers would have the best chance of satisfying the design criteria because they produce the greatest wetted diameter with good water distribution uniformity for a given nozzle configuration. This is because impact sprinklers have a specially designed spring loaded "impact arm" that is driven by the jet from the main nozzle. The impact arm periodically interrupts the jet and strikes the sprinkler body to rotate it. Between strikes the sprinkler's body is stationary, so the wetted diameter is not shortened by having a tangential velocity component imparted to the jet as it leaves the nozzle.
- Rather than re-design or re-invent such a sprinkler, it would be best to locate a manufacturer of standard impact sprinklers who would work with us as technology specialists through IDE-India in developing a suitable sprinkler/nozzle package combination.
- The ideal sizes of available impact sprinklers for small farms would be a rather typical impact sprinkler with 1/2- or 3/4-inch male pipe thread base and bearing.
- The currently available sprinkler nozzles would need to be modified to produce the desired water break-up (giving small drop sizes) and distribution uniformity while still having a large diameter of throw at low operating pressure heads.

Considerable effort was made to determine what has been done by various sprinkler manufacturers to achieve good performance at low pressure. Several different impact sprinklers and nozzle configurations that are available in India were tested. These included metal and plastic bodied sprinklers with 1/2- or 3/4-inch bearings, but none of them met our design objectives. Essentially all of the sprinklers tested had similar nozzle and sprinkler body designs and either required pressures considerably higher that our targets, or produced wetted diameters of less than 10 meters even when operating at 10 meters of pressure head. But reviewing what others have tired was very helpful as it provided insights and guidance for moving forward.

As a result of our search for a suitable manufacturer in India who had field proven brass impact sprinklers and was willing to work with us and modify their sprinkler and nozzle configurations to meet our design criteria, we found L.M. Industries. This is a small sprinkler head and associated accessories manufacturer located in New Anaj Mandi, Nawana and Lehri is the brand name of their sprinklers. They agreed to work with us and that IDE-India will be the exclusive marketer of the sprinklers with the modified nozzles, and they will be marked under the *IDEal Rain* or *KB Rain*[6] brand names.

[6] Brand name used by IDE-India, the KB is short for "Krishak Bhandu", which means "farmers friend" in Hindi.

Nozzle Design

The next step was to begin developing and testing nozzles of various designs in the Lehri sprinkler bodies. These included regular tapered round nozzles with special cross-cuts and nozzles with square and triangular shaped outlets. All of the nozzle configurations were machined out of brass bar stock and some configurations required special hand filing to finish shaping them. We used brass instead of plastic because it was the most cost effective and fastest way to proceed. Using plastic would have entailed making temporary molds, which would have been more time consuming and costly during the nozzle development and testing process.

To speed up the nozzle development and testing process we used radial-leg cup tests and operated the trial sprinkler nozzle configurations under low wind conditions. We then used a computer program, CATCH-3D[7], to convert the radial-leg data into grid data. Then the program overlapped the grid data to compute the distribution uniformity for various simulated sprinkler spacing configurations.

We found that the taper leading up to the discharge face of the nozzles was an important aspect that greatly affected sprinkler performance. Through a strategically guided "trial-and-error" process, sprinkler nozzle packages were developed that reached the design goal of: providing a relatively uniform depth of application over a wetted area with a diameter of 12 to 16 meters when operating at between 7 and 10 meters of head pressure (10 to 15 psi). Table 1 shows the catch values from a single 3/4-inch *IDEal Rain* sprinkler with the final nozzle design package. This nozzle package consists of an equilateral triangular (5.3 mm on each side) main driver nozzle and a 4.0 mm spreader nozzle with a "v notch" across its face.

Table 1. Radial-leg Catch Container Test Data of an *IDEal Rain* Sprinkler with a 5.3 mm Equilateral Triangular Main Driver Nozzle and a 4.0 mm v-cut Spreader Nozzle Operating at 10 and 7 meters of Pressure Head with a 10 m/s Wind from the SSW.

Pressure Head	*Radial Leg Position*	*Catch Container Volume - milliliters/hour (To convert to mm/hr multiply catch volumes by 0.45.)*															
		Radial Distance from Sprinkler – meters															
		0.5	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5
10 m	West	15	13	13	12	12	13	13	14	15	16	14	14	10	2		
10 m	East	20	18	15	13	12	13	13	12	14	13	13	15	12	10	6	4
7 m	West	20	17	15	14	14	15	15	15	15	17	11	6	3			
7 m	East	22	17	14	14	13	14	14	14	16	15	14	14	8	5	1	

Two sprinklers were also operated as they would be in an actual farmer's field and the catch containers were laid out in a grid (instead of simulating the grid results from radial leg test data). The typical application uniformities with the *IDEal Rain* sprinklers spaced on an 8- x 12-meter (26- x40-foot) spacing with a 10 m/s cross wind and operating at a pressure head of 10 m were: CU = 84% and DU = 80%[8], which is quite good. Typical catch values obtained from these tests

[7] Developed by R.G. Allen and G.P. Merkley in the Biological and Irrigation Engineering Department, Utah State University several years ago and periodically upgraded, see http://www.neng.usu.edu/bie/software/catch3d.php
[8] The CU is the Christiansen's Uniformity Coefficient and DU is the Distribution Uniformity. These are statistical measures of sprinkler application uniformity and performance.

are shown in Table 2. The average sprinkler discharge rate is 1260 lph, liters per hour (5.55 gpm), which gives an effective average gross application rate of: 1260/(8 x 12) = 13.1 mm/hr over the 8- x 12-meter (0.52 in/hr over the 26- x40-foot) area. This is the gross application rate that is used for water management purposes when computing sprinkler set times. However, in the field the operating sprinklers are 12 meters apart (see Figure 1) and there is only a small amount of overlap between them, so the maximum field application rate is about 7 mm/hr (0.3 in/hr).

Table 2. Catch Container Test Data (2m x 2m grid) for the *IDEal Rain* Operating at a Pressure Head of 10 meters and an 8-meter x 12-meter Spacing in a 10 m/s Cross-wind.

Container Catch Values – mm/hour					
11.4	10.9	11.8	17.7	14.5	15.0
11.8	10.0	10.5	14.5	15.9	18.5
14.1	11.4	10.9	11.4	15.5	14.1
11.8	10.5	11.4	15.9	16.4	14.1

When operating at only 7 meters of pressure head (10 psi), the sprinkler spacing needed to be reduced to 8- x 10-meters (26- x33-feet) and the resulting CU = 80% and DU = 70%, which are still respectable values. The discharge is reduced to: $(7/10)^{0.5}$ x 1260 = 1050 lph (4.6 gpm), which also gives an effective average application rate of 13.1 mm/hr (0.52 in/hr).

Since it was not practical to hand fabricate the main nozzle with the triangular orifice, we had injection molds made for it so a sufficient number of plastic nozzles could be produced for the field and market testing phase of development. The spreader nozzles are machine made without any handwork so they are still being made out of brass because this is presently less expensive than having molds made so they can be fabricated out of plastic. We have patents pending on both the triangular main nozzle and the spreader nozzle as well as on the nozzle package.

Conventional 1-acre Sprinkle System in India

Conventional 1-acre systems in India have 75 mm diameter 6-meter long rigid plastic pipe sections. Regular brass impact sprinklers with 3/4-inch bearing are supported on 1-meter long metal “riser” pipes. The risers are fitted to the female end of each pipe section or attached to short (0.25 m long) quick coupling pieces that are inserted between adjacent (or every other) 6-meter long pipe sections. The portable line with the sprinkler along it is called the “lateral”.

These conventional sprinkle systems now cost about 30,000 INR, Indian rupees ($750) per acre or 7.5 Indian rupees ($0.19) per square meter and require pump discharge pressure heads of at least 24 meters (36 psi). A typical 1-acre system has 6 sprinklers each discharging 1,600 lph giving a total system discharge of 9600 lph, which is 2.67 lps (42.3 gpm). With the system discharge of 2.67 lps the power required to operate a pump with an electric pumping unit that has an overall (wire-to-water) efficiency of 50% is:

Power = (2.67 x 24)/(102 x 0.5) = 1.26 kilowatts (kW)

The system can be operated with a 2-horsepower pumping unit if the water is available near ground level and the field is close to the water source (such as for pumping out of an adjacent canal). But in many cases the systems are operated with insufficient pressure and the application uniformity is very poor.

IDEal Rain 1-acre System Layout and Components

The best way to reduce system cost is to minimize the weight of plastic required. This can be done in three ways, by using smaller pipe diameters, by using thinner walled pipe, and by using recycled plastic for the mainline. We used all of these tactics to make the sprinkle systems as affordable as possible for use on small fields. Figure 1 shows the *IDEal Rain* irrigation system layout.

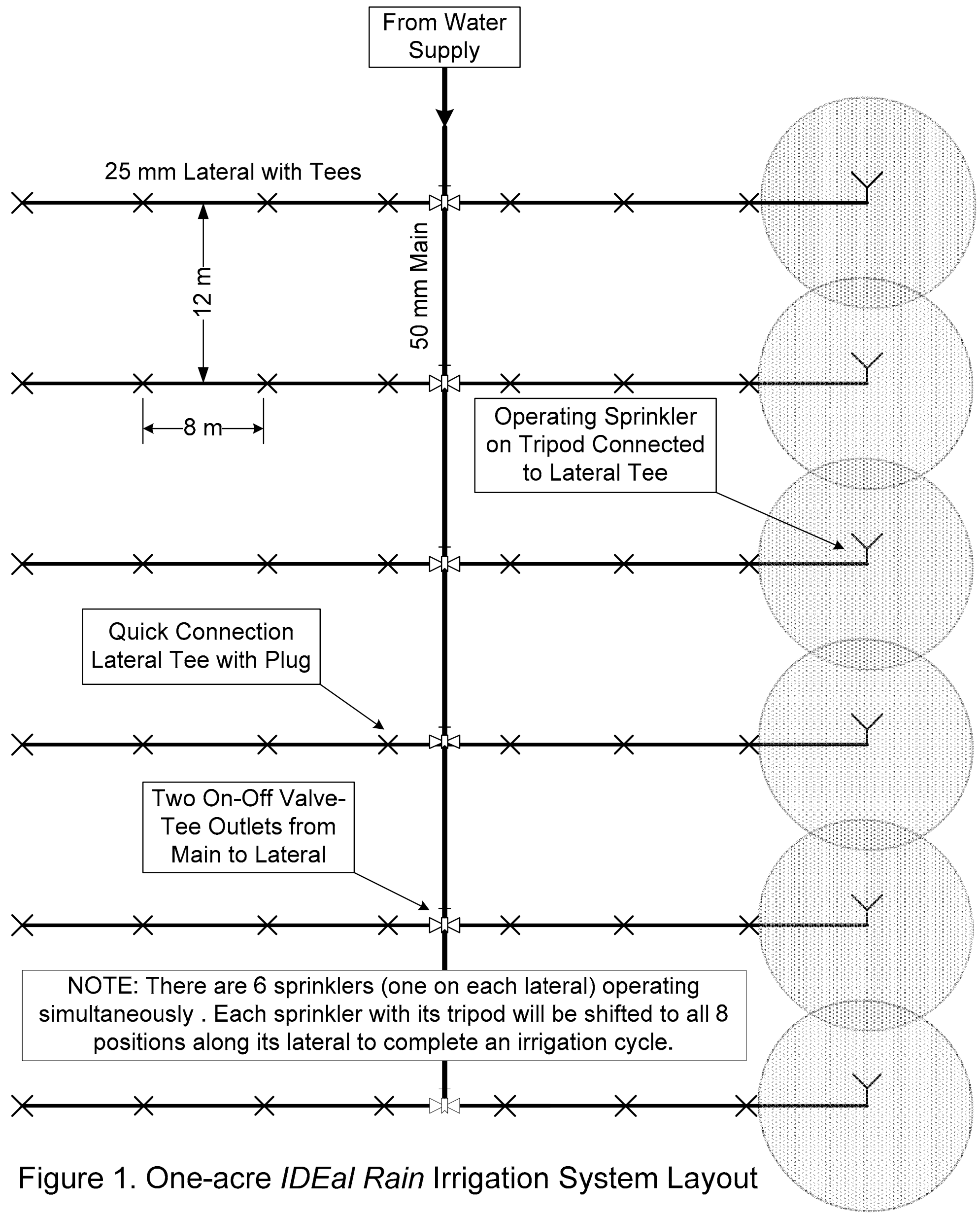

Figure 1. One-acre *IDEal Rain* Irrigation System Layout

Laterals. Rather than having the sprinklers mounted on a 75 mm (3-inch) diameter lateral and periodically moving the lateral, it was decided that it would be more convenient and less expensive to only have one sprinkler operating on each lateral. The sprinklers are then moved sequentially along each lateral (See Figure 1). This requires a lateral for each sprinkler, but the lateral pipe only needs to be 25 mm (1-inch) in diameter and the wall thickness can be as thin as 500 microns (0.5 mm or 20 mils).

For convenience of operation, the ends of each 8-meter (or 4-meter) length of lateral have quick (cam lock) connectors. Each length of lateral also has a Tee at one end (see Figure 1). Quick connection orange (for high visibility) plugs are provided for the Tees when they are not in use (rather than having a valve at each Tee). But an on-off valve is provided for each lateral at its inlet. Figure 2 shows a sprinkler in operation at the end of an 8-meter section of lateral line. There is an orange plug in the Tee at the other end, which can be seen in the foreground.

Figure 2. An 8-meter Section of 25-mm Lateral Line with an Operating Sprinkler Mounted on a Tripod and a Side Outlet Tee with an Orange Plug to Block the Flow Until the Sprinkler is Moved to that Position.

Tripod Sprinkler Stands (patent pending**).** The sprinklers are mounted 1-meter above the ground on sturdy metal tripod riser stands (see Figure 2). The tripods have two movable legs and one fixed leg so they are easy to handle and set up, even on uneven ground. The sprinklers are mounted on short pieces of riser pipe supported by the tripods. A short piece of hose is attached to the lower end of each tripod's riser pipe and a quick connector is provided at the inlet end of the hose so it can be conveniently attached to the Tees along the lateral. Farmers report that it takes less than a minute to move a sprinkler and its stand from one Tee to the next.

Mainlines. 0nly six sprinklers are needed for a 1-acre system (see Figure 1) and the total flow rate based on 1260 lph per sprinkler is: 6 x 1260 = 7,560 lph, which is 2.10 lps (33 gpm). Thus if the area irrigated is near the pump 50 mm (2-inch) diameter tubing with a wall thickness of 1000 microns (1.0 mm) can be used for the mainline. (If the distance to the irrigated area is much greater than 25 meters, it is better to use 63-mm (2.5-inch) tubing for the supply line to the field to reduce the pressure loss due to pipe friction.)

System Operating Pressure Head and Power Requirements

The total dynamic head at the pump discharge needed to operate the 1-acre *IDEal Rain* system with the pipe network shown in Figure 1, which has a 50-mm diameter main and 25-mm lateral pipe, is only 15.0 meters. Following is a breakdown of the system inlet pressure head requirement:

Pipe friction loss between pump and first lateral (25 m)		1.0 m
Pipe friction loss between first and last lateral		0.6 m
Pipe friction loss in lateral with sprinkler operating on end		0.9 m
Miscellaneous friction losses and pump lift		1.5 m
Sprinkler height above ground level		1.0 m
Sprinkler operating pressure head		10.0 m
	TOTAL	15.0 meters

With the system discharge of 2.10 liters per second, the power required to operate a pump with an electric pumping unit that has an overall (wire-to-water) efficiency of 50% is only:

Power = (2.10 x 15)/(102 x 0.5) = 0.62 kW

Thus the system could be operated with a 1-horsepower electric or engine-driven pumping unit if the water is available near ground level and the field is close to the water source (such as for pumping out of a shallow well or an adjacent canal).

System Cost

The cost of the 1-acre *IDEal Rain* system with the pipe network shown in Figure 1 and a 25 meter long 50-mm (2-inch) diameter main and supply line from the pump to the first lateral is 8,888 Indian rupees (~$225). The numbers, sizes and cost of the individual items are presented in Table 3. The area served based on a sprinkler spacing of 8- x 12-meters and 6 laterals to either side of the main supply line with 8 sprinkler positions per pair of laterals is: 8 x 12 x 6 x 8 = 4,608 m^2. Assuming the net (of edge effects) area served is 1-acre, which is 4,000 m^2, the cost per square meter is: 8888/4000 = 2.22 Indian rupees ($0.056).

Table 3. Item Description and Cost Breakdown of the 1-acre *IDEal Rain* Sprinkle Irrigation System Shown in Figure 1.

Item		*Size*	*Quantity*	*Unit Cost*	*Cost*
No.	***Description***			***Indian Rupees***	
1	Supply line tubing	50-mm x 1000 micron	25 m	20/m	500
2	Mainline tubing	50-mm x 1000 micron	60 m	20/m	1200
3	Tee couplers	50-mm x 25 mm	6	50 each	300
4	Valve Tee outlets	25-mm	12	29 each	348
5	Valve connectors	25-mm	12	4.5 each	54
6	Lateral tubing	25-mm x 500 micron	336 m	5/m	1680
7	Cam lock coupler sets	25-mm	48	26 each	1248
8	Lateral Tee outlets	25- x 20- x 25-mm	48	9 each	432
9	Plugs for Tee outlets	20-mm	42	7 each	294
10	Hose connectors	20-mm	6	7 each	42
11	Hose for tripods	20-mm x 0.6 m long	6	25 each	150
12	Metal tripod sprinkler stands	1 m high with 3/4 inch female pipe thread	6	200 each	1200
13	Impact sprinklers	3/4-inch brass bearing	6	240 each	1440
				TOTAL	**8,888**

The cost could be considerably reduced if instead of having enough 25-mm lateral tubing so only the sprinkler with their tripods needed to be moved, only half as much lateral tubing was used and it was shifted from one side of the main to the other side during each irrigation cycle. If this was done the cost of the system would be reduced by: (1680 + 1248 + 432 + 294)/2 = 1,827 Indian rupees. So the total cost would be reduced to: 8888 – 1827 = 7,061, which is 1.77 Indian rupees ($0.044) per m^2.

Field Evaluation of IDEal Rain and Conclusions

IDEal Rain sprinkle irrigation systems provide an important breakthrough in irrigation technologies that are affordable and efficient for use on small farms. Following are some of the unique features and advantages of the *IDEal Rain* irrigation systems that small holder farmers realized during the field tests:

- The systems operated efficiently with the pressure head between 0.5 and 1.0 Kg/cm^2 at the sprinklers, where as the classical sprinkle systems used in India on small farms normally required sprinkler operating pressures of at least 2.0 Kg/cm^2 to obtain similar performance.

- The innovative nozzles designs give good water distribution uniformity and produce reasonably small droplets even at these low operating pressures, which result in an overall irrigation application efficiencies of 70 to 75%.
- Farmers indicated that they used one-third less water and got almost double the yield of forage crops when using the *IDEal Rain* system as compared to classical flood irrigation.
- Because of the low sprinkler operating pressures, the systems only required half as much power to operate compared to classical systems, thus saving energy as well as conserving water. Furthermore, most farmers could operate their *IDEal Rain* system with the same pump they were used for flood irrigation.
- Farmers greatly appreciated not needing to move the pipes as each irrigation cycle progresses, since the only things that needs to be moved are the sprinklers and the tripods that support them. They felt that this resulted in two important advantages:
    - The sprinkler positions could be accurately established when the tubing network was laid out at the beginning of the crop cycle, whereas with classical systems, this laterals must be moved after each sprinkler setting.
    - Moving the sprinklers and their tripods was much easier and quicker than moving the large heavy lateral lines following each sprinkler setting.
- Farmers found the systems to be easy to layout and install, so they were able to use them for supplemental irrigation on more than one field.
- Since the systems utilize thin wall pipe that can be rolled in a coils, farmers were able to easily transport and store the systems, whereas classical systems, typically utilized 6-meter long rigid pipes that were difficult to transport.
- Farmers appreciated being able to space their sprinklers closer together where the discharge pressure from their wells was very low. This is practical because the thin wall tubing comes in rolls and can be cut to the desired length rather than being restricted to having standard (for example, 6-meter) pipe lengths.
- Farmers appreciated having the sprinklers on sturdy tripods that held them in the proper upright position, whereas with classical systems, the risers do not hold the sprinklers firmly upright and they often tip partly or all the way over.
- Farmers greatly appreciated the low cost of a 1-acre system, less than 9,000 Indian rupees or about 2.25 per m^2 (\$225 or \$0.056) as compared to the cost of classical sprinkler systems, which cost about 30,000 Indian rupees or about 7.5 per m^2 (\$750 or \$0.19).
- The systems are modular, so a small initial investment can be made to buy a system with only one sprinkler to irrigate a 600 m^2 plot, and then it can be expanded in the future.
- Because of the low operating pressures, a pressure treadle pump can be used to supply systems with one or two sprinklers to irrigate 0.3- to 0.5-acre plots.
- We have elected to patent the *IDEal Rain* sprinkler nozzles, as well as the unique tripod that support the sprinkler, and allow royalty-free manufacturing to assure that the system remains affordable to small holder farmers and to protect the property rights from exploitation by others.