Improving Water Productivity in Agriculture in India: Beyond 'More Crop per Drop'

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Introduction

Water productivity in agriculture would be the single most important factor driving water use globally in the future (Molden et al. 2000; Rijsberman 2004). Hence, research to evaluate crop water productivity and analyze the drivers of change in the same, has fascinated many researchers and scholars worldwide (Ahmad et al. 2004; Ambast et al. 2006; Grismer 2001; Howell 2001; Kijne et al. 2003; Zwart and Bastiaanssen 2004; Singh 2005; van Dam et al. 2006). As a result, most of the research studies on crop water productivity were undertaken in naturally water-scarce regions of the world. Such regions include western United States, drought-prone areas of arid Australia, semi-arid areas of Punjab State in India, Punjab Province in Pakistan, Turkey and Mexico.

Water productivity in crop production can be expressed in terms of biomass production per cubic meter of water diverted or depleted (kg/m^3), known as physical productivity of water; and net or gross present value of the crop produced per cubic meter of water diverted or depleted (Rs/m^3) known as economic productivity of water (Kijne et al. 2003).

Definition of water productivity is scale dependent (Molden et al. 2003). Water productivity can be analyzed at the plant level, field level, farm level, system level and basin level. According to the scale, the determinants of water productivity would also change. Analyzing water productivity at the plant level would require knowledge of the total biomass per unit of water transpired, and doing the same at the field level would require knowledge of crop yield (kg/ha) or net return from crop production (Rs/ha) against the total amount of water applied or unit of water depleted. Whereas, analyzing water productivity at the farm level would involve the net return from the entire farm against the total water diverted or depleted. The reason is that, as Rothenberg (1980) notes, farmers grow a variety of crops within their farm, and sometimes in combination with dairy farming, which depends on crop residues as inputs. But, if water productivity has to be analyzed at the level of the irrigation system or the river basin, it has to be in relation to the total amount of water depleted rather than the total amount of water diverted. The reason is that not all the water diverted for irrigation would be depleted, and instead might be available for reuse in the form of recharge to groundwater, which can be pumped out by the downstream well irrigators (Allen et al. 1998) or residual moisture in the soil profile available for the next crop.

Again, water productivity can be analyzed for one season or for the entire crop cycle, thereby changing the time scale of analysis. Accordingly, the value of the denominator of water productivity, i.e., 'depleted water' would change. This is because of the following reason. The residual moisture available in the soil might get treated as nondepleted water in a crop-wise analysis. But this soil moisture might eventually get depleted in soil evaporation during the fallow period, and therefore get included in the denominator if the entire annual crop cycle is considered for analysis. This also means that the farm level water productivity analysis should consider the entire crop cycle to capture this time-scale effect.

The classical concept of irrigation efficiency used by water engineers to analyze the 'productive use' of water, omitted economic values (Van Dam et al. 2006) and looked at the actual evapotranspiration (ET) against the total water diverted for crop production (Kijne et al. 2003). Over and above, it does not factor in the 'scale effect' (Ahmed et al. 2004; Van Dam et al. 2006). In the recent past, there have been major advancements in the theoretical discourse on ways to assess how productively every unit of water is used up in crop production, leading to more comprehensive definitions of water productivity.

A recent synthesis of available literature by Zwart and Bastiaanssen (2004) of showed that, water productivity in terms of biomass output per unit of depleted water (kg/ET) or physical productivity of water in crop production has been mostly analyzed across the world at least for some of the major crops; and enough is already known about the factors that explain its variations across locations. But, it also showed that no attention is paid to know how the crops compare in terms of economic returns from every unit of water depleted. But, this is crucial, because the measures to enhance water productivity of a crop such as higher dosage of nitrogenous fertilizers; improved soil management; better agronomic practices, including the use of high yielding varieties, and pest control; water harvesting and supplementary irrigation; and investment in water delivery control measures, have economic imperatives.

The reason for this heavy focus on the physical productivity of water is most of these analyses were done by agricultural scientists, who are concerned with raising the dry matter yield of crop per unit of evapotranspiration. The other factors, which might have been responsible for this bias are: 1) water is a limiting factor at the societal level for enhancing crop production in these regions (Howell 2001), which still have large cropped areas under unirrigated conditions (Loomis and Connor 1996: pp10), and water productivity improvement enables farmers to divert part of the saved water to expand the irrigated area; and, 2) with volumetric rationing and the prices that farmers have to pay for water, they are likely to get higher net returns along with higher yields through efficient irrigation technologies that reduce consumptive use.[1] Another factor could be the fluctuating price of agricultural commodities in the market, which changes the net return per unit volume of water.

But, the avenues to improve agricultural WP through farming system changes are not explored. This is a major shortcoming when we consider the fact that most of the farms in developing economies like India and most of Africa are complex with several crops; and also

[1] As water saving leads to cost saving in irrigation sufficient to offset the additional cost of fertilizer and technology inputs.

composite with crops and dairying instead of one or two crops. After Rothenberg (1980), as farms are organized to maximize net economic return, they are the best fundamental units for economic analysis. Hence, how productively farmers use their water cannot be assessed in relation to a particular crop alone, but in relation to the entire farm. In sum, this dominant paradigm of ‘more crop per drop’ certainly does influence WP research in Asia and Africa.

On the other hand, there has also been a greater recognition of the distinction between securing field level ‘water-saving’ and field-level WP improvement, and water-saving and WP improvement at the basin-scale (Allan et al. 1998; Howell 2001; Molle and Turral 2004; Seckler et al. 2003). The concept of ‘open basins’ and ‘closed basins’ is often used to explain how the determinants of WP could be manipulated and water saving achieved, or otherwise, in different situations. The information obtained discloses that in ‘closed basins’, field-level water saving does not result in water-saving and WP improvement at the basin level, except when the return flows meet with saline aquifers or are nonreturnable; and otherwise basin level water saving and WP improvements comes only from a reduction in consumptive use (Molle and Turral 2004).

This new paradigms in water resource management also seems to have influenced research in many countries in Asia and Africa: 1) in deciding what one should look for as key ‘determinants’ in WP analysis; and; 2) in identifying the drivers of change in WP. They have hardly captured the complex technical, social, economic, institutional and policy settings that govern water allocation policies by the government and water use decisions by the farmers. This concerns the poor technical efficiency and reliability of public canal systems; heavy subsidies in pricing of water and electricity in the farm sector; huge public investments in water harvesting; and, lack of institutional regimes governing the use of water from canal schemes and groundwater.

The overarching objective of this paper is to have a critical look at these two paradigms in agricultural water management to see how far they are useful in exploring new avenues for WP improvements and water saving, particularly in situations like India. It also explores new opportunities for WP improvements and water saving for fields, farms and regions, by analyzing the complex variables which drive these WP parameters, and also identifies new areas for research.

Some of the specific research questions being addressed in this paper are as follows.

1. Given the heavy subsidies in electricity and water used for agriculture and lack of well-defined rights in surface water and groundwater in developing countries like India, does research on raising ‘crop per drop’ make sense, or what should be the new determinants of WP for both farmer and basin water managers?

2. What considerations should be involved in analyzing basin level WP and water saving impacts of efficient irrigation?

3. What are the likely impacts of improved reliability of irrigation, and changing water allocation on crop water productivity and water saving?

4. What are the opportunities and constraints for improving agricultural water productivity at the level of farming systems?

5. What should be the priority areas for research on enhancing regional WP in agriculture, in countries like India where food security, rural employment and poverty alleviation are still major issues?

Why a New Paradigm of Research on Agricultural Water Productivity in India?

More Income Returns versus More Crop Per Drop

The main consideration involved in analyzing WP in the West is reducing the amount of water required to produce a unit weight of crop, as this would automatically ensure higher net return per unit of land. But this is not the concern in many developing economies in Asia, where land use intensity is already very high in many regions. Surface water is heavily subsidized, and pricing is also inefficient (Kumar 2003). There is zero marginal cost of electricity used for pumping groundwater for irrigation (Kumar 2005). Hence, the measures to enhance water productivity through ET reduction and yield enhancement may not result in significant improvement in net income for the farmer for a unit area of irrigated land, though net water productivity in rupee terms may increase. While major investments are required to achieve irrigation efficiency improvements and yield enhancement, the increased benefit farmers get is only in terms of market price for higher yield. The reason is that the real water-saving and energy saving,[2] which are major impacts of technological interventions, do not get converted into savings in private costs of water.

Enhancement in WP (kg/ET) in field crops like wheat can mainly come from crop technologies. A study by Sander Zwart (2006), which involved analysis of system level WP in irrigated wheat in six different regions around the world using SEBAL (Surface Energy Balance) methodology, shows that the variation in WP is not so much due to variations in ET, but due to variations in the yield (see Table 1). The average ET was highest in Pakistan (443 mm) and lowest in Sirsa (361 mm), which is approximately 10 % higher/lower than the average (source: analysis by Sander J. Zwart 2006). Though the potential evapotranspiration (PET) depends on the climate, especially the relative humidity (air temperature and solar radiations remaining in

Table 1. Average system-level water productivity in wheat in six different wheat growing regions around the world.

Location	Average ET/Standard Deviation (mm)	Average Yield (tonne ha^{-1})	Average WP_{ET} (kg m^{-3})
Nile Delta, Egypt	408 (59)	6.1 (0.9)	1.50 (0.12)
Yaqui Valley, Mexico	402 (36)	5.5 (0.9)	1.37 (0.16)
Sirsa, India	361 (16)	4.4 (0.3)	1.22 (0.06)
Linxian County, China	436 (35)	3.8 (1.4)	0.86 (0.28)
Hebei Province, China	380 (50)	2.5 (0.9)	0.64 (0.21)
Sindh Province, Pakistan	443 (82)	(2.2 (0.7)	0.50 (0.11)

Source: Analysis by Sander J. Zwart dated May, 2006

[2] Whether use of efficient irrigation technologies can reduce or increase energy use for irrigation depends on the type of irrigation technology and the extent to which the traditional water supply is pressurized (Loomis and Connors 1996).

a narrow range across these six regions), actual ET could have been manipulated by changing the water available to crops through irrigation. But, this does not seem to have happened. The reason that ET remains the same is that there is a shift from evaporation (E) to transpiration (T), which leads to greater biomass production. As soon as the environment for crop production is improved (fertilizers, weeding, better seeds, water management, etc.,) there will be a shift from non-beneficial to beneficial water depletion. This, of course, requires farmer investments.

Now, the only way to create an incentive among farmers to adopt efficient irrigation technologies for WP improvement is to subsidize it. The idea is to make private benefits offset the private costs (Kumar 2007). While yield enhancement is also a benefit of efficient irrigation technologies (Loomis and Connor 1996: pp 398), it can also come from improved agronomic practices mentioned above. The extent of subsidy for a system which can save 'X' amount of water could be kept higher than the difference between the private costs and benefits. It should be guided by the positive externality that 'X' creates on society.

But, government subsidies for efficient irrigation technologies are extremely limited in countries like India. For instance, the Government of India had provided Rs.5 billion towards subsidy for drip and sprinkler systems in the eleventh 5-year plan. But, this amount is just sufficient to cover an area of 100,000 ha against a total net irrigated area of nearly 55 m ha, accounting for just 0.20 %, if one considers an investment of Rs.100,000 per ha of area under MI system, and a subsidy to the tune of 50 %. Hence, such measures to enhance WP do not result in increased land productivity. Under the much-publicized Andhra Pradesh Micro-Irrigation project of the Government of AP, a total area of 166,100 ha was covered under MI systems over a time period of nearly 30 months. The total subsidy benefit to farmers was to the tune of 209.96 crore rupees, meaning Rs.18,070 per ha. The result is that most of the farmers have installed drip systems for horticultural crops, for which returns would anyway be high even without drips[3] and sprinklers, which are low cost but not technically efficient for small farms (Kumar et al. 2008). If adoption is limited to horticultural crops, which cover small areas in India, the potential of MI systems in WP enhancement would further be limited.[4]

This means that if MI system is used for conventional crops, the farmers have to divert part of the water saved to another plot to sustain their income as net return is WP multiplied by the volume of water. However, in situations where the entire holding is already used, farmers will not have much incentive to go for measures that do not increase their returns from the land but only increase their returns per unit of water. This is the situation in India, where the average holding of farmers is quite low (less than 1 ha) when compared to that in western US or Australia. The size of median landholding in Australia is 300 ha (ABS 2002). This clearly means that what is socially optimal is that farmers look for alternatives that enhance the productivity of their land remarkably, simultaneously reducing the water requirement, or diverting part of the water to other water-based farming systems that have minimal dependence on land. In a nutshell, there is a clear trade-off between enhancing the physical productivity of water, and maximizing income returns. This argument also holds true when it comes to

[3] This was noted by B. D. Dhawan way back in 2000 in an article titled 'Drip Irrigation: Evaluating Returns' (see Dhawan 2000).

[4] Kumar et al. (2008) estimated that the overall potential of MI systems in India is only 5.8 m ha, which is far less than the figures estimated by Government of India's task force on MI.

analyzing the WP impacts of water harvesting for supplementary irrigation, which is analyzed in the case of public investments. This is dealt with in the subsequent section.

Poor Focus on Economics of Water Harvesting and Supplementary Irrigation

In the west, the focus in WP research has been on efficient irrigation technologies, including those for supplementary irrigation. However, in some African countries (Oweis et al. 1999; Rockström et al. 2002), Mexico (Scott and Silva-Ochoa 2001) and in India, the focus has shifted to potential impact of water harvesting.

This is applicable to some of the recent work in eastern African countries. Rockström et al. (2002) have shown the remarkable effect of supplementary irrigation through water harvesting on the physical productivity of water expressed in kg/ET, for crops such as sorghum and maize. However, the research did not evaluate the incremental economic returns due to supplementary irrigation against the incremental costs of water harvesting. It also does not quantify the real hydrological opportunities available for water harvesting at the farm level and its reliability. The work by Scott and Silva-Ochoa (2001) in the Lerma-Chapala Basin in Mexico showed higher gross value product from crop production in areas with better allocation of water from water harvesting irrigation systems. But, their figures of surplus value product, which takes into account the cost of irrigation, are not available in their analysis. In arid and semi-arid regions, the hydrological and economic opportunities of water harvesting are often over-played. A recent work in India has shown that the cost of water harvesting systems would be enormous, and reliability of supplies from such systems would be very poor in the arid and semi-arid regions of India, which are characterized by low mean annual rainfalls, very few rainy days, high inter-annual variability in rainfall and rainy days, and high potential evaporation, leading to a much higher variability in runoff between good rainfall years and poor rainfall years (Kumar et al. 2006).

With the high capital cost of WH systems needed for supplemental irrigation, the small and marginal farmers would have less incentive to adopt such systems. In addition, the incremental returns due to yield benefits may not exceed the cost of the system. This is particularly so for crops having a low economic value such as wheat and paddy, which dominate arid and semi-arid regions in India. But, even if the benefits due to supplementary irrigation from water harvesting exceed the costs, it will not result in higher WP in economic terms in closed basins. The exception is when the incremental returns are disproportionately higher than the increase in ET. This is because, in a closed basin, increase in beneficial ET at the place of water harvesting will eventually reduce the beneficial use down stream. In countries like India, lack of this economic perspective in decisions, however, results in too much public investment towards subsidies to farmers to harvest water locally. To sum up, gain in crop per drop (kg/ET) cannot drive water harvesting for supplementary irrigation in semi-arid and arid regions. Also, incremental net benefit considerations can drive water harvesting at the basin scale only if there is no opportunity cost of harvesting.

Distinction between Consumed Fraction and Evapotranspiration

The real water savings through efficiency improvements at different scales had been thoroughly discussed by several scholars (Allen et al. 1998; Molle and Turral 2004; Molle et al. 2004; Seckler 1996). The main argument is that in 'closed basins', increasing efficiency would only reduce return flows and not reduce the depleted portion of irrigation withdrawals. Thus real water saving is not possible through improvements in irrigation efficiencies in closed basins (Molle and Turral 2004). While there are sufficient evidences on the relationship between ET and yield (Connor and Jones 1985; Grismer 2001; Rockström et al. 2002), at least a few scholars argue that reduction in consumed fraction and, therefore, 'real water saving', is not possible without reducing the yield, unless we use better crop varieties or agronomic practices.

But, these technologies might be able to reduce the consumptive water use as well as consumed fraction[5] (CF), without reducing the beneficial evapotranspiration (ET) and the yield (see page 76 of Allen et al. [1998] for details on ET and consumed fraction), thereby leading to 'real water savings' at the field level. Such reductions in consumption could be achieved through reduced evaporation from excessively wet soil, or reduction in nonreusable deep percolation from water application in excess of the soil moisture deficit in the root zone. However, the distinction between ET and CF is often not made in analyzing the impact of depleted water on yields. Hence, an automatic conclusion is that real water saving at the basin level is not possible without changing ET (Zhu et al. 2004), or affecting other uses in water-scarce basins (Molle et al. 2004). Whereas in reality, improvements in crop water productivity in physical terms and water saving might be possible at the basin level through efficient irrigation technologies. Hence, research on basin level WP impacts of efficient irrigation technologies should consider CF as a determinant.

Are There New Opportunities for Improving Water Productivity in Countries like India?

Opportunities for Improving Field-level Water Productivity

It is widely acknowledged that reliability and degree of control over field-level water allocation are, by and large, very poor in surface irrigation systems in India (Brewer et al. 1999; Meinzen-Dick 1995), leading to poor technical efficiencies (GOI 1999; Ray 2002). Whereas the irrigation systems in the USA and Australia are far more reliable and are designed for a high degree of water delivery control. Two major dimensions of irrigation service, which have significant impacts on crop yields are, timeliness of water delivery (Perry and Narayanamurthy 1998) and excess water deliveries, with the impact of first being positive and that of the second being negative, as illustrated by a study on irrigated rice production in Sone irrigation command in Bihar (Meinzen-Dick 1995). But, the opportunities available with improved reliability of irrigation and 'changing water allocation' in enhancing WP have not been examined.

[5] See Allen et al. (1998) for a detailed discussion on various components of the applied water, such as consumed water, consumed fraction, beneficial transpiration, non-beneficial evaporation from the soil and non-recoverable deep percolation.

Impact of Quality and Reliability of Irrigation on Water Productivity: This research is particularly more important when there are theoretical (Malla and Gopalakrishnan 1995; Perry 2001a) as well as practical issues involved in using pricing as a tool for demand regulation (de Fraiture and Perry 2004; Perry 2001a). But, the task also lies in developing quantitative criteria for assessing quality and reliability. Kumar, Trivedi and Singh (this book) had developed an index, named 'Irrigation Quality Index' for assessing the quality and reliability of irrigation water at the field scale. Implicitly, its application is limited to fields-scale assessments only, where the crops remain the same. The same cannot be extended to farms where the crops change.

There are evidences from different parts of the world that well irrigation results in higher yields than canal irrigation. Though there are sufficient evidences to the effect that well irrigators get a higher yield, and in spite of higher cost of irrigation get higher net returns as compared to canal irrigators (Kumar and Singh 2001; IRMA/UNICEF 2001), there is limited research data on the differential economic productivity of groundwater irrigation over surface irrigation. A recently published study for the Andalusian region (southern Spain) shows that each cubic meter of groundwater used for irrigation provides five times more money and almost four times more jobs than a cubic meter of surface water used for irrigation (Hernández-Mora et al. 1999).

However, the statement about higher reliability of well irrigation is not a universal one. In some canal command areas, particularly in their head reaches, reliability of water supply is found to be very high due to the availability of water throughout the season. Further, the chemical quality of surface water can sometimes be much better than that of well water due to the presence of minerals, which provide micro-nutrients for plant growth as the water comes from mountainous catchments through surface runoff (Kumar, Trivedi and Singh, this book). Against this, the well water can be of poor chemical quality, due to the presence of excessive salts in dissolved form, which can be harmful for soil health and, therefore, affect crop growth. This differential chemical quality of water can improve the overall quality of surface irrigation.

Nevertheless, well irrigation is generally of higher quality as compared to canal irrigation. But, in the case of well irrigation, the manner in which this positive differential reliability gets translated into WP gains is a major point of inquiry. There are two possibilities. First, it is an established fact that the crop yield increases in proportion to the increase in transpiration, and, at higher doses, irrigation does not result in beneficial transpiration, but in non-beneficial evaporation. Irrigation water dosages are normally higher in canal irrigation. This way, increased CF does not result in a proportional increase in the yield of crops (Vaux and Pruitt 1983). Non-recoverable deep percolation is another non-beneficial component of the total water depleted (CF) from the crop land during irrigation (Allen et al. 1998). This also increases at a higher dosage of irrigation, which occurs in the case of canal irrigation. Moreover, with controlled water delivery, efficiency of fertilizer usage would be better in the first case. Hence, with improved reliability and water delivery control, both the denominator (CF) and numerator (yield) of the water productivity parameter (kg/m^3) could be higher. This can be better understood by the negative correlation between surplus irrigation and crop yields in the Sone command where surplus irrigation led to reduced yields (Meinzen-Dick 1995). Since, there are no extra capital investments it would also lead to higher productivity in economic terms.

The second possibility is that with greater quality and reliability of irrigation, the farmers are able to provide optimum dosage of irrigation to the crop, controlling non-beneficial evaporation, and non-recoverable deep percolation. And as a result, the CF remains low and the fraction of beneficial evapotranspiration within the CF or the depleted water remains high. Also, it is possible that with the high reliability regime of the available supplies, even under scarcity of irrigation water, the farmers can adjust their sowing time so that they are able to provide much needed watering. This can bring out high yield responses. Both result in higher WP in kg/ET.

But, are the differences in WP in economic terms (Rs/m^3) caused by well owners growing more water-efficient and water-sensitive crops with assured water supplies? Evidence in support of this argument is found in a recent study comparing the water productivity of shareholders of tubewell companies and water buyers in north Gujarat. The study showed that the shareholders of tubewell companies got much higher returns from every unit of pumped water, i.e., overall net water productivity in economic terms (Rs.4.18/m^3), as compared to water-buyers (Rs.1.3/m^3). The reason was that water allocation for shareholders was quite assured in volumetric terms, and irrigation water delivery was highly reliable, owing to which they could budget water properly, select water-sensitive and high-valued crops and judiciously make investments for inputs; whereas water buyers were at the mercy of the well owners (Kumar 2005).

Now, with expanding well irrigation in many arid and semi-arid countries like India, including canal command areas, new opportunities for improvements in the reliability of water supplies are available. If well irrigation gives positive differential WP over surface irrigation, we can incorporate such features that contribute to higher water productivity in well irrigation in gravity irrigations systems as well. They include creating an intermediate storage system for storing canal water; and lifting and delivery devices for the stored water. That said, in real economics terms, what does the gain in productivity mean given the fact that the economic costs of irrigation is much higher than the private costs for both canal irrigation and well irrigation? Understanding these linkages will help design better policies for water allocation (whether to supply water by gravity or promote conjunctive use) and pricing in surface irrigation. If reliability results in higher WP (Rs/m^3) in well irrigation, which cannot be explained by price variations, then that makes tariff increase in canal water contingent upon improving the quality of irrigation.

Impact of Changing Water Allocation on WP and Water Saving: Water management decisions are often taken on the basis of average water productivity estimates. For the same type of system, water productivity for the same crop can change at the field scale (Singh et al. 2006: pp272) according to water application and fertilizer use regimes. Hence, it is important to know the marginal productivity with respect to water and nutrient use. It helps to analyze the role of changing water allocation strategies at the field level in enhancing WP. But, there are no data available internationally.

For a given crop, the irrigation dosage and the crop water requirement (beneficial use plus beneficial nonconsumptive use) corresponding to the maximum yield may not correspond to the maximum water productivity (Rs/m^3)—(Molden et al. 2003). The WP (k/m^3) would start leveling off and decline a lot before the yield starts leveling off (see Figure 1.2 in Molden et al. 2003). Ideally, WP in terms of net return from crop per cubic meter of water (Rs/m^3) should start leveling off or decline even before the physical productivity of water (kg/m^3) starts showing that trend. When water is scarce, there is a need to optimize water allocation to maximize water productivity (Rs/m^3) through changing the dosage of irrigation. But, this may be at the cost of reduced yield and net return per unit of land, depending on to which segment of the yield and WP response curves the current level of irrigation corresponds.

Recent analysis with data on applied water, yield and irrigation WP for select crops in the Narmada River basin in India showed interesting trends. In many cases, trends in the productivity of irrigation water in response to irrigation did not coincide with the trends in crop yields in response to irrigation (Figures 1 and 2); whereas in certain other cases, the trends in irrigation WP in response to irrigation and the trends in yield in response to irrigation did actually coincide at least for some range in irrigation (Figures 3 and 4). Knowing at what segment of the WP response curve the irrigation dosage to a given crop lies, helps understand how changing water allocation would change the crop yield and WP.

Figure 1. Yield vs Irrigation Dosage in Wheat (Hoshangabad 2002).

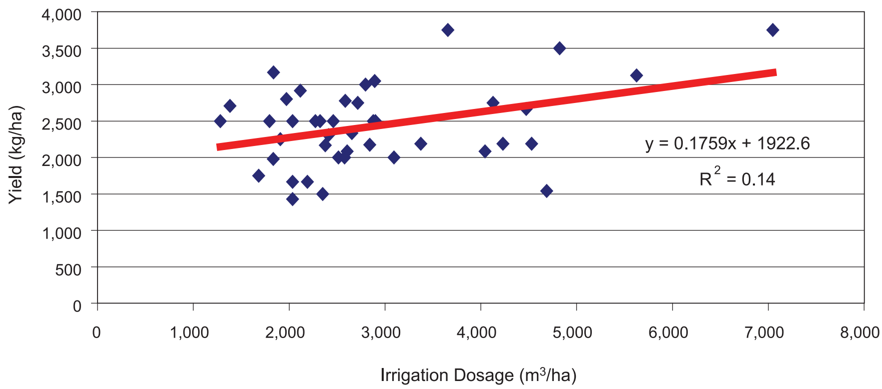
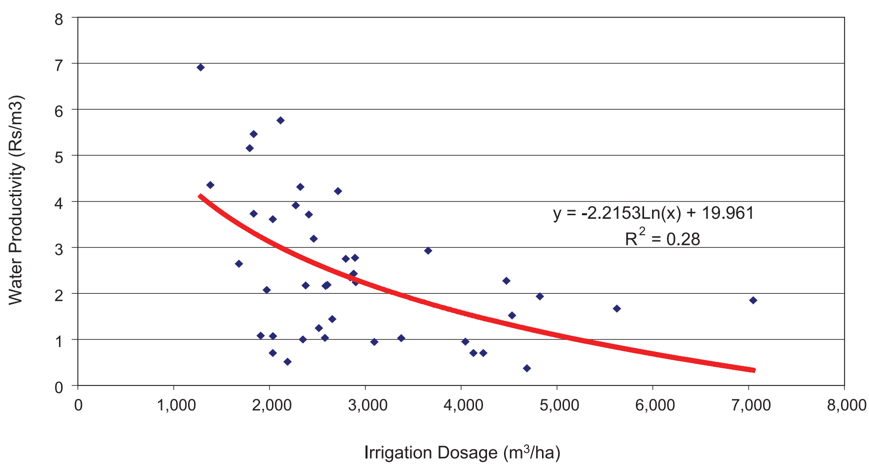


Figure 2. Water Productivity vs Irrigation Dosage in Wheat (Hoshanagabad 2002).



The regression values for the response of yield to irrigation dosage being very small (Figures 1 and 3), one could argue that many factors other than irrigation explain yield variations. But, the data that are presented here are for different farmers, who represent different soil conditions, different planting dates and different seed varieties, all of which have a potential to influence the crop yield. If one takes into account this, one could say that the actual yield response to irrigation would be much stronger if the planting date, soils and seed varieties are

Figure 3. Yield vs Irrigation Water Dosage in Cotton (West Nimar 2003).

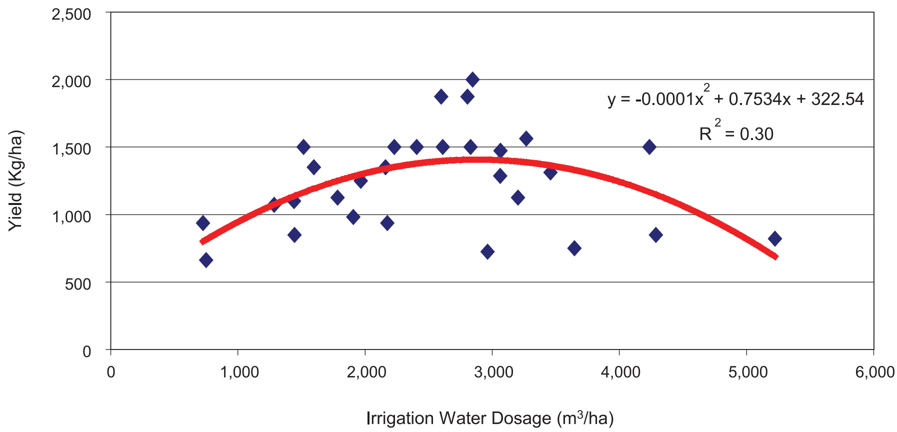
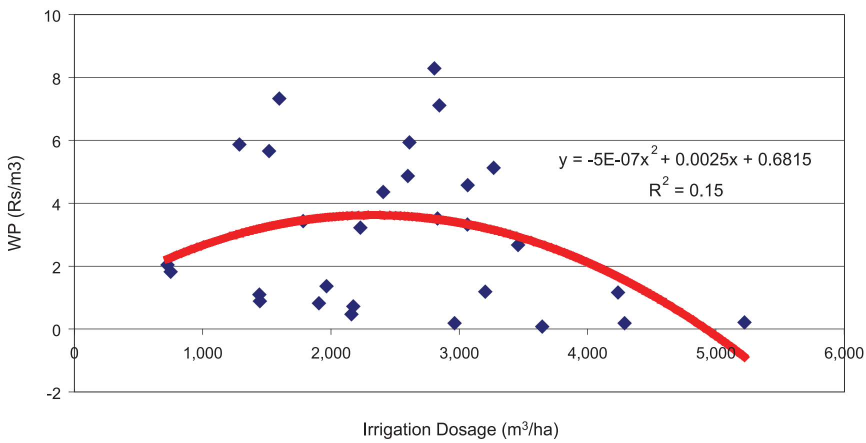


Figure 4. Water Productivity vs Irrigation Dosage in Cotton in (West Nimar 2003).



the same. Also, the slope of the yield curve is very mild in the case of Figure 1. This is quite contrary to what can normally be found given the wide range in irrigation water dosage among the sample farmers. This can be explained by the variation in PET, and the moisture availability across farmers in the sample, which changes the irrigation water requirements.

In the first case, where the level of irrigation corresponds to the ascending part of the yield curve, but to the descending part of the WP curve (Figures 1 and 3), then limiting irrigation dosage might give higher net return per unit of water. But, farmers may not be interested in that unless it gives a higher return from the land. Hence, if the return from the land does not improve, the strategy can work only under three situations: 1) the amount of water that farmers can access is limited by the natural environment, like limited groundwater reserves; 2) there is such a high marginal cost of using water, due to high prices for water or electricity used for pumping water, that WP is much closer to the values attained at the highest levels of irrigation; and, 3) water supply is rationed. In all these situations, the farmers should have extra land for using the water saved. Under condition of supply rationing, farmers would anyway be using water for growing economically efficient crops. But, the issue being addressed here is that for a given crop how far water productivity can be enhanced to a level that the best managed farms do achieve.

In all these three situations described above, the WP improvements would lead to farmers diverting the saved water for irrigating more crops to sustain or enhance their farm income. The reason is that the amount of water being handled by farmers is too small that they need to use the same quantum of water as previously since the WP differences are just marginal. This behavior of the farmer can better be understood from the following equation, which defines net improvement in farm income:

$$\text{Net change in farm income} = \{V - \Delta V\}*\{\Phi + \Delta \Phi\} - V* \Phi = V* \Delta\Phi - \Delta V*\{\Phi + \Delta \Phi\}$$

Where, ‘V’ is the volume of water diverted for irrigation prior to the adoption of productivity improvement measures; ΔV is the reduction in the volume of water diverted for irrigation after adoption (+ive); Φ is the productivity of water when volume V was used for irrigation; $\Delta \Phi$ is the rise in water productivity after adoption (+).

Analyzing the equation, the only way a small farmer can maximize his net farm return in the improved WP scenario is by making ΔV zero. In the case of a large farmer in US or Australia, who might use 100 to 500 times more water than an average farmer in India, there is still an option available for enhanced returns, even if he decides to reduce the volume of water used for irrigation (i.e., $\Delta V > 0$) because V is very large, making $V* \Delta\Phi$ very large.

Hence, the impact would be greater economic outputs for the same quantum of water. Nevertheless, the impact can be different if the farmers get higher returns along with higher WP through changing water allocation as illustrated earlier. Hugh Turral [6] (per. com) argues that to achieve real demand regulation, water for agriculture needs to be formally allocated or re-allocated. If that means less water for agriculture, improving WP will be one of the responses. Howell (2001) cites the example of the Texas high plains. The increased use of irrigation technologies for wheat had resulted in the enhancement of water use efficiency (Kg/ET), which followed significant yield increase, in wheat (Table 8, Howell, 2001). He argues that in such situations, farmers would achieve real water saving. This could result in water saving at the system level, if the farmers do not expand the area under irrigation. But in this case, the farmers can afford to reduce the area under irrigation as the net return per unit of land also might have improved.

In the second case, where both the yield and WP curve are descending (Figures 3 and 4), the impact of change in water allocation on both WP and yield would be similar, i.e., reduced water allocation would result in both yield and WP gain. This is the most ideal situation where farmers have a strong incentive to become adapted to the water allocation strategies enforced by an official agency as in the case of canal irrigation, and voluntarily cut irrigation dosage in well irrigation. But, this is a situation which is not very common in semi-arid and arid conditions. Overirrigation is more common in rich alluvial areas like central Punjab and Haryana, where farmers get free electricity and canal water is heavily subsidized.

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For instance, analysis of soil water balance in rice-wheat fields in the Sirsa District of Haryana by Singh (2005) using the SWAP (Soil Water Atmosphere Plant) model shows that the total water applied was in excess of the estimated ET (in the order of 290 mm to 561 mm). Interestingly, the ET value was higher for the field which had a lower dosage of irrigation (see Table 2). It shows that there is ample opportunity for real water saving through a reduction in non-beneficial E of ET-the part of soil moisture storage change, which would eventually get evaporated from the field. By reducing irrigation dosage in such conditions as cited above, the farmers gain both higher land productivity (return per unit of land) and higher return per unit of water.

Table 2. Water balance in two rice-wheat fields in Sirsa, Haryana during kharif.

Field No.	Irrigation Dosage (mm)	Rainfall (mm)	ET (mm)	Groundwater Recharge (mm)	Soil Moisture Change (mm)
1	1,062	177	949	98	175
2	1,250	177	858	121	440

Source: Ranvir Singh (2005): Table 4.6, pp: 46

In the ultimate analysis, it may appear that to affect demand reductions, it is important to ration water allocation in canals along with changes in the practice of farmers by educating them on better crop management. Proper regional and sectoral water allocation can drive WP improvement. Experiences from the Murray-Darling Basin (Haisman 2003) and Chile (Thobani 1997) show significant improvements in water use efficiency and value of water realized, respectively, in irrigated production after the introduction of volumetric rationing enforced through properly instituted water rights. Nevertheless, marginal WP analysis of the kind presented above can help decide on the allocation and delivery strategies for canal water, provided farmers are quite aware of water allocation and irrigation scheduling policies.

Hence, there is much more one can achieve in WP enhancement and water demand management in gravity irrigation without resorting to water pricing options technically. As Perry (2001a) notes, assigning volumes to specific uses, and effectively rationing water where demand exceeds supplies, would be an effective approach to cope with water shortages. But, its actual potential might depend on the situation in terms of access to land and water, and the institutional and policy environment, such as water and energy prices and water rights regimes. It is clear from the foregoing analysis that water control can help achieve WP enhancement even without pricing and volumetric water rights, if there is a physical shortage of water or extra land for cultivation is not available.

The recent past has shown significant debates over the usefulness of irrigation water pricing as a way to regulate water demand. While, some argue for it (Malla and Gopalakrishnan 1995; Tsur and Dinar 1995; Johansson 2000), some others argue against it, pointing out shortcomings at both theoretical and practical levels (Bosworth et al. 2002; Perry 2001a). There are three major, and important contentions for those who argue against pricing: 1) questioning the logic in the proposition that "if the marginal costs are nil, farmers would be encouraged to use large quantities of water before its marginal productivity becomes zero, consuming much more than the accepted standards and needs" (source:

Molle and Turral 2004); 2) the demand for irrigation water is inelastic to low prices, and the tariff levels at which the demand becomes elastic to price changes would be so high that it becomes socially and politically unviable to introduce (de Fraiture and Perry 2002; Perry 2001a); 3) there are no reasons for farmers to use too much water, which can cause overirrigation (Molle and Turral 2004). But, these arguments have a weak scientific basis. We would discuss them in the subsequent paragraphs.

As regards the first point, the impact of zero marginal cost is not in 'creating incentive to wastewater', but in 'creating disincentive to prevent wastage'. These two concepts are distinctly different for public irrigation systems as control of water delivery devices is not in the hands of the farmers. One exception is the situation where Water Users' Associations (WUAs) function, which considers water use to the point about 'disincentive'. The reason for disincentive is that the direct cost or the opportunity cost of taking measures to prevent wastage would be more than the benefits that can be derived from it in the form of reduction in yield losses. In certain other situations, in the absence of proper control structures in the tertiary systems, water delivery is not regulated. Given that farmers are unsure of getting the next release in time, they apply water excessively and irrespective of the field capacity of the soil. This is common in paddy, which is widely grown in canal commands. So, the impact of a price increase would be the creation of a strong economic incentive to reduce wastage, equal to the irrigation charges they have to pay for the wasted water.

The second point is about linking irrigation charges and demand for water. Merely raising water tariff without improving the quality and reliability of irrigation will not only make little economic sense but also would find few takers. As returns from irrigated crops are more elastic to quality of irrigation than its price (Kumar and Singh 2001), poor quality of irrigation increases farmers' resistance to pay for the irrigation services they receive. Therefore, the 'water diverted' by farmers in their fields does not reflect the actual demand for water in a true economic sense, so long as they do not pay for it. In other words, the impact of tariff changes on irrigation water demand can be analyzed only when the water use is monitored and farmers are made to pay for the water on volumetric basis.

It also means that if positive marginal prices are followed by improved quality, the actual demand for irrigation water might actually increase, though efficiency would improve. To what extent it would increase depends on the availability of land and alternative crops that give a higher return per unit of land. This increase in demand is due to the tendency of farmers to increase the volume of water used to maintain or raise the net income (Kumar and Singh 2001). Hence, water rationing is important to affect demand regulations in most situations (Perry 2001a). The challenge lies in understanding the science of WP, particularly WP response to irrigation and actual consumptive use of water, and managing irrigation water deliveries accordingly. In the case of well irrigation, it is important for farmers to understand this linkage, whereas the official agencies have to ensure that power supply is available for critical waterings.

As regards the third point, often farmers do not make correct judgments about the level of irrigation dosage that corresponds to zero marginal returns. This has been found in the case of well owners, who are not confronted with the positive marginal cost of pumping, resulting in lowering the yield with incremental irrigation (Kumar 2005). Price reforms only make farmers more conscious about the negative economic consequences of giving an overdose of irrigation water.

Opportunities for Improving Farm-level and Regional-level Water Productivity

We have seen that there are clear trade offs between options to enhance physical productivity of water and WP in economic terms at the field level itself. We would see that there is a trade off between maximizing WP at the field level and that at the farm level, though farm level water productivity is dependent on the processes that govern WP at the individual fields. We would also see that the options available to maximize WP in a region, which often is the concern of water policymakers, are far fewer in the case of individual farms. The water policymaker looks for approaches that would not only enhance the economic returns, but also increase the social welfare. Many of the decisions relating to public investment in irrigation systems in countries like India are driven by larger societal concerns such as producing more food, employment generation and poverty alleviation. Often, policymakers are more driven by social and political considerations than purely economic considerations (Perry 2001a). We would elaborate on these issues in the subsequent paragraphs.

From the analysis presented in the previous section, it is evident that the scope for improving field level WP is extremely limited given the social, economic, institutional and policy environment in India. Limitations are greater when we want to use it as a driver for changing water demand. Therefore, WP enhancement should focus on crops that are inherently more water efficient in economic terms and also have a high return per unit of land. As Molden (per. com) notes, "increasing WP is not often relevant to farmers. If it is important to the society, then society should figure out ways to align everyone's incentives."

It is established that many fruit crops have higher WP (Rs/m^3) than the conventional cereals such as wheat and paddy in arid areas. For instance, pomegranate grown in north Gujarat gives a net return of nearly Rs.40,000 per acre (i.e., USD900/acre) of land against Rs.8,000 per acre (i.e., USD180/acre) in case of wheat. The WP is approximately Rs.100/m^3 for pomegranate (Kumar 2007) against Rs.4.46/m^3 for wheat in the same region. Also, there are crops such as potato, cumin, cotton and castor which are more water efficient than rice and wheat, which can be grown in Punjab (see Table 3). With greater reliability, and control over water delivery, farmers using well irrigation would allocate more water for growing water-efficient crops. Perhaps, farmers have already started shifting to high-valued cash crops.

But, there are limits to the number of farmers who can take up such crops due to the volatile nature of the market for most of these crops, its perishable nature, and the high risk involved in producing the crop. For instance, cumin grown in north Gujarat is a very low water consuming crop, with a high return per ha. But, crop failure due to disease is very common in cumin. In case of vegetables, that are fast perishable, markets are often very volatile, and price varies across and within seasons. The problem of price fluctuation is also applicable to cotton grown in western Punjab, which has high WP. Also, the investments for crops are also very high, demanding a high degree of risk-taking.

But, farmers organize their entire farm, rather than the field, to maximize the net economic returns (Ruthenberg 1980). The extent to which farmers can allocate water to economically efficient crops would perhaps be limited by the need to manage fodder for animals. It may also get limited by the poor market support for orchard crops. Many farmers in Punjab and other semi-arid parts of India manage crops and dairy farming together. But, even globally, there is a dearth of research, which analyzes WP in composite farming systems that really take into

Table 3. Applied water productivity in selected crops in north Gujarat, western Punjab and eastern Uttar Pradesh (UP).

Sr. No.	Name of the Crop	Net Water Productivity of Crop (Rs/m^3) of Applied Water in		
		Western Punjab	Eastern UP	North Gujarat
1	Kharif Paddy	7.75	4.78	-
2	Fodder Bajra	2.93	4.78	-
3	Kharif Cotton	40.40	-	-
4	Kharif Castor	-	-	8.09
5	Brinjal	-	-	-
6	Wheat	8.05	9.11	4.46
7	Fodder Jowar	6.32		-
8	Mustard	-	-	4.73
9	Winter Gram	24.48	-	-
10	Jowar	-	-	4.01
11	Cumin	-	-	19.84
12	Summer Bajra	-	-	2.85

Source: Based on Kumar et al. (forthcoming) for western Punjab and eastern UP; and Kumar (2005) for north Gujarat. In the case of north Gujarat crops, the mean values of water productivity figures for different categories of farmers were taken

account water depleted in biomass production. Literature on water use efficiency and WP in dairy farming is also extremely limited. In regions for which they are available, the conditions are extremely different to those in countries like India. Studies from northern Victoria and southern New South Wales analyzed water use efficiency in dairy farms that are irrigated (Armstrong et al. 2000). In these regions dairy farming is not integrated with crop production. Green fodder produced in irrigated grasslands is used to feed the cattle by dairy farmers in Australia and United States, unlike sub-Saharan Africa and developing countries in South Asia.

Recent analyses from western Punjab seem to suggest that the overall net WP in Rupee terms becomes enhanced when the byproducts of cereal crops are used for dairy production (see Table 4).

The reduced area under cereal, crops such as paddy and wheat, would translate into a reduction in the availability of fodder. Farmers may have to grow special crops that give green fodder, and in that case, they might in turn be increasing the intensity of water use in Punjab. In a similar semi-arid situation in north Gujarat, it was found that dairy production, which used

Table 4. Water productivity in crops and dairy production.

Sr. No.	Name of Crop/ Farming	Water Productivity (Rs/m^3)
1	Paddy	7.75
2	Wheat	8.05
3	Milk Production	13.06

Source: Kumar et al. forthcoming (derived from Table 11) irrigated alfalfa, was highly water-inefficient, both physically and economically (Singh 2004; Kumar 2007). Otherwise, farmers may have to procure dry fodder from outside, which would involve more labor. Hence, there could be a 'trade off' between maximizing crop WP and farm level WP, but there is not much literature about economic productivity in dairy farming, especially with cereals and dairying, to understand this trade off.

At the regional level, enhancing WP through either a shift to water efficient crops (like orchards and vegetables) or to a crop-dairy based farming system might face several constraints from a socioeconomic point of view. Food security is an important consideration when one thinks about options to enhance WP. Punjab produces surplus wheat and rice, which are exported to other parts of the country to meet their cereal requirements (Amarasinghe et al. 2004). Nearly 22.1 % of India's wheat production and 10.8 % of its rice production comes from Punjab (source: Ministry of Agriculture, Government of India).

The labor absorption capacity of irrigated agriculture and market price of fruits are other considerations. Paddy is labor intensive. As per some recent estimates by Kumar and Singh (2008), 2.614 million ha of irrigated paddy in Punjab (as per 2005 estimates) needs 159 million labor days during the peak kharif season. This is based on the primary data, which shows that a hectare of paddy creates Rs. 5,000 worth of farm labor in Punjab. This is exclusive of the machinery employed in ploughing and harvesting. With a wage rate of Rs.80 per day, the number of labor days per ha of irrigated paddy is estimated to be 61 (source: primary data from Punjab). This labor requirement is met by migrant laborers from Bihar. Replacing paddy with cash crops would result in a reduction in farm employment opportunities.

On the other hand, the lack of availability of labor and fodder would constrain intensive dairy farming to maximize WP at the regional level, though some farmers might be able to adopt the system. This contradicting situation with regard to labor is caused by the fact that most of the labor used for paddy is obtained from seasonal migrants, who go back to their homes after the main field operations in paddy, whereas dairying would require daily labor, and constant care and attention for the animals. As regards fruits, its large-scale production might lead to a price crash in the market, and farmers losing revenue unless sufficient processing mechanisms are established. Hence, the number of farmers who can adopt such crops is extremely limited.

In the context of a developing country, the potential for poverty reduction or impact of irrigation on food security are more important than the return per unit of water. Food security and poverty reduction are in-built goals for large-scale subsidies in irrigation (Gulati 2002), which enable poor farmers to intensify cropping. Therefore, WP in irrigation too needs to be looked at from that perspective, and not merely on a 'crop per drop' basis. One can argue that with more reliable irrigation, farmers could also produce more food or generate more employment, and with that, achieve higher physical and economic productivity along with meeting social objectives. But, the heavy subsidies in irrigation reduce the ability of the agencies to improve its quality through regular investments.

Perhaps this welfare-oriented policy of keeping irrigation charges low needs a re-look. With extensive well irrigation in India and with the poor paying heavy charges for pump renting or well water to irrigate their crops, the policies to subsidize canal irrigation may not bring about the desired equity and welfare outcomes. In fact, a large portion of the subsidies in canal irrigation goes to large farmers, due to the following of a crop-area based pricing system (Kumar and Singh 2001). These farmers also have access to well irrigation in the command area.

Another fact that supports the above argument is that often the unreliable canal water supplies force farmers to adopt only paddy, and not domestic food security concerns. The stable and high procurement prices offered by the Food Corporation of India for cereals such as rice and wheat allow farmers to stick to this cropping system. But there are major macro-economic imperatives of trying to meet these social objectives (Gulati 2002). The intensive paddy cultivation in Punjab is associated with the intensive use of electricity for pumping groundwater even in canal commands during the summer. Irrigating one ha of winter wheat requires 74 Kwhr to 295 Kwhr of electricity, which costs Rs.300 to Rs.1,175 to the economy (source: field data). The region is already facing a power crisis, which adversely affects the reliability of power supplied to the farm sector. Enhancing productivity of pumped groundwater also means enhancing energy productivity and reducing revenue losses to the government in terms of power subsidies.

If farmers are able to secure a higher net return from every unit of water applied or depleted in well irrigation, this could be a major starting point for irrigation bureaucracies to start charging higher rates for irrigation along with improving the quality, adequacy, reliability and control of water. Following the norms of rationing in water allocation would be crucial in achieving higher WP. Perhaps, what would be required would be higher prices for food crops or special incentives for farmers who grow such crops so as to reflect their social benefit, while reducing the irrigation subsidies heavily. So, the net result would be a compromise between socioeconomic productivity and productivity enhancement in monetary terms, with a positive impact on the water resource system.

Summary of Findings

The data from limited research presented in this paper shows that technically there is great scope for enhancing agricultural water productivity without crop shifts. This can be achieved through improved quality and reliability of irrigation and changing water allocation to crops, and not so much through water harvesting and supplementary irrigation, and MI technologies. But to create economic incentives for large-scale adoption of such measures among farmers as well as irrigation bureaucracy, the electricity/water pricing policies have to change towards pro rata pricing of electricity and volumetric pricing of canal water. Unless we resort to pricing instruments, the avenues for significantly enhancing WP can be generated only through crop shifts, and in certain cases through a crop-dairying mix. But such measures have trade-offs such as increase in farming risk, regional food insecurity and unemployment.

Research to explore potential improvements in physical productivity of water (kg/ET) in crops without due consideration to income returns per unit of water will not be relevant for Indian farmers under the current electricity and water pricing policies in agriculture, and institutional regimes governing water use. The reason is it does not link WP improvement to raising the aggregate of farm income. In countries like India, major determinants for analyzing improvements in basin level WP due to WH and supplementary irrigation should use: i) incremental economic returns from enhanced crop yield; and ii) opportunity costs of water harvesting at the basin scale. Analysis of basin level impacts of efficient irrigation technologies on basin WP and water saving should involve and consider CF as a determinant of WP rather than that of evapotranspiration.

Research on the potential impact of improved quality and reliability of irrigation water and changing water allocation on WP is relevant for India, as it gives due consideration to maximizing farmers' income, while reducing the total water depleted. Nevertheless, their overall potential in improving WP and more so in reducing water demand in agriculture is open to question, unless policies and institutions are aligned to make society's interests and farmers' interests match. This is because farmers can expand the area under irrigation also in areas where land is still left unirrigated due to the shortage of water. For the composite farming systems that are characteristic of countries like India, WP research should focus on optimizing water allocation over the entire farm to maximize returns, through changes in the crop mix and crop-livestock compositions. But due consideration should be given to the risk taking ability of the farmer, investment capabilities etc.

In countries like India, research on measures to enhance regional level WP should integrate socioeconomic considerations such as food production, employment generation along with wealth generated per unit of water used in irrigation. But, often farmers' choice of food crops like paddy is not by design, but by default. Meeting food production needs or other social objectives cannot be an excuse for poor productivity. Given these goals, regional WP scenarios can examine the scope for improving WP through increment in the productivity of crops such as wheat and paddy with reliability and control regimes in irrigation, along with other measures.

Conclusions

There are limited numbers of options available to significantly enhance agricultural WP in countries like India, given the larger objective of addressing food security, poverty alleviation, and employment generation concerns in rural areas. The options are: improving quality and reliability of water; and, changing water allocation. In the short term, focus should be on technical interventions to enhance the WP of existing crops that are based on improving reliability, adequacy, and water allocation for reducing non-beneficial consumptive use, and non-beneficial nonreusable portions of water supplies. The inherent advantages of well irrigation systems need to be built while designing surface irrigation systems and designing water allocation norms. But, in most cases, they could regulate water demand only if water allocation is rationed volumetrically. Hence, in the medium and long term, electricity and water pricing policies have to be made more efficient so as to expand the opportunities for WP improvements without increasing farming risks, domestic and regional food insecurity and unemployment. Only this can link WP improvements to raising the income of the farming households.

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