Low pressure drip irrigation for commercial vegetables in Myanmar

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ABSTRACT

Drip irrigation is used extensively by both large and small commercial vegetable growers in the United States, Europe, Australia, and the Middle East where significant benefits include not only higher water use efficiency, but higher yields, improved product quality, earlier maturity, and reduced disease susceptibility. Imported drip systems are still relatively expensive in Southeast Asia, however, and it is primarily wealthier farmers who currently enjoy these benefits. There are also perceptual barriers to adoption as many farmers are accustomed to applying copious amounts of water to vegetable crops and are unfamiliar with drip or their crops' actual water requirements. As an NGO whose mission is to help boost small farm incomes, IDE-Myanmar began experimenting with low-pressure gravity-fed drip systems in 2006. While the basic design is similar to microtube systems of the 1960s, local improvements include filters designed for low pressures, easy-to-use fittings, and inexpensive collapsible header tanks. After hundreds of controlled tests and farmers' field trials, our locally manufactured drip sets were offered for sale by private dealers throughout Myanmar in 2009. We continue to develop system improvements and support an on-farm demonstration and farmer education program to promote this "new" technology. Supporting materials include illustrated installation guides, system design software, videos, testing/filtering of dissolved iron, and an easy-to-use water requirement calculator. Approximately 5000 small farm drip systems have been installed in Myanmar since 2008 and the number of users is increasing at an accelerating pace.

Keywords

Drip, microirrigation, low pressure, gravity

INTRODUCTION

Commercial vegetable growers in the United States, Australia, Europe, and the Middle East have long enjoyed the benefits of drip (or trickle) irrigation which have been described in numerous research and extension publications over the past 40 years. These benefits include higher yields, improved product quality, earlier maturity, and reduced risk of foliar (and some soilborne) diseases. Other advantages over conventional irrigation include higher water use efficiency and application uniformity that is unaffected by wind and causes less soil crusting. In some cases weed pressures are reduced and farmers can perform weeding and other field operations while irrigating. Less energy and labor are generally required for drip irrigation. Application of plant nutrients through drip systems (fertigation) enables precise fertilizer placement and timing, resulting in better nutrient use efficiency. Drip has also been used successfully on saline soils and with saline water where other irrigation methods failed. Lastly, drip irrigation has synergistic interactions with plastic mulches which further boost yields and product quality.

Drip irrigation also has significant barriers to adoption by small farmers in developing countries. These include high initial system costs (especially if most components are imported), the need for relatively clean water, and the tendency for emitters to clog with contaminants such as dissolved iron. Even more important are *perceptual* barriers which include the seeming complexity of drip systems and the almost instinctual first reaction from farmers that drip will not supply sufficient water to their crops. Some drip components such as LLDPE[1] lateral tubing are also occasionally damaged by rodents or other animals. Seasonal removal and disposal of used drip laterals and plastic mulch is also a problem for commercial vegetable growers in the United States. Overcoming these barriers require not only the appropriate design of hardware, but also an equal or greater emphasis on farmer education and on-farm demonstration.

Having worked with drip irrigation for a dozen years in the United States before beginning work with International Development Enterprises[2] (IDE) in Myanmar, the senior author understood first-hand drip's benefits after numerous demonstrations and trials with small commercial vegetable farmers in the state of Kentucky (Rowell, 1999). Given this background, we did not spend a lot of time doing replicated field trials comparing drip with conventional irrigation methods as such trials have been conducted by many researchers in many countries. Our goal from the beginning was to develop and promote a drip irrigation system which was both easy-to-use and *affordable* to small--but commercial scale--fruit and vegetable growers.

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[1]Low linear density polyethylene is the primary ingredient in drip lateral tubing.

[2]IDE is an international NGO that promotes affordable microirrigation technologies for smallholders as its primary tool for raising incomes and reducing poverty using design thinking and a business development approach. IDE-Myanmar was renamed *Proximity Designs* in 2011 after becoming independent from IDE International in 2009.

Such a system must function well for a reasonable commercial plot size with very low system pressures, usually obtained from an elevated water tank. Another objective was to help establish private local manufacturing of all system components. While the task of developing a low pressure system--without benefit of motorized pumps--was daunting, knowing the high potential benefits was motivation enough to make the considerable investment in time and money.

Myanmar, while largely cut off from its potential export markets, produces large quantities of vegetables to supply its population of 58 million people. The country is blessed with diverse agroclimatic zones ranging from tropical to temperate and grows an enormous variety of vegetable crops including a large number that are considered indigenous. The major commercial crops are chili (12,900 ha), tomato (10,600 ha), onion (71,000 ha), and potato (37,000 ha); these together with a wide variety of other vegetable crops comprise a production area of about 75,000 hectares (Maung Maung Yi, 2009).

Given the fact that motorized pumps are at present unaffordable to most small vegetable farmers and that the electricity grid does not extend to the vast majority of villages in Myanmar, it is not surprising that in most cases commercial vegetable crops are irrigated by hand watering with large sprinkler cans (Figure 1) or by furrow/flood in areas where water is more abundant. Irrigation with sprinkler cans requires backbreaking and time-consuming labor: our own surveys revealed that it is not uncommon for small vegetable growers to carry 4-6 tons of water daily on their backs to irrigate vegetable crops.

Figure 1. Sprinkler cans used on vegetable crops.

Proximity Designs is a non-governmental organization providing humanitarian assistance to the people of Myanmar since 2004; our mission is to increase incomes and improve food security of vulnerable rural households. True to its roots in IDE International, Proximity's social enterprise activities focus on creating and marketing affordable products and services for rural households that enable them to dramatically improve their livelihoods through increases in productivity and income. Products are made in Myanmar and sold at production cost while research and design, marketing, and HR costs are donor funded. With operations in 115 townships across 9 states and divisions, our work reaches an estimated 75 percent of Myanmar's rural population. We currently employ over 140 promotion staff nationwide and have built up distribution channels using 154 private agro-dealer shops and over 600 private independent village "agents" who offer our irrigation products including drip systems. Dealers are motivated to carry our products because we let them charge a profit margin on every sale, while independent village agents install pump and drip systems for small fees.

The following is a description of the evolution and development of our low cost, low-pressure drip system and how this system has been demonstrated and promoted from 2006 to the present. Much of the descriptive text will be found under *Materials and Methods* below. The on-farm demonstration and applied research approaches described are different from those in which the endpoint is publication in a refereed journal article. Our goals from the beginning were to develop a practical and affordable low pressure drip system in as short a time as possible using a combination of rapid prototypes and quick field tests or screenings, leaving the customer or end user to help make final determinations regarding its suitability for its task. This is similar to an approach employed by the Department of Horticulture at the University of Kentucky when well managed but unreplicated trials were used to screen large numbers of commercial vegetable varieties (Rowell, 2006). This paper is a first attempt at describing the process of developing a low cost, low pressure drip system for commercial vegetable growers and other horticultural crop farmers in Myanmar.

MATERIALS AND METHODS

Modern commercial drip systems from Netafim[3] were first introduced by representatives of the company and the Myanmar Agriculture Service (MAS) in one township in Mandalay Division in 1994 and later by an Israeli-local joint venture in 2006 within a government-organized vegetable production zone in Yangon Division. These efforts were soon discontinued or abandoned, however, due to their high management requirements and expense in the first case and as a result of iron precipitate clogging and other problems in the second. The systems were also considered too complex and costly for widespread adoption by local vegetable growers (Dr. U Win Htin and U Kyaw Win, personal communication). Our efforts to introduce this technology also began in 2006 through IDE Myanmar (now *Proximity Designs*) with support from the Bill and Melinda Gates Foundation.

[3]Drip systems were produced and installed by Netafim, a major global drip irrigation company based in Israel.

When the senior author arrived in the country with the task of introducing drip in 2006 it was assumed--even by IDE--that this would be as simple as demonstration and sales of pre-packaged "drip kits" imported from IDE-India. But as we began to work with these kits it soon became apparent that they were not suited to vegetable production in the country. The prepackaged kit sizes were often too small or too large, but a more serious problem was that main or submain-to-lateral connectors were at fixed spacings which did not match the most common row-to-row spacings for vegetable crops in Myanmar. There were also no connectors available for flexible pipe which is ubiquitous in Myanmar. In addition, importation of the kits was slow, difficult, and expensive. For these reasons the Indian lateral tubing, microtube emitters, and screen filters were removed from kits on hand and used in our own custom on-farm installations and test plots from 2006 to 2008, with incremental substitution of locally-made components as they were developed.

The basic design of IDE India's drip kit is an adaptation of an older microtube emitter system first introduced in Israel and the US in the 1960s. While this type of emitter has long since been abandoned for field use in developed countries in favor of more convenient (built-in) and clog resistant labyrinth or turbulent flow path emitters, microtubes are still used in many greenhouses in the United States and elsewhere. Significant improvements to the microtube system have been made based on research by Jack Keller[4] and J.N. Ray in India where use of these systems became widespread through marketing and promotion efforts of IDE-India.

Drip system research and development

Lateral/emitter screening

Somewhat skeptical of the microtube system, we began a series of "quick and dirty" screenings of various emitter types/laterals in a commercial vegetable grower's field at Bauk Htaw, an area of mostly leafy greens production within the Yangon city limits (Figure 2). With these tests we intended to eliminate the worst performers using very low pressures from elevated gravity tanks (height to the bottom of the tanks was 1.1 m or 3½ ft, = 1.5 psi) and dirty surface water together with simple 25 mm (1-inch), 100-mesh screen filters. Leaf lettuce was grown (Dec 2006-Jan 2007) followed by leaf mustard (Feb-March 2007). Both crops were grown in raised beds 15 m (50 ft) long and 1 m wide as is normal farm practice for leafy vegetables in Myanmar. Crop management (other than irrigation) and marketing was the responsibility of the local farmer.

Figure 2. Screening of drip laterals in Yangon, Dec 2006.

Two 15 m lengths of each lateral/emitter type were used on each bed. Six lateral/emitter systems were screened including three with moderate to high flow rates (IDE-India's microtube system, IDE-Nepal's 'baffle' emitter system, Adrilite[5], Table 1) and three low to moderate flow rate lateral/emitter systems including T-Tape[6], Chapin Watermatics drip tape, and a new Indian drip lateral product from Das Agroplastics. These were also

Table 1. Drip lateral and emitter systems tested at Bauk Htaw, Yangon, Myanmar, 2007.

Lateral/emitter type	Source	Emitter spacing	Flow rate
External, "baffle"	IDE Nepal	60 cm	high
External, microtube	KB brand, IDE India	--	high
Internal labyrinth flow path, *Adrilite*	Adritec Group Int., Jordon	30 cm	moderate-high
Internal labyrinth flow path, Das	Das Agroplastics, Pune, India	30 cm	low-moderate
Internal labyrinth flow path, *T-Tape*	T-Systems, now John Deere (USA)	30 cm	low
Internal labyrinth flow path, Chapin	Chapin Watermatics (USA), now Jain, India	30 cm	low

[4] Dr. Keller, CEO of Keller-Bliesner Engineering, Logan, Utah and Professor Emeritus, Utah State University, is a global authority in drip and sprinkler irrigation engineering. He is also the Senior Irrigation Advisor and long-time board member of IDE International. Dr. Keller has spent a large part of his professional career helping develop affordable microirrigation systems for low income farmers in India and throughout the developing world. Most low-pressure drip systems for developing countries, including ours, are based on his pioneering work.

[5] A product from Jordon that is very similar to Netafim products with hard plastic turbulent flow path emitters embedded inside the lateral tubing.

[6] T-tape is a drip lateral product with turbulent flow path emitters formed in the tubing during the extrusion process. Now sold by John Deere and commonly used on vegetable crops in the USA and elsewhere.

compared to a control plot which was watered with sprinkling cans according to the farmer's usual practice. All plots were watered daily using equal amounts of water. Yield and product quality were measured by harvesting all plants in the bed within a 3 m subplot. Emitter flow rates from the different systems were measured indirectly by recording the amount of water discharged hourly from each of six 208-liter (55-gallon) plastic drums providing water to the six drip systems.

Open-pollinated leaf lettuce and leaf mustard were grown at equidistant spacings in 7 rows/bed. Emitter uniformity, while not measured directly, was observed by rating plant uniformity and vigor within the beds under the different drip systems. Any problems with flow or emitter clogging were also noted. Although emitters were soon hidden from view under dense plant canopies, it was easy to know when there were clogging problems by the lack of flow over time from the gravity tanks and resultant poor plant growth.

System performance testing

2009. While some information on low pressure, gravity-fed drip system performance was available from IDE-India, most of it was not applicable to the pipe sizes and drip components used in Myanmar after 2008. We also did not know the best possible arrangement of main, submains, and laterals to achieve maximum application uniformity at very low operating pressures. To answer these and other questions we conducted a series of 118 field tests on a more or less level one-acre vacant plot in front of Myanmar Agriculture Service's Plant Protection Division office in Yangon from March to June, 2009.

In nearly all of these tests the "bottom line" dependent variable was the coefficient of uniformity (*CU*) proposed by Keller (2002) as the standard measure of application uniformity for smallholder drip irrigation systems. The *CU* is derived from the coefficient of variation (*cv*) of catch can observations. The catch can *cv* is a measure of the variability of the amounts of water collected in catch cans from drip emitters at different locations within a test field and is easily calculated using a hand calculator or spreadsheet as follows:

$$cv = sd/q \times 100$$

where *sd* = standard deviation of the catch can amounts of the population, and *q* = overall average of all catch can observations. The *CU* is simply *100 – cv* and therefore a measure of water application uniformity. We used a *CU* of 80% as the minimum acceptable value in our tests as proposed for smallholder drip and sprinkler irrigation systems in developing countries (Keller, 2002).

Three groups of 6 catch cans each (18 total) were buried so that water from individual microtubes flowed easily into the containers. The first group of 6 cans was placed near the end of the first lateral closest to the main line, the second in the center of a lateral at the center of the plot, while the third was near the end of the last lateral (Figure 3). Water was collected in the cans for 3 minutes, after which the *CU* was calculated and the test repeated.

Figure 3. Manometers and catch cans used in drip system performance testing, 2009-10.

Independent variables examined in this first series of tests included water tank height, main line diameter, splitting of lateral lines with a center submain, placement of the main line (side or field center), use of a "T" connector to join the main line to submains, etc. In all cases we determined the maximum number of emitters (and length of laterals) that could be used and still maintain a *CU* of at least 80%. To do this we first selected what we considered a reasonable number of emitters/laterals and then increased or decreased this number after each test until the minimum *CU* was reached.

2010. A second series of tests was designed to pinpoint the source of large pressure losses occurring between the water tank and the first lateral and identify possible solutions. All tests were conducted in early 2010 at the same location as the previous year's tests, but with a different experimental setup. Unlike previous tests, we did not set up a full drip system but used only a 1.8 m (6 ft) high water tank and its fittings together with a 30.5 m (100 ft) length of 32 mm (1¼-inch) locally made soft flexible pipe with a ball valve on the end. We used the ball valve to simulate total system flow. A single 14 m (45 ft) lateral with 6 microtubes at its far end was connected to the main at a distance of 2.7 m (9 ft) from the water tank. Two microtubes were also inserted in the main line between the tank and the first lateral about 30 cm (1 ft) from the lateral-to-main connection.

System pressures were measured using the microtubes described above connected to simple manometers made from transparent tubing sold for medical use (IV tubing). The tubing was mounted on vertical stands made from steel angle iron with cloth measuring tape attached behind the tubing (Figure 3). Pressure was measured as the height of the water column in the tubing and measurements were taken from two microtubes adjacent each area with catch cans (2009) and at the end of the single lateral used in 2010. All 2010 tests were conducted using two system flow rates corresponding to small (average 1890 lph or equivalent to approximately 1000 microtube emitters @ 2 lph/emitter[7]) and medium-sized (average 3667 lph or approximately 1940 microtubes) drip systems. Flow rates were determined before each test by direct measurement at the far end of the main line. High flow was simulated with an open valve while the lower flow rate was simulated by partially closing the valve.

Existing and alternative components and fittings of the water tank and drip set were tested for their effects on application uniformity and system pressure. The following components were evaluated and compared in a series of 80 tests conducted from March-May 2010:

1. PVC elbows vs. current water tank outlet nipple
2. 90° vs. 120° elbow at water tank outlet
3. Long vs. short elbow at water tank outlet
4. Flexible pipe vs. PVC pipe (25 and 32 mm or 1 and 1.25 inch) from water tank to filter
5. Flexible pipe from filter to ground vs. all PVC
6. Ball valve vs. no ball valve
7. 25 vs. 32 mm (1 vs. 1.25-inch) PVC pipe from water tank to ground
8. Ordinary screen filter vs. no filter
9. Myanmar-made vs. Indian screen filter (25 mm or1-inch)
10. External screen filter vs. 3 types of in-tank stainer/filters
11. Ordinary screen filter vs. 4 prototype in-line filters and two screen mesh sizes

Low pressure drip system design software

Low pressure drip system efficiency is highly sensitive to pressure variation. Given the large number of components and fittings affecting performance, and having gone through the laborious process of field testing many of these parts to optimize our system's performance, we believed a computer software design tool would be extremely useful for improving current and developing new system configurations and designs. The program would also enable us to determine the best system configurations for fields larger than the size of two of our current drip sets. While a good MS Excel© program had been developed earlier by Andrew Keller, it was limited to only a few variables.

Our goal was to develop an easy-to-use program for both specialists making component design changes, and for drip technicians and field staff designing custom systems for farmers. To this end we hired irrigation engineer Ryan Weber in early 2011 to develop a low pressure hydraulic model based on field tests in Myanmar. An experimental drip system was installed within a two-acre plot of turfgrass at the FMI Estates properties just across the Yangon River on the west side of Yangon. In addition to the usual IV-tube manometers, in-line pressure sensors with dataloggers were used to monitor small changes in system pressure. Measurements also included tests of water application uniformity of microtube emitters. In addition to recording observations for software development, Weber and Tun Tun Khine also tested samples of large diameter 63 mm (2.5-inch) LLDPE layflat pipe from IDE-India for its suitability for use as main and submain lines in our drip system.

Farmers' field testing and demonstration

The first two seasons, 2007-2008

Ten small preliminary drip sytem tests were established in Jan-March 2007 at Kungyangon Township about 100 km south of Yangon and in Hllegu and Hmawbi Townships 25-30 km north of Yangon. Kungyangon was selected because IDE Myanmar's foot-powered treadle pumps were popular there and because of a local tradition of elevating old oil drums to use for watering vegetables and other crops with hoses. Hmawbi and Hllegu also had a high concentration of vegetable growers using our treadle pumps.

In most cases the plots consisted of 100-200 m of drip laterals applied to a few rows within a farmer's existing commercial planting which was watered by sprinkler cans, furrow, or elevated tank and hose prior to drip installation. Old 208 l (55-gal) oil drums on 1.2-1.5 m (4-5 ft) high stands were used as header tanks to pressurize the systems. Ordinary 25 mm (1-inch), 100 mesh screen filters from IDE-India were used together with *Tape-loc* (T-Systems, USA)[8] main-to-lateral connectors. The main line was 25 mm (1-inch) diameter flexible pipe (recycled PVC) available throughout Myanmar. In some cases treadle pumps were mounted on stands above the oil drums for easy filling. This required the user to operate the pump from above the tank (Figure 4, left) or use treadles on the ground linked to the pump by ropes or cables. This practice of filling elevated tanks with treadle pumps existed in some parts of Myanmar even before we

Figure 4. Elevated ordinary treadle pump (left) and new *Sin Pauq* pump with Proximity drip system (right).

[7] 1890 lph = 500 gph @ 0.53 gph/emitter and 3667 lph = 970 gph.

[8] Inside diameters were only 4 mm which limited overall system performance in larger farmers' field trials.

began introducing drip. In a few cases farmers filled tanks by hand from nearby wells. Either the microtube emitter system (IDE-India) or Das (turbulent flow emitter) laterals were used in these tests. Das laterals were used only at sites where a tube well was the water source.

After completion of the drip lateral screenings and preliminary farmers' field tests described above, we established another 60 demonstrations/trials on small farms within almost every agro-climatic zone in the country in late 2007-early 2008. Locations were chosen according to the interest of our promotion staff and the perceived interest of farmers in those areas. Indian microtube systems were installed at most sites while laterals with extruded turbulent flow path emitters from Das Agroplastics were installed at about a third of the sites.

Unlike the previous year, elevated water tanks used for many of the 2007-08 on-farm demonstrations were prototypes of what came to be known as the "Water Basket". The Water Basket consisted of inexpensive plastic tarp material folded and riveted to form a cubical 200-gallon water container[9]. These tanks were elevated on sturdy 1.8-2.4 m (6-8 ft) tall bamboo or wooden stands and had to be enclosed with bamboo or wooden sidewalls (Figure 4, left).

All of these tests/demonstrations were custom installations (no kits) done directly by the authors together with local field staff as the technology was still unknown to both field staff and farmers. Drip was installed on a wide variety of crops including 9 different vegetables, 6 different fruit crops, 4 different flower crops and betel vine (*Piper betle* L.).

2008-09

On-farm demonstration has been the cornerstone of our drip irrigation promotion program from the beginning, and over 300 demonstrations and installations were conducted across the country during the 2008-09 dry season. While drip system components were provided free of charge to farmers in some areas who had never heard of drip, two-thirds of the total systems installed were sold to farmers already convinced of its value. These farmers and our staff also benefited from the draft publication of *Easy Watering in Six Steps--Drip Irrigation Installation Guide*, an illustrated booklet with simple start-to-finish instructions on how to install a small gravity-fed drip system.

Given the expense and difficulty of importing drip kits and components at the time, we concluded that *drip irrigation would never become economical and accessible to the majority of Myanmar's small farmers without access to inexpensive locally made products*. All of our installations now included components which we had designed and manufactured in-country including a simple punch and connector system for joining drip laterals to flexible pipe and an ordinary 25 mm (1-inch) plastic screen filter. The main or submain-to-lateral connectors were designed both to accommodate variable lateral tubing diameter and for easy installation and good fit in locally available recycled flexible plastic pipe. The connectors were also designed with very large (10 mm) inside diameters to reduce friction losses and increase flow in low pressure systems.

2009-10

After implementing significant system improvements based on our early 2009 system performance tests described above, the 2009-10 season marked the launch of the first drip set made entirely in Myanmar. Components of the new packaged sets are shown in Figure 5. The set was designed for typical installations of about 365 m^2 (3936 ft^2) of vegetables and other crops with typical row-to-row spacings of 1.2 m (4 ft). This was a size we considered large enough for local commercial plantings but still small enough to be affordable to smallholder farmers. In addition, a 20% introductory discount was offered that year as an extra incentive to new customers.

Figure 5. Main components of Proximity's packaged drip set, 2011.

Treadle pumps, Water Baskets, and main line pipe were sold separately but available through the same field staff and dealer shops. It was decided not to package and sell flexible pipe for main or submains as this material was bulky, expensive to transport, and generally available in small hardware and plumbing shops throughout the country.

Over 500 drip sets were installed by our field staff and agents during the 2009-10 dry season. In this first year of formal sales it was decided to target former customers who already owned treadle pumps. We assumed that many pump users would have earned extra cash and would be more interested in new products based on their experience with the pump and their relationship with us and our field staff. These farmers, while not the poorest

[9] The concept and initial design of the Water Basket came from Stanford University's "Design for Extreme Affordability" classes in 2006 and 2007 in collaboration with IDE-Myanmar. We manufactured over 4000 in May and June of 2008 to use for emergency water supplies in the aftermath of cyclone *Nargis*. The Water Basket remains a vital component of Proximity's low pressure drip systems. New self-supporting designs continue to undergo testing and improvement.

or the most risk averse, were much more likely to try this radically new and unfamiliar technology than those with absolutely no spare cash (or in debt) and who were unfamiliar with our products. This launch year also coincided with the first season in which we began offering product loans, and more than half of drip sales were as a result of these loans. The loan program turned out to be a two-edged sword, however, requiring a lot of time to administer by field staff who might otherwise have done more drip installations and on-farm demonstrations.

It has been our policy to provide an interested farmer a drip set or partial set free-of-charge in a new area in exchange for their willingness to take ownership of all other aspects of crop production and marketing while providing us with a minimal amount of feedback. Free demonstrations continued only in areas which had not seen a drip system and for the first time the majority of sets were *sold* by our field staff and dealer shops. These first drip sets were installed by our field staff with the full participation of the farmer, or in many cases, the whole family.

2010-11

Important changes in system components were implemented for the 2010-11 dry season as a result of the performance tests conducted in the spring of 2010. The new drip set included a newly-designed screen filter which greatly reduced pressure losses and all new fittings/pipes connecting the Water Basket to the main line. Even more importantly, Proximity's design team launched the entirely new and inexpensive plastic *Sin Pauq* (Baby Elephant) treadle pump, the first such pump designed for easy mounting above an elevated tank (Figure 4, right). This combination of Water Basket, *Sin Pauq*, and drip set--now with nearly all components optimized for low pressure operation--set the stage for rapid expansion of drip irrigation during the 2010-11 dry season and beyond.

RESULTS AND DISCUSSION

Drip system research and development

Lateral/emitter screening

Only a few examples of the results will be presented here. Figure 6 shows total marketable yields of mustard and leaf lettuce per 15 m (50 ft) bed. These data should be considered as only rough indicators of drip system performance and no firm conclusions are possible without further replication. It was obvious from these simple tests, however, that low to moderate flow rates from turbulent flow path emitter products (T-tape, Das, Adrilite) resulted in higher yields and better uniformity of densely planted leafy greens than from IDE-India (KB) microtube or Nepali 'baffle' systems with their very high flow rates (Figure 6). Some of the drip systems also resulted in yields equal to or slightly higher than sprinkler can watering for leaf lettuce, but not for mustard. Direct comparisons with sprinkler can watering, however, were beyond the scope of this study and no firm conclusions are possible.

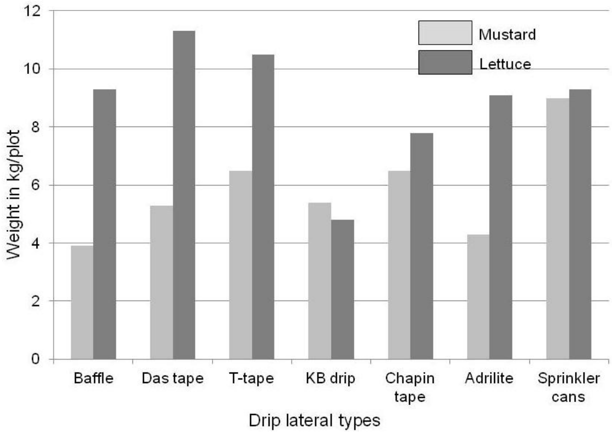

Figure 6. Relative marketable yields of mustard and leaf lettuce from 6 different drip laterals and sprinkler cans, Yangon, 2007.

The reasons why low flow rate drip laterals performed better became obvious as the season progressed. Both lettuce and mustard formed solid canopies of plants which completely covered the bed surface, and within these canopies it was easy to see that plants in rows farthest from the KB (microtube) and 'baffle' emitters were not receiving sufficient water. We believe this to have occurred because of the wide beds and high flow rates. Water behaves differently in soil at high and low flow rates; at high rates the soil matrix becomes saturated and gravity is the dominant force causing more downward movement of the water column. At low flow rates (Chapin, T-tape, Das) water moves more by capillary action through small pore spaces in the soil, resulting in water which is pulled in all directions and the formation of a larger wetted area. This would naturally result in more uniform plant growth across wide beds.

While we do not consider dense plantings of leafy greens in wide beds particularly suitable for drip irrigation because of the cost of multiple laterals, they were quick and easy indicators of emitter/drip system performance. If we had used only these preliminary findings, however, we might have selected a turbulent flow path emitter system as the best choice for Myanmar farmers. As it turned out there were other more important selection criteria including resistance to clogging and ease of manufacturing.

Figures 7 and 8 show water discharge rates for the 6 drip lateral/emitter systems with the leaf lettuce crop on 21 and 27 Dec. The *x* axis indicates the number of gallons remaining in the tanks while the y axis is the number of hours after beginning irrigation that day. Steeper lines indicate faster discharge and higher flow rates. The data shown in Figure 7 indicate more or less normal flow rates at low pressures from all systems. If we examine the lines on 27 Dec, however, it becomes clear that some clogging has occurred in three of the turbulent flow path emitter laterals including T-tape, Chapin, and to a lesser degree, Das (Figure 8). T-tape appears to have been partially blocked when the irrigation began and completely blocked 4½ hours later. Although a thorough flushing the following day resulted in better flow from these laterals, the problem persisted.

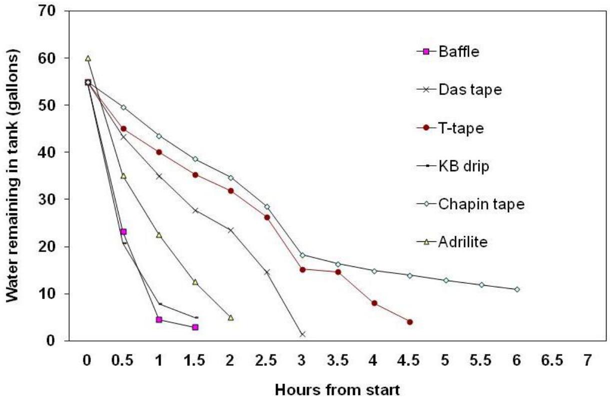

Figure 7. Water remaining in tanks 1½-6 hours after start of drip irrigation on leaf lettuce from 6 lateral types, Yangon, 21 Dec 2006.

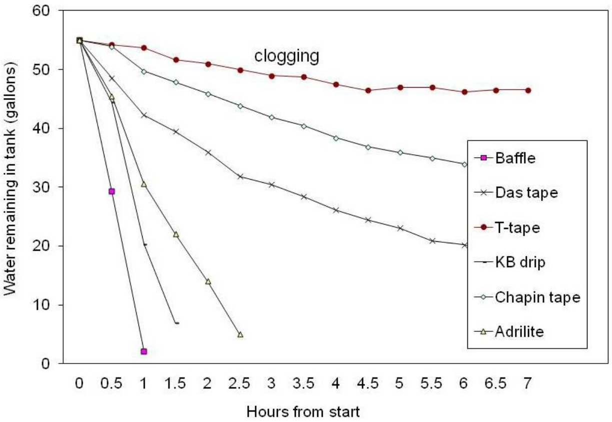

Figure 8. Water remaining in tanks 1-7 hours after start of drip irrigation on leaf lettuce from 6 lateral types, Yangon, 27 Dec 2006.

We continued to measure hourly flow from all treatments for a week after harvesting mustard on 10 March. By 15 March, 90% of the T-tape emitters were clogged, and by 16 March 60% of the Chapin emitters were partially or completely clogged together with 90% of Das emitters. Attempts to clean and re-use these laterals on a third crop were unsuccessful. It should be understood that we purposefully tested these systems under difficult conditions for drip. Water at the site was dirty surface water from a nearby city drainage canal; knowing that most local farmers could not afford expensive sand or disc filters, we used only simple 100-mesh screen filters in these tests. Under these conditions of inadequate filtration, all turbulent flow emitters (with the possible exception of Adrilite) became clogged after only two short-season crops or a period of about 70 days.

While Adrilite laterals appeared to be more clog resistant than other labyrinth flow path emitter products in our tests, this product has complex injection molded emitters that are installed during the extrusion process—a manufacturing process impossible to duplicate at this time in Myanmar. While IDE-Nepal's baffle emitter system was also resistant to clogging, we did not like its fixed emitter spacing nor the very small lateral pipe diameters which could limit its use in larger plantings. For these reasons we selected the microtube emitter system for further testing as it appeared to be the most robust in terms of clogging, was flexible in terms of emitter spacing, and would perhaps be the easiest to manufacture. We also decided to do further farmers' field testing of Das laterals the following dry season in situations with relatively clean well water.

System performance testing

2009. Significant limitations of our custom drip installations became apparent after extensive country-wide farmers' field testing during the 2007-08 and 2008-09 dry seasons. Customer satisfaction was reasonably good but somewhat less than expected with frequent user complaints of "not enough water" from emitters farthest away from the water tanks. In addition, nearly nothing was known regarding the size limits or water application uniformity of the system for given tank heights/operating pressures, main line diameters, and arrangements of laterals.

Only a summary of the most relevant conclusions from the early 2009 uniformity tests are included here. After comparing 1.2, 1.8, and 3 m (4, 6, and 10 ft) heights we chose to use a water tank height of 1.8 m (6 ft, height to bottom of the tank) used in conjunction with 32 mm (1¼-inch) flexible pipe for main and/or submains. Twenty-five mm (1-inch) pipe reduced flow and system performance considerably while the more expensive 38 mm (1½-inch) pipe did not offer sufficient advantages to justify its cost for a small drip system.[10] Several field arrangements of main, submains, and laterals were compared for best performance under low pressures.

These results were simplified as four 'good', 'better' and 'best' configurations shown in Figure 9 and Table 2[11] which were published in our installation guide. These results also led to the design and manufacture of new components for 2009 including two sizes of plastic 'T'-fittings used to join mains to submains (Figure 5). The tests also revealed significant gains in pressure and flow from removing the ordinary one-inch screen filter as was reported by some of our customers. We considered the advantages of having this basic filtration outweighed potential gains in pressure and system size, however, and all results published in our installation guide were from tests which included a screen filter. Filter problems were studied more in depth in the 2010 tests.

[10] These tests used locally available recycled PVC flexible pipe. Larger pipe diameters of this material is expensive and did not improve system performance in 2009 in part because of a small diameter Water Basket outlet used in those tests. Later tests revealed significant advantages if larger diameter LLDPE tubing could be used for main and submains.

[11] Results shown in Table 2 are those from the current (2011) edition of the installation guide.

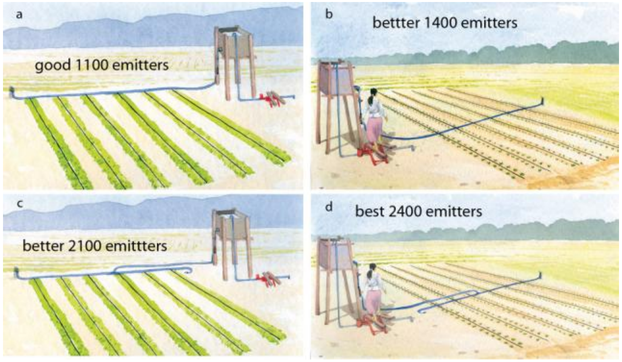

Figure 9. Illustrations used in the installation guide showing results of tests of drip field layouts.

Table 2. Maximum number of 15 m (50 ft) laterals and microtubes (MTs) possible with current drip system and 1.8 m (6 ft) height to water tank outlet using 32 mm (1.25-inch) main and/or submains with 30 cm (12-inch) spacings between microtubes.

Field layout	No. 15 m laterals	Max. no. MTs
side main, no “T”	22	1100
center main, no “T”	28	1400
side submain, with “T”	42	2100
center submain, with “T”	48	2400

2010. While the above tests resulted in a better functioning system that could be optimized in terms of field design, further studies were required after the 2009-10 dry season. The 2009 results were shared with Jack Keller in the interim who observed that we were losing most of our system pressure at some point or points between the elevated tank and the junction of the main or submain to the first laterals. A series of tests was subsequently conducted in early 2010 to try and pinpoint sources of these losses and to redesign the system to minimize them.

While eleven separate components were tested at moderate and low system flow rates for their effects on system pressures and water application uniformity, only the most important results are summarized here. It was found that rigid, nominal 25 mm/1-inch PVC (inside diameter is actually 32 mm or 1¼ in.) pipe functioned better than 30 mm/1¼-inch (30 mm actual i.d.) flexible pipe, at least for the first 60 cm (2 ft) below the water tank where the pipe joined the filter. To simplify installations we chose to use this rigid 1-inch PVC for the entire length of pipe required between the water tank and ground level, at which point 1¼-inch flexible pipe could be used as the main line without significant additional pressure losses. The old outlet used on the Water Basket was also found to restrict flow and was enlarged to 34 mm.

Filter testing and design. Many of these tests concerned high losses of pressure from our standard 25 mm (1-inch) screen filter which is of the same design used in most IDE and other small drip systems around the world. Losses were the same with this type of filter regardless of whether it was manufactured in India or Myanmar and amounted to nearly half (46%) of the total system pressure at low flow rates (Figure 10). This should not be surprising as these filters were originally designed for use with higher system pressures than are obtained from gravity systems using only 1.2-1.8 m (4-6 ft or 1.7-2.6 psi) header tanks. To resolve this problem we tested three filter designs mounted at the outlet *inside* the Water Basket and four prototype screen filters mounted in the usual position between the Water Basket outlet and the ground.

A summary of results comparing pressure losses from several of the filters and prototypes is shown in Figure 10. While all filters mounted inside the Water Basket performed well without significant losses, we decided not to use this type as they were difficult to remove for cleaning. The straight in-line external filter prototype shown in Figure 11a looked very promising with relatively low pressure losses (23% of total head) at low flow rates more typical of our drip set size (Figure 10).

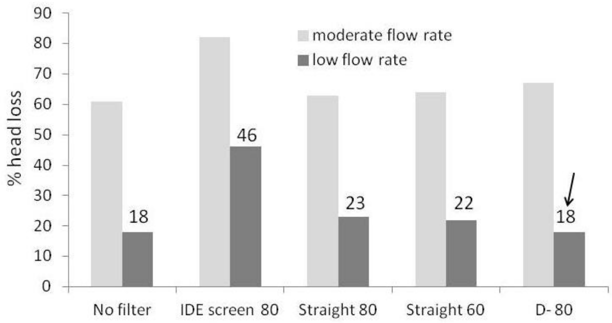

Figure 10. Relative pressure losses (%) from no filter, ordinary screen filter (IDE screen 80), straight pipe filter prototype, and new Proximity filter prototype (D-80).

A filter of this design, however, required that the entire filter body be removed from the line in order to clean the screen element. The prototype in Figure 11b was made to overcome this problem and performed just as well, reducing total head losses from 46% with the ordinary filter to only 18% (equivalent of no filter) while allowing easy access to the filter element for cleaning.

Based on these findings, Proximity’s design team developed the final form of the injection molded filter body shown in Figure 11c which has been used in all our drip sets since late 2010. While designed for tight friction fits with ordinary rigid PVC pipe and small drip systems, local farmers are also using it with flexible pipe submains at higher pressures for larger systems using motorized pumps. Since changing to this filter we have received no further complaints of pressure losses and almost never see drip systems in the field with the filter removed. The net result from these changes in the filter and other components was that with the same low system pressure we could now effectively irrigate over twice the area as the system used prior to the 2010-11 dry season.[12]

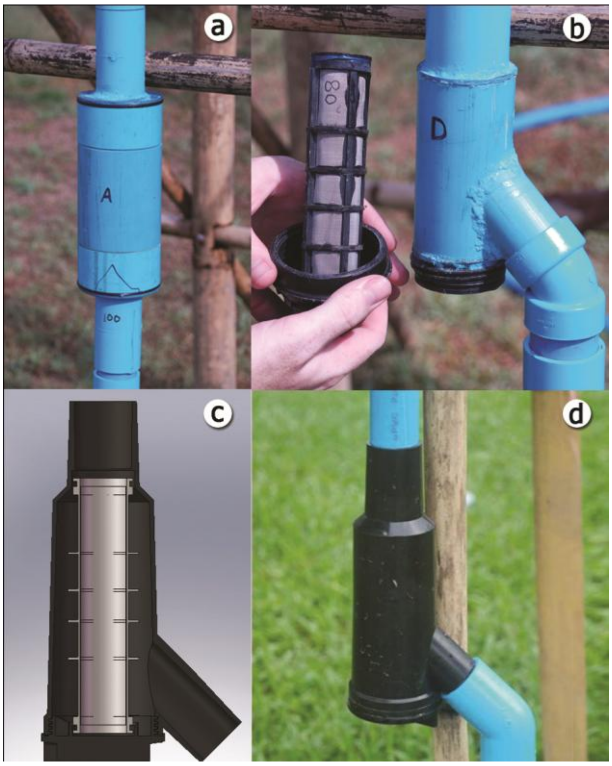

Figure 11. Screen filter prototypes straight (a), D-80 (b) and final product (c-d).

Low pressure drip system design software

While the 2010 tests resulted in significant improvements in low pressure drip system performance, we did not have time to determine exactly what these improvements meant in terms of system size, numbers of emitters possible, and field configurations like those shown in Figure 9. But instead of beginning another time-consuming series of field trials, we invested in software development to answer these and other questions. Weber and Tun Tun Khine conducted a series of field trials in early 2011 which resulted in a computer model for low pressure drip systems. The model is now being used to develop a user-friendly program (for PCs and possibly other portable electronic devices). Weber's model uses basic hydraulic principals along with measured characteristics of individual drip system components to show the effects of component design changes, main, sub-main and lateral diameters, various field layouts, and effects of inlet pressure on overall system performance. The new software is still being tested but will soon be released as a Proximity Designs irrigation product. It was used to determine the maximum number of emitters/laterals for different system configurations using new drip components and fittings first sold in the 2010-11 season. The results were published in the latest (2011) edition of our *Installation Guide* (Figure 9 and Table 2).

Large diameter main/submain system

In addition to drip system modeling, Weber and Khine tested larger diameter (64 mm or 2.5-inch) LLDPE layflat tubing from an IDE-India sprinkler set for use as drip main/submains with some of our existing system components. They obtained further reductions in pressure losses using this pipe which was not only considerably larger, but also has a much smoother inner surface than local flexible pipe. Both factors reduce losses from friction within the pipe, especially at higher flow rates in larger systems.

Further modeling using the software showed that a 51 mm (2-inch) diameter layflat size would be ideal in terms of pressure gains and maximum system size. Using a 51 mm/2-inch layflat main line, a tank height of only 0.6 m (2 ft) was enough for uniform application of water through a system the size of our current drip set. A height of only 1.2 m (4 ft) could uniformly irrigate a plot twice the size of our current set or 732 m^2 (7870 ft^2) of a commercial vegetable crop using 1.2 m (4 ft) row-to-row spacings.

Although using larger pipe requires redesign of several components including the main system valve and filter, the potential gains are significant. Not only will the new pipe be easier to store and transport, it should also be half the price of smaller diameter local flexible recycled PVC pipe while lasting just as long or longer. Our immediate goal is find or help establish another local LLDPE pipe manufacturer while making the required system design changes over the next two years.

Farmers' field testing, demonstration, and sales

The first season, 2006-07

Results of the early 2007 farmers' field trials were mixed and limitations of the systems tested quickly became apparent. Only about half the farmers were satisfied with system performance and some were quick to stop using it and return to watering with sprinkler cans. Those who had to fill elevated tanks by hand using sprinkler cans or other containers could not see any obvious advantages over watering with the cans directly. We concluded early on that *few farmers would adopt drip if required to fill an elevated tank (of any type) by hand*. Other farmers observed that water application was not uniform, especially when long laterals over 21 m (70 ft) were used; still others described the common fear that drip could not possibly supply enough water to their plants.

Other serious challenges observed during this first year included the old oil drum water tanks which were expensive, relatively small, difficult to transport, and difficult to fit with a proper outlet. So it was understood early on that two of *the most critical elements of simple and inexpensive low pressure drip systems would be a cheap and easily elevated water tank in combination with*

[12]The new system can easily irrigate two full drip sets (1200 emitters) or about 730 m^2 of vegetable crops with a CU of at least 80% and a height to the Water Basket outlet of 6 ft (1.8 m).

a treadle pump or other simple means of filling these tanks.

Iron problems

A more serious problem was observed at a tube well site in Hmawbi Township where Das drip laterals had been installed on a plot of chilis. Emitters in these laterals became completely blocked with iron precipitate within a month of installation; the same problem was observed at another site in Kungyangon. We have since learned that dissolved iron is a fairly common problem in well water in parts of Myanmar and now routinely test for it. We feared that without some simple solution to the problem, there might be large areas of the country where drip irrigation would not be possible.

Fortunately one of our field staff showed us a simple solution to this problem used by villagers in an area where iron-contaminated drinking water was commonplace. It is well known in that area that drinking water from local wells could be ‘cleaned’ by letting it pass through a simple container holding burned rice husks obtained from a local rice mill.[13] Using a commercial iron test kit,[14] we found that a 20-gallon container of burnt husks could remove high levels of iron almost instantaneously as the water passed through it. In our tests, water with 5 ppm iron was reduced to 0-1 ppm after passing rapidly through the filter. Taking advantage of this local technique, we manufactured simple 20-gallon containers made of tarp material with porous bottoms; these were filled with burnt rice husks and suspended between an elevated treadle pump and Water Basket. Drip is now used extensively with these filters in areas where the problem is severe and where we thought drip would never be possible[15].

2007-08

The second series of 60 on-farm tests with various crops during the 2007-08 dry season was more successful than the first with over half of the farmer-cooperators showing genuine interest in drip irrigation. An in-depth survey of drip users conducted in early 2008 indicated that 61% liked the system and planned to continue to use it next dry season. While we considered this an acceptable continuation rate for first time users (Commodity Growers Assn., 1998)[16], there were still perceptual and performance problems with the new system. Our survey indicated that the primary concern of 40% of the new drip users was insecurity about the amounts of water applied, i.e., they did not think drip could provide as much water as copious amounts from traditional sprinkler cans. Our installation team also spent a lot of time discussing crop water requirements with farmers who were trying drip, often explaining how equal amounts of water could be applied with drip as with traditional watering methods.

There were also cases of lack of application uniformity, usually resulting from less flow from emitters farthest from the elevated water tank. In addition, we recognized the urgent need for more drip irrigation training for field staff and for the development of drip-related educational tools and materials (Table 3) to use in conjunction with a strong and ongoing on-farm demonstration program.

An unexpected and frustrating hardware problem was the variable inside diameter of the LLDPE lateral tubing purchased from IDE-India. While nominally 16 mm, individual 100 m rolls of tubing varied widely, so much so that laterals would often not fit IDE-India’s own or other commercial lateral-to-main connectors designed for 16 mm tubing. The tubing was often either too large, requiring further securing with wire and resulting in very leaky connections, or in fewer cases was too small, not fitting onto the connectors at all.

During the course of the season we also observed more cases of emitter clogging of Das, “D-tape”[17], and even microtube emitters from iron in well water. While in most cases Das and D-tape did not clog when used for a single season with iron-free tube well water, *we decided not to continue to test or promote labyrinth flow path emitter laterals*. The decision was made in part because of the risk of clogging, but also because of the near term impossibility of setting up local manufacturing for these or similar products.

2008-2011 dry seasons

Over 300 custom drip systems were installed in the 2008-09 dry season followed by over 500 installations of pre-packaged small farm drip sets in their 2009-10 launch year. Over half of the ’08-09 installations were paid for with our product loans first offered in that year. The majority (over 70%) of systems installed after the 3rd season were also purchased with product loans administered by the same field staff who were promoting and installing drip systems. About this time, self-employed independent village “agents” began doing a few drip installations for small fees in some areas.

Our drip user survey conducted just after the third or 2008-09 season clearly indicated a growing satisfaction with the product and its performance with 79% now reporting their intention to continue to use drip compared

[13] Most rice mills in Myanmar are powered by stationary steam engines; rice husks from the milling process are burned as fuel for a boiler which supplies steam to the engine. The burnt residues from this process must be removed and discarded, and it is this material which is used for filtering iron. It is suspected that this material may contain activated carbon.

[14] Hach test kit model IR-18 (for 0-5 mg/l Fe), Hach Co., Loveland, Colorado, USA.

[15] Dissolved iron levels above 1.5 ppm are considered “severe” in terms of clogging hazard for drip irrigation.

[16] This study evaluated the impact of a long term on-farm demonstration program for drip irrigation with small commercial vegetable growers in Kentucky in the southeastern US. The authors reported 50-60% continuation rates for first time users.

[17] D-tape is the brand name for an extruded labyrinth or turbulent flow path emitter drip lateral available in Thailand. Its appearance is very similar to the Das product and may be manufactured using the same or similar machinery. We installed several systems using D-tape during the 2007-08 dry season.

Table 3. Drip irrigation publications and training materials developed for Myanmar*

Guidebooks and bulletins	**Date**	**Length**	**Language(s)**
Easy Watering in 6 Steps—Drip Irrigation Installation Guide. 3rd edition	2011	32 p.	Burmese and English
Drip Irrigation for Fruit Crops and Betel Vine	2010	20 p.	Burmese and English
Filtering Iron for Drip Irrigation in Myanmar	2010	2 p.	Burmese and English
Simple Fertigation for Drip Irrigation in Myanmar	2011	5 p.	Burmese and English
ET-based Water requirement calculators			
Water Wheel Calculator for Myanmar Vegetable Crops	2009	--	Burmese
Water Wheel Calculator for Myanmar Fruit and Tree Crops	2010	--	Burmese
Videos and clips			
Goodbye Sprinkler Cans	2010	4 min	Burmese, English subtitles
How Drip Irrigation Works	2010	5 min	Burmese, English subtitles
What Farmers are Saying about Drip Irrigation	2009	19 min	Burmese, English subtitles
Time lapse of water spread in soil from microtubes (loop)	2011	30 sec	(no soundtrack)

some of these will be available from our website: www.proximitydesigns.org

with 61% the previous year. The perceptions of drip also appeared to be changing as now only 10% of users surveyed reported that drip was 'not supplying enough water' compared with 40% after the 2007-08 season.

Questions about satisfaction with drip and Water Baskets were included in a new *Customer Care Survey* of 200 drip users conducted just after the 2009-10 dry season. Respondents were given four choices of "unsatisfied", "neutral", "satisfied", or "very satisfied" in answer to the questions and 88% were either "satisfied" (37%) or "very satisfied" (51%) with the ease of use of the product. More significantly, 91% reported that they had recommended drip to a friend or neighbor.

When asked about using hired labor for crop production before and after drip adoption, 59% reported that they had used hired labor prior to using drip while only 5% reported having hired labor after drip adoption. These farmers also reported that, prior to drip adoption, the made an average of 119 trips to the field daily using sprinkler cans. This amounts to a daily burden of carrying 4 tons of water to the field on their backs. We know from this and countless interviews with farmers that the *elimination of this heavy labor and the resultant time and energy savings are the primary motivations for adopting drip.*

Sales of drip systems jumped more than fourfold to over 2100 units during the 2010-11 dry season[18]. This can be attributed to a number of factors, not least of which was a new emphasis on drip promotion communicated to field staff by Proximity Design's leadership during the launch meeting at the beginning of the season. It was now clear that drip was a product that was here to stay and that all field staff were expected to actively promote it and conduct at least five on-farm demonstrations in areas where no drip systems had been used before.

Drip sales were also given a boost as a result of our first serious efforts to train self-employed village "agents" who in the past did local treadle pump installations for small fees. Many of these agents installed drip on their own plots after learning how to set up and operate a small system during their training program in Yangon. Given proper 'hands-on' training, these agents often became the first adopters in their communities where they are known and trusted. Nearly all these agents are farmers themselves and help begin the process of farmer-to-farmer observation and discussion which can result in further adoption without the same level of promotional efforts required of our full-time staff. They no doubt multiply the capacity of full-time field staff and will remain key players in the scaling up and further expansion of drip in Myanmar.

Other factors helping boost sales were the availability of credit through product loans and the launch of the easily elevated *Sin Pauq* treadle pump, sales of which skyrocketed in 2010-11, the year of its introduction. Last but not least, the drip system itself had undergone several major changes including a newly-designed screen filter and other components which significantly reduced pressure losses compared with ordinary filters and drip components designed for higher pressures. This year also saw the expansion of sales of individual drip components for larger drip systems using motorized pumps.

[18] This figure does not include a large amount of lateral pipe and fittings sold to customers who were expanding an existing drip set for larger plots or making their own systems using our components.

CONCLUSION

Based on hundreds of controlled tests and on-farm demonstrations conducted over the past five years, we have developed a robust, locally manufactured low pressure drip irrigation system which is becoming increasingly popular with both small and large commercial horticultural crop farmers in Myanmar (see *Appendix*). Over 5000 sets have been installed to date with 85% of these having been sold last season and during the first three months of the current (2011-12) dry season. These have been used on a very wide range of crops including 16 different vegetable crops, 14 fruit crops, 5 ornamental crops and 7 crops grown for other uses such as perfume, betel leaves and coffee.

We have created a market for not only a new product, but an entirely new system of irrigation for which none previously existed. While developing each component of the drip set to function well using very low system pressures was essential, this alone did not ensure success. We could not have developed a drip system in the Myanmar context in isolation and without substantive and concurrent efforts to develop affordable water containers and inexpensive pumps to fill those containers.

In has been our experience that the concept of drip irrigation is more difficult to sell than the hardware. We devoted a considerable amount of time and resources to develop training aids and tools which help change perceptions and which simplify and explain the technology to both staff and farmers unfamiliar with it. In the beginning stages at least, the scaling up of drip requires an extensive network of well-trained, field-based promotion staff and/or private agents who can comfortably explain, install, and demonstrate the technology in areas where it was previously unknown. Strong perceptual barriers must be overcome with effective practical staff training and on-farm demonstration (“seeing is believing”). It is especially important that these staff ensure success of the first adopters so that farmer-to-farmer diffusion can occur. Often overlooked is also the level of technical support/expertise required to ensure their success. This includes the ability to train key staff and counterparts, to solve problems as they inevitably arise, to experiment with system changes, and to produce appropriate educational tools and materials (Table 3) in support of the on-farm demonstration and training programs.

The importance of product loans or other credit cannot be underestimated, especially in countries like Myanmar where farmers currently have little or no access to low-interest agricultural loans. Although time consuming and difficult to manage in the beginning, the product loans made available to our customers since 2009 have accelerated adoption of drip and helped ensure more equitable access to the technology.

Our history of introducing drip in Myanmar has been one of slow growth--testing, improving, and demonstrating custom systems built with imported pieces and parts while gradually substituting locally made components as they were developed[19]. Only in the final stages were drip sets or ‘kits’ assembled and marketed with all locally made components (Figure 5). We are still at the ‘early adopter’ stage in many parts of the country and a generation may be required before the technology is well known and widespread. This poses a challenge to donors supporting social enterprise efforts and organizations implementing those efforts who may expect quick results and impact. It is hoped that the lessons learned and described in this paper will help others shorten the time and effort required to introduce drip in similar socio-economic settings.

Acknowledgements

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APPENDIX

Components of Proximity Design’s low pressure drip system

While we plan to implement further improvements over the next two years, the components of our current system are as follows:

[19] IDE-Vietnam is taking a similar approach in its efforts to introduce low cost drip in one of the poorest and driest provinces in the country.

1. 16 mm LLDPE lateral tubing (200 micron wall thickness) with 1-1.1 mm (inside diameter) microtube emitters

2. Low cost, large capacity (567-945 liter or 150-250 gallon) collapsible Water Basket header tanks with appropriate large diameter outlets and fittings for connections with drip system.

3. Low cost treadle pumps for filling header tanks. Treadle *pressure pumps* can be used at ground level to fill elevated tanks while ordinary suction treadle pumps must be mounted above the tank. The inexpensive plastic *Sin Pauq* pump is now the most popular pump used with our drip systems. All treadle pumps, however, are limited to suction heads of no more than 7.6 m (25 ft) or areas with surface water or relatively shallow groundwater.

4. Simple one-piece 'high flow' lateral-to-submain connectors with punch for easy installation and removal in flexible pipe. Connectors have large 10 mm inside diameters and variable (stepped) outside diameters to accommodate variations in lateral tubing diameter.

5. Lateral-to-lateral couplers to join ends of lateral tubing and for lateral repairs; inside and outside diameters are the same as the lateral-to-submain connectors above.

6. T-fittings for joining main to submains (designed for local 32 mm (1¼-inch) flexible pipe.

7. Large diameter main and submain pipes, main valve, and fittings. We consider nominal 32 mm pipe (1¼-inch with an inside diameter of approximately 30 mm) to be a *minimum* size for main and submain lines for small drip systems of up 0.1 ha (¼ acre). Larger systems are possible with valves and zoning and/or larger pipe diameters. All fittings between the Water Basket and main line have inside diameters of at least 28 mm and are included with either drip sets or Water Baskets.[20]

8. Low cost plastic 'flow through' screen filter. The configuration of this filter was designed to minimize pressure losses in low pressure systems while using a standard screen element which can be cleaned without removal of the filter body from the system. The filter body is designed for friction fits with 32 mm (1¼-inch) PVC pipe with large inlet and outlet diameters (34 mm and 30 mm, respectively).

9. An effective means of filtering dissolved iron from well water when necessary. This has been accomplished with dramatic results by passing water through burned rice husks before entering the primary water tank.

10. A highly illustrated and easy-to-read installation guide with which farmers can install a simple drip set without additional training (included with every Proximity drip set).

11. Easy to use *Water Wheel* water requirement calculators based on local ET and simplified crop coefficients (vegetables) or canopy shading (fruits). Not included in drip sets but used by field staff to help farmers estimate amounts of water to apply with drip.

[20]We plan to replace flexible recycled PVC main/submain pipes with cheaper 2-inch (51 mm) diameter LLDPE layflat pipe for use in both large and small drip systems.