Low Water Saving Technologies
Some Experiences from Literature and Field

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1. Introduction

Fast becoming a rare commodity, water is undoubtedly the *sine qua non* for all irrigation activities, worldwide. In India, particularly, an unpredictable monsoon coupled with an increasing demand for food production (at the self-sustenance as well as commercial levels) has induced an imperative need for irrigation options other than those that are either extremely laborious and time consuming or simply too expensive for the small and marginal farmer. So, while the rich farmer banks on costly systems such as electric and diesel pumps to extract groundwater for irrigating their large acres of land, the small and marginal farmer has no option other than using the tedious traditional water lifting devices, such as *tenda, dhekuli, sena, tar* and *don* to irrigate their smallholdings. The present study looks at water saving technologies through literature, experiments and other attempts to save water in North-west and North India.

There were no systematic attempts in the past to assess the spread for water-saving irrigation technologies in India. The reported area under drip irrigation was mere 7000 hectares in 1994. The most recent data available on the extent of use of micro irrigation devices is the data compiled by International Commission on Irrigation and Drainage (ICID) shows that India has a total of 9.185 lakh hectares of cropped area under drip and sprinkler irrigation, of which 2.6 lakh hectares are under drips[1]. Major problems in the slow rate of adoption of drips are high initial cost, clogging of drippers and cracking of pipes, lack of adequate technical inputs, damages done by rodents; high cost of spare

[1] See: www.oznet.ksu.edu/sdi/News/Whatisnew.htm.

components and insufficient extension education. The National Committee on Irrigation and Drainage says salinity hazards are also there. Difficulty in inter-cultivation was found as another reason for non-adoption along with joint ownership of wells as another reason for non-adoption. Task Force on Micro Irrigation in India shows that in the recent times, peninsular India had recorded highest growth in adoption of drip irrigation systems. Maharashtra ranks first, followed by Andhra Pradesh and Karnataka. Table 1 presents the data of adoption of drip irrigation systems under various programmes, viz., macro management plan; technology mission on horticulture; cotton development program and oil palm development program.

Table 1: Rate of Adoption of Micro Irrigation Systems during 2001-05 under various programs

Name of State	**Area Under Micro Irrigation Systems**				
	2001-02	2002-03	2003-04	2004-05	Total
Andhra Pradesh	9117	4227	12	4200	17556
Arunachal Pradesh	110	100	248	500	958
Assam	22	16	17	350	405
Bihar	500	141	0	0	641
Chhatisgarh	444	227	0	100	771
Goa	70	48	0	305	423
Gujarat	2130	2109	1035	3650	8924
Haryana	226	0	236	230	692
Himachal Pradesh	111	85	0	0	196
Jammu and Kashmir	0	5	30	0	35
Jharkhand	179	0	0	0	179
Karnataka	9480	397	2635	4219	16731
Kerala	939	457	180	488.88	2064.88
Madhya Pradesh	1190	1007	200	375	2772
Maharashtra	14391	6875	248	844	22358
Manipur	10	20	25	100	155
Meghalya	28	0	55	60	143
Mizoram	0	50	20	450	520
Nagaland	60	55	100	50	265
Orissa	250	0	285	650	1185
Punjab	0	80	0	0	80
Rajasthan	1400	1000	1700	1200	5300
Sikkim	30	30	0	50	110
Tamil Nadu	814	635	25	1986	3460
Tripura	118	0	278	300	696
Uttar Pradesh	454	264	0	235	953
Uttaranchal	100	100	0	0	200
West Bengal	0	0	0	99	99

Source: Task Force on Micro Irrigation, Ministry of Agriculture, Government of India.

The major crops for which drip systems are currently adopted are: cotton, sugarcane; banana and orchard crops namely orange, grapes, pomegranate, lemon, citrus, mangoes, flowers, and coconut. Though exact state-wise data on the spread of sprinkler systems are not available, it has been found that sprinkler systems are in vogue in regions where conditions are unfavourable for traditional method of irrigation such as loose sandy soils and highly undulating fields. These are well-irrigated areas. Farmers in other well-irrigated areas have also procured the system under government subsidy programme, but were found to be using the HDPE pipes for water conveyance in the field except during droughts when they are used for providing supplementary irrigation to kharif crops. So far as sprinkler irrigation is concerned, it is used for many field crops such as wheat, sorghum, pearl millet, groundnut and mustard. But the use of sprinklers is often limited to certain part of the crop season when farmers face severe shortage of water in their wells. Normally, this is just before the onset of monsoon when the farmers have to do sowing of some crops or during long dry spells during monsoon. Sprinkler for groundnut is common in Saurashtra in Gujarat; for mustard is common in Khargaon district of Madhya Pradesh and Ganganagar district of Rajasthan. In the high ranges of Kerala and Tamil Nadu, sprinklers are used for irrigating tea and coffee.

2. Green Revolution, Subsidies and Water- use

The success of the Indian Green Revolution was made possible through the use of subsidy programs, which introduced plant-breeding science, scaled up supply chains of agrochemicals, mobilized a grass-roots agriculture extension effort, and ensured minimum support prices. This initial thrust was additionally complemented by irrigation investments in surface water infrastructure. The combination of these programs dramatically changed the agricultural climate of the country. Production of wheat in India, for example, doubled from 1966 to 1976, and doubled yet again in the 10 years following. While these improvements were impressive, however, private investments over the last two decades in pumps that draw groundwater have made the most significant contributions to irrigation. Today, nearly 60 per cent of irrigated agriculture uses groundwater resources. These private investments would not have been possible without state investments-in extensive rural electric grids, as well as in helping fund private suppliers of low cost pumps and tube-well drilling services[2]. The potentially high- energy costs of pumping from increasingly deep groundwater wells have, for the most part, not been passed on to the farmer in the more productive agricultural areas due to the supply of subsidized power to agriculture. Today, according to State Electricity Board figures, nearly 87000 billion units a year of electricity go towards agriculture production. Even assuming that nearly all of the 70 billion kg of additional food that is produced through any form of irrigation (this includes all forms of irrigation, surface as well as groundwater, and electric as well as diesel pumps) is from electricity driven pumps alone, this represents an electricity input of over one unit of electricity for one kg of food.

On the flip side of this success-story, the same subsidies that revolutionized the country's agriculture have also created a system, which lacks incentive to exercise efficiency in water and energy use. Even assuming a situation in which the nation is not energy- or water-constraint for the time being, if the trajectory continues, the resulting strain on the country's groundwater reserves could be unsustainable. The future of Indian agriculture depends upon the creation of a system of incentives for farmers, which allows for long-term protection of the aquifers without compromising, in the short-term, individual farmers' livelihoods. If incentives are structured properly it may be possible to achieve both short- and long-term goals: groundwater sustainability *and* improved farmer livelihoods.

Is there fiscal room to create incentives to improve efficiency at the same time as productivity? Yes. It is, paradoxically, the current high levels of both inefficiency and recurrent subsidies towards fertilizer, agriculture power, and irrigation (among many other subsidies) that could provide the very fiscal space to create such incentives. These initial movements would ideally offer sufficient incentive for farmers to then make greater investments in efficient practices, infrastructure that conserves water and

[2] See Columbia Water Center, The Earth Institute at Columbia University, Columbia.

energy, and a mix of crop choices that would improve livelihoods while also aiding improvements in soil properties that would reduce water demand. Given the desirability both of farm-level diversification and of control over water provided by individual pumps (in spite of erratic power), incentives that allow different farmers to adopt different practices and investments are preferred-in other words, any incentives should allow flexibility to the farmer in allocating resources. Can these incentives be structured so that they can simultaneously improve the non-farm sector? Jyotigram in Gujarat (where metered 24-7 power is provided to all rural villages for non-agriculture use through separation of agricultural feeders) has already shown that reliable power to the non-farm sector can indeed unleash small-industry, agro-processing, storage, and reduction in post-harvest losses, along with the co benefits of reliable power to households, health and educational institutions[3].

Since the fiscal space for any future incentives will arise from existing subsidies, it is useful to connect this thinking to the ideas of subsidy reform. Some have argued that input subsidies are not as effective as government investment in agriculture R&D, education and rural roads. This shift, however, is perhaps unlikely to be politically manageable as it applies far too large a shock to the system. Some have suggested introducing new subsidies for water-saving irrigation technologies[4]. While this suggestion does create an incentive to conserve when the farmers are already water-constrained, there is risk for the farmer in that even if they invest upfront, the deepening of the groundwater well might potentially nullify the benefit. Some have argued for timely supply of power in tune with the needs of local agriculture while retaining the power subsidy for the low-cost access to groundwater that it provides. Indeed this does help the farmers who are constrained by the reliability or the duration of electricity supply; there is, however, no incentive to conserve in this situation and it is

[3] Tushar Shah and Shilp Verma (2009), "Real- Time Co-management of Electricity and Groundwater: An Assessment of Gujarat's Pioneering Jyotigram Scheme" in Surjit Singh and V. Ratna Reddy eds. Changing Contours of Asian Agriculture: Policies, Performance and Challenges, Academic Foundation, New Delhi, chapter 11.

[4] See Columbia Water Center, The Earth Institute at Columbia University, Columbia.

unlikely that the longer-term trajectory would differ greatly from the current reality.

Others have suggested outright cash transfer in lieu of all the subsidies with all inputs being priced, a move that would presumably provide the incentives for efficiency as well as exit from low labour productivity farming while ensuring a politically viable cap on increases in future state outlays. While intellectually appealing in that this system does provide the incentives to conserve, barriers of information disparity might prevent farmers from having access to the technology and financial instruments that would allow them to actually benefit from the move. There are also many issues of implementation detail, information dissemination, trust-building and logistics that will need to be addressed for an incentive of this nature to lead to farmer-level investments and adoption of new practices and technology. With inputs such as electricity or water being fully priced under this system, the cash transfers (and these could be transfers in form of vouchers for specific electricity consumption, which could be exchanged for designated units of electricity or given to another farmer in exchange for payment of pumping services) do, however, provide incentive as well as financial means to allow farmers to finance the infrastructure with minimal risk on their part. Moreover, the incentive might be large enough a lever to mobilize a significant number of farmers to adopt such measures, which could lead to cumulative system-level benefits that might alter the longer-term trajectory.

3. What Water Saving in Rice Wheat Cropping (RW) Systems Means?

The term **water saving** has different meanings to different people. Real water saving occurs when losses that cannot be recaptured are reduced or eliminated, however the magnitude of any water saving can vary considerably depending on the spatial and temporal scales of interest. Despite this complexity, the ultimate objectives of **water saving** are clear ie., to cease unsustainable overexploitation of surface and groundwater resources and increase the amount of water available for non-agricultural purposes (e.g. urban, environmental, recreational). Thus water saving in RW systems has the dual goals of using less water than is currently being used, while increasing production.

For a farmer, **water saving** is likely to mean using less irrigation water to grow a crop - ideally with the same or higher yield (or ultimately profit), thus increasing irrigation water productivity (g grain / kg irrigation water or Rs / kg irrigation water). However, saving irrigation water does not necessarily mean that total water use (from rain and soil water as well as irrigation) is reduced at the field scale i.e. that water is really saved. While saving irrigation water *per se* has many benefits such as reducing costs to the farmer (e.g. pumping, water charges), increasing both yield and total water productivity (g grain / kg water from rain+ irrigation+ soil water) are required to meet the increasing demand for food, and to produce it from less water.

Saving water in cropping systems is ultimately about reducing non-beneficial losses - losses that can't be economically recaptured elsewhere in the system. These non-beneficial losses are evaporation from the soil and irrigation water (as opposed to transpiration), and surface and deep drainage into waters too contaminated for reuse (e.g. saline ground waters, the sea) or into locations from which it is too difficult to recapture (e.g. aquifers with low transmissivity).

It may also be mentioned that saving irrigation water for one crop in one field does not necessarily mean a net saving in irrigation or total water over time. For example, within a field, it may be possible to reduce the amount of irrigation and force a crop such as wheat to use more of the stored soil water while maintaining yield. However, this may also mean that a larger amount of irrigation water is required to refill the soil profile for the next crop, with no net irrigation or total water savings over the cropping system. Thus, in evaluating strategies for saving water it is important to consider the cropping system over time rather than individual crops in isolation.

Issues of scale are also extremely important. For example, if deep and surface drainage can be captured and reused elsewhere at the spatial scale of interest, a reduction in drainage is not a water saving. Evaluation of the impact of irrigation water saving technologies at the field and farm scales on the availability of water at larger scales is complex and requires the use of approaches that integrate the effects over space and time[5].

In this section we review methods for saving water and increasing water productivity at the field scale in RW systems. Much of this work has focused on methods for saving **irrigation** water and increasing **irrigation** water productivity. In some cases the combined productivity of irrigation plus rain (input water productivity) is also considered. However few studies have examined the impact on total water productivity, or whether savings in irrigation water at the field scale translate into true water savings at the field, cropping system or regional scales.

3.1 Increasing Water Productivity

Water productivity can be increased by increasing yield and/or reducing water use. There have been substantial increases in irrigation and total water productivity of RW systems over the past thirty years, largely due to increased yields of both rice and wheat as a result of improved varieties and management of water, nutrients, weeds, pests and diseases. Approaches with the potential to further increase yield and thereby water productivity of RW systems of the IGP include laser land levelling, reduced tillage, raised beds, improved germ plasm, site specific nutrient management, stubble mulching and integrated pest management (RWC-CIMMYT 2003a). Yields can continue to increase through improved varieties (especially increased cold tolerance in rice and selection of wheats for irrigation), and improved rice establishment and soil and water management, aided by precision agriculture.

[5] Such as the 3-dimensional surface-groundwater interaction models developed by Khan et al. (2002a,b; 2003a) for the Rechna Doab basin in Pakistan and the lower Murrumbidgee basin in Australia.

3.2 Saving Water

Rice and wheat production are favoured by vastly, different soil and water management and weather conditions. Therefore, approaches to saving water can be quite different for the two crops, and strategies for saving water in one crop may impact positively or negatively on yield or water productivity of the following crop, and hence the total cropping system. For example, puddling to reduce percolation losses from rice may impair wheat performance. However, there are also generic approaches to saving water or increasing water productivity that can benefit both rice and wheat at the field scale, such as laser land levelling, drainage recycling systems, the ability to forecast rainfall and irrigation water availability, and improved reliability of water supply systems. While some water saving technologies decrease drainage losses without affecting evaporation, others predominantly affect evaporation, and many technologies affect both. Reduction in evaporation is likely to be true water saving, whereas drainage can often be recaptured at some scale in the system.

3.3 Reducing Seepage and Percolation Losses

Percolation or deep drainage loss is the vertical movement of water below the root zone where crops cannot recover it, whereas seepage is lateral flow through bunds. Seepage and percolation losses at the field scale may be recaptured at a higher system scale, however recapture often comes at a cost in terms of energy for pumping, purchase of irrigation water and labour, construction of drainage systems, and greenhouse gas emissions associated with the production or use of energy. Seepage and percolation losses can be reduced by measures such as confining rice to less permeable soils, reducing ponding depth and alternate wetting and drying (AWD) irrigation for rice, laser levelling and raised beds. Puddling is also used to reduce percolation rate during the rice cropping period, but whether the total input of water is actually reduced and whether water is really saved are highly questionable.

3.3.1 Soil type

Soil type has a large influence on irrigation water requirement due to much higher percolation losses on coarser textured soils. This is particularly true for rice grown under ponded or saturated conditions for most of the season. Seasonal percolation losses of 57-83 per cent of the total input water are common in the NW- IGP, with highest losses (up to 1500 mm) on sandy and sandy loam soils, and lowest losses on loams and clay loams (up to 890 mm) (Hira and Khera, 2000). As rice is a shallow-rooted crop, with the majority of roots in the top 20 cm, some of the water percolating beyond the root zone of rice is likely to be recaptured during the wheat phase, when roots can extract water up to depths of around 200 cm[6]. Therefore the percolation losses from rice in many studies probably overestimate the actual drainage losses below the root zone in RW systems. Nonetheless, deep drainage losses below the root zone of the RW system can still be very large. For example, assuming that after rice harvest the plant available water content of the profile in sandy loam and clay loam soils to a depth of 200 cm is 300 and 500 mm, respectively, and that this water is used by a subsequent wheat crop, then the deep drainage losses below the root zone of the RW system in the studies of Tripathi (1996) would range from 390 to 1200 mm. Much of the RW area of the NW IGP is located on sandy loam to clay loam soils with infiltration rates up to 20 mm/day (Velayutham et al., 1999). In addition to the problem of high irrigation water requirement, excessive percolation from channels and fields on permeable soils has led to high water tables and problems of salinisation in substantial areas where groundwater quality is poor, such as in south west Punjab, India (Hira and Khera, 2000). In such regions the groundwater may not be suitable for reuse and reducing percolation losses is real water saving.

3.4 Puddling for Rice

Most rice in Asia is transplanted into puddled soils. Puddling is done for a range of reasons including weed control, ease of field levelling and transplanting, and to reduce

[6] Prihar et al. (1976, 1978a) and Gajri and Prihar (1985).

percolation losses. The relative importance ascribed to each of the above reasons varies. For example, some studies consider that puddling is done primarily for weed control, whereas others like Kukal and Aggarwal (2003) and Gajri et al., (1992) place more emphasis on its role in reducing percolation losses in NW India, where soils are highly permeable. Puddling is not essential for rice growth and yield, with many studies reporting similar yields for transplanted or direct seeded rice with and without puddling (e.g. Aggarwal et al. 1995; Kukal and Aggarwal 2003)[7].

Although it is widely recognized that puddling reduces percolation, there are surprisingly few reports of quantitative field comparisons of percolation losses in puddled and non-puddled soils. These indicate that the effect of puddling on percolation rate ranges from little to reductions from 30 to 13 mm/day on flooded sandy loam soils and from 17 to 3 mm/day on flooded clay soils (Sharma and De Datta 1985; Kukal and Aggarwal 2002).

Despite reducing percolation losses during the rice crop, puddling does not necessarily reduce the total water input for rice. However, there are only a few reports on comparisons of total water use or percolation losses in puddled and non-puddled systems that include the whole period from pre-irrigation to harvest, and that use the same water management after planting. An exception was the study of Singh et al., (2001), which compared water use and yield of water seeded rice with and without puddling on a sandy loam at Delhi, with water depth maintained at 5 cm in both treatments. Averaged over three years there was irrigation water saving of only 75 mm with puddling out of a total irrigation water application of 1537 mm. Thus, even on this highly permeable soil, the irrigation water saving with puddling was relatively small in comparison with the total water use.

Puddling for rice induces high bulk density, high soil strength and low permeability in

[7] The high yielding rice cultural systems of Australia and California, USA, are not puddled.

sub-surface layers (Sharma and De Datta 1986; Aggarwal et al., 1995; Kukal and Aggarwal 2003), which can restrict root development and water and nutrient use from the soil profile for wheat after rice (Sur et al., 1981; Gajri et al., 1992). However the impact of puddling for rice on the performance of wheat after rice is variable across sites and years (Sharma et al., 2003). Sharma et al., (2003) noted that the few negative yield trends for wheat in long- term experiments were mostly observed in medium- to fine-textured soils, which undergo more radical changes in soil physical properties during puddling, while yield trends were positive on the coarse-texture soils of Punjab and Haryana. However results from field experiments show no clear relationship with soil type (Table 2). The results may be confounded by site history, if a site has a history of puddling and a compacted layer prior to the commencement of rice tillage treatments then the initial site conditions may prevent any wheat response to rice tillage treatments. Unfortunately few studies evaluating the impact of puddling for rice on wheat performance report site history or soil physical properties prior to the imposition of the treatments. The findings of Aggarwal et al., (1995) and Kukal and Aggarwal (2003) showed that the effects of puddling on soil physical properties increase with puddling intensity, depth and history of puddling, and that it may take one to several years before this significantly affects the performance of wheat when starting with a soil with no puddling history or compacted layer.

3.5 Reducing Evaporation Losses

Reducing non-beneficial evaporation direct from the soil or free water lying on the field is true water saving, although it may be countered to some degree by increased transpiration rates as a result of impacts on the microclimate experienced by the plant. The size of this effect has not been established. Evaporation from the free water surface accounted for 40 per cent of the total evaporative loss from continuously flooded water seeded rice. Technologies that reduce the extent or duration of free water or surface soil saturation include alternate wetting and drying of rice fields instead of continuous ponding, raised beds with furrow irrigation, laser land levelling, and drip and sprinkler irrigation. Evaporation from the soil surface can be reduced by mulching, by changing the time of crop establishment to coincide with periods of lower evaporative demand, and by faster turn around between crops through direct drilling to use residual surface soil water and perhaps save irrigation.

Table 2: Effect of Puddling and Pompaction for Rice on Yield of Wheat after Rice

Location/Countr y	Soil	Site history	Effect of pudding on wheat yield
Punjab	Sandy loam	Non-rice (cotton-wheat, sugarcane, maize-wheat	Increased – year 1 Decreased – year 2
Punjab	Silty clay loam	Rice-Wheat for last >20 years	Increased – year 1 None – year 2
Punjab	Sandy loam, 1,2&4 pass puddling	Non-rice for last >20 year (maize/pearl millet-wheat)	None – year 1 Decreased – year 2-5 with 4 passes compared with 2 or 1 pass pudding
Punjab	Sandy loam *Rice-Wheat cf. Maize wheat*	Non-rice (maize-wheat)	Decreased rice cf after maize
Punjab	Sandy loam	Non-rice	Decreased
Punjab, Uttar Pradesh Haryana	Sandy loam Silty clay loam	Rice-Wheat for last 9-10 years Rice-Wheat for last >20 years	None – year 1 None – year 1
Punjab Punjab Punjab Uttar Pradesh	Loamy sand Sandy loam Silty clay loam Sandy loam	Non-rice Rice-wheat for last 9-10 years Rice-Wheat for last 9-10 years	None- year 1 None – year 1 None year 1 Decreased – year 1
Punjab		Non-rice for last > 20 years	No effect years 1&2 Decreased with normal ("deep" puddling in 3rd year

Adapted from Connor et al., (2002).

3.6 Sowing Planting Date

In NW India the evapotranspiration requirement of rice declines from around 800 to 550 mm as the date of transplanting is delayed from 1 May to June 30 (Hira and Khera 2000). Substantial irrigation water savings (25-30% or 720 mm) can be achieved by delaying transplanting from mid-May to mid-June (Narang and Gulati 1995). Therefore the recommended practice in NW India is to transplant around mid-June. However, many farmers plant earlier than this (e.g. 57% in Punjab) because of external factors such as increased pest pressure on later planted crops and availability of labour and canal water or electricity for pumping (Hira and Khera 2000; Gajri et al., 2002). Mechanical transplanting could potentially reduce the need for earlier transplanting, but the cost of mechanical transplanters is prohibitive and requires specialized training in seedling production on mats, knowledge of sedimentation rates for different soil types to avoid seedling burial and good land levelling. Direct seeding could help overcome the 'problem of labour availability however the optimum sowing date may need to be earlier than the optimum transplanting date which could increase the crop water use requirement. It is not clear if changing to direct seeding will increase or reduce the water requirement for rice, and the impact may vary depending on sites and systems. Although delayed rice planting can save water, it can also delay planting of wheat beyond the optimal time, causing yield loss of 1-1.5 per cent per day due to grain filling at higher temperatures (Prihar and Grewal 1988).

While delaying transplanting in the NW- IGP to the optimum time saves water, bringing forward transplanting in eastern India enables more productive use of rainfall. Here, irrigation water is scarce, and the need for irrigation can be avoided and total system productivity increased by establishing rice with rainfall supplemented by irrigation from groundwater during the pre-monsoon period, and by raising bund height to 20 cm to capture rainfall (Gupta et al., 2002). This also benefits the subsequent wheat crop due to the opportunity for earlier planting.

3.7 Varietal Duration

Water can also be saved by using varieties of shorter duration however this may come at the expense of yield. It is argued that reducing duration could save up to 10 per cent of irrigation water; it could possibly reduce yield potential and hence water productivity. While there is some evidence for the latter argument as varieties with higher yield potential and shorter duration have been developed. Short duration varieties also facilitate increased water use efficiency of the farming system. For example, earlier maturity allows earlier harvest, increasing the chance of timely establishment of a winter crop after rice and making more efficient use of stored soil water and winter rainfall instead of losing it as deep and surface drainage or transpiration by weeds.

3.8 Mulching

The few reports on the effect of mulching on water use in RW systems refer to mulching of wheat, and suggest that sufficient water is saved (25-100 mm) to reduce the number of irrigations by one or irrigation time by an average of 17 per cent or to increase yield in water limiting situations (RWC-CIMMYT 2003b). Surface seeding and dibbling of wheat followed by mulching with rice straw (4-6 t/ha*)* are practised. The time between rice harvest and wheat sowing is relatively long (60-85 days), and spreading the rice straw mulch immediately after harvest is currently being explored as a technique to control weeds and reduce evaporation. This technique is more attractive where farmers are growing oilseed rape after rice as they can broadcast the seeds, which are small enough to fall through the mulch to the soil surface. Surface seeding of wheat and straw mulching is also practised by a few farmers in the in eastern Uttar Pradesh and Bihar, India.

A novel, promising approach recently developed and tested by Indian collaborators is the *Happy Seeder*, which combines the stubble mulching and seed drilling functions into the one machine (Blackwell et al., 2004). The stubble is cut and picked up in front of the sowing tynes (which therefore engage bare soil) and deposited behind the seed drill as a mulch. Results to date from India suggest that wheat can emerge through 8 t/ha of evenly spread rice straw mulch with no detrimental affect.

In central and NW India a very hot dry period occurs for about two months between wheat harvest and rice planting, during which the fields are bare fallow and evaporative demand is very high[8]. The most efficient and practical strategy is likely to be irrigation management of the wheat to use stored water after rice and achieve dry down of the soil profile by the time of wheat harvest rather than use of mulches to prevent losses after harvest. The majority of the wheat straw is harvested for animal fodder (Gajri et al., 2002). There are few reports of evaluation of mulching for rice.

3.9 Reducing Seepage, Percolation and Evaporation Losses

There are many technologies, which appear to save water in RW systems through a combination of reduced seepage, percolation and evaporation losses; however, separation of these components has seldom been attempted. Some practices that impact on all three are discussed below.

3.9.1 Land Levelling and Layout

The extent of laser levelling is currently extremely small, compared with 50-80 per cent of the rice land in Australian rice-based systems. Land levelling can reduce evaporation and percolation losses from wheat by enabling faster irrigation times and by eliminating depressions and therefore ponding of water in depressions. This also reduces water logging problems, especially on heavy textured soils. Land levelling also reduces the depth of water required to cover the highest parts of the field and for ponding for weed control in rice, and therefore percolation losses, more so on more permeable soils[9].

3.9.2 Water Management for Rice

There are numerous reports of large irrigation water savings when changing from continuously flooded rice to saturated soil culture to alternate wetting and drying, but

[8] The magnitude of the soil water loss by evaporation and the potential for stubble retention or mulching to reduce non-productive evaporative losses during this period has not been explored.

[9] Rickman (2002) found that rice yields in rain-fed lowland laser-levelled fields were 24 per cent higher than in non-lasered fields in Cambodia, and that yield increased with the uniformity of levelling.

yields decrease as soil water content declines below saturation (Sandhu et al., 1980). However, many studies throughout India have shown that continuous ponding is not necessary to maintain rice yields at reasonable levels (Sandhu et al., 1980; Hira and Khera 2000). Results from NW India consistently show substantial irrigation water savings (24-40% or up to 650 mm) with no or small yield loss, and even a yield increase on a sodic soil, in changing from continuous submergence to irrigating 1 to 3 days after the floodwater has disappeared (Sandhu et al., 1980; Sharma 1999). Sandhu et al., (1982) also showed that about 60 mm of irrigation water can be saved, while maintaining yield, by cutting off irrigation 1 week earlier (about 2 weeks before harvest) on a sandy loam. Therefore the recommended practice in Punjab, India is to irrigate 2 days after the water has disappeared and to cease irrigating about two weeks before harvest. Sharma (1989) found no effect on rice yield and water saving of 843 mm (23%) by allowing the soil to dry to -10 kPa at 10 cm depth prior to reflooding for periods of 1-3 weeks. Hira et al., (2002) compared the recommended practice with irrigation at soil matric potentials of -8 to -16 kPa at 15-20 cm depth. The number of irrigations was highest with the recommended practice (29, at 50 mm per irrigation) declining to 18 irrigations when matric potential reached -16 kPa, irrigation water saving of 550 mm with no effect on yield.

Much of the irrigation water saving with reduced water depth is probably due to reduced percolation losses, and therefore may not be a real saving. Kukal and Aggarwal (2002) showed that percolation rate declined rapidly from about 15 to 5-10 mm/day as water depth declined from 100 to 60 mm on a puddled sandy loam, and from 35 to less than 20 mm/day as the water depth declined from 100 to around 20 mm without puddling.

Delayed flooding (intermittent irrigation every 7 days with continuous ponding commencing about 2 weeks prior to panicle initiation) enabled maintenance of both yield and grain quality, with irrigation water savings of around 25% due to reduced percolation losses. It is still to be tested on Indian soils.

3.9.3 Irrigation Scheduling for Wheat

Irrigation of wheat after rice should be scheduled *to* maximise use of stored soil water and winter rain while maintaining yield. Prihar et al. (1974, 1976, 1978a) established guidelines for irrigation scheduling for wheat on the coarse textured soils of northwest India. This work was done in soils without a restricting layer, commonly with maize as the previous crop, rather than the RW situation where there is often a dense layer at about 20 cm (Aggarwal et al., 1995; Kukal and Aggarwal 2003). Prihar et al. (1978b) concluded that wheat should be irrigated at around 60 and 70 per cent depletion of plant available soil water storage to avoid yield loss, with the lower value for the lighter soil, compared with a deficit of 50 per cent determined by Singh and Malik (1983) on a sandy loam in Haryana. The recommended practice involves one irrigation prior to soil preparation, an irrigation (~70 mm) at the crown (nodal) root initiation stage, 3-4 weeks after sowing, then a 70 mm irrigation whenever cumulative pan evaporation minus rain reaches 93 mm (an IW/Pan ratio of 0.75), with the last irrigation no later than mid-March for crops sown on time. This method saved up to 160 mm of irrigation water compared with applying 70 mm at each of 5 key stages. However, translating this into practice for a farmer with no knowledge of pan evaporation is difficult, and published guidelines for farmers are based on prescribed intervals between irrigations according to sowing date, with some adjustments for light and heavy soils but no adjustments for seasonal weather conditions (PAU 2002). Narang and Gulati (1995) suggested that there was scope to reduce wheat irrigations further by publicising data from evaporation and rainfall and training farmers to keep their own evaporation-rain budgets.

3.9.4 Irrigation Method

Pressurised irrigation systems (sprinkler, surface and subsurface drip) have the potential to increase irrigation water use efficiency by providing water to match crop requirements, reducing runoff and deep drainage losses, and generally keeping the soil drier reducing soil evaporation and increasing the capacity to capture rainfall. There are few reports of the evaluation of these technologies in RW systems.

3.9.5 Raised beds

The use of raised beds for the production of irrigated non-rice crops was pioneered in the heavy clay soils for irrigated wheat in the RW areas of the IGP during the 1990s, inspired by the success of beds for wheat-maize systems in Mexico. Potential agronomic advantages of beds include improved soil structure due to reduced compaction through controlled trafficking, and reduced water logging and timelier machinery operations due to better surface drainage. In the IGP beds also create the opportunity for mechanical weed control and improved fertilizer placement. The potential benefits of beds for wheat production in the IGP have been known for some time (Dhillon et al., 2000).

3.9.6 Direct seeding

Input water savings of 35-57 per cent have been reported for dry seeded rice sown into non-puddled soil with the soil kept near saturation or field capacity compared with continuously flooded (~5 cm) PTR in research experiments in NW India (Singh et al., 2002; Sharma et al., *2002).* However yields were reduced by similar amounts due to iron or zinc deficiency and increased incidence of nematodes. In contrast with the results of small plot replicated experiments, the results of participatory trials in farmers' fields in NW India and suggest a small increase or 10 per cent decline in yield of DSR on the flat compared with puddled transplanted rice, and around 20 per cent reduction in irrigation time or water use (Gupta et al., 2002), increasing water productivity.

Farmer and researcher experience with direct drilling of wheat in Haryana, NW India indicates irrigation water savings of 20-35 per cent or *90-100* mm compared with conventional tillage, with the largest savings in the first irrigations, and comparable or higher yields due to earlier sowing. Factors contributing to the saving in irrigation water probably include faster flow across the non-tilled fields, no loss of surface moisture as occurs with cultivation, the ability to sow earlier and take advantage of residual soil moisture and create storage capacity to capture winter rain, and the opportunity to finish the wheat crop in a period of lower evaporative demand. Gajri et al., (1992) found lower yields of direct drilled wheat compared with conventionally or deep tilled wheat over three consecutive years on a sandy loam. Tillage resulted in deeper and denser rooting and increased transpirational and N use efficiency. For a given yield level, higher inputs of irrigation water and N were required with direct drilling compared with conventional tillage.

The area of direct drilled or zero tilled wheat after rice in northwest India

3.9.6.1 Improving water supply systems

Unreliable water supply and cheap water (or power for pumping water) is major constraints to the adoption of many potential water saving technologies, which require more timely and controlled water management.

The canal irrigation system in Punjab, India irrigated 1.67 Mha in 1990/91, and this has declined to 0.99 Mha in 2001/2 due to deterioration in the system, forcing farmers to increasingly rely on groundwater and exacerbating the depletion of groundwater resources (World Bank 2003). The World Bank report recommends removal of subsidies on surface water supplies and electricity to generate funds to rehabilitate the canal and power supply systems. More reliable canal and power systems would then enable adoption of many water management practices with the potential to save water and increase water productivity. In the canal water distribution systems of northwest India there is often a gap between head and tail farm gate supply (Tyagi et al., 2004). Farmers at the tail end are often heavily reliant on the use of moderately saline groundwater to makeup the shortfall of the canal supply, resulting in lower yields of rice and wheat and lower water productivity due to salinisation. Tyagi et al., (2004) suggested that transfer of good quality groundwater from head to tail reaches by introducing water marketing would assist in increasing yields and water productivity in the lower reaches.

4 Water Saving and Water Productivity

There is absolute paucity of research in India quantifying the actual physical (real water saving) and agronomic impacts of water saving irrigation technologies on various crops. An extensive review of literature shows that the more reliable data on water saving are for experimental farms, for limited number of crops and system types and for a few locations. Data on water saving yield rise and water use efficiency improvements with drip irrigation in several crops are compiled from experimental data from different research stations across India (Table 3). The reduction in water consumption varies from a mere 12 per cent for ash gourd and bottle gourd to 81 per cent for lemon.

But, it is a truism that with the same technology, and with the same crop, the water saving and yield impacts of these irrigation technologies would depend on the agro climate. From the data, it is evident that they are generated for a single location. Over and above, the extent of saving would be heavily influenced by the conventional irrigation method practiced for that crop in the region under consideration, and the precision irrigation followed in drip irrigation. It is difficult to simulate the actual field conditions in experimental farms. For instance, farmers may not be able to apply water daily with drips, which is important to get best results, due to irregular power supply and many other field constraints. It is very likely that the data obtained from experimental farms are for ideal conditions. Hence, these figures have to be used more carefully.

Table 3: Water Saving and Productivity Gains through Drip Irrigation

Crops	Water Consumption (mm / ha)		Yield (Ton / ha)		Water saving over FMI (%)	Yield increase over FMI %	Water use Efficiency$	
Vegetables	FMI	DMI	FMI	DMI			FMI	DMI
Ash gourd	840	740	10.84	12.03	12	12	77.49	61.51
Bottle gourd	840	740	38.01	55.79	12	47	22.09	13.26
Brinjal	900	420	28.00	32.00	53	14	32.14	13.13
Beet root	857	177	4.57	4.89	79	7	187.53	36.20
Sweet potato	631	252	4.24	5.89	61	40	148.82	42.78
Potato	200	200	23.57	34.42	Nil	46	8.49	5.81
Lady's finger	535	86	10.00	11.31	84	13	53.50	7.60
Onion	602	451	9.30	12.20	25	31	64.73	36.97
Radish	464	108	1.05	1.19	77	13	441.90	90.76
Tomato	498	107	6.18	8.87	79	43	80.58	12.06
Chilly	1097	417	4.23	6.09	62	44	259.34	68.47
Ridge gourd	420	172	17.13	20.00	59	17	24.52	8.60
Cabbage	660	267	19.58	20.00	60	2	33.71	13.35
Cauliflower	389	255	8.33	11.59	34	39	46.67	22.00
Fruit Crops								
Papaya	2285	734	13.00	23.00	68	77	175.77	31.91
Banana	1760	970	57.50	87.50	45	52	30.61	11.09
Grapes	532	278	26.40	32.50	48	23	20.15	8.55
Lemon	42	8	1.88	2.52	81	35	22.34	3.17
Watermelon	800	800	29.47	88.23	Nil	179	27.15	9.07
Sweet Lime*	1660	640	100.0	150.00	61	50	16.60	4.27
Pomegranate*	1440	785	55.00	109.00	45	98	26.18	7.20
Other Crops								
Sugarcane	2150	940	128.00	170.00	65	33	16.79	5.53
Cotton	856	302	2.60	3.26	60	25	329.23	92.64
Coconut	-	-	-	-	60	12	-	-
Groundnut	500	300	1.71	2.84	40	66	292.40	105.63

Note: *-- Yield in 1000 numbers; $: water consumption (mm) per ton of yield.
Source: INCID (1994) and NCPA (1990) as cited in Narayanamoorthy (2004).

5. Technologies

5.1 Treadle Pump

IDEI had developed a low cost water lifting technology, called the treadle pump. It has several key advantages over the traditional water lifting devices and the costly diesel and electric pumps vis-à-vis the smallholder farmer. Of paramount significance is the affordability factor, which makes this technology accessible for the smallholder. The treadle pump is affordable, easy to install and operate; negligible repair and maintenance problems, light and portable and is sturdy and durable.

The treadle pump (commonly known as pedal pump) is a water-lifting device similar in principle to the hand pump. The difference lies in the fact that a hand pump consists of a single barrel or cylinder and one has to pump up water with one's hands, whereas the pedal pump comprises two cylinders and requires foot operation for lifting water (hence called a pedal pump). It is so easy that even a child, a woman or even an old person can operate the pump by manipulating his/her body weight on two-foot pedals or treadles and by holding a bamboo or wooden frame for support. One may even make a comfortable sitting arrangement and pedal while being seated. Currently four models of the pump are being used in keeping with the distinct soil, water and income conditions in the different regions of operation. They are: 3.5-inch pump (metal barrels) with bamboo treadles; 3. 5 inch pump (metal barrels) with metal treadles; 5 inch pump (metal barrels) with metal treadles; 5 inch concrete pump (PVC sleeves) with wooden pedals; and 3.5 inch Surface Treadle Pump (STP).

The treadle pump is ideal for areas where the water table is high, ranging from 10 feet to 25 feet below the ground. The pump is usually installed on 1.5" tube wells (made of GI, PVC or bamboo) but can also be fitted on 3" and 4" tube wells (by using relevant reducer sockets) that are meant for installing electric and diesel pumps respectively. Besides, most of the models of the treadle pump can be used for drawing surface water, such as from ponds, canals, streams and dug wells (by connecting a suction pipe to the pump with a GI bend pipe). The treadle pump is appropriate for irrigating about one acre of cultivable land and hence is ideal for vegetable cultivation. However, farmers use the pump to cultivate paddy and even wheat in some areas. Treadle pump is best suited for small and marginal farmers.

Scarce water resources and/or a lack of control over water are pervasive constraints facing a large number of the rural poor worldwide. As such appropriate, affordable, and accessible irrigation technology can provide a much-needed premise for increased agricultural production and income generation. For the large population of small and marginal farmers, the high initial cost of drip irrigation has been found to be a major deterrent in the spread of drip irrigation.

Nutrient dynamics under drip irrigation

Various doses of water-soluble fertilizers were applied through a drip system, for comparison with ordinary fertilizer application combined with a conventional irrigation method. For fertigation treatments of broccoli, it was observed that the ammonium form nitrogen was dominant in the upper soil layers and almost the entire amount of applied nitrogen remained confined to the root zone. For irrigation by check basin, the nitrate form of nitrogen dominated the root zone concentrations and a significant amount leached beyond the root zone. Some leaching losses were observed when fertilizer was applied to soil, with accompanying watering by drip. In a second experiment with radish, it observed that in fertigation treatments, potassium was confined to the root zone of the radish crop, while it moved beyond the root zone in significant quantities for the convent furrow irrigation. Movement beyond the root zone was observed in the soil-based fertilizer application with water provided by drip, but to a lesser degree. These experiments have n that at least 40 percent of fertilizer use could be saved through fertigation with similar or higher yield in addition to water savings (Kumar Singh, D. Chakraborty, P. Mishra and D. K. Singh Water Technology Center, Indian Agricultural Research Institute, Delhi).

5.2 Low Cost Drip Irrigation Kits

Drip irrigation systems used on larger commercial farms are expensive, complicated to operate and maintain and not divisible to fit small plots. The prevalent drip systems are neither appropriate nor affordable for the marginal farmers who then have no choice but to revert to the conventional flood irrigation system. IDEI has developed a variety of low-cost drip irrigation kits and customized systems that are appropriately sized and affordable for smallholders. KB drip systems is affordable for the marginal farmer, offers several advantages over the conventional flood irrigation. It saves at least 50 per cent water, reduces irrigation labour, reduces soil erosion and increases crop productivity

5.3 Affordable Drip Irrigation Technology Intervention (ADITI)

IDEI has developed affordable micro irrigation technologies to meet the needs and aspirations of marginalized farmers. ADITI works better for small farmers because the technologies have been developed for small and marginal farmers through four years of rigorous R&D and field testing; the technologies are divisible and available in convenient packages (in the form of kits) which the farmers can install and maintain themselves; besides, the farmers have the option to begin with one unit and expand it later at their convenience; these kits are easily assembled by local farmer groups with little training and back-up support; IDE sources components from a large number of manufacturers and uses the most cost-effective ones; and IDE also tests all the MI components developed and available all over the country and uses the ones most appropriate for small farmer's requirements. IDEI is currently promoting KB drip systems in the form of kits in the water scarce regions in India, namely, drum kit, bucket kit, family nutrition kit and customised systems. IDEI's approach to development begins with new products. However, IDEI does not invent such products, rather it looks at products that meet the existing needs of marginal farmers, and seek to adapt such products by reducing their cost and enhancing their utility. IDEI's main objective is firstly a product that can be manufactured, distributed and sold at a cost reasonable for a small producer, and secondly, a product that can return its investment cost 100 per cent in the first season of use. IDEI identifies potential new products through a process called Product Identification and Commercialization (PIC) through which a variety of potential products are identified, field-tested, developed and subsequently brought to the market. Following is a brief preview of products currently under development: low cost water storage, UV solar light, low cost gassifier, rope and washer pump and pressure pump.

5.4 Water Saving and Yield Improving Crop and Irrigation Technologies

Some other water saving and yield enhancing irrigation technologies in use in Western India are shown below:

Pressurized drip systems (inline and on-line drippers, drip taps) technology can be used ideally for all fruit crops; cotton; castor; fennel; maize; coconut; aracnut; chilly;

cauliflower; cabbage; ladies finger; tomatoes; brinjal; gourds; mulberry; sugarcane; water melon; flowers. It reduces non-beneficial evaporation (E) from the area not covered by canopy; reduces deep percolation; water saving also comes from reduction in evaporation from fallow after harvest, extent of water saving higher during initial stages of plant growth and raises yield growth significantly.

Overhead sprinklers (including sprinkler guns) can be used ideally for Wheat; pearl millet; sorghum; cumin; mustard; cow pea; chick pea. It reduces the losses in water conveyance; improves the distribution efficiency slightly; reduces deep percolation and improves yield growth marginally.

Micro sprinklers can be ideally used for Potato; groundnut; alfalfa. It reduces the seepage and evaporation losses in conveyance through open channels; reduces deep percolation over furrow irrigation and small border irrigation and improves yield growth significantly.

Plastic mulching can be ideally used for Potato; ground nut; cotton; castor; fennel; brinjal; chilly; cauliflower; cabbage; ladies finger; flowers. It completely checks the evaporation component of ET; stops non-beneficial evaporation (E); extent of water saving higher over drip irrigation and facilitates faster germination and significantly improves yield growth.

Green houses can be used ideally for all vegetables, high valued fruits such as strawberry; and exotic flowers. It controls the ambient temperature and humidity, checks the wind, thereby reducing transpirative demand of plant and the water-saving is highest as compared to other technologies and raises substantially the yield growth.

Micro tube drips can be used ideally for all horticultural crops. It reduces non-beneficial evaporation and has poor uniform distribution and depends on number of micro tubes on a lateral.

6. Individual and Group Efforts

6.1 Tamil Nadu Experience

Water is very precious commodity in Tamil Nadu; SHGs have oriented women to protect the areas around hand pumps. The women canalize the wastewater and use it to water vegetable and fruit gardens and collect water users' fee from every household for maintenance of the hand pumps. Women are also trained to repair hand pumps and trained to harvest rainwater.

6.2 Rotate Seed Variety to Address Water Shortage- Pudang Sikkim

In one village facing water problem for paddy cultivation, women farmers decided to change the variety of seed planted each year. The farmers switched to a variety called ADDE and alternates every 2-3 years with another variety DUdhe, which requires less water. The usual practice in the region is to grow a particular variety for 2-3 years and when the seeds' quality starts deteriorating farmers exchange the seed with the seed of another variety most suited to their conditions to help them adapt to changes.

6.3 Daler Singh

Daler Singh of the JDM Foundation in Lodhowal, Ludhiana has been working on the concept of a low water-use variety of paddy. Since 2000, Daler Singh has demonstrated to farmers in several locations in Punjab that paddy can survive and thrive on much less water. The innovation is simple: Rice seedlings are transplanted onto the ridges spaced 24 inches apart by furrows that are filled with water. While the crop is irrigated daily for the first week after transplantation, subsequent irrigations is at weekly intervals, with special attention during the tillering and grain setting stages. Since less water is used in ridge-furrow system of paddy cultivation than in flooded rice fields, the crop requires about 30 per cent less fertilizers application.

7. Water Conserving Technologies in Maize Systems

Traditionally, maize and other crops in sequence are grown either in crops in sequence are grown either in row geometry or by random broadcasting, mostly after thoroughly tilling the field till proper tilth is obtained for good field emergence. The traditional practice of growing these crops has limitations such as inconvenient input management when sown by broadcasting, improper plant geometry, and uneven plant population resulting in inefficient utilization of space and plant competition leading to low productivity and input efficiency. Tillage is one of the soil management practices that usually used to conserve soil profile water content by increasing the percolation rate, checking the water run off and later conserves through the soil mulching and also help to regulate hydrothermal status of soil in root zone. Since time memorial, tillage is practiced to create fine tilth, considered desirable for better crop establishment. More over, tillage is known to increase infiltration rate, reduce evaporation and enhance root penetration in to deeper layers. Increased filtration results in higher soil-water storage in the depth and density of rooting by modifying mechanical impedance, continuity, stability and size distribution of pores, air-water dynamics and the thermal regime of the soil. Contrary to the common notion, it is now believed that tillage can be dispensed without affecting crop yield. Intensive tillage systems results to a decreased in soil organic matter and biodiversity. Tillage practices contribute greatly to the labour cost in any crop production system resulting to lower economic returns. In certain situation, tillage operations caused delay in sowing and add to the cost of production. Conservation tillage management systems are effective means in reducing water loss from the soil and improving soil moisture regime. The beneficial effect of conservation tillage practices compared to conventional tillage on water use efficiency through soil water retention properties were reported by many researchers. Soil pore geometry, infiltration and soil structure are affected by tillage management and influence soil water storage and transmission. Reduced or conservation tillage system is gaining more attention in recent years with the rising concern over natural resource degradation. Intensive tillage systems result in increased soil compaction, decreased soil organic matter and biodiversity. The sub-soil compaction due to repeated tillage leads to reduced water and nutrient use. Hence, Conservation Agriculture in its version of Water Conservation Technologies, viz. zero/ minimum tillage and permanent beds, may offset the production cost and other constraints associated with land preparation.

Through conservation tillage in maize systems is a common practice in many western countries but, the farmers in India have just initiated growing maize systems with conservation agriculture technology packages. Several Resource Conservation Technologies options for various maize systems under different situation have been evaluated and found promising for improving crop productivity, resource use efficiency and farm profitability. Adoption of no-till practice helps in timely seeding either of the crops in sequence, hence leads to increase in productivity. Results of various on-farm participatory trails under maize-wheat and rice-maize cropping systems conducted in Indo-Gangatic plains and peninsular India revealed little or no difference in zero-till maize when compared to best managed conventional crop and despites the similar yields, the economic advantage with zero-till maize to the farmers was recorded to the tune of US$ 50 ha^{-1} due to saving in tillage and first irrigation. Raised bed planting of maize helps in proper plant establishment, increases input efficiency, increases yields, and opens up avenues for double no-till systems. The results of the experiment carried out on conservation tillage techniques in maize-wheat cropping systems on a sandy loam soil indicated that maize productivity was highest under permanent beds followed by no-till and lowest in conventional-tillage. Whereas, wheat yield was highest under no-till followed by permanent beds and conventional-tillage. Overall maize wheat-wheat system productivity was similar under permanent beds and no-till and the lowest being under conventional-tillage. Further, conservation agriculture in its version of zero-tillage and permanent beds resulted in over US$

300/ha annum profitability of maize-wheat system compared to conventional tillage practices due to dual benefits of higher yields with lower cost of production under conservation agriculture. In addition, the water productivity functions showed that permanent beds had significantly higher water productivity both in maize and wheat crops but the benefits were more in maize than wheat. Remarkably higher water productivity of either crop of maize and wheat was recorded in permanent beds followed by no-till and the lowest in conventional-tillage. The increase in water productivity was the resultant of both increases in yield and saving in irrigation water.

Rice-maize, which is an emerging cropping systems in peninsular and eastern India diversifying respectively winter rice and wheat with maize owing to adverse effects on winter rice due to winter scarcity and wheat due to terminal heat. Under such conditions, the Resource Conservation Technologies are serving as potential drivers for realizing the potential benefits of this diversification. Results of the studies carried out in Bihar and Andhra Pradesh revealed that though there has been little yield penalty with no-till in rice but the productivity of succeeding maize had significant yield advantages over conventional tillage practices and hence the total system productivity higher under no-tillage and permanent bed compared to conventional tillage. Further, keeping residues on surface under conservation agriculture further added the yield advantage. The overall farm profitability was significantly improved with conservation agriculture practices compared to conventional tillage.

7.1 Genotype × tillage × environment interaction

The response of different genotypes varies with tillage and environment. Investigations carried out on maize hybrids under conventional and conservation tillage in monsoon and winter season revealed that response of different maize genotypes to various tillage practices varied with season. It was recorded that through the yield of ‘HQPM 1’ was remarkable higher over other genotypes during both the seasons however during both the seasons however during monsoon season, irrespective of the genotypes, significantly higher maize productivity was recorded under permanent bed planting system compared to conventional till. But, during winter season no tillage × genotype interaction was recorded in 'HQPM 1' and 'HM 5' but alike monsoon season, the productivity of 'Shaktiman 4' was remarkably higher under conservation agriculture compared to conventional tillage. This suggests the response of different genotypes to tillage practices varies with season. Therefore, the selection of genotypes has great bearing on productivity and profitability of crops under various resource conserving technologies.

7.2 Water Conserving Technologies for Diversification with Maize+ High Value Intercropping Systems

In the context of diversification, the debate has always focused on what areas, in which season, and how to diversify. Farmer need to consider the yields in respective areas and cropping season keeping in mind how to relocate the more remunerative crops over large areas to generate employment and foster sustainable food and nutritional security. In this respect, intensification through relay cropping and intercropping and intercropping through crop establishment technologies viz., **Furrow Irrigated Raised Bed Planting** is an option for promoting diversification. For example, innovative maize+ vegetable systems, appropriate tillage and cultivar choices are currently being tried with farmers in their fields and can lead to high system productivity in the risk free winter season. Intercropping of winter maize with potato, vegetable and pulse crops with raised bed planting technique has the potential in the eastern Gangetic plains not only to intensify it through crop substitutions. Options for winter maize intercropped with high value crops were assessed in on-station and on-farm trails' using raised bed planting technique thus provides an option for intercropping of high value cash crops with row crops like maize during the winter season. The maize was sown in the center of the beds with two rows of intercrops planted on the sides of the bed. Although the yield of sole maize was highest, the profitability was higher in maize+ gladiolus. Farmer participatory trails were also conducted using wider beds 100 cm on the top and with a 20 cm wide furrow used for irrigation. Intercropping of red beets or cabbage with baby corn on the wider raised beds did not adversely affect the yield of baby corn or of the intercrops. However, crop compatibility was higher if red beets were intercropped with baby corn than with cabbage. It has been our experience that productivity of red beets in corn intercropping system was higher on wider beds than on the narrow beds. Red beets planted on either sides of the corn gets more space for light and nutrition for a healthy growth.

8. Land Levelers

CIMMYT (International Wheat and Maize Research Centre), Mexico City has developed a useful and purposeful instrument for water saving that costs around Rs.450000. It is being put under trails by Punjab Agricultural University, Ludhiana. Only after the feedback and field trials which are part of the collaborative research project between PAU and farmers, the university would formally recommend the use of this land leveler after appropriate modifications in the same.

> Two fields are prepared side-by-side, one leveled with ordinary implements and the other with the help of laser land leveler, before sowing a crop. Their comparative yields and performance can be compared. The farmers were being given live demonstrations on the use of bed maker-cum-planter, multi-crop planter and pulverizing roller. It is very handy when crops recommended for sowing on beds are to be sown by the farmers, as along with making of the beds, seed is also sown simultaneously. Bed planting reduces water requirement by about 30 per cent and gives better crop yield, improves the drainage in case of heavy rains and saves water sensitive crops. On the other hand, multi crop planter is useful for precision sowing for crops like groundnut, soybean, maize, cotton and sunflower. The pulverizing roller is an attachment commonly used with cultivator. It costs around Rs 5000.
>
> Another interesting implement is crop transplanter for transplanting use in vegetables and other crops on beds or even in flat field. PAU has already gifted a laser land leveler to Sandhora village Cooperative Society of Moga district for custom hiring.

Improved agro-economic practices result in enormous saving of water. In Indian Punjab, the farmers usually transplant the paddy rice during the month of May against the recommendations of June 10^{th} to June 30^{th} by Punjab Agricultural University, Ludhiana. The early transplanted rice has much higher evapo-transpiration (799 mm) than the timely sown crop (561 mm). About half of water table fall can be arrested if the farmers start rice transplantation at the right time and judiciously plan the irrigation schedule. It is being demonstrated that this can help farmers gain in production and incomes. This would change the present “grim picture of the agriculture”.

> The rice grown in Indian conditions require continuous submergence. A major component of pounded water is lost as percolation. The percolation losses may be as high as 71 per cent of total water applied. The increase in puddling intensity, intermittent submergence and transplanting at the optimal time were conceived as suitable measures to contain losses. A study undertaken to assess the effect of puddling intensities in combination with continuous and intermittent submergence on soil physical environment, water use and yield of rice showed that puddling of soil not only increase rice yield but also reduce unproductive water losses viz. percolation and evaporation. The intermittent flooding resulted in higher water efficiency but decline in yield. The combination of high intensity puddling with intermittent flooding resulted in higher water use efficiency[10].
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> **Puddling depth and Intensity Effects in Rice-Wheat Systems on Water use and Crop Performance in a Sandy Loam Soil**
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> A 3 year field experiment was conducted on a sandy loam soil to study the effect of puddling intensity and puddling depth on irrigation water use in rice *(Oryza sativa)* and the performance of rice and wheat *(Triticum aestivum)* crops. The treatments in main plots included (i) unpuddled plots; (ii) and (iii) medium puddling-2 passes of a tractor-drawn cultivator followed by levelling with a wooden plank; and (iv) and (v) intensive puddling-4 passes of a tractor-drawn cultivator followed by levelling with a wooden plank, each at shallow (5-6 cm) and normal (10-12 cm) depths. Percolation losses decreased by 14-16percent with increase in puddling intensity from medium to high, whereas irrigation water applied decreased by 10-25 per cent. Intensive puddling intensity resulted in higher root mass density in 0-5 cm and 5-10 cm soil layers. Root mass density in shallow-puddled plots was 17 per cent more in the 0-5 cm soil layer than in normal-puddled plots. Puddling treatments had no effect on total dry matter and grain yield of rice during all 3 years of study. Root mass density of wheat in the 0-15 cm soil layer increased from 301.9μg cm^{-3} in 1994-95 to 318.7μg cm^{-3} in 1996-97, whereas in the 15-30 cm soil layer it decreased from 85.1 to 47.1μg cm^{-1}. High puddling increased the canopy temperature of wheat by 0.5-1.7°C and decreased xylem water potential by 4-7 per cent. Total dry matter and grain yield of wheat

[10] K.B. Singh, P.R. Gajri and V.K. Arora (2001), “Modelling the Effect of Soil and Water Management Practices on Water Balance and Performance of Rice”, *Agricultural Water Management*, 49, Elsevier.

was 19 and 8 per cent more, respectively, in shallow-puddled plots than in normal-puddled plots during 1996-97 (S. S. Kukal, *Department of Soils, Punjab Agricultural University, Ludhiana, India).*

Groundwater Exploitation in Punjab State

Punjab State is conscious of the food security of the country and intends to continue with maximum share towards central pool of food grains on sustainable basis. Due to favourable production and marketing environment in the State, the area under rice has increased to unsustainable level of 26 lakh hectares. The water table, soil health and environmental status of the State has been badly affected by large scale cultivation of paddy, The agriculture scientists, various committees/panels constituted, have suggested that Punjab can sustain 16-18 lakh hectares of paddy cultivation depending Up on the average annual recharge of the aquifer. The water table in the central districts of the State producing-paddy, having 70 per cent of the tube wells, is receding at an alarming rate of 2 to 2.5 feet annually. At present about 30 per cent of the tube wells have become submersible and it is estimated that during the next 10 years practically all the centrifugal pumps will become non-functional and will need to be converted into submersible pumps requiring much more financial investment and also power to draw the water to irrigate the same area. So area under rice has to be stabilized at 40-45 lakh hectares and ensure production on a sustainable basis. For this hard decisions have to be taken (a) sowing of nursery before 10th May has to be restricted by some Law/Legislation, (b) Financial support for R&D efforts to evolve hybrids/varieties with better yield potential and (c) introducing a crop (maize/pulses/oilseeds) which is needed in the country. Hybrid maize has emerged as a promising, crop in the State. This season hybrid maize has covered about 2.5 lakh acres and it is feared that in case farmers do not get remunerative price for their produce, they may get disheartened and further expansion of area may get set back (The Punjab State Farmers Commission, September 2006).

Technologies for Improving Crop Productivity and Income in Kashmir Region

Raised bed farming maintains aerobic conditions and the irrigation in furrows saves irrigation water by about 35 per cent. In temperate region water from the Kool or glacial melt are to cool, holding them in 10-15 cm deep layers before application in the evening increases productivity. Instead of concentrating on irrigated areas, irrigation should be extended to unirrigated areas where dividends are much more. Saffron a high value crop in Kashmiris raised under rainfed conditions. Studies at SKUAST-K have revealed that micro-irrigation @ 70m^3 /ha in 10 irrigations during reproductive period increases productivity by over 50 per cent. Apple in Kashmir is raised on karewas under rainfed conditions with average productivity of 10t/ha whereas under irrigated condition productivity is easily about 30t/ha, some harvest as high as 50-60t/ha. Pressurized irrigation system needs to be created in Kashmir karewas to realize their potential. Plastic mulching in apples increases productivity by 25per cent. Temperate regions have great prospects of surface covered cultivation. Strawberry under low cost poly-house natured 45 days earlier than outdoors and productivity increases substantially. Nursery raising and vegetative propagation under poly house: conditions is efficient and economically rewarding, enable raising when the outdoor conditions do not permit. For efficient use of water and energy proper stop planning is essential. Areas where water is to be lifted from, great depth better to raise crops of low water requirement, drought tolerant crops (Anwar Alam, Vice Chancellor, Sher-E-Kashmir University Sciences and Technology of Kashmir).

9. Porous Clay Pots

Porous clay pots and pipes conserve water and enable crops to grow in areas where they otherwise could not grow. With this technology, it becomes possible to save water and irrigate small vegetable gardens in rural areas. It has, however, some difficulty. The initial labour required to manufacture the pots/pipes and install this technology is very high. The use of clay pots can be more labour intensive than traditional methods of watering crops, and may have difficulty in coping with providing adequate water for crops with high water requirements. Also, the porosity of pots decreases with time, and they have to be replaced at intervals. Pot lifespans are greatly reduced by the use of turbid water with a high silt and clay content. The silt accumulates in the pores, effectively sealing the pipes/pots. Since this technology uses clay pots and clay pipes that are locally manufactured, the costs are normally low. The major cost is the cost of labour. Material Needed is the locally available clay/ unglazed clay pots and this technology is most suitable for dry areas with less than 500 mm rainfall/year. Communal farmers, especially women, can manufacture the pots/pipes without having to develop special skills.

Pitcher Irrigation or Clay pots irrigation is an inexpensive small-scale irrigation method practiced in the semi-arid area of Karnal, Haryana. The system consists of burying unglazed clay pots in the soil up to their neck. When the pot is filled with water, the natural pores in the pot's walls allow water to spread laterally in the soil, creating the moist conditions necessary for plant growth. Pitchers are filled as needed, maintaining a continuous supply of water directly to the plant root zone. Pitcher irrigation is used for small-scale irrigation where:

- Water is either scarce or expensive.
- Fields are difficult to level such as under uneven terrain.
- Water is saline and cannot be normally used in surface methods of irrigation.
- In remote areas where vegetables are expensive and hard to come by.

One of the advantages of using pitchers for irrigation is the result of their water saving capacity. To compare pitcher irrigation to flood or sprinkler irrigation one must correct for the fact that the scales are radically different. Pitcher irrigation is used on small-scale, while flood and sprinkler systems are for more extensive irrigation. Taking this into account, pitcher irrigation is still more efficient. Pitcher irrigation uses water more efficiently than other systems since it delivers water directly to plant root zones, instead of to broader areas of the field. With pitcher irrigation, deep percolation losses are negligible since water is released from smaller areas, and the rate of water loss can be controlled site to site by the amount of water put in each pitcher. Water requirements in a pitcher irrigated field can be even less than those of a drip irrigated system (of the same scale) due to the very low hydraulic conductivity of the pitchers, as well as reduced evaporation losses.

9.1 Clay Pipes

Clay pipes irrigation is based on the same principle. Both clay pipes and clay pots can be homemade and can be installed by individual householders. The pipes are joined to form tubes of 250 mm in length with an inside diameter of 75 mm. The pipes are placed along the entire length of the beds by laying them end-to-end in a leveled trench. At one end, a right angle fitting is attached and an upright section of pipe installed. The trench is then backfilled with soil to a depth of 100 to 200 mm, depending upon the soil type. Water is poured into the porous pipe through the upright pipe. Each plant bed is about 3 to 6 m in length. The water seeps into the root zones through the joints between the individual pipes, or through the pipe walls if unglazed clay pipes are used. Alternatively, porous pots (made of unglazed clay) are buried in the soil up to their necks next to the plants or between plant rows at intervals of 300 mm. Water seeps from each pot through the pores and form a wetted zone. Varying the frequency of filling, the size of the pots and the spacing between pots affects the watering process. The type of crop governs selection of the most suitable size of pot and its placement. Adoption is fairly limited, possibly due to the fact that the initial stages are very labour-intensive. Trials in the dry areas have shown that communities are interested in this technology. Once the systems are installed, there is very little maintenance required. Operation is quite simple. Farmers, researchers and extension workers must work together to implement this technology. Communities can construct and operate the system. However, government officials and / or NGOs may have to work with pipe / pot manufacturers to ensure availability of supplies of suitable pots and pipes. Extension workers can assist farmers in pipe / pot placement for best effect and at depths / densities best suited for various types of crop.

Material for clay pipes and pots, and local skills for pot-making, are readily available at negligible cost. This method provides a uniformly-wetted area, and, because water is applied at depth, often helps to reduce any weed problems- weeds generally have shallow root systems that are not well-served by this technology. Also, pots can be placed next to individual plants. Once the technology is installed the system can be used for several seasons. Effectiveness of the Technology It was found, during the replicated trials, that water savings varied from 11 to 28 per cent of the water used with traditional irrigation.

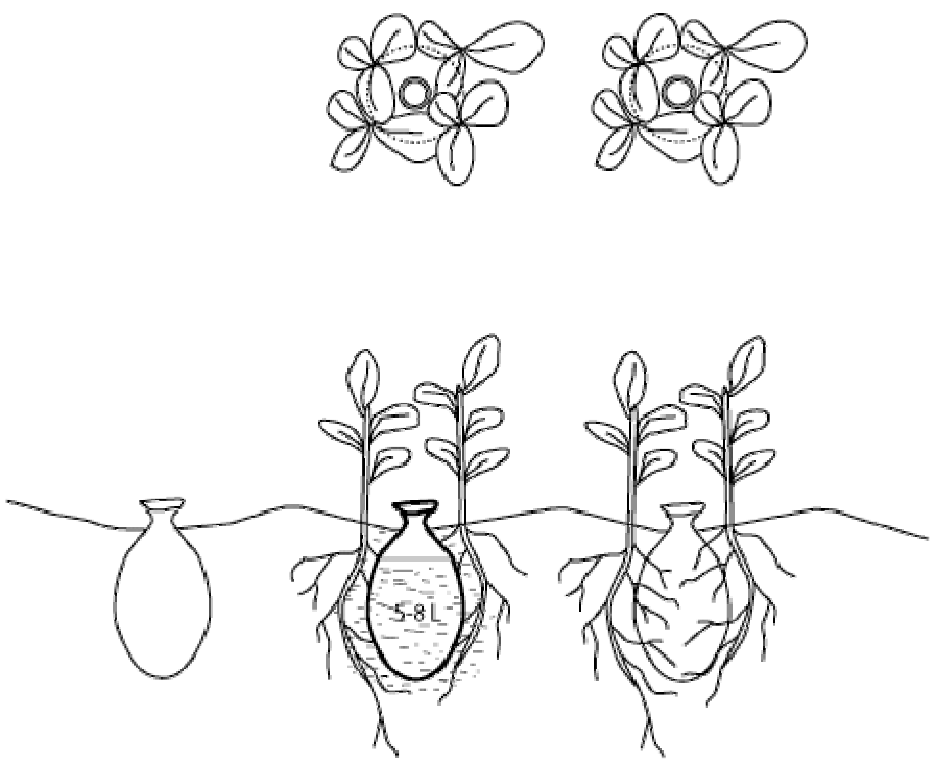
The initial labor required to manufacture the pots / pipes and install this technology is very high. The use of clay pots can be more labor intensive than traditional methods of watering crops, and may have difficulty in coping with providing adequate water for crops with high water requirements. Also, the porosity of pots decreases with time, and they have to be replaced at intervals. Pot life spans are greatly reduced by the use of turbid water with a high silt and clay content. The silt accumulates in the pores, effectively sealing the pipes/pots. Note: the turbidity and the salinity of the water can be reduced by the use of a sand filter.

There are a variety of crops that can benefit from pitcher irrigation practices. Upright vegetable crops require a 7-10 liter clay pot and 3-6 plants can be grown surrounding each pot. For creeping crops, or vines (i.e. melons, gourds, tomatoes...), the pot size can be 1-2 liters smaller and can be spaced further apart, requiring fewer pots per hectare. Researchers at CSSRI (Karnal) found that the most profitable crops for pitcher irrigation in that area were (in order): **tomato> bottle-gourd> bitter-gourd> watermelon> cauliflower**. The muskmelon was unprofitable, thus they do not recommend its cultivation with pitcher irrigation. Trees will require larger, deeper pots. Depending on tree spacing and species, one tree may require up to 3-4 pots.

Research with pitcher irrigation at the Central Soil Salinity Research Institute (CSSRI) in Karnal India indicates that the amount of water which seeps out of the pots--and thus the number of plants which can be sustained by each pot--depends on the soil type, the porosity of the pot wall as well as the shape of the pot used. Pitchers are generally placed at distances so that wet areas do not overlap. Soil moisture and salt distribution in the plant rootzone are much more favorable with pitcher irrigation than with any surface method of irrigation. Under pitcher irrigation salt accumulates at the soil surface, leaving the salt content of water in the rootzone more favorable than the salinity of water used in the pitcher. Thus even saline water can be used for irrigation in the pitcher irrigation system. Watermelon and muskmelon both tolerated water salinity levels of up to 12 dSm^{-1}. A tomato crop yielded almost 29 t/ha at 12 dSm^{-1} with 5000 pots/ha. Water of good quality for irrigation has a conductivity below 2 dSm^{-1}, while sea water has a conductivity of about 46 dSm^{-1}. Scientists at the Central Soil Salinity

Research Institute have found that seven to ten litre pots are sufficient to grow most vegetable crops. The number of pitchers needed per hectare varies with the crop. At least four plants of most vegetable crops could be grown around one pot. A creeping crop such as bitter gourd required 2000-2500 pitchers per hectare. Upright crops, or crops producing a canopy around the pot required more pots, up to 4000-5000 pots per hectare. The profitability of pitcher irrigation must consider the labor of acquiring, burying, and filling the pots, in addition to the labor involved in managing the crop. The prospects of pitcher irrigation are reasonably high, especially in areas where water scarcity and salinity limit cultivation. The only difficulty with this method is the high labor demand which it places on the farmer. Pitcher irrigation may be an inappropriate solution where the labor needed to set up and run the system would fall on already overworked laborers.

Porous clay pots and pipes are a means of water application that conserve water by applying water directly to the roots of plants, thereby limiting evaporation losses.



10. Water Technologies More Evidences

10.1 Land and Water Conservation Practices

Land and water conservation practices are planned changes in land use and vegetative cover and other nonstructural and structural actions that are made on a watershed to achieve ecosystem-based multiple-use management objectives. Watershed management practices implemented in rain-fed regions are oriented largely toward rehabilitating degraded lands; protecting soil, water and other natural resources on lands management to produce food, forage, fiber and other products; enhancing the flow of high-quality water from upland watersheds to downstream places of use. While many land users can occur on watersheds, natural resources production and environmental protection are equally important managerial objectives. Conservation practices provide a diversity of benefits to local inhabitants and to a greater number of people through the flow of water and other natural resources off the watersheds. Inhabitants of watersheds manage their land for the production of forage, food and fiber that they require to survive and generate income. Therefore, water, timber, forage and other natural resources on the watersheds should be managed in the most economically efficient and environmental sound combinations possible to obtain the products, commodities and amenities that people need. Importantly, the consumption or otherwise use of the natural resources on upland watershed must also be balanced with the needs of people living downstream and in the larger river basin. As a consequence, the proper management of watersheds is prerequisite to sustaining the flow of water that is necessary to maintain large-scale agricultural production within watersheds. How these watersheds are managed is also crucial to sustaining the flows of other commodities and amenities that are necessary to the livelihood of the people living on the watersheds and to downstream.

10.1.1 Technological Interventions

- Harvesting, conservation and judicious use of rainwater,

- Rejuvenation of depleted aquifers by adopting suitable artificial ground water recharge technologies
- Crop planning for rain-fed areas,
- Developing water, fodder and seed banks,
- Rehabilitation and management of degraded grazing lands,
- Launching afforestation program in a big way
- Crop diversification and adaptation of horticulture and medicinal land use models,
- Adaptation of improved cattle breeds and their health management
- Creation of technological awareness among watershed farmers,
- Providing financial support and credit facilities to watershed farmers for program implementation.

10.1.2 Success Stories[11]

Under R&D programs and based on research output, the Central Arid Zone Research Institute, Jodhpur has developed model watersheds for land and water conservation in different agro-ecological zones within Indian arid-ecosystem. The basic features and success made in are presented here.

10.1.2.1 Baorli-Bambore Watershed

Baorli-Bambore watershed is a classical example of resource conservation for drought proofing in hostile arid ecosystem. It has attracted attention of several people and organization in understanding and disseminating the success. The watershed covers an area of 870 hectares and is located on Jodhpur-Jaisalmer highway about 39 km from Jodhpur. Based on natural resources and after Participatory Rural Appraisal a master plan for adopting developmental activities and suitable land use models was prepared. The following watershed management activities were taken up.

[11] These case studies are due to M.A. Khan, Principal Scientist, CAZRI Jodhpur.

Soil and water conservation measures: As envisaged in the master plan, soil and water conservation measures was given priority and implemented in watershed. Soil and water conservation program by constructing and 2270 m contour bund was done in 15 hectares arable lands. Three check dams with stream gauging structures on main stream and several earthen and sand bags gully plugs were constructed to protect lands from erosion, protection of arable lands from sand and gravel casting, conservation of runoff and safe disposal of excess water. With the adoption of soil and water conservation, programs the highly degraded lands that were untilled before initiation of watershed management program have brought under crop cultivation. With the construction of gully control structures, gullies have been reclaimed, soil moisture regime has been improved, and groundwater reserve has been enhanced through recharge processes.

Khadin: Three *khadins* in sequence covering 3 hectares, 6 hectares and 10 hectares have been constructed on farmer fields. The inputs to khadins are uplands with catchments to command area of 12:1. With the construction of *Khadins* the land productivity has improved significantly. The farmers of *Khadins* are taking chickpea and mustered on stored profile moisture. In the year 2001 farmers could get Rs.20000-24000 per hectare net return out of sale of chickpea. Even during the severe drought of 2002 when nothing could be grown due to moisture limitation, farmers of *Khadins* were able to grow sorghum for fodder and earned Rs.28500 per hectare as gross income. The year 2003 was a good rainfall year and all the *Khadins* received rainwater in excess (20-45%) to their capacities. In Rabi season 2003 chickpea and mustard were taken on stored soil profile moisture in 19 hectares *Khadin* farms as well as in 24 hectares out side with pre-sowing irrigation from *Khadins. Khadins* have changed hydro morphology of watershed.

Tanka and Nadi: Five tankas of 20000 litres capacity each and one tanka of 10 lakh litres capacity were constructed for raising Kisan nurseries, forest plants on field boundaries and developing fruit orchards. The stored water in bigger tanka is used for developing Zizyphus (ber) orchard using drip irrigation. In order to improve drinking water availability, both for human and livestock in the watershed he existing nadis have been renovated and structures to store 87000-m^3 rainwater. This has helped the local population to save their time and energy used in transporting water from long distances. Crop Production and Productivity: Several conservation agronomic measures have been undertaken to increase the land productivity and to reduce the erosion in the watershed. Beside conservation measures, crop demonstration s were conducted on farmer fields with improved package and practices which included certified improved varieties of seed, balanced fertilizer, maintaining optimum plant population, soil working and control of pests and pathogens. Adoption of agronomic practices resulted in better productive performance of crops due to increase in soil moisture and enrichment in soil fertility. During 2000-2003 certified improved variety seeds, 171 kg of HHB-67 pearl millet, 348 kg of cluster bean (RGC-836), 236 kg of mung bean (K-851), 212 kg of moth bean (RMO-40) and 100 kg of chickpea (RSG-44) were distributed among the watershed farmers. Besides seed distributed, farmers also produced themselves improved variety seeds and sold in the market. By the year 2003, improved variety of major crops had covered over 80 per cent arable lands. Impact of technology on productivity of monsoon (kharif) crops is presented in Table 4.

Table 4: Impact of Technology on Productivity of Monsoon Crops

Crop	Grain Yield (quintal / ha.)			
	1999*	2003	% increase	Reasons
Pearl millet	3.80	12.24	226	Introduction of hybrid varieties (HHB-67, MH-169 and Raj-170) and improved management practices
Mung bean	3.40	8.50	150	Introduction of hybrid variety (K-851) and improved management practices.
Moth bean	2.10	5.80	171	Introduction of hybrid varieties (RMO-40) and improved management practices
Cluster bean	3.50	8.50	140	Introduction of hybrid varieties (RGC-936) and improved management practices

Note: * Before initiation of watershed management program.

Conservation forestry: Conservation forestry has an important role in regulating water regime, soil loss and maintaining biological diversity. Large-scale plantation on field boundary as well as in degraded uplands has been taken up in the watershed. Total 2650 saplings of *Acacia senegal* (1900), *Tecomella undulata* (250) *Dalbaria sisso* (250) and

Ailanthus excella (250) were planted and maintained with supplemental irrigation from *tankas*. Large-scale plantation has improved the ecology of watershed.

Silvi-pasture: Fodder to maintain large number of animal population was a major constraint before initiation of watershed management program. In order to check animal migration and mall nutrition by creating fodder bank, silvi-pasture activities were taken up in the degraded community owned upland. Over 2250 plants of different forest tree species were planted and Cenchrus cillaris grass was sown between trees spacing. Ditch-cum-mound fending around the area was constructed. Three land use models of silva, silvipasture and controlled grazing land were developed. Hydrological monitoring under different land use models is being carried during monsoon period. The average annual grass seed production from silvi-pasture block is about 100 kg ha^{1}.

Horticulture: Under crop diversification programme, large-scale plantation of *Zizyphus nummularia* (ber) and *Cordia mixa* (Gunda) were taken up. Over 920 bet saplings were planted and maintained on farmer's fields. In addition, ber budding of Gola variety on 180 rootstocks was done. On the boundaries of khadins Cordia mixa saplings were planted and being maintained. With the development of fruit orchards, farmers have been economically benefited even during severe drought year.

Improvement in livestock production: Several interventions in balanced nutrition and disease control were taken in watershed area to increase the milk productivity of cow and buffalo. Efforts were also made to increase the availability of green and nutritious fodder for the animals. It was observed that milk productivity of cow and buffalo was increased by average 118 and 61 per cent respectively. The increase in cattle and buffalo population between 1999 and 2003 was 58 and 204 per cent respectively, see table 5. This was possibly due to increased water and fodder availability and health management by watershed farmers.

Table 4: Impact on Cattle Population and Milk Production

	Cow			Buffalo		
Item	1999	2003	% increase	1999	2003	% increase
Population (no.)	148	234	58	42	128	204
Milk production (kg/animal)	4.8	10.5	118	11.5	18.6	61

Groundwater recharge: Construction of check dams, khadins, nadis and other mechanical measures have significantly improved the groundwater reserve in the zone of influence in the watershed. There was considerable increase in groundwater level to the extent of 1.8- 3.5 m annually. Data on recharge processes in using artificial recharge method of water pounding indicated that at the initial stage of water inflow in pond and increased wetted area during June the rate of deep percolation was as nigh as 120 mm day^{1}. De-siltation of pond before the monsoon season hastens the recharge processes. Thereafter, the percolation followed the receding trend till next high spell in the month of August. Deposition of fine soil matrix on pond surface reduced percolation rate. Due to heavy recharge from pond, the rise in wells located in immediate vicinity of structure was instant.

Hydrological monitoring: In watershed the hydrographs obtained from untreated uplands, treated area with silvi-pasture, forest, agriculture fields with conservation measures revealed relative recession time in untreated area followed by treated agriculture fields and forest block. The initiation of runoff was earliest with respect to untreated areas, whereas, the same was delayed by 15- 30 minutes in case of treated blocks, indicating the impact of conservation measures on infiltration of rainwater. As compared to untreated area, the reduction in silt load in runoff from treated silvi-pasture block was 60 per cent.

Strategies for More Crop and Income per Drop of Water
CRIDA's Views

Improving the income and water productivity through water harvesting and supplemental irrigation in high value rain-fed crops.

CRIDA has identified dominant rain-fed districts for various crops with opportunity, for water harvesting for supplemental irrigation during dry spells or for pre sowing irrigation during the rabi crop. About 11.4 mham surplus is available for harvesting from those districts.

Rain-fed rice uplands in Central and Eastern India generate large amount runoff. Opportunity exists for harvesting of the runoff, which would not only protect rain-fed low lands from water logging but also provide supplemental irrigation during dry spells.

Water productivity can be enhanced by supplemental/pre-sowing irrigation with harvested water in soybean cropping system, as potential for water harvesting is high.

Suitable interventions in these districts through small-scale water harvesting systems can be taken up immediately. The interventions would ensure both assured availability of water, better management practices and increased use of inputs thus increasing the water productivity.

Promotion of *in-situ* conservation technologies with need based water harvesting in semi arid areas in Peninsular and Western India.

New technologies of irrigation (drip and sprinkler) to increase the application efficiency in existing perennial plantations (fruit trees) in semi arid areas in Peninsular and Western India

Water user groups to be created in rain-fed areas for ensuring efficient utilization of available resources (both surface and ground water) within a watershed including minor irrigation schemes (on the lines of water user associations in canal command area).

Organizing awareness among farmers on water use by crops through participatory monitoring (especially in rain-fed regions of South and western India).

Promotion of integrated farming system like fish-duck-rice cropping system can be taken up in humid areas of Eastern India (GR Korwar, KV Rao and YS Ramakrishna, Central Research Institute for Dryland Agriculture (ICAR), Santoshnagar, Hyderabad).

10.1.2.2 Sar Watershed

Sar watershed covering an area of 1480 hectares is located about 30 km south of Jodhpur City. The benefit of the watershed activities is substantial in terms of water availability, more crop and fodder and milk production. Imposition of land treatment technologies resulted in reduced runoff and higher moisture conservation to benefit crop production. Soil and water conservation measures in agricultural fields reduced surface runoff and enhanced in situ moisture conservation on slopes. In the control average annual runoff was 133.5 mm (28%) with the soil loss was 5.42 ha^1. Conservation measures, namely contour bunds with vegetative barrier, were found most effective exhibiting only 19.1 mm or 4 per cent runoff and 0.67 t ha^1 soil losses. Contour vegetative barrier of *Cenchrus setigerus* and contour bunding were also effective in controlling runoff as well as soil loss. Peripheral bunding, a common practice in this region was effective for in *situ* moisture conservation.

Conservation forestry: Under afforestation programme, 42344 saplings of *Acacia tortilis, Acacia senegal, Acacia nilotica, Prosopis juliflora, Prosopis cineraria and Chlorophospermum mopane* was planted during 1991, 1992 and 1993 on common community grazing land. The saplings were established with supplemental irrigation from conserved water in a 142 m^3 masonry open tanka constructed in this part of watershed. The overall plant survival was over 79 per cent. Development of silvipasture in degraded grazing land with conservation measures and seeding of improved strain of Cenchrus cillaris (CAZRI-358) reduced runoff by 28-63 per cent and soil loss by 12-54 per cent, thereby improving water regimes and overall ground cover. Social fencing for 5 years with active participation of watershed farmers and conservation measures helped in improved forage production by 280 per cent (2.15 ha^1 yr^1 dry matter) and improved woodlot by 416 per cent.

Rainwater harvesting and recycling: Construction of tank of 10000 liters capacity at 15 locations on farmer field for supplemental irrigation in the fruit orchards and for raising ber (Zizyphus mauritiana) and forest nurseries raised farmer’s income to Rs. 6000 to 7000 annually. This has been achieved with the sale of fruit plants. With supplemental irrigation (50lit/ierr/plant) the fruit yield of ber and pomegranate increased significantly. Compared to control (no irrigation) increase in fruit yield with 2.4 and 6 irrigations for ber was 46.4, 80.3 and 124 per cent in the case of pomegranate it was 69.8, 112.5 and 191.7 per cent respectively. Before the initiation of watershed management work drinking water was scarce in villages. To improve drinking water availability a tanka of different capacities with artificially prepared catchments were constructed. Roof water-harvesting system at School to store 64000 liters and at Matt to store 50000 liters rainwater in tanka were also developed. These additional water resources are sufficient to meet drinking water demand for 272 persons round the year. The resultant benefit of rainwater harvesting system is Rs.136000 annually, saving in the cost of hauling of water by farmwomen from long distances.

Crop production and productivity: Conservation measures in conjunction with improved agronomical practices and improved varieties resulted higher grain yield of pearl millet, mung bean and cluster bean. The highest average grain yield of pearl millet (HHB-67), mung bean (K 851) and cluster bean (RGC 936) was 15.9, 10.5 and 46.7 q ha^{1}, respectively in plots treated with contour bund +vegetative barrier, followed by contour bunding, peripheral bunding and lowest was obtained in contour vegetative barrier. However, farmers preferred peripheral bunding to other measure, because it acts as property bund cum fence against stray catches. The farmers almost for all crops preferred the adoption of improved varieties on large scale. Initially project staff facilitated farmers in purchase of improved varieties from cooperatives. However, from fourth year onwards farmers adopted independent approach on their own level for purchase of improved seeds. They also facilitated farmer from other areas in adoption of improved crop husbandry.

Groundwater recharge: In order to induce groundwater recharge, an existing pond was desilted and structured to store 28000 m^3 expected water yield from its catchments. Three 20 m deep infiltration wells in the bed of pond were constructed. The annual runoff from catchments harvested ranged from 28-67 per cent of the rainfall. In a season 18000-20000 liters of stored water was added to depleted aquifer through induced recharge. The enhanced groundwater is a major source of drinking water during lean period.

> In Rajasthan, especially in the western desert region, people traditionally have saved water even for drinking purposes with developing food culture, which entails consumption of hot chillies. They help in extra saliva secretion and food digestion.

11. Importance of Micro-irrigation

Micro-irrigation technologies are increasingly seen as a means of addressing the growing competition for scarce water resources. Appropriate low-cost drip systems have shown to have positive effects on yield, incomes, and food security. With the right institutional support, these systems can help poor farmers improve water productivity and incomes.

11.1 Promoting Micro-irrigation Technologies that Reduce Poverty

According to research done by the International Water Management Institute (IWMI), one-third of the world's population will face absolute water scarcity by the year 2025. Among the worst hit will be regions in Asia, the Middle- East and Sub-Saharan Africa, home to some of the largest concentrations of rural poverty in the world. Policymakers, researchers, NGOs, and farmers are pursuing various technical, institutional and policy interventions to meet this challenge.

Micro-irrigation technologies, commonly in use in water scarce areas of developed countries, constitute one such intervention with the ability to use water more efficiently in irrigated agriculture. These technologies can improve productivity; raise incomes through crop yields and outputs; and enhance food security of households. Numerous studies have established the gains from micro-irrigation adoption and several government and non-government organizations are engaged in actively promoting the technologies.

More Crop and Income per Drop of Water: Gujarat Experience

Gujarat has constructed lakh from ponds and 75000 check dams with people's participation in last 4 years. Therefore, area under Kharif and Rabi cultivation has increased from 95 to 115 lakh hectares. In Saurashtra, the water table has increased substantially because of recharging and rain harvesting. Due to this the pumps which used to run for 2 hours a day now runs for more than 8 hours a day. The Heros who controlled the drought by water harvesting technologies are the silent crusaders. Shri Mansukhbhai Sawagia of Jamka village in Junagadh district has constructed 51 check dams with people's participation, now formed a Jalkranti Trust, have guided 4800 villages for constructing farm/village ponds and check dams. There are crusaders like "Premji Bappa" who are spreading the message of "Plant a tree and get rain". He is educating villagers to recharge open wells. Shri Chhaganbhai of Bhenkra village in Savarkundala taluka of Amreli district started the watershed development by blocking the water drains by mud and stones, resulted in all the village wells flowing with water in peak summers. Mr.Shyamjibhai Antala, the reviver through "Saurashtra Lok Manch" has taken the task of reviving the dry wells in drought prone Bhavnagar and Amreli district and other parts of Gujarat. Government of Gujarat launched Gujarat Krishi Mahotsav in 2005 and 2006, wherein scientists of Agricultural Universities visited villages to spread the technologies, which helped doubling agriculture income of the farmers. Gujarat has made a noteworthy initiative to promote micro- irrigation by establishing Gujarat Green Revolution Company with 1500 crore and to cover 20000 hectares with a target of 1 lakh hectares.

Potential farmers like: Mr. Gunvantbhai R. Patel of Sarsa village of Anand, having 25 hectares has installed drip in 23 hectares. He is growing Banana in 10 ha yielding 60 tons/ha with an average bunch size of 30 kg. The maximum bunch is of 60 kg. potatos in 10 hectares and fodder in 3 hectares. He has doubled his income. Narsibhai Patel of Nayaka village of Kheda district has 8 hectares drip installation and grows only vegetables like Bitter guard, Brinjal, Tomato, Chilli and Okra. He used to earn 40 to 50 thousand Rs/ha now earns 90 thousand/ha. Similar are many more examples of the potential users of pressurized irrigation systems.

Derol Drilled Paddy Research Station has released G-9 variety of drilled paddy in 2005-06 having a productivity of 2.5 tons/ha and having high water use efficiency. Many farmers have been benefited from it. The production of cotton was 27 lakh bales 6 years before, which has now increased to 89 lakh bales/year due to more area under irrigation, development of high yielding new varieties and improved technology. The area, which was 26 per cent four years before is now 32 per cent because of proper water resource management. The state is having an expansion of output for fruits and vegetables. A model for providing support for the produce is developed by NDDB. The same model can be replicated. Gujarat is setting up a perishable air cargo complex at Ahmedabad, International Air port as a special export zone (SEZ) for mangoes, sapota, vegetables and onion. It is expected that Gujarat will leave no stone unturned to achieve more than 4 per cent growth in Agriculture so that 11 per cent over all growth rate is achieved in 10th Five Year Plan of India (M.C. Varshneya Vice-Chancellor Anand Agricultural University, Anand).

In India, micro-irrigation technologies have been marketed for more than three decades. The main vehicle of government policies to promote micro-irrigation systems are product subsidies-in certain cases up to 90 per cent. However, there has been a lukewarm response to such initiatives from farmers, especially smallholders. This can be attributed to several causes: lack of access to groundwater, lack of cash, crop specificity of the available micro-irrigation technologies, lack of know-how, poor product quality and absence of adequate credit facilities[12]. Studies show that despite active promotion, the appeal of these technologies has remained confined to *"gentlemen*

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[12] A. Narayanamoorthy (1996), *Evaluating Drip rrigation System in Maharashtra*, mimeograph series No. 42, Agro-Economic Research Centre, Gokhale Institute of Politics and Economics, Pune, March, pp. viii+114.

farmers"-wealthier farmers who produce commercial crops[13].

Despite these constraints, in certain pockets of India, these technologies have become a popular choice among farmers. It is notable that, in some of these cases, the technologies have been adopted in the absence of government subsidies. However, IWMI's work shows that in general special efforts are required to market cost appropriate technologies to the poor and smallholder farmers. Drip irrigation is often promoted for reasons that do not match with the farmers' main concerns. While the government promotes drips as long-term investments for water saving and sustainable agriculture, the farmers look for more immediate and assured benefits, such as lower costs and increased incomes.

11.2 Micro-irrigation Technologies

Micro-irrigation technologies can be broadly categorized into two types based on their technical and socioe-conomic attributes: low-cost micro-irrigation technologies and the commercialized, state-of-the-art micro-irrigation systems. Low-cost systems include the *Pepsee* easy drip technology, bucket and drum kits, micro sprinklers, micro tube drip systems and others that have been designed by organizations such as the International Development Enterprises (IDE), along with innovative farmers. The more sophisticated, capital- intensive systems are conventional drip and sprinkler systems.

The technical, economic and social attributes that distinguish the low-cost irrigation systems from commercial state-of the-art irrigation systems are as follows:

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[13] Tushar Shah and Keller (2002), "Micro-irrigation and the Poor: A Marketing Challenge in Smallholder Irrigation Development" in H.Sally and C.L Abernathy (eds.) *Private Irrigation in Sub-Saharan Africa: Regional Seminar on Private Sector Participation and Irrigation Expansion in Sub-Saharan Africa*, Accra, Ghana, October 22-26, pp.165-83 (as cited in Water Policy Briefing Issue 23, IWMI, Colombo).

Criteria	Micro-irrigation systems	
	Low cost systems	*Conventional systems*
Affordability	Require little initial capital	Require little initial capital
Local manufacturing capacity	Based on local skills and materials	Require relatively sophisticated Facilities
Payback period	Usually covers investment cost in one or two seasons	Require several years
Compatibility to the farming System	Available in a range of small packages and expandable	Generally adopted by large farms, but small versions of high- systems are also being marketed
Pressure requirement	Require low pressure	Require high pressure
Ease of technical understanding By users	Simple and easily understood	Sophisticated and need technical expertise
Operational convenience	Low operational conveniences	High operational conveniences
Compatibility with local micro-Entrepreneurship	Compatibility with local micro-entreprises and require limited skills and capital to design, service and maintain	Require special skill

Source: Water Policy Briefing Issue 23, IWMI, Colombo.

Low-cost micro-irrigation technologies are largely promoted to poor farmers, hence their competitive pricing and compatibility with smallholder farming systems. Farmers can generally recover their initial investment capital between one and three years, although the extent of economic gains from investment depends on the type of crop. Subsidies and options for financing from organizations and government schemes like IDE, the AKRSP and the Gujarat state government in India can further increase the profitability of investing in micro-irrigation[14], which makes a crucial difference in adoption by poorer farmers. It has also been noted that there is often a progression from low-cost to conventional systems-IWMI's study of micro-irrigation adoption in India found that farmers who have adopted low-cost micro-irrigation see it as a step towards modernizing their farming systems, and may go on to up-scale to more capital intensive systems later on.

[14] Regassa E. Namara, Bhawana Upadhyay and R.K. Nagar (2005), *Adoption and Impacts of Micro-irrigation Technologies: Empirical Results from Selected Localities of Maharashtra and Gujarat States of India*, IWMI Research report 93 (IWMI RR 93), Colombo.

11.3 Improving water productivity and yield

The use of micro-irrigation technologies generally results in a significant yield improvement over traditional irrigation practices such as flood irrigation (Table 6).

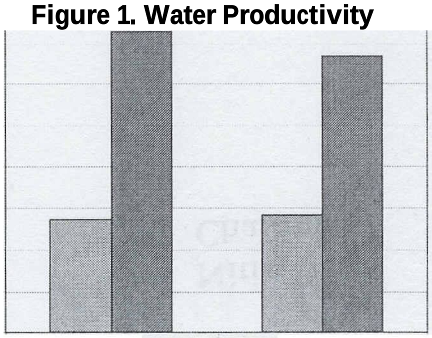
Table 6. Realized extra yield due to micro-irrigation over and above what's possible under traditional methods such as flood irrigation

	Change in yield under micro-irrigation (t/ha)		
Micro-irrigation	Banana	Groundnut	Cotton
Low-cost drip Micro-tube drip	+14.2		+0.7
Conventional drip Micro-sprinklers		+0.4	+0.5
Conventional sprinklers	+18.1		+0.9
Micro- sprinkler		+0.7	
Conventional sprinklers		+0.5	

Source: Water Policy Briefing Issue 23, IWMI, Colombo.

Research in Gujarat has shown that yield improvements from micro-irrigation technologies are dependent on the crops grown and the type of irrigation system used. Various studies have also shown that for many different crops, drip systems produce more per unit of water used, thus increasing water productivity (Figure 1, Tables 7 and 8). When water is pumped for irrigation, savings in energy required for irrigation can also be significant. It is notable that the magnitude of water productivity difference between the conventional and micro-irrigation systems is by far larger than the magnitude of land productivity differences between the two systems (Table 8). Hence, micro-irrigation technologies are even more appealing for water scarce environments.

Figure 1. Water Productivity



Source: IWMI RR 93.

Table 7: Water Productivity under Different Irrigation Methods

	Water Productivity (kg/ m^3)	
	Conventional	Drip
Cotton	3.1	11.6
Sugar beet	85.0	132.0
Sweet potato	6.7	23.4
Beetroot	0.7	5.0
Radish	2.25	11.0
Papaya	0.06	0.32
Mulberry	138.6	375.0

Source: Water Policy Briefing Issue 23, IWMI, Colombo.

Table 8:. Land and Water Productivity of Selected Crops under Conventional and Drip Irrigation Systems in India

	Yield (t/ha)		Yield (kg/ m^3)	
Crop	Conventional	Drip	Conventional	Drip
Banana	57.5	87.5	3.3	9.0
Grapes	26.4	32.5	5.0	12.0
Sugarcane	128.0	170.0	6.0	18.1
Tomato	32.0	48.0	10.7	26.1
Watermelon	24.0	45.0	7.3	21.4
Cotton	2.3	3.0	0.3	0.7
Chillies	4.2	6.1	0.4	1.5
Papaya	1.3	2.4	0.1	0.3

Source: NCPA, 1990 as cited in Water Policy Briefing Issue 23, IWMI, Colombo.

11.4 Changes in cropping patterns

An interesting outcome *of* micro-irrigation adoption in the study area is its impact on cropping patterns. Farmers who adopted alternative technologies in the study locations changed their crops and also the extent of cultivation. More specifically, micro-irrigation adoption proved to encourage farmers to increase their overall cropping intensity or to shift their cropping patterns to high-value, water intensive crops (Table 9). For example, in Maharashtra, the main change in cropping pattern observed was a shift from groundnut and oil seeds to high-value, water intensive crops, such as banana. In Gujarat, an increase in vegetable production was observed. If the result is an increase in total water use, there could be conflict between the positive impact on poverty and food security and the sustainability of water resource use, especially groundwater, when micro-irrigation is adopted.

Table 9: Comparison of the cropping patterns of micro-irrigation adopters and non-adopters

Crop	Gujarat		Maharashtra	
	Adopters%	Non-adopters%	Adopters%	Non-adopters%
Groundnut and other oilseeds	54.7	63.7	1.2	7.1
Cotton	20.1	6.7	31.1	48.8
Cereals	9.7	15.5	28.7	25.0
Fruit crops	7.6	10.3	25.0	3.6
Vegetables	6.0	2.9	4.8	4.8
Sugarcane	0.9	0.7	0.8	1.2
Pulses	0.3	0.0	8.2	9.6

Source: IWMI RR 93.

11.5 Increasing incomes and reducing

Low-cost drip systems increase income for poor farmers by enabling more efficient use of water resources, improving yield, improving quality, and reducing labour costs. Drip systems have a particular niche in monsoonal climates. 'They allow farmers to plant earlier so that the crop is already established at the onset of rains and can make efficient use of rainwater. This helps to avert a crop loss, or a decline in yield that could arise from a dry spell or the early withdrawal of rain. One of the key advantages of using such technologies is that it helps to extend the use of water during times of drought or water scarcity, and mitigates the risk of losing a crop. Micro-irrigation can thus improve livelihood security to poor farmers vulnerable to rainfall variability.

Studies have shown that crop yields improve when drip irrigation is used. Yields are higher because the systems allow for multiple crops to be grown; for crops to be grown under circumstances where it was not possible when there is an early withdrawal of the monsoon; and for cropping to be intensified in the same field. Farmers who adopt the system also have the possibility of extending irrigated or cultivated area on their land. This has a significant effect on the incomes of farmers, as higher yields bring higher earnings.

Drip systems have the potential to improve the quality of the harvest because it is a form of precision irrigation, and applies water directly to the root zone. Each plant is able to receive the right amount of water at regular intervals, and less water is lost due to conveyance. When farmers use traditional irrigation methods, such as flood irrigation, they often tend to over irrigate or under irrigate their crops depending on the amount of water they are able to pump and not necessarily on the amount that their crop requires. In addition to quality and yield, farmers may choose to use drip systems because it reduces labour. Micro-irrigation allows for early harvesting of the crop, which reduces the labour costs of farmers. Weeds, insects and other plant diseases have also proven to occur less frequently with the adoption of this technology, cutting down the efforts that farmers have to make to protect their crop. The lower energy expended when micro-irrigation is used in cultivation has an effect on the overall cost of production, making this one of the main reasons why farmers switch to the technology. Interviews with mulberry farmers in Kolar, India recorded that the labor requirement reduced drastically from using drip irrigation over flood irrigation[15].

> Drip kits provide women with opportunities to earn incomes from homestead plots, enhancing household food and nutritional security

The impact of micro-irrigation adoption on rural women differs depending on whether they are small or large cultivators, primarily because the systems adopted are different. In IWMI's study women from sma11 cultivator households used drip kits for vegetable farming in their homesteads, while women from large cultivator households used customized systems. Micro-irrigation was able to benefit both cultivators. It provided the women smallholders with an income generating opportunity and they received revenue from the sale of their produce. The women from larger farms benefited from the technologies as it led to a reduction in the labor requirement. Micro-irrigation technologies can improve the food and nutritional security of sma11 cultivator households that have adopted the technology. In the study, there was a marked improvement in household food security and nutritional intake for women small

[15] Tushar Shah and Keller (2002), “Micro-irrigation and the Poor: A Marketing Challenge in Smallholder Irrigation Development” in H.Sally and C.L Abernathy (eds.) *Private Irrigation in Sub-Saharan Africa: Regional Seminar on Private Sector Participation and Irrigation Expansion in Sub-Saharan Africa*, Accra, Ghana, October 22-26, pp.165-83 (as cited in Water Policy Briefing Issue 23, IWMI, Colombo).

cultivators who adopted bucket and drip irrigation for homestead vegetable cultivation. The adoption of drip and bucket irrigation helped farmers to grow vegetables for household consumption that were otherwise missing from their daily diets, often using land that had been bare. Diets improved also due to the additional income from surplus produce being sold in the market. This additional income remained mostly in the hands of women who were responsible for bringing it in. It was observed that this particular factor had an impact on food security for the family, as women tended to prioritize spending on household food items. Research from an IWMI study on micro-irrigation in Nepal[16] corroborates these findings from Gujarat and Maharashtra. They found that in Nepal where the NGO IDE has worked to promote livelihoods, women farmers once introduced to drip kits, were able to increase vegetable production in their homesteads. They also grew vegetables over a larger area and their crops were of better quality and size. Vegetables became a part of the daily diet of these families, and the women were able to increase their incomes from selling a portion of their produce.

11.6 Poverty Outreach of Micro-irrigation technologies

11.6.1 Socio-economic variables influence adoption

When the poverty outreach of micro-irrigation technologies was assessed it was revealed that the largest group of adopters were farmers that fall into the wealthier categories on one poverty index. In Gujarat, the distribution was somewhat even amongst the middle, rich and the very rich farmers-whereas in Maharashtra, the richest farmers in the sample represented the highest proportion. The difference between the patterns of adoption in the two states can be attributed to the activities of NGOs operating in Gujarat, whose policies included subsidizing the cost of the technology and providing other forms of support (such as credit and training) as well. These efforts have helped middle and lower income farmers in the state to make the change to drip systems.

- In Gujarat, the current micro-irrigation adopters are somewhat evenly distributed among the middle, rich and very rich groups.

[16] As cited in Water Policy Briefing Issue 23, IWMI, Colombo.

- Currently, the largest proportion of micro-irrigation technology adopters in Maharashtra belongs to the relatively very rich group
- The slight difference in the poverty outreach of micro-irrigation technologies between Gujarat and Maharashtra is due to differences in the support system; there are many NGOs operating in Gujarat
- In both Maharashtra and Gujarat, the poor and the very poor categories are the least represented.

11.7 Influencing micro-irrigation technology adoption

11.7.1 Institutional systems for Micro-irrigation Technology Dissemination

11.7.1.1 Direct Marketing vs. Government Extension

In the study areas, NGOs, governmental organizations and private businesses are involved in promoting micro-irrigation technologies. In Gujarat, the NGO most prominently involved is the Aga Khan Rural Support Program (AKRSP), while International Development Enterprises (IDE) works in both Gujarat and Maharashtra. These organizations have different approaches to promoting technologies. IDE engaged in designing the actual technology to be more easily accessible to poor fanners. They concentrate their training and other support activities on disseminating information on how new designs actually work. They hold events such as video shows, field demonstrations, and exhibitions in village markets, and meetings with farmers to do this. IDE does not provide financial support to acquire the technology but links farmers to financial institutions and output markets. The AKRSP on the other hand, takes a slightly different approach. They undertake training for 'Assemblers' and Village Extension Officers on micro-irrigation technology, which are mainly private entrepreneurs. The extension oft1cers function as the marketers of the technology and are responsible for disseminating the information to the fanners. Once they meet and interact with a farmer who is willing to 'volunteer' to tryout the technology the assemblers prepare a proposal based on the feedback of the volunteer. AKRSP's technical staffs then review this proposal, and once approved, the system is installed in the farmer's field and a subsidy *is* given directly to the farmer. AKRSP also deals directly with farmers who may want to interact with the organization or the assemblers directly. How women can help in water saving see figure 2.

Figure 2: Water Pyramid

In the case of Gujarat, the state government has also played an active role in promoting micro-irrigation technology among poor farmers. It has done this through a subsidy scheme that has different rates depending on the socio-economic status of the farmer. For example, small, marginal, backward, tribal and female farmers may receive a 50 per cent subsidy for installing drip, sprinkler and pipeline systems. Large cultivators may avail of a 35 per cent subsidy for drip systems, and 40 per cent for pipelines. There are also centrally administered programs that give subsidies to farmers for micro-irrigation technologies, but the rate is set at 25 per cent for all farmers irrespective of their socio-economic standing. Although these opportunities are available, actually procuring a system using one of these subsidies is a long and painful process. Farmers are often reluctant to engage state or central government subsidies for this reason. However, the result has been more even distribution in economic status amongst adopters than occurred in Maharashtra where no such government subsidies existed. The direct marketing approach taken by NGOs has shown to be more effective in bridging the gap between the supply and demand of micro-irrigation technologies than the traditional government extension approach. Through activities that disseminate information, raise awareness and most importantly demonstrate the use and benefits of the technology, they seek to create a market for the product amongst farmers.

11.8 The Challenge - bridging the gap between farmers and policy

Economic efficiency is only one of the many factors that influence farmers' decisions to adopt micro-irrigation. The successful adoption of micro-irrigation requires, in addition to technical and economic efficiency, some additional preconditions:

> The target beneficiaries need to know about the technical and economic advantages of using these technologies, which may be achieved through extension services.
>
> Creating a market for new technologies is slow and expensive. It takes sustained effort and resources to raise awareness on and demonstrate the effectiveness of a product.
>
> The technologies need to be accessible to the potential users. Awareness or knowledge does not guarantee actual adoption unless the technologies are made accessible to the farmers through institutional support systems such as credit provisions and subsidies (Water Policy Briefing Issue 23, IWMI, Colombo).

11.10 Strategic recommendations

The low cost and compatibility of micro-irrigation systems for small cultivators lends itself to targeting the poor, but without specific institutional support and strategies a market for this technology cannot be created, and its uptake will be slow. Hence the most important aspects that int1uence the adoption of micro-irrigation are the efforts of policymakers and organizations in long-term service provision and training. Policies must have a strong poverty focus that emphasizes the potential to improve incomes and outputs for poor farmers, while building awareness and demonstrating the potential of micro-irrigation technologies in accordance with their priorities and concerns.

> Shifting Water Saving Technologies from Investment Mode to Input Mode: If smallholders and poor farmers are to be targeted, policymakers must understand that

promoting micro-irrigation technologies through capital investments that offer returns over 8-10 years is not the way forward. Even when they are convinced about the returns, poor farmers might not be in a position to incur the huge capital costs due to poor access to credit facilities. Poor farmers are more likely to experiment with options such as *Pepsee* systems that cut initial capital costs by having lower recurrent input costs promising returns within a year. Although these innovative low-cost systems have a shorter lifespan, once the returns start flowing in, farmers may decide to shift to the more durable varieties.

Creating 'First Mover Advantage': Micro-irrigation is seen as a high risk venture, and farmers tend to wait for others in the neighbourhood to tryout and test new technologies first before they adopt their own systems. Some programs have tried to overcome this obstacle by providing special incentives to 'first movers'. In IWMI's North Gujarat Initiative in Banaskantha, demonstration plots let the farmers see for themselves what works and what do not in their immediate context. These also help educate the farmers about a variety of micro-irrigation technologies. The AKRSP (I) in Saurashtra, Gujarat is providing greater support to initial adopters, which it gradually reduces over the years.

From Custom- Solutions to Package Solutions to Farmer-Assembled Systems: The market for micro irrigation products is experiencing its second major shift today. From the sophisticated custom built drip irrigation solutions for the commercial farmers, the technology has shifted towards package solutions provided in the form of drip kits popularized by organizations such as IDE. Today, there is a need to transfer the technology into the hands of the users. Farmers are demanding components of drip kits like pipes, drippers etc., which they can assemble locally and the biggest example of this shift is the popularity of *Pepsee* systems. Similar trends can be seen in the grey drip markets in Kolar district in India. AKRSP (I), which is promoting micro irrigation in Saurashtra, Gujarat has supported private entrepreneurs to set up manufacturing and assembling plants locally. AKRSP's experiment with 'assemblers' and village extension officers is also a step in this direction (Water Policy Briefing Issue 23, IWMI, Colombo).

The diversity of conditions and situations in which micro-irrigation has proved successful shows that no single technology or practice can be a panacea. However, participatory approaches that encourage and support the creativity and innovation of farmers, by offering options that can be adapted and combined as needed, can help farmers improve their outputs and escape from poverty.

12. Conclusions

Water Conserving Technologies should form an important component of the regional strategy for food security, rural development, enhanced profitability, improved environmental quality and sustainability. Some of the cases cited here do have capacaity of replecation. Water is going to be vital given the climate change and more efforts are required to development water saving crop varieties, domestic water tools and gadgets that use less water and above life styles should change to conserve water.

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