Leveraging Renewable Small-Plot Pumping Energy with Drip Irrigation

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Summary

The authors worked as an International Development Enterprises (IDE) team (the Team) to develop affordable irrigation and auxiliary products for smallholder farmers with plots of land of less than a hectare and family incomes of less than $3/day. To improve production of food crops during the dry season they develop water supplies along water courses or rely on manually drilled or dug wells. Over the past 20 years IDE has been using a social marketing approach to sell manually operated treadle pumps to provide irrigation for smallholder farmers in several states in India in areas where the water table is less than 6meters from the surface. Treadle pumps are also extensively used in other Asian countries, particularly in Bangladesh where IDE first introduced them.

Smallholder farmers use treadle pumps for lifting and pressurizing water to irrigate small-plots where reliable electric power is not available, which is almost always the case in Africa, the Americas, and in much of SE Asia. Assuming an average dynamic pumping head of 6 meters, the average pump discharge is in the neighborhood of 2800 liters/hour. When all household members participate in manual pumping, they typically produce 11,000 to 17,000 liters of irrigation water per day.

To reduce the treadle pumping labor IDE (in collaboration with their Indian affiliate, IDE-I) has developed water application products that are more efficient than the traditional surface (or flood) irrigation systems used by most smallholder farmers. These systems include two types of low-cost drip irrigation, two types of low-cost low-pressure sprinkle irrigation, and a very low-pressure low-cost piped surface irrigation system.

IDE-I sponsored a controlled study on a farmer's field to compare the water use efficiency and productivity of the two types of drip with traditional surface irrigation. One of the drip systems costs about 5.00 USD/100 m^2 and utilizes simple layflat thin-wall polyethylene tubing throughout and hot-punched holes instead of emitters. The other has side passage button emitters that are inserted into the hot-punched holes by hand after the system is installed in the field (which takes 4 to 8 hr/1000 m^2) and costs about 6.00 USD/100 m^2.

Sponge gourds were grown on the IDE-I test plot which was located in the Sehore region of Madhya Pradesh. The planting and end of harvest dates were 12/04/2010 (which was almost a month late and resulted in low yields) and 27/06/2010, the plant spacing was 0.45 x 0.9 meters, and the soil is a silt loam. Water applications were volumetrically controlled and based on the average depth of evaporation from two small 100-mm diameter by 100 mm deep cups with mesh screen covers. Surface sub-plots were irrigated every six days with application depths based on 100 and 125 % of the depth of cup evaporation (CE); the drip sub-plots were irrigated every two days with applications based on 50, 75, and 100 % of the CE.

The CE for the 77 day growing season was 455 mm and the peak daily CE was 10 mm. The productivity with applications of 100 % of CE was 206 Kg/1000 m^2 with button drip versus 75 Kg/1000 m^2 with surface irrigation. Based on treadle pumping 15,000 liters per day, a smallholder could irrigate a 1,500 m^2 plot and it would require 244 hours of household labor to apply 455 mm of irrigation water to it.

The sponge gourds sold for 42 Indian Rupees (0.93 USD) per Kg. So even with the late planting resulting in low yields, the gross return from a 1,500 m^2 plot with drip would be 288 USD but only 105 USD with surface irrigation. Thus the 90 USD cost of a 1,500 m^2 drip system would be easily covered by the increased yield during its first crop season.

Key words: drip-irrigation, scheduling, water-efficiency, treadle-pump, smallholder

Introduction

International Development Enterprises (IDE) has been engaged for over 20 years in assisting smallholder farmers increase their incomes by using a social marketing approach to sell manually operated treadle pumps to provide irrigation water for them. The targeted farmers are ones with plots of less than a hectare and with incomes of less than $3/day. Treadle pumps are also extensively used in the river basins of Asian countries where the water table is 6 meters or less from the surface, particularly in Bangladesh where IDE first introduced them (see Shah, et.al., 2000).

Smallholder farmers use treadle pumps for lifting and pressurizing water to irrigate small-plots where reliable electric power is not available, which is almost always the case in Africa, the Americas, and in much of SE Asia. Table 1, which is taken from the IDE manual: *Design and evaluation of small plot irrigation for agricultural* (see Keller and Keller, 2011), is based on field observations. It shows the typical discharge rate in liters per hour (L/hr) of labor for treadle pumps when extracting water from different depths. It also shows the discharge rates for different combinations of suction lifts and discharge pressure heads for both suction and pressure treadle pumps.

Table1. Average suction and pressure treadle pump discharge rates in liters per hour for different total suction lifts and discharge pressure heads.

Type of Treadle Pump and Discharge Pressure Head	**Discharge Rate - L/hr with Different Total Suction Lift**			
	2 m	**4 m**	**6 m**	**8 m**
Suction with outlet 0.35 m above the ground surface	3600	3000	2800	1800
Pressure pump with 3 m Discharge Pressure Head	3000	2800	2000	1600
Pressure pump with 6 m Discharge Pressure Head	2800	2000	1800	1200
Pressure pump with 9 m Discharge Pressure Head	1800	1200	900	---

The IDE manual also provides estimates of the pumping durations every day (7 days per week) for the following situations:

Household sharing the pumping labor:	Maximum – 6 hr/day	Average – 4 hr/day
Typical adult males alone:	Maximum – 4 hr/day	Average – 2 hr/day
Typical adult females alone:	Maximum – 3 hr/day	Average – 2 hr/day

The Team (as well as many others) is working on affordable photo-voltaic (PV) powered pumping because manual water pumping is such a laborious task. But simple suction treadle pumps only cost between 15 and 40 USD depending on the type and location, while a PV powered pump with a similar capacity would probably cost well over 300 USD. Thus it is important to find ways for reducing the pumping labor or increasing the return to pumping labor by increasing irrigation water use efficiency and/or the yields.

Over the past several years IDE and their Indian affiliate IDE-I have been collaborating in an effort to develop affordable irrigation technologies to increase irrigation water use efficiency. During the past three years this collaborative effort has been done as part of IDE's Rural Poverty Initiative which was funded through a grant from the Bill and Malinda Gates Foundation. During this three year period the Team developed several water application products that are more efficient than the traditional surface (or flood) irrigation systems used by most smallholder farmers. These systems include two types of low-cost drip irrigation, two types of low-cost low-pressure sprinkle irrigation, and a very low-pressure low-cost piped surface irrigation system.

Table 2, which is taken from the IDE manual developed by Keller and Keller, 2011, shows the estimated costs of these smallholder irrigation product (SIP) systems. These system costs are based on the retail prices available to smallholder farmers in India. Costs in the Americas and Africa are usually more than 1½ to 2 times higher due to freight, import duties, and typically higher sales markups due to the additional middlemen, handling charges and inventory expenses.

Table 4. Average cost, crop season fixed cost, and the typical required system inlet pressure head for various types of SIP application systems.

Type of SIP Application System	System Durability: Most	System Durability: Least	System Cost*	Fixed Cost Per Crop**	System Pressure Head
	% of System & # of Crop Seasons		USD per 100 m^2		m
Drip Kits with Head Tank and Button emitters – 100 to 1,000 m^2 systems	100% & 6 Seasons		13.00	1.75	1
Button (emitter) Drip System – 2,000 to 20,000 m^2 (2 ha or 5 ac)	40% & 10S	60% & 4S	6.00	1.50	3
Pre-punched Drip System – 2,000 to 20,000 m^2 (2 ha or 5 ac)	50% & 10S	50% & 4S	5.00	1.10	3
Portable Impact-Sprinkler System – 2,000 to 20,000 m^2 (2 ha or 5 ac)	80% & 10S	20% & 4S	5.00	0.80	8 to 15
Fixed Mini-Sprinkler System – 2,000 to 20,000 m^2 (2 ha or 5 ac)	60% & 10S	40% & 4S	5.00	1.00	7 to 13
Shifted Mini-Sprinkler System for Pressure Treadle Pumps – 1,000 to 2,000 m^2	30% & 10S	70% & 4S	4.00	1.05	8 to 9
Piped Row or Basin System for Suction Treadle Pumps – 1,000 to 2,000 m^2	100% & 8 Seasons		1.25	0.20	0.3 to 0.4

* Costs are based on delivered prices in India, application system prices in Africa and the Americas are usually more than 1½ to 2 times higher.
** Based on India cost weighted average of most and least durable system components sets; 1-year of interest at 25%; and uniformly prorated over the number of crop seasons shown in System Life column.

There is considerable literature available that compares the water application efficiencies of the various irrigation application methods, for example see the non-copyrighted chapter: *Irrigation Efficiency* by Howell, 2003. The fact that well maintained standard commercial drip irrigation systems provide the highest efficiencies and vegetable crop yields grown on small plots is well established. But there is no published data available based on controlled field studies using the low-cost SIP drip systems developed by the Team and socially marketed by IDE and IDE-I.

In view of the above, the Team solicited the support of IDE-I to conduct a controlled study on a farmer's field to compare the water use efficiency and yields of the pre-punched and button drip irrigation systems shown in Table 2 with traditional surface irrigation. The pre-punched drip system utilizes simple to manufacture layflat thin-wall (125 to 200 micron) polyethylene (PE) lateral tubing and a hot needle to punch holes in it to make the drip (water) outlets. The button emitter drip system has small (about the size of a carpet tack) side passage emitters that are inserted into the hot-punched holes by hand after the system is installed in the field, which takes 4 to 8 hr/1000 m^2.

Field Study Objectives, Materials, and Methods

Objectives: Neither IDE nor IDE-I had previously conducted a controlled study on a farmer's field that was related to the water application efficiency and performance of the affordable SIPs the Team had helped develop. Thus the Team took this opportunity to broaden the study (as reported in IDE-I, 2010) to cover the following objectives:

- To compare the water saving and productivity of pre-punch and button emitter drip systems with typical surface irrigation practiced by Indian farmers. (Additionally the performance of shallow (125± mm deep) buried button drip laterals was studied but results are not reported herein because of not being applicable for treadle pump supplied small-plot irrigation systems.)

- To test a convenient small plot farmer-friendly way for scheduling irrigation applications.
- To study the effects of water stress on water use efficiency and yield (quantity and quality).
- To estimate labour input for weeding under drip compared to traditional surface irrigation.
- To study the effect of irrigation method on germination (percentage and & timing), flowering and fruiting and on fertilizer use.
- To estimate the water saving/loss and application uniformity with respect to drip lateral length.

The costs of materials and labor for the field study and presentation of this paper, was roughly 13,300 USD. Writing it required about 100+ hours of donated time. The study had two parts:

1. Comparing the performance of pre-punch and button drip sub-plots with conventional surface irrigation sub-plots in terms of irrigation water requirements, energy, yield, etc.
2. Analyzing application uniformity and productivity under 16-mm diameter 60 m long low-cost drip laterals with simple pre-punch outlets as compared to laterals with button emitters.

Materials: Prior to laying out and planting the sub-plots a tractor driven plow was used to cultivate the entire area. The irrigation sub-plots were then surveyed and separate water supply pipelines were installed with water meters at their inlet ends and on/off valves were installed so the water supplied to each of the sub-plots could be controlled and accurately measured. Figure 1 shows the water meters, and Figure 2 shows the drip laterals and 63-mm layflat polyethylene pipelines.

Figure 1. Volumetric water meters.

Figure 2. Layflat tubing.

Water was supplied from a tube well in which the dynamic water lift was 30 m. An electric submersible pump was used to lift the water from the well and to supply pressurized water to the entire study area.

Figure 3. Evaporation cup.

Based on practical ET monitoring ideas suggested by the former Director General of IWMI (David Seckler, 2011), the evaporation from two small 100 mm diameter by 100 mm deep plastic cups with plastic screen covers, as shown in Figure 3, was used as the estimated reference crop water use. The cups were set on the soil surface in a metal ring to keep them secure. They were re-filled every two days. The average evaporation from the two cups is referred to as the cup evaporation (CE) herein. Standard FAO crop coefficients (Allen et. al., 1998) were used in conjunction with the two-day CE readings to schedule the irrigation applications.

Methods: For the comparative performance studies, there were three 12 m wide by 15 m long sub-plots for each of the drip technologies studied. Three levels of irrigation water intensity, based on 50%, 75% and 100% of the two-day CE multiplied by the crop growth coefficient were accurately measured and applied to each drip sub-plot on alternate days. Color coding was used on the meters and water supply lines to facilitate the field operations.

There were only two surface irrigation sub-plots and they were 7.5 m wide by 36 m long. Water was applied to these two sub-plots every six days at two levels of irrigation intensity, based on 100% and 125% of CE. The accumulated CE over the six day period was multiplied by the crop growth coefficient and accurately measured and applied to each sub-plot

The drip lateral studies were conducted on three 16 mm diameter by 60 m long laterals for each of the drip technologies. Water applications of 100% of the two-day CE multiplied by the crop growth coefficient were accurately measured and applied through each lateral on alternate days. Three different lateral inlet pressure heads (2, 2.5, and 3m) were used throughout the study for each of the three laterals representing a given drip technology. The strip of the field where the laterals were laid was adjacent to the comparative performance sub-plot study area. The ground was essentially level except for a 0.1 m gradual rise from about 50 m from the lateral inlets to their distal ends. The spacing between laterals and rows was 0.9 m and both the spacing of the sponge gourd seed/plants and the emission outlets was 0.45 m.

The crop grown on the test plot was a local variety of trellised sponge gourd (that was not trellised), which followed a crop of chickpeas, and the farm location is in the Sehore region of Madhya Pradesh. The planting date was 12/04/2010 (which ideally should have been about a month earlier in this region) and the harvest was terminated on 27/06/2010, which gave a season length of only 77 days. Normally the sponge gourd crop season length should be about 90 days; the late planting and shortened season resulted in significant yield reductions.

Both the plant and drip outlet spacing was 0.45 x 0.9 m and the soil is a uniform silt loam and relatively uniform throughout the area where the field tests were conducted. The actual irrigated cropped area of the surface irrigated sub-plots was 228 m^2 and 152 $m^2$for the drip sub-plots. A single dose of soluble N:P:K (19:19:19) fertilizer was applied at the rate of 6 Kg per 1000 m^2 through the irrigation water at about 45 days after planting. All the sub-plots were weeded one time about 45 days after planting.

Results for the Comparative Technology Performance Studies

Labour for weeding: The labour required for weeding the total irrigated cropped area (456 m^2) of the surface irrigated sub-plots was 99.6 hours. This compares to 61 hr of the labor required to weed the same cropped area of drip irrigated sub-plots. Thus the weeding labor differential between surface and drip irrigated sub-plots per 1000 m^2 would have been: 1000/456 x (99.6 – 61) = 85 hours.

Seed germination: There was no significant difference in germination between different irrigation levels and technologies under drip. There was 28% more germination in drip irrigation compared to surface irrigation for the same amount (100%) of water application.

Flowering and fruit setting: Flowering and fruit setting was 4 days earlier for the drip irrigated sub-plots with applications based on 75% and 100% CE compared to the surface irrigated sub-plots with applications based on 100% and 125% CE.

Cup evaporation: The cup evaporation (CE) values reached a maximum depth of 11 mm/day during the last week of May and much of June. The total net crop water requirement (CWR) base on a CE of 100% was 455 mm for the growing season. Thus all sub-plots receiving gross irrigation applications based on a CE of 100% received 455 mm of irrigation water irrespective of the application technology, i.e. surface, pre-punch drip, or button drip irrigation.

Yield: The sub-plot yields under different treatments converted to Kg/1000 m^2 are presented in Table 3 along with the total amount of water applied for each technology and irrigation intensity. The table also shows the comparison between the yield with gross irrigation applications based on 100% of CE for the surface irrigated sub-plot and the yields of the other sub-plots.

Table 3. Sponge gourd yields for the different irrigation systems and water application levels.

Irrigation System	Gross Water Application		Yield, Kg/1000m[2]	Yield Increase Over Surface @100% CE
	Based on % of Cup Evap.[1]	Total mm[2]		
Surface	100	455	75.2	0
	125	568	105.0	39.6
Pre-punched Tubing	50	227	66.3	-11.8
	75	341	152.2	102.3
	100	455	201.3	167.6
Button Emitter	50	227	83.6	11.1
	75	341	181.0	140.6
	100	455	206.5	174.6

[1] Gross Irrigation applications were based on the crop coefficient times the given % of CE.
[2] Total for season, also it rained an additional 36 mm during the later part of the crop season.

Quality: The size and weight of the fruit were measured but no conclusion was reached regarding any quality differences between water application technologies.

Energy saving: The pressure head needed to operate these drip systems, which are specifically designed with small plot farmers in mind, is only 3 to 4 m, including the filter pressure losses and lateral inlet pressure requirements; and the dynamic pumping lift was 30 m. Thus the energy requirement differential needed to operate the drip systems compared to surface irrigation is closely related to the differences in the amount of water applied.

Results of 60 m Long Drip Lateral Study

A simple water filled manometer was used to measure the pressure heads at the inlet and distal ends and three points in-between on each tested drip lateral. The data from the three pre-punch drip laterals and three button emitter drip laterals with inlet pressure heads of 2, 2.5, and 3 m was measured and plotted. The equation of the best fit curves for these plotted points was used to generate pressure head data for any point along a lateral. For example, the best fit equation for the button emitter drip lateral with an inlet pressure head of 2 m is: $y = 1.993\ e^{-0.019x}$, with an $R^2 = 0.9934$.

Table 4 shows the calculated outlet pressure heads at 5 m incremental distances along the 60 m long pre-punch and button emitter drip laterals. These values were calculated using the best fit equations from the plotted field data for the two drip technologies with three lateral inlet pressure heads.

The crop row served by each of the six laterals was irrigated every two days and supplied with a calculated gross volumetric amount of water based on the crop coefficient times 100% of the CE. Table 4 also shows the average percentage of the average depth of application received in the lateral sections between the respective lateral inlets and 15 m down-lateral, between 15 m and 30 m down-lateral, and between 30 m and the distal end of each set of three laterals. The averaged crop yields harvested from these six respective areas is also provided. For example, in the mid section (between 15 m and 30 m down-lateral) the sponge gourd yield was equivalent to 320 Kg/1000 m^2 in the area served by the three pre-punch drip laterals and 401 Kg/1000 m^2 in the area served by the three button emitter drip laterals.

Table 4. Pressure heads and percentages of average emitter discharges along the 60 m length of pre-punch and button emitter drip laterals with inlet pleasure heads of 2, 2.5 and 3 m.

Distance from Inlet	Pre-punch Drip Laterals					Button Emitter Drip Laterals				
	Inlet Pressure Heads			% of Avg.	Yield	Inlet Pressure Heads			% of Avg.	Yield
m	2 m	2.5 m	3 m	*	**	2 m	2.5 m	3 m	*	**
0	2.00	2.50	3.00			2.00	2.50	3.00		
5	1.70	1.90	2.86	127	282	1.81	2.16	2.98	118	377
10	1.49	1.67	2.56			1.65	1.96	2.63		
15	1.30	1.47	2.29			1.50	1.77	2.32		
20	114	1.29	2.05	101	320	1.36	1.60	2.05	104	401
25	0.99	1.13	1.84			1.24	1.45	1.81		
30	0.87	0.99	1.65			1.13	1.31	1.59		
35	0.76	0.87	1.48			1.02	1.19	1.41		
40	0.66	0.77	1.32			0.93	1.07	1.24		
45	0.58	0.67	1.18	72	189	0.85	0.97	1.09	78	292
50	0.51	0.60	1.06			0.77	0.88	0.97		
55	0.42	0.52	0.95			0.70	0.80	0.85		
60	0.35	0.50	0.87			0.65	0.75	0.80		

*The water volumetrically applied to each lateral was equal to 100% of CWR, i.e. based on 100% of CE, for the areas served by each lateral irrespective of the lateral inlet pressure head.
** Sponge gourd yields harvested in corresponding % of Avg. lateral application rate reaches converted to Kg/1000 m^2.

Discussion of Technology Comparisons

Overview: This trial was carried out on a farmer's field because the Team wanted the results to be representative of typical Indian farm husbandry and irrigation practices. Thus the Team elicited the farmer's advice in decision making regarding cultural, fertilizing, weeding, and harvesting practices, and managing the water applications on the surface irrigated sub-plots. The farmer (see Figure 4) took care of managing and paying for all sowing, cultivation, weeding and harvesting labor plus paid for the electric power, seed and fertilizer. In return for these inputs and the use of his land he harvested roughly 370 Kg of sponge gourds from the field test area and sold the produce for 42 INR/Kg, which resulted in gross receipts of: (370 x 42) = 15,500 INR (345 USD).

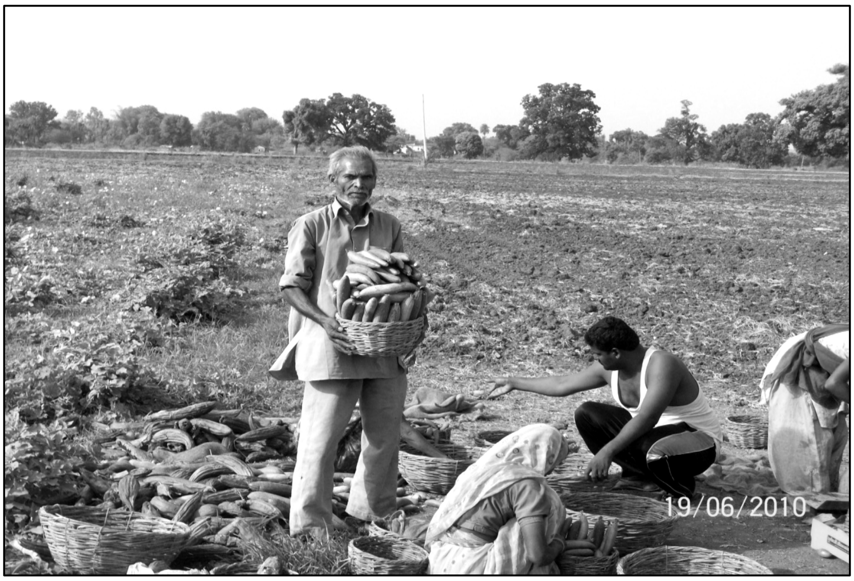

Figure 4. Picture of cooperating farmer holding basket of sponge gourds.

The sponge gourd crop was planted on 12 April 2010, which is over three weeks behind the optimal sowing date, which is mid-March. The harvest was terminated 27 June 2010, which resulted in a season length of only 77 days, compared to the optimum season length, which is 90 days for sponge gourd in the region. The later than normal planting date was in part due to complications with getting the field trial hardware in place and operational. The reason the harvest was terminated early was because the farmer wanted to prepare the field for a crop of soya beans before the rainy season started, which is the normal practice in that region. Sowing the sponge gourd seeds late and having a shorter than normal growing season resulted in low yields.

The field trial results are clearly not representative of a typical "rigorous academic research study" in terms of crop water requirements versus yields. The sub-plots were not replicated and the field technicians who were responsible for day-to-day management of the study were not experienced research assistants. However, the Team believes this is relatively unimportant, and that the results are quite useful for making practical decisions regarding comparative water use efficiencies and the productivity of the various irrigation technologies under realistic "real farm field" situations.

Evaporation Cup: The Team found that the small evaporation cup shown in Figure 3, which provided the CE values, proved to be a relatively accurate and farmer friendly means for scheduling irrigation water applications. The CE values also compared quite favorably with reference crop water use estimates based on local weather station data.

Water versus Yield: Table 3 shows the water applications that were volumetrically measured using flow meters, and the resulting yields for the different irrigation application systems and water application intensities. It also shows the comparison between the yields of the surface irrigated sub-plot that received gross irrigations based on the crop coefficient multiplied by 100% of the CE depth and the yields harvested from the other sub-plots.

The yield in all the drip sub-plots, except for the pre-punch based on 50 % of CE, was higher than the surface sub-plot receiving irrigation applications based on 100% of CE. Drip applications based on 100% of CE resulted in yields that were roughly 2.5 times higher for the same amount of water applied by surface irrigation. The pressure head at all the emission outlets within each drip sub-plot represented in Table 3 was nearly the same. However, the button emitters had a field measured discharge coefficient of variation of: $v_c \approx 15\%$, and for the pre-punched tubing: $v_c \approx 19\%$. Also small water jets spray out from the pre-punched tubing whenever the orifices are not facing down, but inserting the button emitters eliminates this problem. This in part explains why at the lower water application levels the sub-plots with button emitters outperformed the ones with simple pre-punch outlets.

The yield under surface irrigation was 1050 Kg/ha with irrigation applications based on125% of CE. The same total yield could have been obtained: a) on the same cropped area with less than half as much water, i.e. irrigation applications based on about 60% CE with drip irrigation; or b) on half as much cropped area with drip applications based on 100% of CE. Thus, in either case, by converting to drip irrigation the manual treadle pumping labor required for the same gross yield would be less than half as much as with traditional surface irrigation.

Treadle Pumping Economics: The depth of irrigation water with applications based on 100% CE for the 77 day growing season was 455 mm (see Table 3) and the peak daily CE was 11 mm. The productivity with applications based on 100% of CE was 206 Kg/1000 m^2 with button drip versus 75 Kg/1000 m^2 with surface irrigation. Assuming a total water lift of 6 m and household members treadle pumping for 6 hours per day during the peak water use period, they could produce roughly: (2800 x 6) = 16,800 liters/day (see Table 1). Thus based on a gross water application of 11 mm/day they could irrigate a: (16,800/11) ≈ 1,500 m^2 plot. And based on a seasonal water requirement of 455 mm, it would require a total of: (455 x 1500)/2800 = 244 hrs (or a little more than 3 hrs/day during the 77 day growing season) of household pumping labor to irrigate the 1,500 m^2 plot.

The sponge gourds sold for 42 INR (0.93 USD) per Kg, as mentioned above. So even with the late planting resulting in low yields, the gross return from a 1,500 m^2 plot with a button drip SIP system would be 288 USD but only 105 USD with surface irrigation. Thus the 90 USD cost of a 1,500 m^2 button drip system (see Table 2) would be easily covered by the increased yield during its first crop season.

Discussion of Drip Lateral Study

Hydraulic Analysis: The total hydraulic friction losses for the 16 mm diameter 60 m long laterals operating with an inlet pressure head of 2 m shown in Table 4 are 1.65 m and 1.35 m for the pre-punch and button drip laterals respectively. These values confirm the lateral friction head loss equation recommended by Keller and Bliesner, 1990 for use with small diameter plastic pipe:

$$H_f = [L + f_e \cdot (L/S_e)] \cdot K \cdot (Q^{1.75})/(ID^{4.75}) \quad (1)$$

Where:

- H_f = friction head loss in the pipe or tubing, m
- L = length of the pipe or tubing, m
- f_e = connection loss equivalent for each emitter or outlet connection, m
- S_e = emitter or outlet spacing on the lateral or sub-main, m
- K = conversion factor, 0.47 for Q in lph and 610 for Q in lpm; dimensionless
- Q = flowrate in the pipe, lph or lpm
- ID = inside diameter of the pipe or tubing; mm

For example, in an analysis using an excel spreadsheet program that uses Eq. 1 and the discharge equations for pre-punched drip outlets: $q = 7.0 \times H^{0.5}$, and for the button drip outlets: $q = 4.5 \times H^{0.5}$; and f_e = 0.05 m for the button emitters, the computed friction head losses are 1.67 m and 1.33 m.

Design Uniformity: The same excel spreadsheet program mentioned above was used to compute the design Coefficient of variation Uniformity (CvU_d) values shown in Table 5.

*Table 5. D*esign Coefficient of variation Uniformity (CvU_d) *for various lengths of 16 mm diameter pre-punch and button emitter drip laterals with an inlet pressure head of 2 m and outlets spaced at 0.45 m intervals on level fields.*

Lateral Length m	**Discharge Uniformity, CvU$_d$, %**		**Lateral Length m**	**Discharge Uniformity, CvU$_d$, %**	
	Pre-punch	**Button Emitter**		**Pre-punch**	**Button Emitter**
0	81	85	30	80	85
5			35	79	84
10			40	78	84
15			45	75	83
20			50	72	81
25			55	69	79
30	80		60	64	77

Keller et. al. 2003, recommend using CvU_d to evaluate drip system uniformity for design purposes. They also recommended targeting the design to provide a CvU_d value close to 80% or higher for smallholder irrigation systems. The equation used in the spread sheet for computing CvU_d is:

$$CvU_d = 100\{1.0 - [(v_m/\sqrt{N_p})^2 + (v_p)^2]^{0.5}\} \quad (2)$$

Where:

- CvU_d = design Coefficient of variation Uniformity, percent
- v_m = coefficient of emitter discharges due to manufacturing variations

N_p = number of emitters each plant can obtain water from
v_p = coefficient of emitter discharges due to pressure variations along lateral

The coefficients of emitter discharges due to manufacturing variations used for the pre-punched drip laterals was v_m = 0.19 and v_m = 0.15 for the laterals with button emitters as mentioned above. IDE-I's low-cost drip systems laterals with button emitters spaced at 0.45 m could be up to 60 m long and still provide a reasonable CvU_d of 77%, but with the higher flow rate and v_m of the simple pre-punch drip laterals the lateral length should not exceed 40 to 45 m to achieve the same application and water use efficiency.

Crop Water Requirement: The drip yields in Kg/1000 m^2 from the rectangular sub-plots used for comparing the various irrigation application technologies are considerably lower (see Table 3) than the drip yields from the 60 m long lateral study (see Table 4). The Team cannot explain this discrepancy, but it is interesting to note the highest yields occurred in the lateral sections between 15 and 30 m from the inlet for both drip systems where the effective water application was near the average applications based on 100% of CE. Lateral reaches to either side that received more or less water produced lower yields. This suggests that the small evaporation cups (see Figure 3) provided a reliable reference crop water use estimate for irrigation scheduling purposes.

Return to Land, Water, and Labor: Assume the average area weighted yields in Table 4 are typical, i.e. 245 and 340 Kg/1000 m^2 for pre-punch and button emitter systems. Then, based on a return of 42 INR/Kg and 45 INR/USD, the gross return to cover input costs, land, water and labor would be: 0.23 USD/m^2 for pre-punch and 0.32 USD/m^2 for the button emitter drip systems.

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