Creating wealth from groundwater for dollar-a-day farmers: Where the silent revolution and the four revolutions to end rural poverty meet

Paul Polak · Robert Yoder

Abstract More than 550 million of the current 1.1 billion people earning less than $1-a-day earn a living from agriculture in developing countries. A revolution in water control is needed to develop and mass-disseminate new, affordable, small-plot irrigation technologies. A revolution in agriculture is required to enable smallholders to produce high-value, marketable, labor-intensive cash crops. A revolution in markets is needed to open access to markets for the crops they produce and the inputs they need to produce them. Finally, a revolution in design, based on the ruthless pursuit of affordability, is needed to harness shallow groundwater. The experiences of suppliers of treadle pumps, low-cost drip irrigation and water storage systems were examined. The wealth these technologies generated, coupled with falling prices for small diesel pumps in countries like India and China, created a suitable environment for the rapid adoption of affordable diesel pump tubewells, which in turn created vigorous water markets and expanded access to affordable irrigation water for smallholders. The combination of smallholder-centered revolutions, along with the 'silent revolution in groundwater' described by Llamas and Martinez-Santos (Water Sci Technol 51(8):167–174, 2005) provide new practical options for meeting the UN Millennium Development Goals on poverty and hunger by 2015.

Résumé Sur les 1.1 milliards de personnes qui gagnent actuellement moins de 1 $ par jour, plus de 550 millions tirent leurs revenus de l'agriculture dans les pays en voie de développement. Une révolution du contrôle de l'eau est nécessaire au développement et à la propagation de techniques d'irrigation nouvelles, abordables et à petite échelle. Une révolution de l'agriculture est essentielle pour permettre aux petits propriétaires de produire des cultures commerciales de qualité, commercialisables, et générant de la main-d'œuvre. Une révolution des marchés est nécessaire pour ouvrir les marchés aux récoltes qu'ils produisent et aux investissements dont ils ont besoin au préalable. Au final, une révolution conceptuelle, basée sur la recherche acharnée du moindre coût, est nécessaire pour exploiter les eaux souterraines peu profondes. Les expériences de fournisseurs de pompes à pédales, de systèmes d'irrigation goutte-à-goutte bon marché et de systèmes de stockage d'eau ont été analysées.

Couplée à la chute des prix des petites pompes diesel dans des pays comme l'Inde et la Chine, la richesse générée par ces dispositifs a constitué un environnement favorable à l'adoption rapide de puits tubés bon marché avec pompes diesel. Ceci a entraîné l'établissement de marchés de l'eau résistants et la démocratisation de systèmes d'irrigation bon marché pour les petits propriétaires. La combinaison de révolutions centrées sur les petits propriétaires et de "la révolution silencieuse des eaux souterraines" décrite par Llamas et Martinez-Santos (Water Sci Technol 51(8):167–174, 2005) génère de nouvelles alternatives fonctionnelles pour atteindre les objectifs du Millénaire pour le développement des Nations Unies contre la pauvreté et la faim en 2015.

Resumen Más de 550 millones de las 1.1 mil millones personas que actualmente ganan menos de US $1 al día, se ganan la vida trabajando en agricultura en los países en desarrollo. Se necesita desarrollar una revolución en el control de agua y unas nuevas tecnologías económicas, de irrigación para parcelas pequeñas. Se requiere una revolución en la agricultura que les permita a los propietarios de minifundios producir cosechas con alto-valor, comerciables y cuyo intenso trabajo se transforme en dinero efectivo. Se necesita una revolución en los mercados, que abra el acceso a los mercados para las cosechas que ellos producen y para las entradas que ellos necesitan para producirlas. Finalmente, se necesita una revolución en el diseño, basado en la búsqueda sin descanso de accesibilidad, para aprovechar el agua subterránea poco profunda. Se examinaron las experiencias de proveedores de bombas del pedal, de irrigación

Received: 7 October 2005 / Accepted: 24 October 2005
Published online: 21 February 2006

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P. Polak (✉) · R. Yoder
International Development Enterprises (IDE),
10403 W. Colfax, Suite 500, Lakewood, CO 80215, USA
e-mail: ppolak@ideorg.org
Tel.: +1-303-232-4336
e-mail: ryoder@ideorg.org

por goteo económica y de sistemas de almacenamiento de agua. La riqueza que estas tecnologías generaron, junto con los precios descendentes para las bombas pequeñas de diesel en países como India y China, crearon un ambiente conveniente para la adopción rápida de bombas diesel económicas para pozo, que a su vez creó mercados de agua vigorosos y expandieron el acceso al agua de bajo costo para irrigación, a los propietarios de minifundio. La combinación de revoluciones centradas en el propietario de minifundio, junto con 'la revolución silenciosa en agua subterránea' descrita por Llamas y Martinez-Santos (Water Sci Technol 51(8):167–174, 2005), dan nuevas opciones prácticas para lograr las Metas de Desarrollo del Milenio de la ONU, en cuanto a pobreza y hambre para el año 2015.

Keywords Irrigated agriculture · Treadle pumps · Drip irrigation · Small-holders · Water markets

Introduction: With business as usual, Millennium Development Goals will not be met

Today, 1.1 billion people continue to earn less than $1-a-day and 800 million continue to go hungry. The United Nations' Millennium Development Goals for 1990–2015 aim to reduce the number of poor and hungry people by 50% by the year 2015. With business as usual, these will not be achieved. From 1990 to 1999 the percentage of South Asians living in extreme poverty only decreased from 44 to 37%. In Sub-Saharan Africa over the same period, extreme poverty was only reduced from 48 to 47% (Sachs et al. 2005). Nothing less than a revolution in development theory and practice is required to achieve the millennium poverty and hunger targets.

With at least two-thirds of rural poor deriving their primary livelihood from agriculture, achieving the Millennium Goals will require finding ways to substantially increase small farm income potential. What is required is the immediate implementation of a series of practical, market-driven strategies to increase the income of poor people from $1-a-day to $3 or more. Seventy percent of $1-a-day people live in rural areas in developing countries. Ravallion projects that this will not fall below 50% until 2035 despite rapid urbanization (Ravallion and Chen 1997). At least two-thirds of rural poor people derive their primary livelihood from agriculture, which requires finding ways to substantially increase small farm income and profitability, which will in turn increase both employment and wage rates. Unfortunately, none of this can happen without the development community recognizing that the majority of worldwide poverty eradication efforts must center on farms smaller than 1 ha.

Practical solutions to rural poverty depend on increasing the profitability of smallholders

The single most important feature of $1-a-day farms is their extremely small size. From 1960 to 1990, the average farm size in India shrank from 2.7 ha to less than 1.6 ha, divided into 3–10 separate plots. The average farm size in Bangladesh in 1999 was 0.72 ha, down from 0.9 ha in 1983, and 70% of the farms are less than 1 ha (Shah et al. 2000). While farm size in Sub-Saharan Africa is somewhat larger, only 3% of cropland is irrigated (as against 40% in South Asia). For this reason, African land productivity is substantially lower than in Asia. Achieving the Millennium Goals for poverty and hunger reduction requires finding ways to substantially increase bottom-line profitability of 1 ha farms divided into separate 1,000-m^2 plots, the common plot division of smallhold farms. Primary focus on profitability dictates that smallholders must exploit their comparative advantage in the marketplace, which is the production of labor-intensive, high-value, marketable cash crops. Micro-irrigation is a powerful force in improving both the profitability of small farms and the income earned by farm laborers.

From $1-a-day to Middle Class

International Development Enterprises (IDE) has extensive experience with smallholders spanning 25 years (Postel et al. 2001). Current and past projects indicate that smallhold families can earn an additional annual income of US $500 (net) with the following scalable practical steps.

1. *Open access to water control for crops.* This requires farmer investment in affordable, small-plot water pumping, storage, and application technologies coupled with sufficient and available water sources.
2. *Increase yields and productivity of staple crops.* If farm size and climate permit, each small farm family can grow a 12-month supply of staple crops such as rice. Most smallholders are highly risk averse and are reluctant to invest in cash crops until they can grow enough staple crops to keep their families fed. IDE employs simple intensification techniques in several countries such as deep placement of fertilizer pellets in subsistence rice plots, which both lowers cost and significantly increases yields. If the risk of hunger is eliminated, most smallholders are ready to risk growing diverse, labor-intensive, high-value cash crops. Improving productivity of staple crops on small farms has a limit. As farm size keeps dropping below threshold farm size, it becomes impossible to grow enough wheat, rice, or maize to keep the family fed. For farms under 2,000 m^2, the only way to feed the family and move out of poverty is to produce and market high-value cash crops and use some of the generated income to address staple food deficits.
3. *Invest in labor-intensive, diversified, high-value marketable crops.* Labor rates in rural areas in the United States are 50 times higher than rates for rural areas in developing countries. To take advantage of the low labor cost, as well as the superior agricultural performance of small family farms, $1-a-day farmers must invest in growing high-value, intensively cultivated, irrigated cash crops. To lower risk, as future market prices are

 DOI 10.1007/s10040-005-0011-2

virtually impossible to predict, farmers most often prefer to grow four or five different high-value cash crops rather than one. Farmers in Maharastra, India, for example, have routinely earned net cash returns of US $500 per year from a variety of drip-irrigated crops such as pomegranate, sweet lime, baby banana, eggplant, and other vegetable crops during the dry season (Shivani Manaktala, IDE-India, personal communication, 2004).

4. *Exploit market opportunities and remove key constraints to market access*. Wealth creation for smallholders depends on access to local, regional, national, and/or export markets for high-value crops.

Four revolutions to end rural poverty

To make real progress in achieving the Millennium Goals on poverty and hunger, nothing less than four revolutions centered on the specific context of the 1,000-m^2 plots and 1-ha farms of typical smallhold families is essential. A revolution in water control is needed to open access for rural poor to income-generating, affordable, small-plot irrigation technologies.

A revolution in agriculture is needed to open opportunities for small farm enterprises to develop new varieties of fruits, vegetables, herbs, and other labor-intensive, high-value crops optimized for small farms as well as smallholder-based agricultural practices required to produce these high-value crops. A revolution in design, based on the ruthless pursuit of affordability, is essential to develop a new generation of income-generating technologies to serve the rural poor.

Finally, a revolution in markets is needed to create new markets providing smallholders access to affordable, small-plot irrigation, valuable agricultural inputs such as clean seed and fertilizer and providing new markets for the high-value crops they can produce.

A revolution in water control

Conventional Western water pumping, storage, and conveyance technologies are far too expensive to be affordable for most small farmers in developing countries and far too large to fit the needs of their small plots. The design and mass dissemination of a whole new generation of affordable small-plot irrigation technologies will have a more dramatic positive impact on the lives of the rural poor than the introduction of personal computers created in the West. But to fill this huge market gap, radically different new approaches to the design and dissemination of irrigation technology are required.

Just as the success of the Green Revolution was based on the adoption of large-scale Western irrigation technologies in developing countries, rapid expansion of irrigation contributes greatly to the adoption of high-yielding varieties of seeds. Operation and maintenance problems of large canal systems were addressed by a second irrigation revolution advocating farmer-managed systems. The extensive infiltration of water from canal systems increases groundwater levels and provides lower-cost access to groundwater irrigation through farmer investments in tubewells. Unfortunately, even the cost of a shallow diesel tubewell in Bangladesh in the 1980s started at US $500, which was far too expensive for $1-a-day farmers.

Affordability: Rather than starting with large expensive technology and assuming that it could be used effectively by smallholders, the *affordable irrigation revolution* starts with defining the irrigation needs on individual small farms and designing irrigation technology affordable to $1-a-day farm families, small enough to fit existing plot sizes and attractive enough to reach at least one million small customers through private-sector marketing.

Commercially-promoted drip irrigation systems, at US $1800 per ha (US $0.18 per m^2) for vegetable crops in India and substantially more in Sub-Saharan Africa, are far too expensive for smallholders (Keller et al. 2005). The same could be said for conventional water pumping and water storage technologies. Treadle pumps brought the entry level price for efficient pumping in Bangladesh down to just $25 from the original US $500 for a five horsepower (hp) diesel pump set available in the market. At present, low-head drip irrigation is now available for 4 cents per m^2 in India, down from 18 cents per m^2 for conventional high-pressure drip systems. Field experience in South Asia and Sub-Saharan Africa suggests that the tipping point for market take-off requires reducing the cost of conventional irrigation technology by roughly 80%.

Divisibility: A 40-kg bag of fertilizer or a 20-kg bag of seeds can be divided easily into any size that fits the customer's needs. Most mechanical technologies, like tractors or drip irrigation systems, are "lumpy" inputs because they cannot easily be divided into smaller pieces. Radical changes in the design process for irrigation technology are required to bring the effective size down to the scale of 1,000-m^2 and smaller plots. For example, a variety of low-cost IDE drip system is now available that starts at a 20 m^2 kitchen garden-sized system, at an entry level price as low as US $2.50 (Polak 2005a; see Fig. 1).

Expandability: To be attractive to small farm customers, small-plot irrigation systems must be available at an appropriate entry level cost and must fit small plots without modification. Each technology should ideally be infinitely expandable as farm income increases. A small farmer in India who invests US $8 in a new 200-m^2 IDE drip system that generates US $100 in new net income can seamlessly double or triple drip acreage size for the second season by re-investing some of the generated US $100 income.

Profitability and market attractiveness: Due to vast unmet need in the marketplace, a practical threshold for new small farm irrigation technology must show a net return of at least 100% on its purchase price (300% is more common) in one growing season and must command a market for the sale of at least one million units at an unsubsidized, fair market price. Repeated demonstration that shifting from rain-fed crops, using affordable irrigation to grow higher value crops for markets, significantly reduces

 DOI 10.1007/s10040-005-0011-2

Fig. 1 Photograph of a 20 m^2 "Family nutrition kit" irrigation system that sells for $2.50

livelihood risk for $1-a-day farmers. This is a compelling reason for farmers to shift their focus.

A revolution in agriculture

A revolution in agriculture comparable to the Green Revolution is needed to customize production of high-value labor-intensive cash crops like fruits, off-season vegetables, herbs and medicinal plants, to the specific conditions of 1-ha farms broken into multiple plots. A process developing new, high-yielding varieties of marketable cash crops, optimized for smallholdings, is an important part of this new approach to smallholder agriculture. Accomplishing this will be a major challenge, given the current focus of agricultural research on optimizing the productivity of staple crops.

A revolution in design

The revolutions in water control, agriculture, and markets required to meet the Millennium Goals on poverty and hunger cannot take place without the design and mass dissemination of a new generation of affordable technologies capable of improving the livelihoods of the rural poor.

Affordable design makes the revolutions in agriculture, markets, and water control feasible. It is no accident that the tipping point for sales of technologies like treadle pumps and low-cost drip systems occurred when IDE reduced the price to one-fifth of that of comparable devices. Because of this, the term "Factor Five Design" describes the ruthless pursuit of affordability key to effective design for poor customers. This process systematically designs around key contributors to cost for existing technologies and identifies tradeoffs between efficiency and affordability acceptable to customers to break through cost barriers.

An obstacle facing the design revolution needed for eradicating poverty is that students get little or no exposure to affordable design principles. Students graduating from university design courses in developing countries are too often expected to use their education to garner government jobs, providing no opportunity to design affordable solutions to village problems. In the West, 90% of the graduates of design schools focus their time on solving the problems of the richest 10% of the world's customers. To design products and services to meet the needs of the three billion customers earning less than $2 per day requires a revolution in the way design is taught, both in the Western and developing countries. Finally, an organizational structure is needed to harness the creative energy of 10,000 of the world's current designers in a process of finding practical solutions to village problems (Polak 2005a).

A revolution in markets

Markets provide institutional structure for transactions in which smallholders are buyers and/or sellers. Small subsistence farmers in Cambodia, purchasing ammonium nitrate fertilizer and able to occasionally sell surplus rice, are participants in the market. Millions of peri-urban farmers in Sub-Saharan Africa, who irrigate 400-m^2 vegetable plots with watering cans and carry vegetables to the village market, are participants in the market. The critical question for smallholders is not whether they participate in markets, but how they can more effectively identify and capitalize on their comparative advantage in the global marketplace.

 DOI 10.1007/s10040-005-0011-2

Most rural markets in developing countries are hazardous for smallhold farm families because they have more obstacles to overcome than mature Western markets. Some obvious reasons include corruption, scarcity of credit, and frequent absence of protection of intellectual property rights. A series of economic studies are needed to more fully understand and remedy rural markets in developing countries that function so inefficiently. The symbiotic relationship between entrepreneurs and markets that works well in Western markets, providing wealth for one side and efficiency for the other, appears to operate sluggishly in village markets. As village markets provide huge untapped opportunities for entrepreneurial investments, opportunities remain. Experience demonstrates that the most effective way to put critical inputs like treadle pumps, low-cost drip systems, fertilizer and high quality seeds into the hands of smallholders is through the stimulation of a profitable private sector network of manufacturers, rural dealers, and technicians (Heierli and Polak 2000). There also exist huge unexploited opportunities to create new markets for the high-value products produced by smallholders.

The saying "If you build a better mousetrap, the world will beat a path to your door" is as false in the rural marketplace in developing countries as it is in mature markets. Each player in the private sector supply chain becomes profitable only when threshold sales volume is reached. A public or private sector investment in promotion and marketing, three times as large as the investment in technology development, is a necessary condition for opening small farmer access to affordable small-plot irrigation devices (Heierli and Polak 2000).

In Zambia, one-third of the proceeds smallholders receive from the sale of their vegetables goes to transporting them from the farm to the nearest road. This obstacle provides opportunities for short-haul rural entrepreneurs. Until this market gap is filled, smallholders will continue to pay excessively high prices for short haul transport. Supermarkets, both in developing countries and in Europe, are playing an increasingly dominant role in markets for fruits, vegetables, and other high-value crops that can be grown advantageously by smallholders (Reardon et al. 2003). To effectively gain access to supermarket buyers, smallholders may need training to meet new quality standards. Mechanisms to aggregate smallholder production to meet market volume requirements through strategies like co-operative (co-op) formation or equitable contract farming are even more important.

The price a smallholder receives for a high-value crop may only be a tiny fraction of its eventual retail price. Applying the principles of affordable design to the development of small, decentralized value-added village processing plants provides opportunities for increasing smallholder income as well as adding rural jobs, but they must effectively exploit a profitable niche in the marketplace. Lemon grass, for example, is a frequently grown crop in India and Sub-Saharan Africa, commonly used to season Asian dishes. But lemon grass oil (citronella) has a high-value use in cosmetics. A bottle of citronella sells at a retail price of US $14 per ounce ($493 per kg). Several extraction methods exist with increases in capital cost and efficiency of oil extraction from each one to the next. The cheapest and least efficient is hot water extraction, followed by steam, chemical extraction, and CO_2 extraction. Would small, village-based steam extraction workshops partially or wholly owned by a smallholder co-op, and funded by social venture capital, be profitable and provide economic advantages to smallholders and landless laborers? This prototypical question applies to products as diversified as roasted, vacuum-packaged Arabica coffee and partial processing of paprika. IDE's experience in establishing profitable decentralized processing enterprises producing desiccated coconut for the confectionary industry in Vietnam (Salter 1998) and dried Brazil nuts in the Amazon Rainforest for Ben and Jerry's ice cream in Vermont (Polak and Edesess 1992) suggests that similar opportunities for adding value at the village exist.

Silent groundwater revolution intersection with four revolutions to end rural poverty

In the past 50 years, millions of farmers worldwide gained access to irrigation water by investing their own money in wells that tap aquifers. In India, for example, groundwater now serves 50% of irrigated land and groundwater abstraction structures have grown from 4 million in 1951 to nearly 17 million by 1977 (Indian Water Resources Society 1999) and these numbers have increased significantly by 2004 (Shah 2004). This market-driven groundwater development approach to irrigation expansion has remained largely unregulated by government water agencies, but has made disproportionately high contributions to agricultural productivity per unit of irrigation water ('crop per drop'). This new phenomenon has been referred to as "the silent groundwater revolution" by Llamas and Custodio (2003) and Llamas and Martinez-Santos (2005). What, then, is the relationship of this silent groundwater revolution to the 800 million poor people in rural areas deriving their livelihood from farming? How many have moved out of poverty as a result of it?

The first step out of poverty for the 800 million $1-a-day people is gaining water control for their crops. Unfortunately, hundreds of millions of smallholders in places like Uttar Pradesh are surrounded by brown dry fields during the dry season when vegetable prices are the highest, with groundwater trapped just 5–6 m below ground. Unless they can gain access to that groundwater, at a price they can afford, obstacles to success are too great. Many of the wells, the basis of the silent revolution, have been too expensive for smallholders. For many smallholders, the most affordable source of irrigation water is shallow groundwater. Over the last 25 years, the advent of the treadle pump, low-cost 3–5 hp diesel pumps such as those now being widely exported from China, and the rapidly growing water markets they have created, show great promise for bringing affordable, shallow groundwater to $1-a-day smallholders.

 DOI 10.1007/s10040-005-0011-2

Shallow groundwater and affordable smallholder irrigation in river deltas

Many of the major river delta areas like the Gangetic delta areas of Bangladesh, Nepal, and Eastern India, have dry seasons when water is unavailable to smallholders despite its abundance in shallow aquifers. In countries like Bangladesh, where the majority of irrigation water comes from groundwater rather than canals, the critical constraint in smallholder access to groundwater is affordability of water-lifting devices. The shallowness of water tables in many major river deltas makes it possible to design water-lifting devices that are affordable, but the crucial role of affordability in irrigation has not often been highly valued in practice. In Bangladesh in the 1980s, for example, the World Bank subsidized mechanized deep and shallow tubewells, which expanded acreage under irrigation but disenfranchised farmers cultivating small plots (Polak 2005b).

Much of the rapid expansion of traditional canal irrigation in the last half of the twentieth century provided new access to shallow groundwater as a result of canal leakage. Farmers who could not rely on the regular supply of irrigation water by canal, either because they were tail-enders or because they had no access to canal irrigation, could gain access to dependable irrigation water by investing in wells. Once again, affordability remained the major barrier to $1-a-day farmers and, as water-lifting technology got cheaper or water markets were created by diesel pump farmers selling excess water, they have also begun to gain access to affordable irrigation.

Affordable water-lifting devices from shallow aquifers

In the last 25 years, affordable water-lifting devices like the treadle pump and dramatic breakthroughs in the affordability of small diesel pumps have begun to break the affordability smallholder access barrier to the economic benefits available from the groundwater revolution.

Treadle pumps: Experience over the last 15 years with treadle pumps provides a powerful illustration of the kind of positive impact on poverty eradication that can be triggered by widespread adoption of affordable small-plot irrigation technologies. In the 1980s, the World Bank had invested in a deep and shallow tubewell initiative in Bangladesh that made available subsidized diesel pump sets capable of irrigating 2–20 ha. While these initiatives were successful in expanding irrigated acreage, they had a negative, or at best neutral, effect on poverty because they tilted access to irrigation toward larger wealthier farmers. IDE began a project to mass market treadle pumps that had been designed by Gunnar Barnes and introduced by the Rangpur Dinajpur Rural Service, the development organization he worked for, to improve the productivity and income of small farmers in Northeast Bangladesh (Orr et al. 1991). As with other forms of affordable small-plot irrigation, farmers themselves were key players in the evolution of the technology. The unsubsidized retail cost of a treadle pump and the tubewell it is installed on is US $25, compared with the US $500 cost of the cheapest diesel-powered pump and tubewell assembly available at the time it was introduced. The treadle pump is a suction pump powered by human energy that activates two reciprocal cylinders through a walking motion on two bamboo or metal treadles.

In the late 1980s, with support from the Canadian International Development Agency (CIDA) and later the Swiss Agency for Development and Cooperation (SDC), IDE implemented a program to stimulate the rural mass marketing of treadle pumps through the local private sector. The marketing program IDE developed consisted of a network of 75 manufacturers, several thousand village dealers, and several thousand village well drillers who graduated with a certificate from a 3-day IDE training program. This program focused on a variety of marketing and promotion activities aimed at increasing sales volume. These included wall posters, troubadours performing at village markets, rickshaw procession, and a 90-min entertainment movie with the treadle pump in a central role that played to an audience of a million people a year (Heierli and Polak 2000).

The economics of the treadle pump program in Bangladesh provided an instructive illustration of the leverage made possible through the wide-scale dissemination of affordable small-plot irrigation technologies. Over a 15-year period, 1.5 million treadle pumps were purchased and installed by small farmer customers at an unsubsidized fair market price. The total donor investment in IDE's treadle pump development and dissemination program, provided by CIDA and SDC activities, was US $10 million. Donor funds leveraged an investment of US $40 million by smallholders themselves, who purchased the pumps and wells. This small farmer investment continues to generate a net return of US $150 million each year for these $1-a-day farmers who purchased the pumps (Sauder 1992; Shah et al. 2000; Lipton 2001; SOMRA-MBL 2003).

Another 500,000 treadle pumps have been disseminated by IDE in India, Nepal, Cambodia, and Zambia. Meanwhile, Enterprise Works Worldwide has disseminated treadle pumps in Francophone West Africa (Perry and Dotson 1996) and KickStart (formerly ApproTEC), a development organization disseminating treadle pumps through the private sector in Africa, has sold some 35,000 treadle pumps in Kenya and Tanzania (Martin Fisher, KickStart, personal communication, 2004). FAO and many other organizations are now involved in treadle pump programs in a variety of countries in Asia and Sub-Saharan Africa (Kay and Brabben 2000; Bielenberg and Allen 1995).

The global impact of treadle pumps on the alleviation of rural poverty is unmistakable. But does this represent one unusual high-impact technology that can never be repeated, or does it represent the tip of the iceberg in a whole host of high-impact affordable small-plot irrigation technologies for smallholders?

In the 1980s, the cheapest diesel pump available to pump groundwater in Bangladesh costed in the range of US $500. Because this price was out of the reach of the vast majority of $1-a-day smallholders, the popularity of treadle pumps

DOI 10.1007/s10040-005-0011-2

soared. When the government of Bangladesh removed import duties on diesel pumps from China and the price of the smallest Chinese diesel pump-sets dropped steadily, farmers could purchase a preferred mechanized 3 hp diesel pump-set for a price in the range of US $150. With 1.5 million treadle pump farmers earning at least an additional US $100, and some 300,000 of them earning an additional US $500 net annually, combined with the precipitous drop in price of diesel pumps, rapid growth in sales of low-cost diesel pumps in Bangladesh have led to a gradual decline in treadle pump sales.

From treadle pumps to water markets

Hundreds of thousands of smallholders in areas like Bangladesh and Eastern India now own small diesel pumps bringing water out of shallow aquifers. As a 5 hp diesel pump produces enough water for 2 ha or more of vegetables and most farmers need to irrigate less than half of that, they had excess water to sell. Smallholders, who still could not afford a treadle pump, with a neighbor with a diesel pump, were faced with monopolized water markets. As more diesel pumps were installed, more smallholder buyers of irrigation water had two or more neighboring diesel pump owners with water to sell. Competitive market forces brought the price of irrigation water down. In both Bangladesh and India, IDE's field experience demonstrates that as water markets develop, demand for treadle pumps decreases. Twenty years ago, villagers in Bangladesh reported that just 30% of small farmers in the village had access to affordable irrigation water. In 2003, the reported percentage had increased to between 70 and 100% (Nanes et al. 2003).

Irrigation application technology for dollar-a-day smallholders: Low-cost drip irrigation

Increasing ‘crop-per-drop’ in the Semi-Arid Tropics increases in importance with growing water scarcity. The adoption of efficient irrigation water application technologies for smallholders has been hampered by high cost and limited divisibility. Unfortunately, efforts to reduce the cost were never widely adopted. Thirty-five years ago, after receiving drip irrigation equipment from Mexico, Chou En-Lai sponsored an initiative to lower the equipment cost so that it could be widely adopted in China. The resulting micro-tube systems developed at the Yanshan Institute by Qui Wei Duo and his colleagues were widely tested on greenhouse crops, fruit trees, and wheat planted in rows but have never been widely adopted in China (Qui WD, Yanshan Institute, personal communication, 1999). In the United States, Dick Chapin, whose company pioneered the use of drip tape, began introducing $12 kitchen garden bucket kits in Africa in the 1980s (Chapin Living Waters Foundation 2006).

IDE began applying what it had learned from treadle pumps to the design and private-sector marketing of low-cost drip systems in Nepal in the 1990s with a shiftable drip system using simple punched holes for the outlets with baffles over them (Polak et al. 1997), and IDE India developed a micro-tube-based system (Postel et al. 2001). A significant feature of low-cost drip systems is the pressure head operation of only 1–3 m, thus water can be supplied from simple tanks supported 1–2 m above the ground. Small farmers created a drip irrigation system price breakthrough for pre-monsoon cotton using very clear, thin-walled “Pepsi” lateral lined tubing (Verma et al. 2004) with wall-puncturing pinholes delivering water to each cotton seedling. The system lasted approximately 6 weeks, which worked well for pre-monsoon cotton but did not last long enough for crops like vegetables. IDE India engineers then strengthened the “Pepsi” system by adding carbon black to retard deterioration from sunlight and used high-quality linear low density polyethylene for the lateral lines. Varying wall thickness made it possible for smallholders to choose the life and cost of the system to fit their needs.

Configuration of low-pressure, low-cost drip system

IDE low-cost drip systems in India are now selling at about one-fifth the cost of conventional systems for an unsubsidized price of US $360 per ha. Systems are purchased for as little as US $2.50 for a 20-m^2 kitchen garden kit (see Fig. 2). Similar to treadle pumps, low-cost drip systems are made available to small-farm customers through a private sector network of manufacturers, village dealers and farmer-technicians, who install a one-acre drip system in 2 days for US $4. The tipping point for sales occurred at the point where the retail price dropped to one-fifth that of conventional systems. Sales in India were projected to be 30,000 systems in 2004. Well over 100,000 IDE low-cost drip systems have already been purchased by small farmers in India, Nepal, Sri Lanka, and Zimbabwe, and the introduction of low-cost drip systems opens up the possibility that newly installed village household water systems can pay for themselves by being combined with drip irrigated high-value horticulture plots (Polak et al. 2004a). It is clear that conventional quality standards must be adjusted to small farm conditions (Keller 2002). Rapid initial adoption curves suggest that eventual adoption of low-cost drip systems will significantly surpass that of treadle pumps. As far as poverty eradication for smallholders is concerned, low-cost drip systems have the added advantage of facilitating improved crop quality, as well as ‘crop-per-drop’, lending themselves to agricultural intensification and the cultivation of high-value marketable crops (Keller et al. 2001).

The tip of the iceberg for smallholder irrigation

Some two and a half million small farmers in the world have already purchased treadle pumps, and market demand for technologies like low-cost drip systems and low-cost

 DOI 10.1007/s10040-005-0011-2

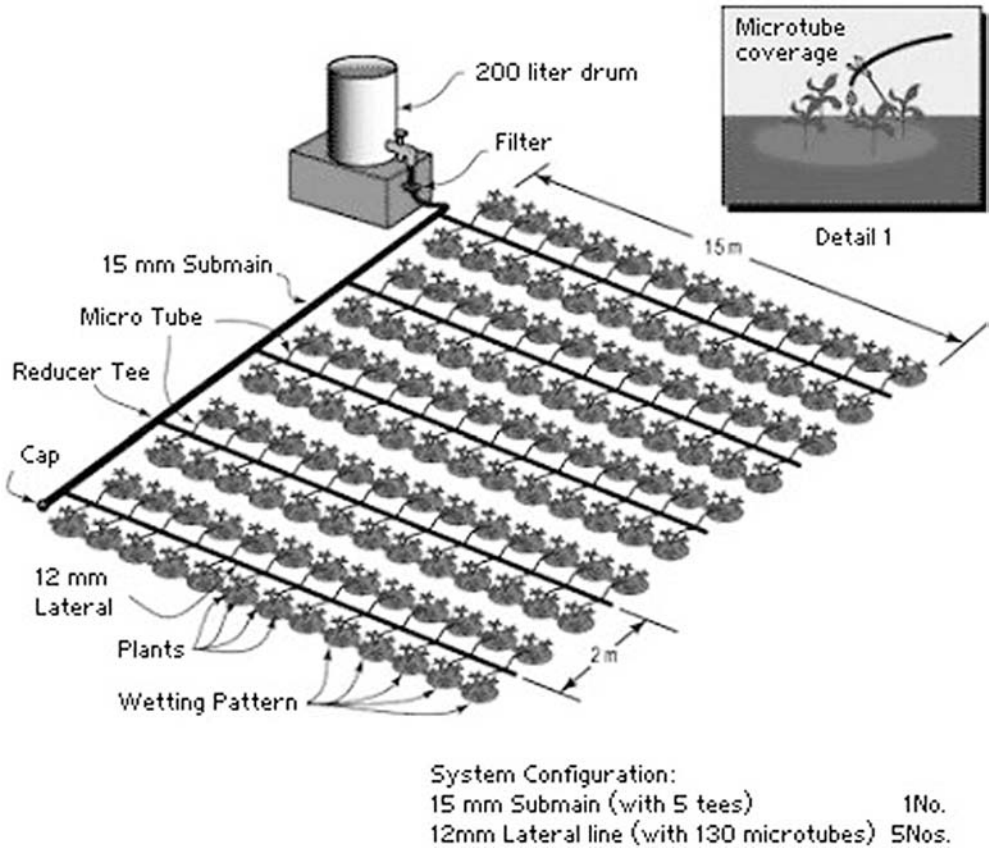

Fig. 2 Schematic diagram of a low-pressure drip irrigation system

water storage is likely to far surpass the adoption of treadle pumps. But the main lesson to be learned from this early experience is that these initial technologies only represent the tip of the iceberg; a whole range of affordable smallholder irrigation technologies is still waiting to be developed. Jack Keller and IDE engineers are working on the development of a range of affordable low pressure small-plot sprinkler systems, for example, as well as a low-cost improved uniformity surface irrigation system for small farms, and IDE India is working on a 0.6 hp US $100 diesel pump. A whole range of affordable small-plot irrigation devices remains waiting to be developed.

Low-cost water storage: In many semi-arid areas, the majority of annual rainfall occurs in a few monsoon months consistent with rain-fed agriculture schedules. As irrigation water is either scarce or not available during dry months, when growing conditions are quite favorable and vegetable and fruit prices are at their highest, small-scale farmers are not able to compete at market. Capturing and storing monsoon rainwater for future use is constrained by the relatively high price of conventional water storage systems. The cheapest ferro-cement tank costs a rupee (slightly more than US 2 cents) per liter in Mahrastra, India. IDE is now field-testing in Maharastra a 10-m long, 1-m diameter, double-walled plastic tube that rests in an earthen trench. If these field tests are successful, IDE anticipates retail cost of US $40, one-fifth the cost of existing ferro-cement storage, for a 10,000 liter, enclosed water storage tank system (Polak et al. 2004b). Low-cost storage systems can be used to drip irrigate vegetables at the driest time of year when prices are the highest or can be used to store a 12-month supply of drinking water for a family of five. Initial farmer response indicates that if the field tests prove successful, low-cost water storage will have a small-farm customer demand in the private sector comparable to that of low-cost drip.

Summary and conclusions

While the groundwater revolution has made major contributions to 'crop-per-drop' and 'jobs-per-drop' productivity through irrigation and its share of global irrigated acreage is rapidly increasing, it would be a mistake to assume that its accelerating prominence as a source of irrigation water will inevitably lead to poverty eradication. Affordability remains the key constraint in access to shallow groundwater by the dollar-a-day smallholders who form the backbone of rural poverty. The provision of subsidies for deep and shallow groundwater tubewells in the 1980s in Bangladesh made for significantly increased national irrigated acreage and rice production. But it adversely affected the poverty of small farmers who lacked access to both the subsidy and the water it produced, and lost ground to the larger farmers who benefited. The rapid adoption of one and a half million treadle pumps in Bangladesh, on the other hand, added a net US $150 million per year to the income of dollar-a-day farmers, and also contributed to national food production.

 DOI 10.1007/s10040-005-0011-2

The key difference lies in the affordability and therefore the accessibility of groundwater for the rural poor.

Access to affordable irrigation water is usually a necessary but not sufficient condition for effective poverty alleviation in rural areas. To move out of poverty, dollar-a-day smallholders need to successfully negotiate a change from a single-minded focus on subsistence crops to a major new focus on producing the labor-intensive high-value crops like fruits, vegetables, and herbs that provide for a comparative advantage in the marketplace. To accomplish this, they need to gain access to inputs, credit, and new intensive agricultural methods customized for 1 ha farms and 1000 m^2 plots. Finally, they need to gain access to sustainable markets for the diversified high-value crops they produce. To make this possible, a whole new generation of affordable irrigation and value-added processing technology must be developed, and new markets created to provide sustainable smallholder access to them. The groundwater revolution can make an irreplaceable contribution to poverty eradication for smallholders, but only if it is integrated with approaches that provide affordable access to irrigation water for smallholders. To achieve its enormous potential contribution to rural poverty alleviation, the groundwater revolution must be integrated with simultaneous smallholder-centered revolutions in water control, agriculture, markets, and design.

Acknowledgements We would like to thank Alison Sides, Communications Manager, and the rest of the IDE-International staff members for their assistance and review of this paper.

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