Opportunities and Constraints to Improving Water Productivity in India

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Introduction

To assess the current levels of water productivity in agriculture and the scope for improving the same would require a clear understanding of the various considerations that should be involved in assessing it. Needless to say, assessing water productivity in agriculture merely on the basis of the crop output or income returns per unit of water diverted or depleted would lead to inappropriate policy decisions for improving agricultural water management. The reason is that improvement in field level water productivity alone is not the objective in agricultural productivity growth (Loomis and Connor 1996; Kumar and van Dam 2008). Policymakers and farmers alike are equally concerned about the changes that occur in the farming system as a result of such changes, and their impact on the resilience of the farming system and implications for farmers' risk taking ability. The policymakers are also concerned about how the water is used at the level of the irrigation system and the river basin, and what economic outputs it generates (Chakravorty and Umetsu 2002; Molle and Turral 2004). Other concerns are: what happens to food security, the regional agricultural economy and the environment as a consequence of the interventions made at the field level to raise crop water productivity.

Analyzing water productivity in agriculture involves complex considerations arising out of the intricate nature of the water supply and water use system, the farming systems, the regional, social and economic environment in which the farming system is embedded and the physical environment with which the farming system interacts. As we are aware, there are major differences in the hydrological, economic and environmental considerations involved in analyzing water productivity in accordance with the differences in: 1) scale of analysis of 'irrigation efficiency' from field to farm to irrigation system to the river basin (Keller et al. 1996; Seckler et al. 2003); 2) objectives of water productivity analysis; 3) parameters used in analysis, i.e., in physical or economic values or a combination of physical and economic values (Kijne et al. 2003); 4) environmental considerations; 5) food security considerations; and 6) concerns in regional economic growth (Kumar and van Dam 2008). Surely, there are trade-offs between addressing these concerns in agricultural productivity growth and enhancing water productivity.

In this paper, first we discuss these complex considerations that should be involved in assessing water productivity in agriculture. Concurrently, we also discuss how the incorporation of such considerations change the way we evaluate water productivity or even limit or expand our options to improve water productivity in agriculture. In other words, we examine the trade-off between raising water productivity in agriculture and improving farming system resilience, food security, employment generation in rural areas and regional economic growth. Based on an understanding of these considerations and trade-offs, we identify the opportunities and constraints for improving water productivity in both rain-fed and irrigated agriculture in India. Finally, a quick assessment of the scale of enhancement of water productivity in India is made on the basis of the range of physical, technical, socioeconomic and institutional and policy factors influencing the future potential for its improvement.

Different Considerations in Analyzing Water Productivity

Scale Considerations

The 'scale considerations' are important in the comparative analysis of water productivity (Molden et al. 2003; Kumar and van Dam, 2008; Palanisami et al. 2008). This is more so when the type of irrigation changes, for instance from canal irrigation to tank irrigation to well irrigation. This is owing to the fact that generally, 'irrigation dosage' is higher than the crop water requirement (ET-effective precipitation) for water-abundant surface schemes as compared to groundwater based schemes; and the frequency of irrigation is definitely lower than in well irrigation. This leads to a high dosage per watering, resulting in runoff, percolation and non beneficial evaporation in canal irrigation. But many of the 'losses' at the farm level such as percolation and field runoff appear as 'gains' at the system and basin level as these outflows get captured at the lower side of the system or basin. This is particularly important in Punjab as irrigated paddy with continuous ponding of water is extensive there. As 'depleted water' rather than 'diverted water' will have to be considered while estimating water productivity functions, the unit of analysis has to move away from 'field' to the 'system' and then to the basin.

But, an alternate view is provided by Palanisami et al. (2008) who argues that since the irrigation bureaucracy is concerned with maximizing the returns per unit of water delivered from the reservoir, system level water productivity for surface irrigation schemes should be assessed in relation to the total amount of water delivered from the reservoir. They used the total water released from the system for assessing water productivity at the system level and showed that water productivity declined when moved from 'field' to 'system'. However, this study did not take into account either the production or the income generated from the use of return flows pumped by well irrigators inside the command of the irrigation system.

In the transit from system to basin, there could also be opportunities for improving the water productivity of a given crop due to climatic advantages. The appropriate selection of agro-climate plays an important role in enhancing productivity levels, without any significant changes in water control regimes (Abdulleev and Molden 2004; Zwart and Bastiaanssen 2004). Besides this, Chakravorty and Umetsu (2002) showed that with optimal allocation of water over the entire basin, increase in economic benefits is much more under modern methods than the traditional methods of irrigation. Their conclusions were on the basis of simulation studies of economic benefits from basin-wide optimization of surface water allocation for irrigation for traditional and modern methods of irrigation after incorporating the use of return flows from canals through wells. ,. Hence, considerations for enhancing regional or basin level productivity would be different from that for maximizing the field level productivity (Cai and Rosegrant 2004; Gichuki 2004; Molle et al. 2004). Furthermore, at the basin level, several competing water using sectors exist. So, opportunities for improving water productivity exist through: 1) transfer of water to alternative uses in any part of the basin; 2) growing certain crops in regions where ET demands are low involving inter-regional water allocation; and, 3) allocating water to economically efficient crops within the same region.

These are very important factors. For instance, an analysis of water productivity in the Narmada River basin showed that WP of wheat in both physical and economic terms varies significantly from the upper catchment area of the Narmada to its lower catchments. This difference was mainly due to the variations in climatic conditions, which change the denominator of water productivity, i.e., the consumed water (Kumar and Singh 2006). Even within the small geographical unit of the Bist Doab area, the variations in agro-climatic conditions between central Punjab and sub-mountainous area in the foothills of the Shivalik induced by difference in rainfall regime, temperature, humidity and soils are wide (source: Hira and Khera 2000). But, paddy and wheat are the dominant crops in the entire region.

As farmers' water allocation decisions are for the farm as a whole rather than for the field (Loomis and Connor 1996: pp 393-394), scale considerations are extremely important in analyzing water productivity even at the individual farmer level. Within a farm, there are several crops cultivated during the same season. Often, crops and dairying are practiced in an integrated manner. There are very few pockets in India where farmers practice mono-cropping. Even in the most intensively irrigated Punjab, which is criticized for its paddy-wheat system, sugarcane, fodder crops and low water-consuming mustard are all grown in the same farm by farmers who simultaneously cultivate paddy and wheat. The determinants of water productivity would change as one moves from the field to the farm i.e., the determinants would be the net return from the farm against the total amount of water diverted or depleted at the farm level. For estimating the denominator, the amount of water imported into the farm or exported from the farm should also be factored, rather than the total water applied by the farmer in the field or used for feeding cattle. Hence, judging the productivity of water usage in agriculture by looking at a few major crops would be misleading. As seen in the case of Punjab, water productivity in dairy farming, which heavily depends on residues from paddy and wheat, was much higher than that of water productivity in individual crops (Kumar and van Dam 2008).

Now, to what extent the irrigation water applied to the system is a 'loss' from the system would be determined by whether groundwater is shallow, or saline or deep or whether waterlogging conditions exist. The plains of central and north eastern Punjab are underlain by alluvial aquifers. At present, farmers pump water mostly from the upper phreatic aquifer, which is shallow. Hence, in such areas, a major share of the return flows from irrigated fields, especially paddy fields, and are likely to end up in the groundwater system. But, such areas are very rare in India. The exceptions to this are perhaps many. In areas with deep water table conditions, having a deep vadoze zone, not all the water, which moves vertically down, would end up with the groundwater system. Most of the semi-arid and arid regions of India, where water scarcity is an issue, have deep groundwater table conditions, be it in the alluvial North Gujarat, arid areas of Rajasthan or in the southern peninsular. In such areas, soil conditions do not favor the fast percolation of water. Thus the gain in applied water productivity would result in a gain in real water productivity in most situations.

In areas with saline groundwater, like in western Punjab, the return flow cannot be treated as a ‘gain’ but a ‘loss’ from the system, as groundwater quality is far below the standards required for irrigation. Hence, geo-hydrological environment is an important physical consideration in analyzing water productivity functions.

Parametric Considerations

‘Parameter considerations’ are extremely important in comparing water productivity. Choosing the right parameter for assessing water productivity is important while judging which irrigation source yields higher water productivity. Following are the reasons: a) it has been found that farmers in well command areas prefer crops that are less water consuming (ET) as compared to those grown in fields irrigated by canals, hence capturing the economic value of outputs is extremely important, in addition to looking at the irrigation efficiencies and physical productivities; b) both the public cost of production and supply of water (water storage, diversion and irrigation) and private cost of water supply (irrigation) can vary widely between gravity irrigation and well irrigation, and hence need to be understood by looking at economic efficiency; c) the opportunity cost of using water could vary significantly between surface water and groundwater, as the scope/ opportunity for transferring water to alternative (higher-valued) uses could be different. Hence, economic returns from a unit of water depleted in surface irrigation against the opportunity costs of depleting that water in groundwater irrigation should be considered in a comparative analysis of water productivity between wells and canals or between wells and tanks.

Parameter consideration is also important when comparing water productivity in agriculture across two regions which have differential water endowments. It is quite well known that the incremental return from every unit of water diverted would be much higher in a water-scarce region as compared to a water-rich region even when the farmers are not confronted with the opportunity cost of using the water. This is because of the difference in the balance between arable land and water availability between the two regions (Kumar et al. 2008a).[1] But, it is also well understood that the opportunity cost of using a unit volume of water would also be different. So if the full opportunity cost of diverting the water for agriculture at the societal level is considered, does the gain in marginal productivity that is observed in water-scarce regions, offset the differential opportunity cost of using water to give a better return for every Rupee spent on water? Hence, taking the crop yield or crop returns from a unit volume of water diverted or depleted won’t be sufficient under such circumstances.

Objective of Analysis of Water Productivity

In crop productivity analysis, one important issue is knowing which ‘crop’ and which ‘drop’ is referred to (Molden et al. 2003; Bastiaanssen et al. 2003). The ‘objective of analysis’ would change with the underlying concerns. In the recent decades, the need to consider the ‘depleted fraction’ as a determinant of water productivity, rather than the total water applied to the crop, has gained acceptance. Scholars are increasingly concerned about the amount of water depleted

[1] In the naturally water-poor region, the land that can be brought under cultivation is extensive, a factor that contributes to the high demand for irrigation water, whereas in the water-rich region, there is a shortage of arable land, which keeps the demand for irrigation water low.

in the system rather than the total water applied to the field (see for instance, Allen et al. 1998; Molden et al. 2003; Molle and Turral 2004). Such views ignore productivity losses due to deep percolation in inefficient irrigation systems. This is because water resources management alone becomes the primary concern for those who are engaged in the research on water productivity. Whereas as Palanisami et al. (2008) notes, irrigation bureaucracy would be primarily concerned with what is generated out of the water delivered from the scheme and, therefore, they would assess the system level water productivity in relation to the total water supplied.

The underlying concern should depend on which resource used in crop production, apart from water, is scarce; i.e., whether it is energy or other inputs, and which resource is critical from a management point of view. In a region, where energy is scarce, allowing excessive return flows in the form of recharge and runoff would not be justifiable, as it would require precious energy to pump it for reuse. This would have major economic imperatives and the objective should also be to maximize the return from every unit of energy used. Especially in a country like India, where 65 % of the irrigation occurs through pumping, analysis of irrigation efficiency cannot ignore energy efficiency. Therefore, the estimates in the 'opportunity cost' of using water should include the cost of production of the energy required for lifting the 'return flow fraction' and the incremental value of the benefits accrued from alternative uses of the depleted fraction. This means that in regions which are facing a power crisis, the concern should also be in reducing the deep percolation of irrigation water besides reducing the depletion fraction, and raising the yield and net returns.

Food Security Considerations

A nation, although facing water shortages, may decide to produce food within its own territory instead of resorting to imports due to social and political reasons. In such situations, economic efficiency of production may not be of great relevance, as the country may strategically decide to subsidize the farmers to procure systems that provide control over irrigation water delivery and thereby improve the physical productivity of water. Instead, the opportunity cost of importing food may be taken into consideration and treated as an additional benefit while estimating the incremental value of crop output for estimating the 'economic productivity' function. These considerations seem to be extremely important for India if one goes by the recent analysis by Shah and Kumar (2008). The analysis shows that the social benefits due to incremental food production (42 million tonnes) through investment in large reservoir projects, since Independence, in terms of lowering food prices, was to the tune of Rs. 4,290 crore annually. If food security impacts of certain crops are integrated with the analysis of crop water productivity, then the arguments of low water productivity in gravity irrigated paddy-wheat systems would be irrelevant. In fact, paddy and wheat are the staple food of many Indians, and self-sufficiency of these two crops is very important despite their low water productivity. But, as pointed out in 'Paper 2' of this book, food security itself cannot be an excuse for low productivity. Many canal irrigation systems, in fact, suffer from poor quality and reliability of water supplies, which impacts on water productivity adversely.

The attempt should, therefore, be in improving the productivity of water through improving the quality and reliability of water supplies in the canal irrigation systems that mimic well irrigation. This assumes greater significance when one considers the fact that most of the irrigated cereals such as paddy, wheat, bajra and jowar have much lower water productivity in simple economic terms than oil seeds, vegetables and fruits (Kumar and van Dam 2008).

Environmental Considerations

In a region where rising groundwater tables and increasing salinity is a concern, one of the objectives of water productivity improvement should be to reduce the return flows, along with reducing the depletion fraction. This is because the opportunity cost of leaving the water underground through return flow is high, owing to the environmental damage it causes. Intuitively, there could be significant differences in return flows between canal irrigation and well irrigation. Therefore, comparative analysis of water productivity between well irrigated crops and canal irrigated crops in such regions should involve opportunity cost considerations rather than the volume of water diverted or depleted. Here, the opportunity cost of using the diverted water should include the cost of providing subsurface drainage for the recharge fraction of the return flow, and the benefits that can be derived from alternative use of the depletion fraction part of the total water diverted. Here again, since there is a spatial mismatch between the demand for water and supplies available through return flow, ideally, the incremental value of the benefits that can be accrued from alternative uses of the 'total applied water' should be considered in estimating the opportunity cost rather than the 'water depleted'. This is because the return flows won't find much beneficial use in the area.

Let us examine how environmental cost and benefit considerations can alter water productivity assessments. For that, we consider the canal command areas. Many canal command areas in India have shallow groundwater due to seepage from canals and irrigation return flows from the fields. Examples are Sutlej Canal commands in Punjab and Haryana; Ukai-Kakrapar command in south Gujarat; Mula command in Maharashtra and Krishna and Nagarjunasagar commands in Andhra Pradesh. In certain cases, the return flow from canal irrigation is a boon as it provides the additional recharge to sustain groundwater irrigation. Whereas in certain other cases, it is a bane as it causes waterlogging conditions. Whether it becomes a boon or a bane depends on the original groundwater table conditions in the area before the introduction of canal water, and the balance in groundwater use.

Now, well irrigation exists in canal command areas, in lieu of the poor reliability of canal water supplies. In cases like central Punjab, the area irrigated by tubewells has surpassed the area irrigated by canals over the years. In certain cases, well irrigation is sustained by return flows from canals as in the case of central Punjab and Mula command in Maharashtra. Whereas in certain other cases, well irrigation prevents conditions of waterlogging, which can occur due to excessive seepage and return flows from canals as seen in Ukai-Kakrapar and Mahi commands in south and central Gujarat, respectively. In the first case, while analyzing the productivity impacts of canal irrigation, the environmental benefit of providing the critical recharge that protects the groundwater environment can be considered in the numerator of water productivity. In the second case, while analyzing the water productivity impact of well irrigation, positive environmental effects of preventing waterlogging conditions should be considered in assessing the net returns, while there may not be any opportunity costs associated with its use for irrigation.

Regional Economic Considerations

A standard approach to improve water productivity in agriculture and to reduce the stress on groundwater would be to replace low water-efficient crops by those which are highly water-efficient (Kumar 2007). An approach as such will have differential impacts on the economy in different regions.

For example, in North Gujarat, there is a severe problem of groundwater depletion, resulting primarily due to dairy production. Although Diary production accounts for a major portion of its rural economy (Kumar 2007), it is highly water-intensive due to green fodder production (Singh 2004; Kumar 2007). The introduction of highly water-efficient crops, such as orchards and cash crops like cumin in such an area would result in the replacement of dairying. But, this would result in lower production of milk, which provides a stable income and a regular cash flow for the farmers. Hence, it is a difficult proposition from the farmer's perspective. Moreover, dairy cooperatives have already invested heavily for processing and marketing of milk and milk products. Thus there are strong political economic considerations that go against measures of protecting groundwater ecology in North Gujarat. Also, although it is easier for the farmers to maneuver inputs such as dry fodder and green fodder to the farm, it is difficult for the region as a whole to import large fodder requirement for dairying. Thus, at the regional level, replacement of dairying by cash crops and orchards would have significant impact on the region's milk production, which not only sustains its rural economy, but also produces a surplus for export to other deficit regions.

In order to analyze the opportunities and constraints for improving regional water productivity in agriculture and to reduce the stress on groundwater, farm economy in four sub-regional (talukas) of Banaskantha District in North Gujarat were simulated using linear programming. The results from two different optimization models (minimization and maximization models), for the four talukas were more or less similar. Results from the Vadgam Taluka of Banaskantha District of North Gujarat showed that the volume of groundwater used for agriculture can be reduced to an extent of 49.5 % through the introduction of cumin or lemon. This would not affect the initial level of net farm income or compromise the food security needs of the region's population. However, while doing this, the milk production would undergo a sharp decline. This is because milk production is relatively more water intensive, and any effort to cut down groundwater use would result in reducing milk production and substituting it with crops that are highly water productive.

With the introduction of water-saving technologies (WSTs) for field crops including alfalfa, the extent of reduction that was possible in groundwater use was higher (60.1 %), with lower extent of reduction in milk production. The net farm output, however, would not be adversely affected. Further analysis showed that using WSTs, the groundwater use could be brought down by 17.5 %, if milk production in the region has to be maintained at the previous level. The extent of reduction possible in groundwater use decreases with the degree of unwillingness to compromise milk production. This means that, the amount of leverage available for enhancing regional water productivity and cutting down groundwater use for farming becomes limited if the income from dairy production as a percentage of the total farm income is to remain high.

A great deal of risk taking by farmers is involved in the adoption of orchard crops and drip irrigation systems. In the former, it is due to the need for finding markets and in the latter, it is the capital intensive nature of the system. Hence, the small and marginal farmers show great reluctance to adopting such systems. Thus, there is a trade-off between enhancing the water productivity of the farming system through crop and technology selection and reducing farming risks.

In certain other regions, the greatest constraints in enhancing agricultural water productivity are: a) arable land availability; b) market for farm produce; and c) labor absorption. In regions like Punjab, which are intensively cropped, improving the productivity of water use in agriculture through crop shifts could be at the cost of the regional agricultural economy itself. The reason for this is that many of the highly water-efficient crops have low land productivity, and higher water productivity could be essentially due to the low water requirement of the crops. Shift towards such crops would lead to an overall decline in the economic outputs from farming, since farmers won't have the opportunity to expand the area under irrigation to sustain the income from farming.

It is established that many fruit crops have both higher water productivity and land productivity than conventional cereals such as wheat and paddy in arid areas (Kumar and van Dam 2008). Also, there are crops such as potato, tomatoes, cumin, cotton and groundnut which are more water efficient than rice and wheat, which can be grown in Punjab. Farmers from this region have already started shifting to high-valued cash crops in a moderate way. But, the number of farmers who can take up such crops is limited due to the volatile nature of the market for most of these crops, their perishable nature and also the high risk involved in their cultivation.[2] Furthermore, given the high investments required for the crops, there arises a need for greater risk-taking ability. But, the extent to which farmers can allocate water to economically efficient crops would perhaps be limited by the need to manage fodder for dairying, which is more water efficient than the conventional paddy-wheat system. It may also be limited by poor market support for orchard crops.

The foregoing discussion shows that the potential trade-off exists between maximizing field level water productivity through crop shifts and maximizing water productivity at the level of the farming system. The possibility exists for simultaneously enhancing both field and farm level water productivity through the introduction of high-valued crops such as vegetables and fruits—if those crops have water productivity values higher than those in dairy production. Otherwise, if the water productivity of the newly introduced crop is not higher than that of dairying, but higher than that of the cereals, fodder will have to be imported to practice dairying. However, in both cases, the risk involved in farming might increase. The reason is the volatile nature of vegetable prices and the high probability of a drastic price increase or fodder scarcity, in the event of a drought (Singh and Kumar Paper 5, this book).

Now, at the regional level, attempts to adopt water efficient crops or crop-dairy based farming to enhance agricultural water productivity might face several constraints from a socioeconomic point of view. National food security is an important consideration when one thinks about crop choices. Punjab produces surplus wheat and rice and supplies them to many other parts of India, which are food-deficit, including eastern India (Amarasinghe et al. 2005; Kumar et al. 2007). Twenty percent of the country's wheat production and 10 % of its rice production comes from Punjab, and they contribute 57 % and 34 %, respectively, to the central pool of grains for public distribution (Kumar et al. 2007).

Labor absorption capacity of irrigated agriculture and market prices of fruits are other equally important considerations at the regional level. Paddy is labor intensive and a large portion of the migrant laborers from Bihar work in the paddy fields of Punjab. As per our

[2] The markets for fast perishing vegetables 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 water productivity.

estimates, 2.614 million ha of irrigated paddy in Punjab (as per 2005 estimates) creates 159 million labor days[3] during the peak kharif season. The total percentage of farm labor contributed by migrant laborers during the peak season was reported to be 35 % as per the Economic Survey of Punjab 1999-00 The total number of labor days contributed by migrant laborers to paddy fields in Punjab was estimated to be 55.75 million (Singh and Kumar Paper 5, this book).

Replacing paddy by cash crops would mean a reduction in farm employment opportunities. On the other hand, the lack of availability of labor and fodder would be constraints for intensive dairy farming to maximize farming system water productivity at the regional level, though some farmers might be able to adopt the system. Large-scale production of fruits might lead to price crashes on the market, resulting in farmers losing revenue unless sufficient processing mechanisms are established. Hence, the number of farmers who can adopt such crops is extremely limited.

Summary on Trade Offs

Enhancing field level water productivity in many situations would involve trade-offs in the form of reducing return flows to groundwater that is crucial for increasing the productivity of water at the basin level through well irrigation. The trade-off can also be in the form of increasing farming risk due to a shift towards risky cash crops with volatile markets. But, as Palanisami et al. (2008) notes, the irrigation bureaucracy may not consider this as a trade-off when it comes to surface water, as they are preoccupied with the task of maximizing their revenue and, as such, are interested in maximizing the area directly irrigated by the canals and other surface water sources.

At the regional level, enhancing agricultural water productivity would be constrained by existing farming system and the consideration of food security, employment generation and regional economic stability. Nevertheless, WP improvement might come from a shift from cereals and high labor absorbing crops to capital-intensive and risky cash crops that decrease the farming system's vulnerability to market risks. Whereas integrating environmental considerations in water productivity improvement measures would justify the investments for the same in waterlogged areas.

Choosing the right parameter for assessing water productivity is important when judging which irrigation source yields higher water productivity. While comparing water productivity between two sources of irrigation, with the differential opportunity costs of using the resource, one must assess the economic productivity of water. The objective of water productivity analysis should determine the major determinants for assessing it. In regions where energy is scarce, the cost of pumping back the return flows from irrigation should be added to the opportunity cost of the depleted water while comparing water productivity between cases of differential return flows.

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[3] This is based on the primary data which show 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 labor charge at the 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).

Opportunities for Improving Regional Water Productivity in India

Discussion on Hot Spots for Water Productivity Improvements

Opportunities for Water Productivity Improvement in Rain-fed Agriculture: With the rapid expansion in well irrigation, India does not have purely rain-fed areas now in the strict sense of the definition. But, there are rain-fed crops in many regions, including central and peninsular India. This is because some crops are always irrigated in every region, though some farmers might be growing those crops under rain-fed conditions there. Often, farmers who do not have irrigation facilities resort to the purchase of water to provide critical supplementary irrigation. An example is cotton growing in Maharashtra and Madhya Pradesh. However, the situation with regard to the extent of irrigation keeps varying with rainfall variability. In a high rainfall year, a certain crop might give high yields without irrigation, whereas in a low rainfall or drought year, securing optimum yield would not be possible without supplementary irrigation.

Most of India's 'so called' rain-fed areas are in central India and the peninsular region. Of these, the central Indian belt deserves special mention. This region is dominated by tribes, who are the first or second generation agriculturists (Phansalkar and Verma 2005). In spite of abundant natural resources, by and large, the population in this region is not able to improve their farming considerably, owing to their peculiar cultural and socioeconomic conditions. Instead, they mostly practice subsistence farming and grow most crops under rain-fed conditions. Development of water resources for irrigation is poor in these regions; the use of modern farming practices including the use of fertilizers and pesticides and crop technologies is extremely low. The result is that the productivity is low for cereals, and the total factor of productivity growth is also very poor. The other food grain crops grown extensively in this region have a low productivity (Amarasinghe and Sharma, Paper 2 of this book). Hence, this region is characterized by agricultural backwardness.

Amarasinghe and Sharma (Paper 2, this book) show that there are 208 districts where the average consumptive use of water for food grain production is low (below 300 mm), due to larger areas being under rain-fed pulses such as green gram, black gram and horse gram. These crops have very low grain yields, resulting in low WP. The study which used an analysis of the district level aggregate for data on crop outputs and average consumptive use of water (CWU), also shows that supplementary irrigation can boost both yield and WP significantly (Amarasinghe and Sharma, Paper 2 of this book). This boost would be through farmers shifting from short duration food grain crops to long duration irrigated crops, such as wheat in winter and from rain-fed paddy to irrigated paddy.

This tribal region forms the upper catchment of important river basins in India such as Mahanadi, Godavari, Tapi, Mahi, Narmada, Krishna, Sabarmati and Banas, spread over the states of Orissa, Madhya Pradesh, Chattisgarh, Maharashtra, Gujarat and Rajasthan. These regions form the rich catchments responsible for a major portion of the basin yields, which are appropriated for down-stream uses (GOI 1999; Kumar et al. 2006). The flows in some of these basins are already exploited to their full potential for irrigation and other uses through storage and diversion systems, and further exploitation in the upstream areas would be at the cost of downstream uses—Mahi, Krishna, Sabarmati and Banas (Kumar et al. 2006).

Large-scale irrigation projects are coming up in the Narmada River basin, where 29 large, 125 medium and around 3,000 minor schemes are planned to be built. Work on some of them is already completed. The percentage cropped area currently irrigated in the basin is very small. The rain-fed crops occupy large areas in the basin (Kumar et al. 2004). The rain-fed crops account for a major part of the basin's water economy. Many of these crops are those which need supplementary irrigation to realize their yield potential. Kumar and Singh (2006) show that the irrigated crops and crops receiving supplementary irrigation in the basin have much higher water productivity as compared to rain-fed ones in both physical and economic terms. Once built, these irrigation schemes will be able to bring the rain-fed areas in the basin under irrigated production, and thereby raise crop water productivity. The productivity impacts would be visible in crops such as irrigated cotton, pulses such as gram, black gram and green gram; and cereals such as paddy and wheat.

But, there are still a few basins, where small-scale water resources development is possible without causing negative effects on the downstream. They are Tapi, Mahanadi and a few small river basins (Karjan and Damanganga) in South Gujarat. Since the geo-hydrological environment is not very congenial for storage of the harnessed water underground due to hard rock strata, water can be stored in small-scale reservoirs such as anicuts, check dams, ponds and tanks. But, the water resources being developed should be put to beneficial use immediately after harvest. The reason is that the potential evaporation rates are high in most parts of these regions even during the monsoon (Kumar et al. 2006) and as a result the stored water can be lost to evaporation. This means that the supplementary irrigation of kharif crops is the best option for use of this harvested water.

In peninsular India, rain-fed crops are still grown in many parts due to: a) low and erratic rainfall b) poor surface water availability; and c) groundwater endowment. This region is mostly underlain by hard rock formations. The problem of natural water scarcity in the basins is compounded by demand for water far exceeding the renewable water resources. The basins are also closed or are on the verge of closure (Kumar et al. 2008b). Small water harvesting interventions in the upper catchments of such basins would only help basin-wide redistribution of water, with negative implications for basin water use efficiency (Kumar et al. 2006). The only exception to this is the Godavari River basin, which is water-surplus. Augmentation in water resources would be possible and the same water could be used to bring rain-fed crops under irrigation to boost crop yields. In any case, large-scale water resource development projects based on river lifting are coming up in this region and would help expand irrigated agriculture, and thereby boost crop water productivity.

In addition to the low water (ET) consuming short duration rain-fed (food) crops or water stressed rain-fed (food) crops, there are rain-fed crops, which require a moderate use of water (300-425 mm) in 117 districts of India. These crops, which are essentially long duration fine cereals, are concentrated in eastern India and central India. Amarasinghe and Sharma (Paper 2 of this book), show the yield gap of these food grain crops is very high. Use of better crop technologies, and better inputs could also result in significant improvement in water productivity through yield enhancement, which would be the effect of nutrients and proportion of the ET being used for transpiration.

Opportunities for Water Productivity Improvement in Irrigated Agriculture: Kumar et al. (2008c) demonstrated on the basis of a detailed study of three river basins in India (Narmada, Sabarmati, parts of Indus and Ganges) that there are five major avenues for improving water productivity in irrigation crops, with other scholars sharing similar views. They are: 1) water delivery control; 2) improving quality and reliability of irrigation water supplies (Palanisami et al. 2008;

Kumar et al. Paper 3, this book); 3) optimizing the use of fertilizers; 4) use of micro- irrigation systems (Palanisami et al. 2008; Sikka, Paper 4, this book); and, 5) growing certain crops in regions where they secure high water productivity. Studies in the Narmada Basin show that great opportunities for improving water productivity (in economic terms) exist through control over water delivery. This can mean allocating less water in many instances with a resultant reduction in yield but rise in WP to allocating more water in certain instances with a resultant increase in both yield and WP (Kumar and van Dam 2008). Amarasinghe and Sharma (Paper 2, this book) show results that conform to the fact that water productivity in irrigated crops could be enhanced significantly through deficit irrigation, a key strategy in water delivery control in 251 districts. These are districts which already show very high yield per unit of land, and receive intensive irrigation.

Different types of micro-irrigation systems that are amenable to different crops and cropping systems are available. While some are only technically feasible and economically viable for row crops and orchards, some are feasible and economically viable for field crops also. They can improve crop water productivity by reducing the non-beneficial evaporation or non-recoverable deep percolation in the field, resulting in total depletion or consumed fraction (CF).[4] Or they can increase the proportion of the beneficial fraction of the applied water that leads to improved crop yield. Nevertheless, in both cases water productivity is improved without any reduction in yield (for details, Please see Kumar et al. 2008c; Palanisami et al. 2008). There are other conservation technologies such as zero-tillage and bed planting, which can improve water productivity in wheat (Sikka, Paper 4, this book).

The determinants of physical productivity of water such as yield and evapotranspiration are influenced by climatic factors—with solar radiation and temperature affecting yield, solar radiation, temperature, wind speed and humidity affecting ET (Agarwal et al. 1995; Loomis and Connor 1996) and agronomic factors—with crop variety affecting the potential yield and ET requirement (Hussain et al. 2003). Since yield affects the gross returns, the climate would have implications for water productivity in economic terms as well. Hence, certain crops give higher water productivity in both physical and economic terms by virtue of the climate under which they are grown without any additional inputs of nutrients and improved crop technology (Loomis and Connor 1996: pp 398). Studies in the Narmada Basin show major differences in water productivity of wheat and irrigated paddy across nine agro-climatic subregions (Kumar and Singh 2006).

In the case of wheat, the physical productivity of applied water for grain production during the normal year was estimated to be highest for the northern region of Chhattisgarh in Mandla District (1.80 kg/m^3). Although falls in the traditional wheat-growing belt, WP was lowest for Jabalpur in Central Narmada Valley (0.47 kg/m^3). This is mainly due to the major difference in irrigation water applied, which is 127 mm against 640 mm for Jabalpur. This is a significant difference, with the highest being 250 % more than the lowest. The difference in irrigation can be attributed to the difference in climate between Jabalpur (dry semi-humid) and Mandla (moist sub-humid), which changes the crop water requirement. Higher biomass output per unit volume of water (physical productivity) should also result in higher economic output,

[4] Please see Allen et al. (1998) for various definitions.

especially when the difference is mainly due to climatic factors, which changes the ET requirements, unless the factors which determine the cost of inputs significantly differ. In this case here, it was found that the net economic return per cubic meter of water was highest for the same region for which physical productivity was higher (Rs. 4.09/m^3). But the same was lowest for Narsinghpur (Rs. 0. 86/m^3), which had the second lowest physical productivity.

As regards paddy, there are only two regions which irrigate paddy. The physical productivity for grain during the normal year was estimated to be higher for the northern region of Chhattisgarh in Mandla District (2.13 kg/m^3), whereas it was only 1.62 kg/m^3 in Jabalpur District of Central Narmada Valley. Likewise, the combined physical and economic efficiency of water use was found to be higher for Chhattisgarh (Rs. 3.59/m^3) against Rs. 1.43/m^3 for Jabalpur in Central Narmada Valley. Climatic advantage exists in many major basins such as Indus, Ganges, Cauvery, Sabarmati and Narmada) with lower aridity, higher rainfall and higher humidity experienced in the upper catchments (based on Kumar et al. 2006; and Kumar et al. 2008b). For instance, within the paddy-wheat growing area of Punjab, the climate varies from hot semi-arid to hot and sub-humid. This advantage can be tapped to allocate more land for water-intensive crops in localities where ET requirement is less and there is greater sunshine.

Another major opportunity for water productivity improvement comes from crop shifts. In every region, the agro-climate permits the growing of several different crops in the same season, and our analysis shows that there are major variations in water productivity in economic terms across crops (Kumar and Singh 2006; Kumar et al. 2008c). Several of the cash crops, such as castor, cotton, fennel, cumin and ground nut, and vegetables, such as potato, are found to have a higher water productivity than the cereals grown in the same region (Kumar and Singh 2006; Kumar et al. 2008a; Kumar and van Dam 2008). But, if we consider the food security benefits of growing cereals, the opportunity available for WP improvement through a crop shift may not be significant in major food producing areas. In such areas, the opportunities for shifting from less water-efficient nonfood crops to water-efficient cash crops and fruits should be explored. Semi-arid pockets such as North Gujarat, Saurashtra, central Madhya Pradesh, western Rajasthan, northern Karnataka, parts of Tamil Nadu and western parts of AP are ideal for such crop shifts to improve crop water productivity and reduce the stress on groundwater. These, however, are not major food producing areas.

There are many irrigated districts in eastern India which are dominated by food crops. The yield of food crops such as wheat and paddy is very low in these districts, and yield gaps are high (Kumar et al. 2008d), and also the total factor growth is very low (Evenson et al. 1999). Amarasinghe and Sharma (Paper 2, this book) show that there are 202 districts in the country which fall under the category of medium consumptive water use of irrigated crops (300-425 mm), but with high yield gaps. Improved agronomic inputs (high yielding varieties and better use of fertilizers and pesticides) can significantly raise the yields. This will have a positive impact on water productivity, though water productivity is not a concern for farmers in this water-abundant region of India. While there are districts in central India, where better use of fertilizers would help enhance crop yields, these areas also require optimum dosage of irrigation to achieve this (Kumar et al. 2008c).

As regards improvements in quality and reliability of irrigation, it is more relevant for canal irrigated areas, and areas receiving tank irrigation (Palanisami et al. 2008). The area irrigated by canals is high in Punjab, Haryana, Uttar Pradesh, Bihar, Maharashtra, Tamil Nadu and Andhra Pradesh. Some of these areas have good native groundwater and farmers could supplement canal water with well water. Such areas include central and north eastern Punjab, Uttar Pradesh and Bihar. Whereas in parts of Maharashtra, Tamil Nadu and Andhra Pradesh, the hard-rock aquifers get replenished due to return flows from canal irrigated fields and seepage from canals. This is already extensively practiced in Punjab, Maharashtra and South Gujarat.

Sikka (Paper 4, this book) shows that introducing horticulture, fish and prawn farming, and rearing ducks through secondary reservoirs and raised bed-cum trench could enhance water productivity in economic terms in the seasonally waterlogged areas of Bihar, under the rice-wheat system in order of magnitude. Also, in seasonally waterlogged paddy areas, introduction of horticulture-fish production in raised bed cum trench was found to be economically viable. Sikka's work also shows that many rice farms in eastern India are multiple use systems with significant values being added by trees, fisheries and dairying, and assessing their water productivity in relation to the returns from paddy production against the total water delivered would lead to a significant underestimation of water productivity of such agricultural systems. Nevertheless, the water accounting procedure adopted in the study did not take into account the increased water demand induced by trees or the actual amount of water directly used by trees from the subsurface strata. Hence, it is quite likely to have resulted in the overestimation of incremental water productivity obtained under the farming system.

In some other areas, where groundwater is scarce or is of poor quality; quality and reliability of irrigation water supplies could be improved through creation of intermediate storage systems like the one found in Bikaner District of Rajasthan. But, one pre-requisite for this is the availability of land area for cultivation and farmers' ability to spare land for construction of such storage systems. Area irrigated by tanks is high in the South Indian states of Andhra Pradesh and Tamil Nadu.

Constraints to Improving Water Productivity in Agriculture

Constraints to Rain-fed Agriculture

Socioeconomic and Financial Constraints: Rockström et al. (2002) show that supplementary irrigation through water harvesting will have a remarkable effect on the 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 a higher gross value product from crop production in areas with better allocation of water from water harvesting irrigation systems. But, the 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 it very poor in 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; Kumar et al. 2008b).

Given that incremental returns due to yield benefits may not exceed the cost of the system, as indicated by the comparison between the unit cost of water harvesting and recharging schemes and the net returns from a unit volume of water obtained in irrigated crops (Kumar et al. 2008b), small and marginal farmers will not have the incentive to go for water harvesting. But, even if the benefits due to supplementary irrigation from water harvesting exceed the costs, it will not result in basin-level gain in 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 ET down stream, causing income losses there. Also, as Kumar and van Dam (2008) point out, incremental net benefit considerations can drive water harvesting at the basin scale only if there is no opportunity cost in harvesting.

In open basins, water harvesting and recharge schemes could be attempted to improve water productivity of crops, but, the following are prerequisites: 1) the harvested water is put to high-valued use, making the system economically viable from the point of view of economic costs and the incremental benefits; 2) the system is used to produce crops which provide very high social returns, especially in improving the regional food security and employment. In closed basins, it would be difficult to justify investments in water harvesting and recharge schemes from an economic perspective, unless the incremental returns due to the upstream interventions are far higher than the opportunity costs of downstream economic losses and mechanisms are in place to compensate for these losses.

Unfortunately, the regions, which are endowed with water-rich basins, have a very high concentration of tribal population. They are used to grow subsistence crops like paddy and maize which have low economic returns and water productivity (Rs/m^3). Hence, most of the preconditions for achieving water productivity gain through supplementary irrigation are not likely to be satisfied. This poses socioeconomic constraints.

Investments for water harvesting and groundwater recharge schemes that can help improve water productivity in rain-fed farming systems are very high in terms of cost per cubic meter of water (see Table 1), even if they are economically viable or are able to generate high social returns. The poor tribes are least likely to mobilize these resources. Hence, there are financial constraints too. Large-scale government financing of water harvesting and groundwater recharge systems would, therefore, be required.

Table 1. Estimated unit cost of artificial recharge structures built under pilot scheme of CGWB.

Sr. No	Type of Recharge Structure (Life in years)	Expected Active Life of the System	Estimated Recharge Benefit (TCM)	Capital Cost of the Structure (in Lakh Rs.)	Cost of the Structure per m^3 of water (Rs/m^3)	Annualized Cost* (Rs/m^3)
1	Percolation Tank	10	2.0-225.0	1.55-71.00	20.0-193.0	2.00-19.30
2	Check Dam	5	1.0-2100.0	1.50-1050.0	73.0-290.0	14.60-58.0
3	Recharge Trench/Shaft/	3	1.0-1550.0	1.00-15.00	2.50-80.0	0.83-26.33
4	Subsurface Dyke	5	2.0-11.5	7.30-17.70	158-455.0	31.60-91.00

Source: Kumar et al. (2008b) based on GOI 2007, Table 7: pp14

Note: *Estimated by dividing the capital cost by the life of the system

Social Constraints: Water productivity improvement in rain-fed farming really matters for socioeconomically backward regions, and is actually important for those who do not have the wherewithal to invest in conventional irrigation systems. There are many ways productivity (both land and water) in rain-fed farming can be raised. Some of them are: a) use of drought resistant varieties; b) use of irrigation combined with high yielding varieties and fertilizers and pesticides; and c) use of highly water-efficient and high-valued dry land crops. Sikka (Paper 4, this book) shows that the introduction of fishery in a water harvesting pond meant for supplementary irrigation of paddy could enhance farm returns and water productivity significantly in rain-fed paddy areas. But, the poor people in these backward regions lack the knowledge and capacity to adopt the technologies needed, including the appropriate fish variety, the feed etc. Poor knowledge about modern agricultural practices, compounded by poor information about markets and lack of marketing skills, prevent them from investing in high productivity farming systems.

Constraints to Improving Basin-level Water Productivity in Irrigated Agriculture

Physical Constraints

We have seen that within the same basin, great opportunities for improving water productivity of a given crop exist if we can earmark certain regions for certain crops, on the basis of the climate. But, along with water productivity, total agricultural output is also a concern for the agricultural and water sector policymakers. The regions which have favorable climate for growing a crop with less water should also have sufficient land that can be allocated to the crop in question. From that angle, constraints seem to be emerging. Many water-intensive crops like paddy and wheat are today grown in regions which have large arable land, but having hot and arid climates. Shifting these crops to areas with a more moderate climate within the same basin or elsewhere can result in a sharp decline in production, as these areas have much lower arable land, as shown by a recent analysis provided in Kumar et al. (2006) for five major river basins of India, viz., Narmada, Indus, Krishna, Sabarmati, and Cauvery. Also, crop yields might be lower in those regions due to ecological reasons such as lower temperature and solar radiation which actually can reduce ET, but have negative implications for potential yield (Loomis and Connor 1996: pp 398). An example is growing paddy and wheat in Bihar instead of Punjab and Haryana.

Institutional Constraints

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. Changing water allocation strategies at the field level can help enhance WP. For this it is important to know the marginal productivity with respect to changing the dose of irrigation water and nutrients. Farmers' water allocation decisions are governed by institutional regimes determining the use of water. Let us examine the constraints in achieving marginal productivity gains from an institutional perspective.

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 sharply before the yield starts leveling off (Molden et al. 2003). Ideally, WP in terms of net return from a crop per cubic meter of water (Rs/m^3) should start leveling off or decline even before 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) by changing the dosage of irrigation. But, this may be at the cost of reduced yield and net return per unit of land, depending on which segment of the yield and WP response curves the current level of irrigation corresponds to.

Recent analysis with data on applied water, yield and irrigation WP for select crops in the Narmada River basin in India showed that 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. In this case, limiting irrigation dosage might give higher net return per unit of water. But, farmers may not be interested in that unless it gives higher return from the land. The reason is that they are not confronted with an opportunity cost in using water, due to the absence of well-defined rights in use of surface and groundwater. Though at the societal level, the resource might be scarce, at the individual level, the resource-rich farmers might enjoy unrestricted access to it. This is the major institutional constraint in improving water productivity.

Hence, if the return from the land does not improve, the strategy of restricting water allocation can work only under three situations: 1) the amount of water farmers can access is really limited either by the natural environment, e.g., limited groundwater reserves; 2) there is a high marginal cost of using water due to the high prices for water or electricity used for pumping water that it is much closer to the WP values 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 rationing of supply, farmers would anyway be using water for growing economically efficient crops (Kumar 2005; Singh and Kumar 2008). But, the issue being addressed here is for a particular crop that how far WP of this crop can be enhanced to a level that the best managed farms achieves at present. 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.

But, situations like those described above, where farmers are confronted with the opportunity cost of using water, are not very common. Even in the hard-rock areas with poor groundwater environment, farmers are frantically drilling bore holes to tap water from deeper strata, thereby overcoming the constraints imposed by physical shortage. While restriction in power supply is being tried by governments to limit farmers' access to groundwater, in reality this is leading to greater power theft and more inequity in the distribution of benefits from a subsidized power supply. There are very few locations in India where canal water supply is heavily rationed in volumetric terms. Hence, the only way to create an incentive among farmers, who are inefficiently using irrigation water, to initiate measures to improve WP is by enforcing volumetric water rights or entitlements with pro rata tariff for canal water (Kumar and Singh

2001) and groundwater (Kumar 2005) or energy quotas combined with high power tariff in case of groundwater (Zekri 2008).

Market Constraints

Major gains in water productivity (economic terms) are possible through crop shifts towards more water-efficient ones such as low water consuming fruits and vegetables that give high income returns (Kumar and Singh 2006; Kumar and van Dam 2008) at the level of individual farms, though the possibility of doing that is determined by the climate. For instance, pomegranate fruit produced in North Gujarat has an applied water productivity of Rs. 39/m^3 of water under tube- well irrigation under normal market conditions. But, highly volatile market conditions and poor marketing infrastructure induces major constraints to improving water productivity and reducing the stress on water resources.

Although the demand for fruits and vegetables is increasing steadily in India with increasing income, due to the seasonal nature of these crops, local markets often get flooded with the produce during those seasons, leading to a price crash. In order to avoid this, the supply of this produce to the market needs to be regulated so that a significant portion of it reaches the market when the production is low. Another intervention is to take the produce to distant markets where the climate is not favorable for producing such crops, but provision of cold storages and instant freezing technologies are needed for this. Earmarking of large areas under traditional crops to such high-valued crops can add to the woes of the farmers. The reason being that most of these crops (many fruits and vegetables) perish quickly, and hence need to be brought to the markets immediately after the harvest.[5] These areas require good road infrastructure for transport. Whereas, for other crops such as onions and potatoes, infrastructure for post harvest treatment of the produce would be required. However, many regions in India, where productivity levels are very low also lack good infrastructure facilities including electricity.

Policy Constraints

Inefficient pricing of electricity in the farm sector, characterized by heavy subsidies and charging on the basis of connected land, is a major policy constraint to improving water productivity in agriculture (Kumar 2005; Kumar et al. 2008c; Zekri 2008). Nearly 60 % of India's irrigated area gets its water supplies from wells (Kumar 2007). Well-irrigated fields are more amenable to technologies and practices for improving crop water productivity, because of the greater control that farmers wield over irrigation water application. One of the most important agricultural technologies to improve water productivity in crops is micro-irrigation, while in terms of practices, control over water allocation (Kumar et al. 2008c) and improving the quality and reliability of water (Trivedi and Singh 2008) can help improve water productivity. Heavy subsidies and flat rate pricing of electricity in agriculture leaves no incentive among farmers to secure higher water productivity through improved water allocation and micro-irrigation systems, as they do not lead to improved returns from a unit of land (Kumar and van Dam 2008; Kumar et al. 2008c).

[5] Storing such produce in cold storage etc., will not be economically viable.

Several of the recent studies from Uttar Pradesh, Bihar and Gujarat highlight the positive impact of introducing pro rata pricing of electricity in agriculture on field level water productivity (Kumar 2005 for Gujarat) and water productivity of the entire farming system (Kumar et al. 2008e; Singh and Kumar 2008 for all the three states). Kumar et al. (2008) showed that the price of electricity could be raised to such a level that the marginal cost of water for the farmer who owns an electric well becomes equal to that of the farmer who owns a diesel well, provided good quality power supply is assured (Kumar et al. 2008e). But, the proposals for metering electricity in the farm sector and introducing pro rata pricing get rejected on flimsy grounds. One of them is that farmers are rural vote banks, and that raising power tariff is highly unpopular as it would make farming less attractive. It is to an extent true that merely raising the power tariff would only lead to increasing the cost of irrigation in areas where power supply is of very poor quality. This is because farmers would be discouraged from choosing a cropping system that is water-efficient, but often high risk, due to the fear of supply interruptions and crop damage. Another argument against metering and pro rata pricing is the transaction cost of metering large number of wells in remote rural areas.

But, one important factor that is missed in the entire discussion on raising power tariffs is the improved quality of power supply that is possible under a metered tariff. Under flat rate tariff, it is important to regulate the power supply to reduce the negative effects on welfare, such as excessive pumping, misuse of groundwater and electricity, inequity in distribution of subsidy benefits and greater revenue losses to the electricity board. This affects the quality of irrigation, but this is not necessary under pro rata pricing. Improving the quality of power supply would change the energy-irrigation nexus (Kumar 2005). Singh and Kumar (2008) showed that pro rata pricing with high energy tariff leads to better equity in access to groundwater, and apart from securing higher water productivity, the farmers got higher returns per unit of land and used lesser amounts of groundwater. All these are achieved through the careful selection of crops, and farming systems that use lesser amounts of water, but give higher returns per unit of land, and use all inputs including water more efficiently.

But, these were rather excuses used by officials and other functionaries of electricity departments to cover up the revenue losses due to poor operational efficiencies, resulting from transmission losses and distribution losses, which included thefts. Also, unmetered connections attract more bribes, as detecting power theft is much more difficult under a flat rate system. A recent survey in North Gujarat showed that farmers are resorting to under-reporting of connected load, after the implementation of the much-publicized *Jyotigram Yojna*[6] in villages, which made direct power theft from feeder line difficult. Obviously, detecting thefts like this would require field visits by the technicians, and checking the connected load. Hence, the flat rate system is patronized by a section of the engineering staff of electricity boards. As a result, the state's governments find it rather convenient to continue with such policies. Such degenerative policies act as a major constraint to improving water productivity in agriculture. But, it is important to recognize the fact that resistance to metering is not from the farming lobby, but from the bureaucracy itself.

[6] It involved separation of feeder line for agriculture and domestic power supply.

Technological Constraints

We have seen in an earlier paper that one of the most effective ways of improving water productivity is by ensuring greater control over water delivery. In the case of well irrigation, farmers can exercise good control over water delivery, provided electricity supply is reliable. Diesel well owners were found to be securing very high water productivity in economic terms in spite of incurring high marginal costs for irrigation water due to high diesel prices, in comparison to electric pump owners who incur very low cost for using energy and water (Kumar et al. 2008e; Singh and Kumar 2008). The control over irrigation water is one major factor which enables them to allocate water optimally. There are very few states in India where power supply to agriculture is reliable and adequate. Gujarat is one among them. Many states are facing power crises, and agriculture has been at the receiving end, which has to be satisfied with irregular, erratic, untimely and short duration supply of electricity (GOI 2002). Under such a supply regime, controlled and quality irrigation is not at all possible. Erratic and short duration power supply also induces constraints to farmers adopting precision irrigation systems like drips and sprinklers which are energy-intensive in certain cases.

One disincentive for well irrigators for improving crop water productivity is lack of opportunity cost of using groundwater and electricity in many states. One way of inducing this opportunity cost is by restricting the energy use by farmers. Technologies exist for controlling energy consumption by farmers. The pre-paid electronic meters, which are operated through scratch cards and work on satellite and internet technology, are ideal for remote areas to control groundwater use online (Zekri 2008). As Zekri (2008) notes, such technologies are particularly important when there are large numbers of agro wells, and the transaction cost of visiting wells and taking meter readings is likely to be very high. Hence, they are ideal for the Indian condition. But, such technologies are still not accepted in India. Resistance to introducing such technologies due to vested interests within the state electricity departments is also notable.

In the case of canal irrigation, devices which provide control over water delivery to the lowest delivery regions in the irrigation system are lacking in most of the old gravity irrigation systems. This is a major hindrance for farmers to exercise sufficient control over water application. Most irrigation systems are designed using old design concepts with very few control structures. While intermediate storage systems like the 'diggie' in Rajasthan can help farmers leverage control over water application, in many instances they are not feasible due to problems in land availability. In the case of Bikaner in Rajasthan, Amarasinghe et al. (2008) showed that 'diggies' in Rajasthan are economically viable when the landholding is larger than four acres.

Scale of Agricultural Water Productivity Improvements and its Potential Implications for India's Future Water Scenario

Assessing the scale of water productivity improvement in agriculture is a complex task given the range of physical (climate, geo-hydrology and soils) conditions, the socioeconomic conditions (cropping patterns, overall economic condition of farmers, and the infrastructure conditions, and the institutional and policy environment that determine and influence the water productivity levels that are achieved at present, and the water productivity improvements that are possible in the future. The physical environment, which is more or less static, would influence the future enhancement possible in crop water productivity, irrespective of the intervention chosen.

Water Productivity Improvement through Micro-irrigation

In the case of micro- irrigation systems, not only the physical environment but the water supply systems and the socioeconomic environment also would determine the ultimate scale of adoption of MI systems. After Kumar et al. (2008f), water productivity improvements through the use of micro-irrigation systems are likely to be significant for crops planted in rows and orchards. Furthermore, it would be higher in regions/basins where climate is semi-arid to arid, soils are light and sandy and where the groundwater table is deep. This is because in the case of row-planted crops, the evaporation component of the consumptive water use by crop (ET) is quite large, especially under arid conditions (Kumar et al. 2008f). Again, the area under row-planted crops is very small in the sub-humid and humid areas and water abundant areas. Regions with sub-humid to humid climatic conditions, heavy soils, and with shallow groundwater tables, improvements in water productivity through MI systems are likely to be negligible. But, so far as their adoption goes, that is likely to occur in well-irrigated areas, and not so much in canal irrigated areas owing to the need for special storage systems for water.

Peninsular India and western India have substantial area under crops that are conducive to micro-irrigation technologies; north and central India has very little area under such crops with the exception of Uttar Pradesh. Western part of Mahanadi is another area that would be conducive to WSTs. Use of micro-irrigation system can significantly reduce crop water demand per unit area of cultivated land in semi-arid and arid area, with deep groundwater table conditions or with saline aquifers. But, in these areas, farmers would use the saved water to expand the area under irrigation and thereby maximize their aggregate returns in the presence of sufficient uncultivated land. As a result, the aggregate demand for water may not change. Exceptions would be those where intensity of irrigation is already high like in central Punjab and Haryana.

Kumar et al. (2008f) estimated the total area that can be brought under micro-irrigation systems in India, where their adoption would actually lead to water productivity improvement as much as 5.9 million hectares. The reduction in agricultural water requirement that was estimated to be possible through this was 44 billion cubic meters (BCM)—(Kumar et al. 2008).

All these measures will be for well-irrigated areas. Still, a large part of the irrigated area (23.606 M ha in 1999-2000 in India, source: Ministry of Agriculture and Cooperation, GOI), which is from surface sources, would be left untouched. The first step to bring these areas under MI systems is to either change the delivery practices or to increase the economic incentives. The water delivery systems need to be designed in such a way that farmers can directly connect the source to their distribution systems. The irrigation schedules need to be reworked in such a way that the duration between two turns becomes much shorter than the present 2-3 weeks. In the most ideal situation, the supply has to be perennial. This can happen in the most advanced stage of irrigation systems design, and would take time. Over and above, it can be thought about only in the case of new schemes.[7]

[7] One of the reasons why the farmers in Israel adopt micro-irrigation systems at such a large-scale (with 95 % of the irrigated crops are under drip systems) is that the surface water is delivered in their fields under pressure through pipes.

Economic incentives for MI adoption in canal commands can be improved by increasing the price of irrigation water. High prices for irrigation water would affect cost saving as a result of applied water saving. Alternatively, the cost of building the intermediate storage systems can be reduced through the proper design of subsidies. The justification for subsidizing the systems is that the private benefit-costs ratio would not be very attractive with very high capital costs and the additional infrastructure that is required, whereas the social benefits accrued from saving the scarce water resources would be high when compared against the social costs. In the command area of Indira Gandhi Canal Project, most of the farmers are using intermediary storage tanks, which are locally known as ‘diggies’. The farmers are using electric pumps for lifting this water and they irrigate crops whenever required. The government has started providing subsidies for the construction of ’diggies’. Many farmers are using sprinklers to irrigate their crops from tank water. But, such responses have come from the farmers due to the drastic cuts introduced by the irrigation department in the allocation of water.

Apart from saving the cost of water, the differential economic returns farmers get under lift irrigation over canal irrigation (IRMA/UNICEF 2001; Kumar and Singh 2001) and the differential return in drip irrigated crops would be the strongest incentive for farmers to go for intermediate storage systems. The differential returns could be due to better control over water delivery possible with lift irrigation (IRMA/UNICEF 2001) or due to the increased ability to grow cash crops such as cotton, banana, and fruits and vegetables in the command areas. In canal commands where water becomes a limiting factor for expanding irrigated area, area expansion would be the strongest economic incentive for adopting intermediate storage systems and MI systems. This is what drives farmers in IGNP towards ‘diggies’ and mini sprinklers (Amarasinghe et al. 2008). With this, the actual area that could be brought under MI systems would be larger than the estimates we have provided for the potential area under MI system.

The canal command areas in the semi-arid parts of Andhra Pradesh, Maharashtra, North Gujarat, Rajasthan, Madhya Pradesh, northern Karnataka and Tamil Nadu are ideal for this. The sub-humid and humid areas should be excluded from being considered for MI interventions in canal commands, as the benefits of yield and water saving are likely to be insignificant. We estimate the total canal irrigated area to be around 9.54 million ha from the six basins namely, Godavari, Krishna, Cauvery, Pennar, Narmada, Sabarmati; and the west flowing rivers of Saurashtra and Kachchh; the east flowing rivers between Mahanadi and Pennar; and the east flowing rivers south of Pennar. But, of this, a small fraction could actually be brought under drip systems, as the crops amenable to this system (such as cotton, castor, fruits and vegetables) would cover a small area in these surface irrigation commands. A slightly larger area could be covered under sprinklers as crops amenable to this technology such as potato, groundnut, fodder crops, wheat, bajra, jowar and mustard would cover a much larger area.

Water Control and Improving Quality and Reliability of Irrigation

Empirical studies, which compared crops receiving well irrigation with their counterparts under canal irrigation, show that the differential quality and reliability of water has a positive impact on applied (Kumar et al. Paper 3, this book) and depleted water productivity (Palanisami et al. 2008) of crops. The measures for water productivity enhancement through improvement in quality and reliability of irrigation water and ‘water delivery control’ are more relevant for field crops and surface irrigation systems. This is due to the poor quality and reliability of irrigation, and the poor control over water delivery that they generally experience due to heavy discharge rates, low frequency of water delivery and absence of proper schedules followed in irrigation.

The gains in water productivity per applied water through 'water control' are similar to the gains in water productivity per depleted water, only in semi-arid and arid regions. In these regions the depth to groundwater table is large[8] and non-beneficial evaporation from fallow land is high. All the applied water or a significant portion of the applied water would be depleted in these regions. Hence, there would be basin level productivity gains through control over water delivery.[9] But, for farmers to agree to water control measures, they must have extra land to bring under irrigation. This is because the net return per unit area might decline due to water control measures. Hence, at the aggregate level, there would be no reduction in the demand for water.

The basins that are conducive to measures for water productivity improvement through water control are: 1) all east-flowing rivers of peninsular India; 2) rivers north of Tapi in Gujarat and Rajasthan, Mahanadi, and in some parts of the Indus Basin covering south-western Punjab; and 3) west- flowing rivers of South India. This is because these basins are falling under semi-arid and arid climatic conditions, and have moderately deep to deep groundwater levels. These basins have very large areas which are unirrigated due to limited availability of groundwater and canal water. Hence, farmers would have an incentive to improve water productivity as in the process they would be able to maximize the aggregate returns.

There are some regions in India where water productivity is not a consideration for individual farmers. But, the economy here would benefit a lot by reducing the amount of water depleted and the energy used in growing crops. Such areas include parts of Indus in central Punjab, Haryana and UP, which are groundwater irrigated. In such areas, water productivity improvement measures should help raise income returns from every unit of land irrigated. Hence, the only option to enhance the available water productivity is water delivery control, which can be used in situations where excessive irrigation leads to yield losses. According to Amarasinghe and Sharma (Paper 2 of this book), there are 251 districts in which a calculated reduction in irrigation water supplies could result in improved water productivity. In some of them, measures for WP improvement could result in enhanced crop production as farmers would be able to expand the irrigated area using the water saved. Whereas in some others, yield gain due to controlled irrigation can occur in situations if excessive irrigation is leading to yield losses.

In two of the earlier papers, we have seen that improvement in quality and reliability of irrigation water would have a positive impact on water productivity in both physical and economic terms (Palanisami et al. 2008; Kumar et al. Paper 3, this book). In Punjab, Haryana, the canal irrigated areas of Maharashtra, Andhra Pradesh and Tamil Nadu, improving quality and reliability of canal water supplies, in addition to reducing non-beneficial depletion and improving water productivity, would lead to a greater yield for cereal crops. Hence, the irrigation department should have an incentive to go for improving both the quality and reliability of irrigation water, and 'water control' as well. Such measures are even applicable for water-rich regions like Bihar where excessive irrigation resulting from poor quality and reliability leads to yield losses as reported by Meinzen-Dick (1997).

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[8] Deep groundwater table and aridity means that the return flows from applied water are not significant; and evaporation of residual soil moisture from fallow is very high.

[9] In other regions—sub-humid and humid regions with shallow groundwater, the basin level water productivity gain would be very much lower.

Water Productivity Improvement through MUS

Going by Sikka (Paper 4, this book), water productivity in rice-wheat systems could be significantly enhanced through the introduction of fisheries, agro-forestry and duckery. This involves the use of a secondary reservoir fed by canal seepage with replenishment from tubewell for fish-duck production; and, fish trench cum raised bed for fish-horticulture production. As pointed out by Sikka, the regions which are ideal for this are those where seasonal waterlogging occurs during the monsoon. The reason is that high water table conditions would reduce the requirement for replenishing the fish ponds with pumped or diverted water. The high water table areas in North Bihar plains, which have a rice-wheat system of farming, would be ideal for such approaches.

Multiple use systems of dyke and pond for horticulture-fish farming would be ideal for the waterlogged areas of coastal Orissa (Puri District), Surat and Valsad districts in South Gujarat and Alleppey in Kerala, which not only experience high rainfall, but also receive large amounts of canal water. Also, these areas are dominated by paddy as the main crop and the yields are not very high. Hence, farmers will have strong economic incentives to adopt fish and horticulture production. In all these pockets, raised bunds can be used for growing banana.

Secondary reservoir cum fish pond for improving water productivity in paddy farming can be adopted in coastal Orissa, coastal Andhra Pradesh, and North Bihar, which receive excessive canal water for irrigating paddy. High water table conditions would ensure not only low costs for the energy required for pumping groundwater, but also increased irrigation return flows (Kumar et al. 2008f). But, it is to be kept in mind that in all these situations, it is not the water productivity which would motivate the farmers to go for fisheries, duckery etc., but the enhanced returns from the land. The reason is that all the locations that are ideal for MUSs, water is available in plenty while land is scarce.

Water Productivity Improvement in Rain-fed Areas

Amarasinghe and Sharma (Paper 2, this book) shows that there are two ways in which rain-fed areas can experience water productivity improvement: 1) through a shift from low yielding short duration rain-fed crops to high-yielding long duration crops requiring irrigation with increase in ET as well; and 2) reducing the yield gap of certain long duration food grain crops through agronomic inputs. Most of India’s so called rain-fed areas are in the central Indian belt and south Indian peninsula. Vast improvements in crop yield and water productivity are likely to occur in the central Indian belt encompassing the basin areas of Narmada, Tapi and Mahanadi. Water productivity improvement for food grains in this region is also likely to take place through farmers shifting from short duration rain-fed course grain crops and cash crops (like cotton) to long duration food grain crops which consume more water, but have high water use efficiency. This will be enabled by supplementary irrigation.

The changes will show up on the cropped area of winter crops viz., wheat and cotton, and kharif paddy receiving supplementary irrigation, which will lead to an enhanced production and water productivity of food grain crops in the region (Amarasinghe and Sharma, Paper 2 of this book). In the case of Narmada, this would be the result of large-scale water resource development projects, which are being completed or are coming up in the basin. For the other basins, this could result from small-scale water harvesting interventions, as viable sites for large reservoirs are already tapped in these basins. But, the water harvested through such structures will have to be diverted for growing water-efficient crops for the schemes to be viable (Kumar et al. 2008b). Again, similar changes are likely to occur due to exploitation of water from the Godavari Basin, which still has large un-utilized potential of surface water (GOI 1999), large-scale diversion of which is already planned. All these would result in more water being diverted and used in agriculture. As per GOI, 1999, the gross irrigated area in the Godavari Basin would be 11.013 m ha by the year 2050 covering parts of the four states of Madhya Pradesh, Maharashtra and Andhra Pradesh. This is a quantum jump of 7.0 m ha from the current level. Most of this expansion is going to come from increasing cropping intensity in the basin states, but, its positive impact on crop water productivity would be major. Therefore, it would actually reduce agricultural water demand in the country. Going by the estimates provided by Amarasinghe and Sharma (Paper 2, this book), this can cover 281 districts.

According to Amarasinghe and Sharma (Paper 2, this book), in a total of 117 districts, the water productivity of food crops can be enhanced by reducing the yield gap. Since the ET value for these crops is not going to change, this will have no impact on the water supply requirement, but it can bring down the overall water demand for food grain crops. But, this is not going to be easy as these are very backward regions, where farmers lack resources to invest in high yielding varieties and fertilizers and pesticides. The agro-ecology in these regions also poses challenges, due to floods.

In summary, many arid and semi-arid regions in India, where water development is already high, there seem to be a higher scope for improvement in water productivity in agriculture. It will come through MI systems, water delivery control, improving quality and reliability of irrigation, and economically efficient water allocation within and across the regions. This can significantly reduce water demand in agriculture, provided institutional mechanisms are in place for rationalizing the allocation of water to this sector.

Whereas in other regions, where water resources are not much developed, irrigation water use is quite low. At the same time, the yields, crop water productivity and crop production are also disproportionately low. The current production is not able to meet the cereal demands, and agricultural growth needs in these regions. Here, the demand for water and land for meeting food production can actually be substantially reduced, if the water resources in these regions are properly harnessed and allocated to agriculture. That in turn would help enhance yields and water productivity. In a nutshell, less water would be required to meet the cereal and agricultural growth requirements. But, how much of water actually gets consumed depends on the investments in development of water and institutions for water allocation.

Summary

To summarize, water productivity assessment in countries like India should involve complex considerations of the ‘scale of analysis’; food security and regional economic growth impacts; environmental costs and benefits; and, an objective of water productivity analysis. With changes in considerations, the assessments would also change. Integrating these considerations in the technological, institutional and policy interventions to enhance agricultural water productivity would mean limited scope for raising agricultural water productivity in many cases, and greater opportunities in certain other cases.

Nevertheless, as studies presented in this book show, there are several opportunities for improving water productivity in both irrigated and rain-fed agriculture in India. These measures together cover vast areas of the crop land in the country. Measures such as water delivery control, including deficit irrigation; improving quality and reliability of irrigation water supplies; optimizing the use of fertilizers; use of micro- irrigation systems; encouraging multiple use systems; and, growing certain crops in regions where they secure high water productivity, offer great potential for improving water productivity in irrigated agriculture. Micro-irrigation alone can cover an area of 5.9 m. ha, if we just consider the well-irrigated areas that are most ideal for MI adoption. There is 23.6 M ha of canal-irrigated area in the regions where MI can improve water productivity. But, for this, the water supply systems have to be made amenable to MI adoption. The first step to bring these areas under MI systems is to either change the delivery practices or to increase the economic incentives. Economic incentives for MI adoption in canal commands can be improved by increasing the price of irrigation water, in that high prices for irrigation water would affect cost saving as a result of applied water saving.

Measures such as ‘water delivery control’ and improvement in quality and reliability of irrigation are relevant for regions such as Punjab, Haryana and intensively canal irrigated pockets of Madhya Pradesh, Maharashtra and peninsular India (Kumar et al. 2008c; Palanisami et al. 2009). Also, there are many basins like the Narmada, Indus, Sabarmati and Cauvery where certain pockets can be earmarked for growing certain crops with a relatively lesser amount of water, but can give higher yield and water productivity by virtue of the climate (Kumar and Singh 2006). This needs to be explored for agro-climatic planning for crops, while the constraint imposed by land availability also needs to be examined.

Besides this, as illustrated through the cases of Punjab and North Gujarat, farming system improvement can raise agricultural water productivity in economic terms. While in the case of Gujarat, it will be a shift from milk production to orchards and cash crops, in the case of Punjab, it was a shift from paddy-wheat system to orchards and vegetables.

But, the ability of these regions to move away from the low water-efficient conventional cropping system would depend very much on the pressure on these regions for food self-sufficiency. The regions which are largest water users in agriculture are Punjab, Haryana, Andhra Pradesh, Gujarat and Maharashtra. Of these, Punjab, Haryana and Andhra Pradesh are the largest contributors to India’s granary (Kumar et al. 2008d). Crop shift from food grains to water-efficient fruits and vegetables and cash crops (such as cotton, groundnut) in these regions would have negative implications for India’s food security. But, regions such as Madhya Pradesh (MP) and parts of Andhra Pradesh (AP), which have rain-fed cereal crops such as wheat and paddy in MP and paddy in AP, will be able to enhance the production through irrigation facilities. This, in turn, would ease the pressure on groundwater resources in the existing cereal producing regions such as Punjab, Haryana and parts of Andhra Pradesh. As regards Gujarat and Maharashtra, the possibility for a crop shift to improve water productivity exists.

As shown by Amarasinghe and Sharma (Paper 2 of this book), there are vast areas under rain-fed production in central India’s tribal belt and peninsular India, extending over 211 districts, which could experience quantum jumps in crop yields and water productivity through supplementary irrigation. These are essentially areas, which are already experiencing or going to see large water development projects for irrigation. But, some of the basins in these regions, where water resources are already utilized to their full potential, have to be left out as they won't benefit from the gain in water productivity. The impact of increased irrigation in these regions would mainly be on cereals such as wheat and paddy, and cotton.

Introduction of multiple use systems would help enhance water productivity in selected pockets in India but, these pockets are characterized by water abundance and land scarcity. The important consideration for farmers to go for such farming systems would be increasing returns from every piece of land, which is either productive or unproductive at present. Successful introduction of such farming systems in those regions will have a significant impact on agricultural growth and rural poverty.

In the estimates of the irrigated area that can be brought under micro-irrigation, we have left out the areas that are highly susceptible to waterlogging conditions as areas not suitable for micro-irrigation systems. The reason is water-saving is not a consideration here, and the adoption of MI technology will not lead to any improvement in water productivity. In such areas, interventions to improve applied water productivity, which perhaps would also increase productivity of depleted water through micro-irrigation, water delivery control and improvement in quality and reliability of water would make sense from an environmental perspective and would give larger social benefits.

In the intensively canal irrigated areas, while introducing measures for improving the quality and reliability of canal water supplies and water delivery control, it is important to see the changes in the groundwater conditions. The reason is that the returns from groundwater irrigation are high in these regions, and canal return flows sustain the groundwater ecology in such areas. As Dhawan (2000) notes, reduction in return flows resulting from water management interventions in canal irrigation would threaten the sustainability of well irrigation (Dhawan 2000) though that would raise crop water productivity. But, this has to be compared against the saving in opportunity cost of leaving the water underground, which is equal to the saving in the cost of energy required for pumping out the return flows.

Long, Medium and Short-term Policy Measures

To sum up, much less water would be required to meet the increased demand for cereals and other agricultural outputs if water productivity in agriculture could be raised. But, how much water actually gets consumed in the sector would depend on the investments in water development, and institutions for water allocation. Having said this, it is important to recognize the constraints to improving water productivity. These constraints can be classified into those which are physical, technological and infrastructural; institutional and policy-controlled; and, market-related. The policy constraints concern the pricing of water used in canal irrigation and electricity used in well irrigation, whereas the institutional constraint lies in the lack of well-defined water rights for both surface water (Kumar and Singh 2001) and groundwater (Kumar 2005). Both these factors leave minimum incentives for farmers to invest in measures for improving crop water productivity as such measures do not lead to an improved income in most situations (Kumar et al. 2008c).

The electricity used for groundwater pumping needs to be metered and charged on a pro rata basis in regions where well irrigation is intensive for the energy costs to reflect the actual consumption. Gujarat has already started doing this, wherein nearly 40 % of the agricultural connections are metered. The introduction of pro rata pricing of electricity in the farm sector, and volumetric pricing of canal water for irrigation, are the most important fiscal measures for improving water productivity in agriculture. By doing this, the farmers would be confronted with a marginal cost of using electricity/groundwater and canal water for irrigation. Introduction of pro rata pricing would also encourage well irrigators to adopt MI systems, which can serve as medium-term measures.

Enforcement of water rights is the most important institutional reform needed in the groundwater sector (Kumar 2007; Saleth 1997), but, this would be rather a long-term measure, as allocating water rights for individual users, and enforcing the same would be an arduous task (Kumar 2000; Kumar 2007). Also, there are practical issues in enforcing water rights as rights can be often ‘correlative’, especially in hard-rock environments (Saleth 1997). But, to begin with, the latest technological advancements in energy use metering through the use of mobile phone and internet technology can be used to monitor or restrict the use of electricity by farmers on the basis of various socioeconomic or hydrological considerations, with minimum transaction costs (Zekri 2008).

Short-term Institutional and Policy Measures

Targeted Subsidies for MI Systems: Today, subsidies for MI are available everywhere, without any due consideration to the social costs and benefits. Subsidies are generally provided when they are positive externalities associated with the use of a product. In the case of MI systems, the positive externalities are induced water saving. The extent of real water saving that is possible with MI systems is a function of the soil, climate, geo-hydrology and type of technology used. Subsidies should be made available only in regions where the positive externalities induced by the use of MI systems on society are likely to be high. This would help scale up the adoption of the technology in the areas where it creates maximum benefits.

Provision of Subsidies for Intermediate Storage Systems: In canal command areas, the better the yield that farmers can get with improved control over irrigation water, itself, could justify the investments needed for intermediate storage systems like the ‘diggies’ in Rajasthan (Amarasinghe et al. 2008). But, provision of subsidies would create an additional incentive for them to adopt MI systems, and shift to crops that have high water productivity.

Improving the Processing and Marketing Infrastructure for Agricultural Produce: To avert the risk of a price crash in the market and for value addition, adequate processing and marketing infrastructure for the perishable agricultural commodities is important. Only this can ensure that a large number of farmers from one region stick to producing highly water-efficient fruits and vegetables that involve high production and market risks.

Improvement in Farm Power: It is well established now that the returns from well irrigation are more elastic to the quality of power supply than its cost. Improved quality of power supply would not only help farmers to secure higher returns from farming owing to greater control over irrigation, but also allow them to use water-efficient irrigation systems such as the MI.

Improvement in Electricity Infrastructure in Rural Areas: In many rural areas of eastern India, power supply infrastructure is in bad shape. Securing a power supply connection is extremely difficult. As a result, the electric well owning farmers charge ‘monopoloid prices’ for water from the small and marginal farmers. The high cost of irrigation water prevents the water buyer farmers from investing adequately for irrigation and optimal use of other inputs. The result is that they obtain poor yields. Improved electricity infrastructure would reduce the monopoloid prices' for water, thereby giving more flexibility to the farmers in investing adequately for other inputs.

Concluding Remarks

To conclude, water productivity enhancement in agriculture is not only relevant, but also very crucial in meeting future water demands for agriculture and other sectors. There are several constraints in enhancing water productivity in agriculture. But, there are several opportunities too. The constraints can be reduced and opportunities enhanced through appropriate institutional and policy interventions. It is time that India's water policymakers shed the myopic view and start thinking about these policy issues more seriously considering the larger economic and social benefits of policy reforms. As Kumar (2007) notes, one such view is that raising power tariff would adversely affect the economic prospects of farming. In that context, understanding the latest technological advancements in monitoring and metering electricity consumption is very important. The pre-conceived notion that electricity metering in rural areas involves huge transaction cost has to be replaced by an informed understanding. Also important are the new concepts in water management such as water and energy productivity and their various determinants.

Water productivity improvement would definitely reduce the need for future investments in new water resource development projects in some regions. But, the extent of reduction in demand for additional water for meeting future needs will not be the same as the scale of enhancement in water productivity achieved. On the contrary, it might result in more water being available for environmental uses or other sectors in some regions. The other outcomes of water productivity improvement will be in terms of reduced poverty due to a rise in farm income in the agriculturally backward regions; reduced environmental stresses caused by excessive pumping of groundwater or diversion of water from streams/rivers; better availability of water from basins for allocation to environmental uses; and freeing up of a large amount of cultivated land under rain-fed production resulting in increased stream flow generation from catchments. This is what makes water productivity improvement in agriculture an extremely attractive proposition for a developing economy like India.

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