WATER PRODUCTIVITY IN AGRICULTURE- A REVIEW OF EMPIRICAL EVIDENCE FOR SELECTED ASIAN COUNTRIES AND INDIA

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Abstract

In the context of the growing demand for water and the emerging water crisis, this paper examines the prospects for improving water use efficiency in agriculture that will help water savings and also increase crop yields per unit of water input. Evidences from experimental or farmer participatory trials in a cross section of regions, countries, sites in Asia and the Indo-Gangetic plains suggest that alternate agronomic and crop management practices such as zero-tillage, bed planting, non-puddled rice culture and laser leveling can result in water savings and also improve rice and wheat yields per unit of water input.

1. INTRODUCTION

Although water seems to be the most abundant resource available on the earth, it is paradoxical that governments, international organizations and policy makers are talking of an emerging water crisis. This paradox can partly be explained by the fact that although water is seemingly so plentiful, of the world's water resources about 97.5% is salty and hence unfit for human consumption and crop production (Saleth and Dinar, 2004). Of the remaining water resources which constitutes fresh water resources most of it, i.e., an estimated 35 km^3 per year, cannot be fully accessed since most of it is locked either in the ice cover of the Artic or Antarctic regions, or in deep underground aquifers (Saleth and Dinar, 2004). The physically accessible freshwater potential of the world is estimated at only 90,000 km^3 per year or just 0.26% of global freshwater resources (Saleth and Dinar, 2004). However, even of the physically accessible freshwater resources only about 12,500 m^3 can be accessed under present economic and technical conditions (FAO; 1996, Saleth and Dinar, 2004). In relative terms, however, water resources or water availability or water withdrawals show wide variations across countries, regions and sites. For instance, the per capita annual water withdrawals during 2003 ranged from 10 m^3/person in Congo D.R. to 1607 m^3/person in Canada (www.wri.org, 2005). For Asian countries these figures ranged between 60 m^3/person for Cambodia to 1451 m^3/person in Nepal (www.wri.org, 2005). Owing to increasing population, incomes, and economic growth, extension and intensification of agriculture, rapid urbanization and industrialization, demand for water is expanding fast putting great strain on the available water resources and on global, regional, national and local economies. Added to that climatic-induced variations in the level and spatial pattern of global temperature and precipitation are going to further affect utilization of the accessible freshwater resources (Saleth and Dinar, 2004). In fact, water is turning out to be the most important constraint for sustaining human life and economic activity, and in the days to come the water crisis, as it is popularly referred to, is going to be the most important factor impeding and sustaining economic growth.

What is more disturbing is that it is the developing countries especially in Africa and Asia struggling to increase their living standards that are going to be hit the hardest by the emerging water crisis. By the year 2025 it is estimated that about 2 billion people will live in countries or regions with absolute water scarcity. Most countries in the Middle East and North Africa are presently classified as having absolute water scarcity (www.iwmi.org, 2005). By 2025 these countries will be joined by Pakistan, South Africa and large parts of India and China (www.iwmi.org, 2005). It is reported that many countries especially in the Middle East are

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nearing or exceeding their renewable water supply limit (Gleick, 1993; Saleth and Dinar, 2004). Fifty-five countries in Africa and Asia are unable to meet the basic water needs of their growing population. It is noted that about 2.2 billion people in the world especially in developing countries do not have access to clean water and about 2.7 billion people do not have access to sanitation services (Gleick, 1998; Saleth and Dinar, 2004). Poor access to safe water and sanitation also leads to high health and economic costs due to water borne diseases such as diarrhea, typhoid, gastro-enteritis, malaria, and water pollution.

Against the background of the global water scenario, this study seeks to assess the prospects and constraints for sustainable use and management of water resources. This study, therefore, seeks to focus attention on an important aspect i.e. water productivity which has a bearing on sustainable use and management of water resources.

2. OBJECTIVES

The specific objective of this paper is to analyse water productivity in agriculture across countries, regions or sites and crops in selected Asian countries and India.

3. DATA AND APPROACH

The study is based on secondary data and sources of information drawn from official publications, research reports and journal articles. The data analysed here are drawn from experimental trials or farmer participatory trials conducted in a cross section of countries and regions in Asia and India between 1998-2002. Dose-response method or with and without treatment approach have been used to assess the impact of different treatments, technologies or crop practices on water productivity of crops, and water savings. The analysis covers rice and wheat, which are the two important staples in Asia and the Indian sub-continent and account for a major share of irrigation water use. In fact more than 80% of the developed freshwater resources in Asia are used for irrigation purposes, and about half of the total irrigation water is used for rice production alone (Bhuiyan, 1992; Guerra et al., 1998). However, while comparing the estimates of crop water productivity across regions and countries in Asia and India, one must not lose sight of the fact that rice and wheat are grown under diverse agro-climate situations and environments in Asia and India.

4. WATER PRODUCTIVITY

Agriculture and especially the irrigation sector accounts for bulk of the water consumption in most regions, and more so in Asia. For instance, agriculture's share in annual freshwater withdrawals for the world as a whole is about 71%, as compared to 9% for domestic and 20% for industrial sectors. In most Asian countries, agriculture's share in annual freshwater withdrawals exceeds 70 – 90%; in fact in most South and Southeast Asian countries agriculture's share exceeds 90%. However, with growing water scarcities and growing competition for available water from the domestic, industrial and environmental sectors as well as the prohibitive costs of future irrigation investments, economizing on water use and improving water use efficiency especially in agriculture, assumes importance. In this context, improving crop yields per unit of water input and reducing water losses need attention.

Rice, which is the staple food for nearly half of the world's population especially in Asia, is a heavily irrigated crop. More than 90% of the world's rice is produced and consumed in Asia (Barker and Herdt, 1985; vide Guerra et al., 1998). In fact, more than 80% of the developed freshwater resources in Asia are used for irrigation purposes and about half of the total irrigation water is used for rice production (Bhuiyan; 1992:vide Guerra et al., 1998). The abundant water environment in which rice grows best differentiates it from other important crops (Guerra et al., 1998). However, with water becoming increasingly scarce and with agriculture's share of water projected to decline faster because of increasing competition for available water from the urban, industrial and environmental sectors, economizing on water use in agricultural production is an important objective. For instance, it is noted that in many Asian countries, per capita availability of freshwater declined by

40-60% between 1955 and 1990 and is expected to decline further by 15-54% over the next 35 years (Gleick, 1993; Bouman and Toung, 2000). Rice being a water intensive crop, it is believed that there is tremendous scope to economise on water use in rice production and thereby improve water use efficiency and water productivity. Consequently, many resources are being invested on research to find ways for improving water use efficiency and water productivity in agriculture especially of water intensive crops like rice.

Before discussing crop water productivity, we briefly deal with the issue of irrigation efficiency in general. Irrigation efficiency is generally defined as the ratio of the amount of water that is required for an intended purpose divided by the total amount of water diverted to a spatial domain of interest (Guerra et al., 1998). The domain may refer to a farm, system or basin level. Overall irrigation efficiency of an irrigation system is defined as the ratio of water used by the crop to water released at the headworks. It can be sub-divided into conveyance efficiency, field channel efficiency and field application efficiency. Water losses could occur at different levels, i.e, at the farm, irrigation system or basin level. Reducing water losses at each stage and overall water loss is an important goal for saving water and improving water use efficiency. Table 1 gives an idea of the overall irrigation efficiency of selected irrigation systems in some Asian countries. It is interesting to note that the overall irrigation efficiency of the irrigation systems in four countries under review show large variations. These range from around 30-38% in India to 40-65% in Indonesia. In Thailand for the irrigation system under review the irrigation efficiency for wet season was 37-46% and between 40-62% for dry season. If these figures could be taken as indicative of the level of water use efficiency of irrigation systems in Asia it suggests that there is tremendous scope to cut down water losses and improve water use efficiency in irrigated agriculture.

Table 1: Overall Irrigation Efficiency of Selected Irrigation System in Some Asian Countries

Country/Irrigation System	Overall Irrigation Efficiency%	Remark	Source
Indonesia	40-65		Hutasoit, 1991
Malaysia - Kerian Irrigation System	35-45	Command area = 23,560 ha	
Thailand - Northern, Maeklong Chao Phraya, >12800 ha	37-46 40-62	Irrigable area >12,800 ha Wet season Dry season	Khao-Uppatun, 1992
India - Canal system, north India - Tungabhadra Irrigation System, Karnataka State	38 30		Ali, 1983 Bos and Wolters, 1991

Source: Guerra et al., 1998

Note: Overall Irrigation Efficiency of an irrigation system is defined as the ratio of water used by the crop to water released at the headworks. It can be subdivided into conveyance efficiency, field channel efficiency and field application efficiency.

Rice, as mentioned earlier, is a heavily irrigated crop. Rice grown under traditional practices in medium to heavy textured soils in the Asian tropics and subtropics requires between 700 to 1500 mm of water (Bhuiyan, 1992; Guerra et al., 1998). This consists of: (1) land preparation requirement of 150 to 250 mm, (2) water requirement of about 50 mm for growing rice seedlings in the nursery or seedbed before transplanting, and (3) water need of between 500 to 1200 mm (5-12 mm per day for 100 days) to meet the evapotranspiration (ET) demand and unavoidable seepage and percolation in maintaining a saturated root zone during the crop growth period (Guerra et al., 1998). The actual amount of water used by farmers for land preparation is often several times higher than the typical requirement of 150-250 mm. For instance, in the Ganges-Kobadak irrigation project in Bangladesh it is reported that farmers used as high as 1500 mm for land preparation (Ghani et al., 1989; Guerra et al., 1998). This may be due to the need for land soaking to maintain a wet soil condition to facilitate plowing, harrowing, puddling, and land leveling so that rice seedlings can be easily transplanted (Guerra et al., 1998). In evaluating water productivity one needs to take care of the following. Crops require water to satisfy their evapotranspiration (ET) needs. Further during crop growth, the amount of water applied to the field is often much more than the actual field requirement. This leads to high surface runoffs. In fact, Seepage and Percolation (S&P) losses are considerable, and according to one estimate, S&P accounts for 50-80% of the total water input in the field (Sharma, 1989; Guerra et al., 1998). Reducing the amount of S&P losses would help in improving farm water efficiency. It may, however, be noted that water lost at the farm level may seep downstream and be recovered for crop use and hence doesn’t constitute a loss for the irrigation system. Similarly, water loss at the irrigation system level may not contribute to losses at the water basin level. These need to be taken note of while discussing about improving water use efficiency and reducing water losses. Further one also needs to take note of the fact that policies for improving water use efficiency and water productivity cannot be considered in isolation from other factors that contribute to crop yield improvements such as better crop varieties and agronomic practices, crop duration etc. The concept of water productivity, therefore, needs to be clearly specified. For instance, there are number of water productivity concepts such as irrigation water productivity, basin water productivity, transpiration water productivity, etc. (cited in Bessembinder et al., 2005). However, a simple definition is to consider the amount of food or crop yield produced per unit volume of water used. Here it is also important to specify the water use components taken into account while assessing water productivity such as evapotranspiration, seepage and percolation, drainage during land preparation and crop growth period, as noted earlier.

Keeping in view the above points, we may examine Table 2 which presents the on farm water productivity of rice for three Asian Countries when different components of water inputs are taken into account. These water components are Evapotranspiration (ET), Seepage and Percolation (S&P), and Land Preparation Requirement (LPR). The table shows that rice yields per unit ET varies from 1.61 kg/m^3 of water use in Philippines to around 0.88-0.89 kg/m^3 in Malaysia and India. When other water components (i.e., S&P and LPR) are taken into account, the rice productivity declines from 1.61 to 0.39 kg/m^3 of water used in Philippines; similarly from 0.88 to 0.33 kg/m^3 of water used in Malaysia. The water use efficiency, i.e., the ratio of ET to water input, shows wide variations for the countries under review. For instance, if the water components ET, S&P and LPR are taken into account, the water use efficiency ratios for rice range from 0.22-0.24 in Philippines to 0.35-0.61 in Malaysia. This shows that the on farm water productivity of rice varies considerably across the three Asian countries under review. However, in making such inter country comparisons and drawing possible policy inferences one should not lose sight of the fact that local level conditions under which rice is grown in the different countries vary. For instance, East Asian systems including in China have a much higher degree of management and control than those in South and Southeast Asia, and rice cultivation practices are markedly different even within the same region (Guerra et al., 1998).

Bouman and Toung (2000) report the results of experimental trials in two contrasting rice growing areas, one in the sub tropics of Central Northern India and the other in the tropics of the Philippines. The data set pertains to the period 1966 to 1997, and covers a wide range of experimental conditions in terms of

Table 2: On-Farm Water Productivity of Rice in kg. per m^3 of Water used when different components of water inputs are taken into account

Location	Rice Description	Water Productivity of Rice with respect to			Source
		ET	ET+S&P	ET+S&P+LPR	
Philippines	West seeded Rice	1.61	0.68 (0.42)	0.39 (0.24)	Bhuiyan et.al., 1995
Philippines	Transplanted Rice	1.39	0.48 (0.35)	0.29 (0.22)	Bhuiyan et.al., 1995
India	-	1.10	0.45 (0.41)	-	Sandhu et al., 1980
Malaysia	Dry season	0.95	0.66 (0.69)	0.58 (0.61)	Kitamura., 1990
Malaysia	Wet season	0.88	0.48 (0.50)	0.33 (0.35)	Kitamura., 1990
India	Continuous flooding	0.89	0.34 (0.36)	-	Mishra et al., 1990
India	Alternate wet and dry	0.89	0.37 (0.42)	-	Mishra et al., 1990

Source: Guerra et al, 1998

Notes: 1. ET – Evapotranspiration; S&P – Seepage and Percolation; LPR – Land Preparation Requirement.
2. Figures in parenthesis are water use efficiency ratios, i.e., ratio of ET to water input.

environment (from pots in greenhouses to on-farm fields), rice variety, soil type, hydrology and climatic conditions. The experiments and treatments had two components, one to study the drought effects on rice and the other on the water saving effects on rice yields. Most of the experiments used transplanted rice, while some used direct seeded rice and others both transplanted and direct seeded rice. The water saving experiments included treatments with just saturated soil either continuously or during part of the growing season and alternate wetting/drying treatments. The latter were treatments where irrigation was given only for certain number of days after ponded water had infiltrated into the soil or after a certain level of soil water potential in the root zone was reached, or after symptoms of soil cracking at appeared. The relationship between water savings and yield reductions were quantified using data of all experiments reporting water input and yield. Since the experiments spanned a wide range of conditions, yield levels and water inputs were not comparable and hence the study used relative yields and relative water scarcities that were calculated by normalizing the yields/ water inputs obtained in the drought or water saving treatments to the yield/water inputs obtained in the reference treatment (in percentage). The reference treatment consisted of continuously ponded water of 5-10 cm depth, which is generally considered as the optimum depth for rice growth. While yield was assessed in terms of rough grain yield, water input was assessed as the sum of effective rainfall and irrigation applications from transplanting to harvest, or from sowing to harvest in the case of direct seeding. The vegetative stage of growth was defined as the period from sowing to panicle initiation, and the reproduction stage from panicle initiation to harvest. The study notes that in 93% of the cases water input reduced compared with the continuous 5-10 cm ponded water treatments. The study notes that water productivity i.e. grain yield over water input increased with water savings from the standard practice of continuous 5-10 cm ponded water. Water saving irrigation treatments that continuously kept the soil just at saturation, or allowed for only one day soil drying before re-applying a shallow layer of water were effective in reducing water input while maintaining high yield levels of 33 treatments, the mean water savings were 23% whereas yield reduction was only 6%. The study notes that typically water productivity was 0.2-0.4 g. grain per kg water in India and 0.3-1.1 g. grain per kg water in the Philippines. The relatively higher water productivities in the Philippines as compared to that in India is attributed to the higher yield levels and lower S&P rates of the soils. The study also examined the water productivity water input relationship from all experiments. The study notes that the Indian field data reported the highest water inputs, roughly 500-3000 mm, with the lowest water productivities of 0.1-0.6 g. grain per kg water whereas for the Philippines field experiments water inputs were comparatively lower 300-1500 mm and water productivities higher at 0.3-1.4 g. grain per kg water. There were, of course, exceptions with high water productivities of 1.6-1.9 g. grain per kg water with low water input. The study notes that reducing water input from continuous ponded water levels increases water productivity, up to a maximum of 1.9 g. grain per kg water. However, when ponded water depths drop to zero or when soil water potentials in the root zone become negative, yields (i.e., land productivity) get reduced. The overall conclusion of the study is that the most promising option to save water and increase water productivity without decreasing land productivity too much is by reducing the ponded water depth from 5-10 cm to the level of soil saturation. Water savings were on average 23% (+ or – 14%) whereas yield reductions were only 6% (+ or – 6%). The adoption of such techniques will have implications for irrigation systems because water delivery to the field needs to be very accurate and timely. Farmers operating pumps would likely benefit most from this water-saving irrigation technique. However, most Asian farmers in public irrigation systems have little incentive to reduce water input to their fields since irrigation water is mostly charged on area basis. Volumetric based charging of irrigation may induce farmers to economise and optimize on water use. Although water savings may reduce yields, the water so saved could be used to irrigate more area, which can help increase total rice output.

Alternate agronomic and crop management practices such as zero-tillage, bed planting, non-puddled rice culture and laser leveling are advocated to reduce costs and water use in crop farming and as well as improves productivity (Gupta et al., 2002; Hobbs and Gupta; 2002). For instance, in the Indo-Gangetic Plains where rice-wheat cropping system is predominant, wheat is usually sown after rice. Traditional land preparation practices for wheat after rice in this region involve as many as 12 tractor passes. But, under zero-tillage system farmer sow wheat in a single tractor operation after the rice harvest, planting the seed directly in the rice stubble (CIMMYT, 2002). The practice reportedly saves 75% of more fuel, obtains better yields, uses about half the herbicide, and requires at least 10% less water (CIMMYT, 2002). Because zero-tillage takes immediate advantage of residual moisture from the previous rice crop, as well as cuts down on subsequent irrigation requirements, it results in considerable water savings. An estimate suggests that changing to a zero-tillage system on one ha of land, besides saving 60 lt of diesel, saves approximately one million lt of irrigation water (CIMMYT, 2002). This also has significant environmental benefits by reducing carbon dioxide (CO_2) missions. For instance, using a conversion factor of 2.6 kg of carbon dioxide per liter of diesel burned, this represents about a quarter ton less emissions of carbon dioxide per ha which is the major contributor to global warming (CIMMYT, 2002). If zero-tillage system is widely adopted in the rice-wheat system of the Indo-Gangetic Plains, it is estimated that if just 5 out of the 12 million ha adopts zero-tillage, it will result in annual diesel savings of nearly 0.3 billion lt equivalent to a reduction of nearly 800,000 tons in CO_2 emissions each year as well as increase water availability and efficiency in the rice-wheat cropping system in the Indo-Gangetic Plains. Farmers adopting zero-tillage save around USD 65/ha in production costs (CIMMYT, 2002). The area under zero-tillage wheat in India and Pakistan which was estimated at around 3000 ha in 1998-99 is expected to increase to 0.3 million ha by 2001-02 (CIMMYT, 2002). Bed planting is another technique promoted to raise crop productivity and reduce farming costs and inputs. Bed planting is becoming popular in wheat cultivation in India and Pakistan, and being tried in rice cultivation as well. It is reported that planting wheat on raised beds improves yields, increases fertilizer use efficiency, reduces costs and inputs such as herbicides, seeds and water (average 30% water savings) and reduces production costs by 25-35% (CIMMYT, 2002). All the above resource conserving technologies like bed planting, zero tillage, non-puddled rice culture etc., when combined with leveled fields help improve water use efficiency (Hobbs and Gupta, 2002).

These technologies are being tried in the Indo-Gangetic Plains spread across five countries i.e., India, Pakistan, Nepal and Bangladesh in South Asia, by a consortium, which includes CIMMYT, IRRI and other national research organizations. The predominant cropping system in the Indo-Gangetic Plains is rice and wheat, as stated earlier. However, the cropping practices vary across this wide expanse. For instance, while in the northwest region rice is mostly irrigated, in eastern India rice is mostly raised as a rain fed crop. The two crops have contrasting requirements. The total water requirement for wheat varies from 238 mm to 400 mm and for rice from 1144 mm to 1560 mm across different locations in the Indo-Gangetic Plains (Gupta et al., 2002). While rice is commonly transplanted into puddled soils and gets the benefit of continued submergence, wheat is grown in upland well drained soils having good tilth (Gupta et al., 2002). Transplanting rice seedlings into puddled soils is an age old practice and helps to reduce water percolation and control weeds (Gupta et al., 2002). However, puddling degrades the soil and affects the soil conditions for the establishment of the next crop, which is usually wheat in this region. With a view to get a better wheat crop, farmers in the region generally do 6-8 preparatory plowings in rice drying soils to achieve good seed bed (Gupta et al., 2002). However, excessive tillage results in late planting and reduced yields of wheat. Since rice is the major water user, saving water use in rice cultivation is a major goal. Non-puddled rice cultivation is therefore, advocated. Evidences from India suggest that a 3 day drainage period in rice cultivation can effect a minimum of 40% saving in water with marginal decline in rice yields. Table 3, which presents the relevant data shows that water savings across different states in the Indo-Gangetic Plains in India varied from 40 - 54%. In Ludhiana, Punjab, the irrigation requirement after a 5 day drainage period was around 96 cm , as against 190 cm per ha under continuous submergence scenario. The corresponding rice yields were 5.2 and 5.5 ton/ha respectively. Although there is some reduction in rice yields, the water so saved could be diverted to bring more area under cultivation, which will help increase total rice (or agricultural) output. This can improve food security and meet the expanding food needs due to increasing population and incomes. Zero-tillage also helps in water savings, as stated earlier. Zero-tillage is possible after harvesting rice where the residual moisture is available for wheat germination. In many instances, where wheat planting is delayed after harvesting rice, farmers have to pre-irrigate their fields before planting. Zero-tillage saves this irrigation. Further, water advances quicker in untilled soil than in tilled soil, which helps save water (Gupta et al., 2002). Because zero-till wheat takes immediate advantage of the residual moisture from the previous rice crop, as well as cuts down on subsequent irrigation, water use reduced by about 10 cm per ha or approximately 1 mil lt per ha (Gupta et al., 2002). Further, there is less risk of water logging and yellowing of the wheat plants after the first irrigation, which is common on normal ploughed land (Gupta et al., 2002).

Table 3: Effect of Intermittent Irrigation on Rice Yield and Irrigation Water Requirement at Various Locations in the Indo-Gangetic Plains

Location	Soil Type	Yield (t/ha)				Saving in Irrigation Water ***
		Continuous Submergence	Irrigation after Drainage Period*			
			1 day	3 day	5 day	
Pusa (Bihar)	Sandy loam	3.6 (81)	3.5 (60)	3.3 (46)	2.9 (35)	43
Madhepura (Bihar)**	Sandy loam	4.0 (35)	-	4.0 (16)	4.0 (11)	54
Faizabad (UP)	Silt loam	3.8 (65)	2.9 (42)	-	-	-
Pantnagar (UP)	Silt loam	8.1 (121)	7.6 (112)	7.4 (90)	6.9 (60)	44
Ludhiana (Punjab)	Sandy loam	5.5 (190)	5.4 (145)	5.1 (113)	5.2 (96)	40
Hissar (Haryana)	Sandy loam	5.7 (220)	5.2 (196)	4.7 (126)	-	43
Kota (Rajasthan)	Clay loam	5.4 (145)	5.3 (86)	5.1 (68)	-	53

Source: Chaudhary, 1997 vide, Gupta et.al., 2002

Note: * - Drainage period in days after disappearance of ponded water

** - High water table condition

*** - With 3 day drainage vs.continuous submergence

Figures in parenthesis show irrigation water requirement (cm)

Table 4 presents data on wheat yields under zero-till technologies in farmer participatory trials in India. As evident, the water savings realized range between 26% to over 35% for zero-tilled wheat as compared to conventionally tilled wheat. The wheat yields are also conspicuously higher in zero-tilled wheat ranging between 5780 to 6500 kg/ha as compared to 5190 kg/ha in the case of conventionally tilled wheat.

Table 4: Wheat Yield with Zero-Till Technologies in Farmer Participatory Trials

Item	Paired Planting*	Controlled Traffic**	ZT	FP-CT
Water Saving (%)	26.2	30.8	35.4	@
Yield (kg/ha)	6500	5800	5780	5190

Source: Gupta et.al., 2002

Notes: * - Spacing between set rows (14 cm); and between paired sets (25 cm)
** - One row behind each tractor tyre not sown
@ - Compared with conventional tilled wheat planted a week later

Information about the effects of crop residues on zero-tilled wheat yields and savings in irrigation time in farmer participatory trials in Ghaziabad and Meerut districts in Uttar Pradesh State in India are presented in Table 5.

Table 5: Effects of Crop Residues on Yield of Zero-Till (ZT) planted Wheat and Saving in Irrigation Time in Farmer Participatory Trials in Ghaziabad and Meerut districts in Uttar Pradesh, India

Treatment	No. of Plants/m^2	No. of Weeds/m^2	Total Irrigation Time (hrs)	Grain Yield kgs/ha
Manually harvested Rice followed by ZT wheat	133	30	43.4(31.8)	5650
Partial Residue burning followed by ZT wheat	132	30	46.2 (27.4)	5780
ZT planted wheat in combine harvested rice, mulched with shrub master	129	21	40.3 (36.7)	6000
Farmer Field Practices Convental Tilled	117	54	63.6	52.0

Source: Gupta et.al., 2002

Note: Figures in parenthesis are percent saving in water in terms of irrigation time in relation to farmers practices

As evident, not only there is considerable saving in irrigation time for zero-tilled wheat compared to conventionally tilled wheat, but also wheat yields under zero-till situation are conspicuously higher (5650 to 6000 kg/ha) as compared to wheat yields under conventionally tilled situation (5200 kg/ha). A comparison of zero-tilled and conventionally tilled (farmers' practice) wheat yields after rice crop in Pakistan Punjab at different locations, where the planting dates for the two methods differ, indicates that on average wheat yields under zero-till at 3677 kg/ha are conspicuously higher than under farmers' practice at 2598 kg/ha (see Table 6).

Table 6: Wheat Yields after Rice in Zero-Tillage and Farmers' Practice Situations in Punjab, Pakistan at locations where the planting dates for the two methods differ

Locations	Wheat Yield (kg/ha)		Days Difference
	Zero-Tillage	Farmers' Practice	
Daska, Site 2	3143	3209	10
Daska, Site 2	3842	2735	13
Ahmed Nagar	4308	3526	20
Maujianwala	2689	2198	22
Mundir Sharif	4245	2660	33
Daska, Site 3	3838	3420	44
Average	3677	2598	24

Source: Aslam et.al., 1993 vide Hobbs and Gupta, 2002

Table 7 also presents evidence on the effect of different tillage options such as direct seeded rice on beds, transplanted rice on beds, zero-tilled rice on flat, conventionally tilled rice fields etc., on rice grain yields. The table shows that in general other tillage options result in water savings and better rice grain yields as compared to conventionally tilled rice. Bed planting is another resource conserving technology that is being tried. Evidences from India suggest that farmers report 30-45% water savings during the wheat season and still higher during the rice growing season (Gupta et al., 2002, Hobbs and Gupta, 2002). Farmers indicated that it is easier to irrigate with bed planting. When beds are kept submerged for the first few weeks and irrigation supply

Table 7 : Effect of Tillage options on total irrigation time, yield attruibutes and grain yields of rice.

Tillage option	Total Experi-mental Area in ha	No. of plants m^2	Tillage/ Plant	Total Irrigation Time Hrs/ha	Produc-tion Tillers/ Plant	Spike Length cm	Grains/ Panicle	Grain Yield Mg per ha
Directed seeded Rice on beds+	14(22)*	34	24	152.5 (39.0)	15	22.6	165	50.2+
Transplanted Rice on beds	12(20)*	35	24	146.0 (41.5)	19	23.4	173	56.2
Zero-Tilled Rice on Flat	12(10)	56	16	205.0 (17.8)	13	21.9	163	56.9
Reduced Tilled Transplanted Rice on Flats	1.6(7)	32	13	216.3 (13.3)	13	22.6	169	51.9
Conventional Tillage	14(35)	27	16	249.5	12	21.5	163	52.9

Source: Gupta et.al., 2002

Notes:
1. * Figures in parenthesis in Column 2 (i.e., Total experimental area) are the number of farmers participating in the trials.
2. Figures in parenthesis in Column 5 (i.e, Total irrigation time) are the percent saving in water in terms of irrigation time in relation to farmers practices.
3. \+ - Reduced yields due to severe iron chlorosis in initial crop growth stages and 8 missing beds per ha due to farmer experience

frequency is reduced later, the farmers were able to save around 30% water as well as overcome weed and iron chlorosis problems associated with bed planting systems (Gupta et al., 2002). Another study notes that raised bed planting system gives rise to other problems such as the stability of bed slopes getting eroded due to rainfall and irrigation, transplanting on raised beds being disadvantageous as it requires higher man-days than flat lands, uneven beds leading to non-uniform plants along the bed, and weed problem (especially grass), since the bed is often under aerobic conditions (Cabangon et al., 2002).

Another study analysed the effect of different sowing methods i.e., laser leveling, zero tillage and bed planting as compared to normal planting on water savings, wheat yields and water productivity in Mona Project in Pakistan (Table 8). All sowing options leads to considerable water savings, higher wheat yields (4.1 - 4.8 ton/ha as against 4 ton/ha in the case of normal planting) and water productivity (i.e. 1.4 - 1.8 kg/m^3 as against just 1.1kg/m^3 in the case of normal planting). The average water saved with laser leveling, zero tillage and bed planting over the traditional method was 715, 689 and 1329 m^3 per ha valued at Rs 522, 503 and 907per ha based on a water rate of Rs. 900/acre-foot for private tubewells for the year 1999-2000 (Hobbs and Gupta, 2002). Timely planting of rice also benefits the succeeding wheat crop by improving yields and water efficiency. Evidences from Eastern India, for instance, show that timely planting of rice improves wheat yields. Rice wheat system productivity in farmer participatory trials was nearly 12-13 ton/ha when rice was transplanted before June 28; this was reduced by more than 40% to 6-7ton/ha when fields were planted after August 15 (Hobbs and Gupta, 2002).

Table 8: Wheat Yields and Irrigation Water Productivity under Alternative Resource Conserving Technologies in Mona Project, Pakistan

Item	Laser Levelling	Zero Tillage	Bed Planting	Normal Planting
Water applied (m^3/ha)	2849	2933	2281	3610
Yield (t/ha)	4764	4188	4134	3968
Water Productivity (kg/m^3)	1.67	1.43	1.81	1.10

Source: Gill et.al., 2000 vide Hobbs and Gupta, 2002

While the above discussion focuses on ways of improving water use efficiency and productivity in irrigated agriculture, problems of rainfed agriculture and less endowed or fragile regions cannot be overlooked. With prospects for bringing more area under irrigation being limited and the prohibitive costs of future irrigation investment, attention also needs to be focused on improving crop yields and water use efficiency and productivity in arid, semi arid and fragile regions. Managing water in agriculture should not exclusively focus on improving the productivity of the 2500 km^2 of water diverted to irrigation, but must also include improving the productivity of the 16,000 km^2 used in rainfed agriculture (IWMI, 2003). Rainfed agriculture contributes to about 60% of cereal production on 70% of the global cereal area (IWMI, 2003). For these areas, research needs to be focused on evolving crop varieties and technologies that can tolerate droughts and moisture stress as well as thrive on low-quality water (IWMI, 2003). Reducing land degradation, supplemental irrigation combined with on-farm water harvesting practices such as mulching or bunding can reduce vulnerability to drought and help farmers to get the most out of the scarce resources. Mitigating the effects of short term drought is a key step in achieving higher yields and water productivity in rainfed areas (IWMI, 2003). In fact, deficit irrigation a strategy, which maximizes the productivity of water by allowing crops to sustain some degree of water deficit and yield reduction is being advocated for water stressed areas (IWMI, 2003). Various forms of precision irrigation such as sprinkler, drip irrigation systems and dead-level basins can increase yields over good but ordinary irrigation systems by 20-70%, depending on the crop and other conditions (IWMI, 2003). The use of drip irrigation for sugar cultivation is picking up in Maharashtra. The potential of drip irrigation for rice (especially ratoon rice or upland rice) and wheat cultivation in economizing water use as well as increasing incomes needs to be probed. Water reuse or recycling is also becoming an integral part of water management in water scarce areas. For instance, in the Indo-Gangetic plains many farmers employ shallow tubewells to recycle the water that percolates through the soil layer, thereby effectively capturing and using water before it flows out of the basin (IWMI, 2003).

5. CONCLUSIONS

In the context of the growing demand for water and the emerging water crisis, attention is focused on finding appropriate strategies and mechanism to promote sustainable use and management of water resources. Since the prospects for supply augmentation are limited due to prohibitive cost of future irrigation investments and water infrastructure projects, focus is on demand management. Through proper pricing and institutional reforms in the water sector, it is hoped that people and governments will be able to meet the increasing demand for water in various sectors. Reducing water wastages and improving water efficiency and productivity is an important goal. In this context, efforts are underway to improve water productivity in agriculture, and the water so saved may be diverted for bringing more area under agriculture to boost food output, and meet the water needs of other sectors. Evidences from experimental or farmer participatory trials in a cross section of regions, countries, or sites in Asia and the Indo-Gangetic plains suggest that alternate agronomic or crop management practices such as zero-tillage, bed planting, non-puddled rice culture and laser leveling can result in water savings and improve rice and wheat yields per unit of water input. The water so saved can be used to bring more area under irrigation and thereby increase food production to meet the food needs of the growing population. While the benefits of drip irrigation in the case of dry and plantation crops, and more recently sugarcane, are well known. Its potential in economising water use and improving incomes in the context of rice (especially ratoon rice or upland rice) and wheat cultivation needs to be probed. Recycling waste water, rediscovering traditional water harvesting practices are receiving considerable attention in recent years with a view to economise water use and meet the increased demand for water.

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