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Technology Options to Enhance Crop Water Productivity: An Overview

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Abstract : In view of current water scarcity due to over-mining of groundwater in Punjab, it is imperative to enhance crop water productivity (economic yield per unit of water consumed as evapo-transpiration, ET). It calls for adopting measures that reduce percolation and soil water evaporation components of root-zone water balance. A critical appraisal of technology options show that most of the resource conserving technologies like land levelling, bed planting, zero-tillage and improved irrigation method and timing cause irrigation (apparent water) and energy saving, but they have little effect on ET. A part of irrigation saving is translated to ET (real water) saving through diversification to short-duration crops and varieties, shift of planting time to periods of low evaporative demand and straw mulching during hot periods of crop growth. It is the ET saving component that affects groundwater levels.

Keywords: Evapotranspiration, Groundwater use, percolation, water productivity, water saving

INTRODUCTION

Punjab has registered an impressive agricultural growth in the last 50 years. The food grain production enhanced from 3.2 million ton (m t) in 1960-61 to over 27 m t in 2008-09 that helped to ensure food security of the nation. This has been possible primarily due to large-scale adoption of high yielding crops / cultivars, along with assured irrigation, and high fertilizer use supported by remunerative marketing. These developments, however, have been accompanied by negative impact on water resources of the state indicated by alarming depletion of groundwater. This paper provides an overview of current water scenario in the state and technology options to enhance crop water productivity with the objective of reducing groundwater use.

WATER SCENARIO

Water scenario of a region can be viewed in terms of supply of and demand for water. The major sources of water supply comprise rainfall, surface water from canal network, and groundwater. These sources are inter-linked. Based on a comprehensive study, it has been estimated that annual good quality water supply is 3.13 million hectare-metre (m ha-m) comprising 1.45 m ha-m of surface water at canal outlets and 1.68 m ha-m of replenishable groundwater in the state (Prihar *et al.*, 1993). Based on the 2001 population statistics, per capita annual water supply (availability) is between 1250- 1300 m^3 indicating that the state is heading towards water scarcity limit of 1000 m^3. Water demand comprises evapo-transpiration (ET) from vegetated and forested lands and civic and industrial use. Annual water demand for agricultural (based on crop ET, Table 1) and non-agricultural (civic and industrial) activities enhanced from 2.76 m ha-m in 1970 to 4.76 m ha-m in 2008 (Minhas *et al.*, 2010). This increased water demand has largely been met by over-drafting of groundwater (from 0.21 m ha-m in 1969 to 2.9 m ha-m in 2008) that resulted in declining water tables.

The water table data for the year 2007 from the Directorate of Water Resources and Environment, Chandigarh, showed that out of 142 blocks in the state, 107 blocks were over-exploited (withdrawal > 100 %) more so in central region dominated by rice-wheat cultivation. Only 26 blocks were safe (withdrawal < 70 %) that were located either in foot-hill region (having deep groundwater) or in southwest region (having poor quality groundwater). A report by Punjab State Farmers Commission (Singh, 2006) showed that cumulative fall in groundwater in central Punjab in 33 years period (1973-2006) averaged more than 9 metre (m). The rate of fall in water table was 0.09 m y^{-1} during 1974-85, 0.20 m y^{-1} during 1986-97, and 0.65 m y^{-1} during 1998-05. Time-series analysis of changes in water table depth during the period from 1990-2005 (Singh, 2009) is quite interesting (Figure 1). Though there is a general decline in annual water table during these years, but water table changes for the two cropping seasons, i.e. June to October (mainly rice), and October to June next (mainly wheat) are generally opposite. The water table data shows a usual rise (0.80± 0.56 m) after rice and a fall (1.24± 0.25 m) after wheat.

Table1. Seasonal ET of principal field crops in Punjab

Crop	ET, mm
Rice*	600
Maize	480
Pulses	450
Cotton	600
Wheat	380
Chickpea	320
Raya	280
Sugarcane	1350
Sunflower	550

*rice transplanted June 15
Source: Minhas *et al.*, (2010)

The water table decline has serious economic and ecological implications. Not only, the shallow centrifugal pumps are being replaced with submersible pumps, but also energy (power) required to pump water from lower aquifers has increased substantially. Another effect of falling water tables is deterioration of groundwater quality due to reverse flow of groundwater from contiguous poor-quality aquifers.

TECHNOLOGY INTERVENTIONS

In order to address the problem of declining groundwater in the central region, there is a need to reduce groundwater use by applying interventions that enhance crop water productivity. These interventions include diversifying from rice to low ET crops, optimizing planting time, proper scheduling and methods of irrigation, and emerging resource conservation technologies like use of crop residues with judicious tillage. Proper use of poor quality groundwater either in conjunction with good quality surface water or with amendments (gypsum or organics) also needs to be promoted in south-west region.

Crop / varietal diversification

Large-scale cropping of high ET rice-wheat has been a major factor in over-use of groundwater. Therefore, there is a need to replace this system

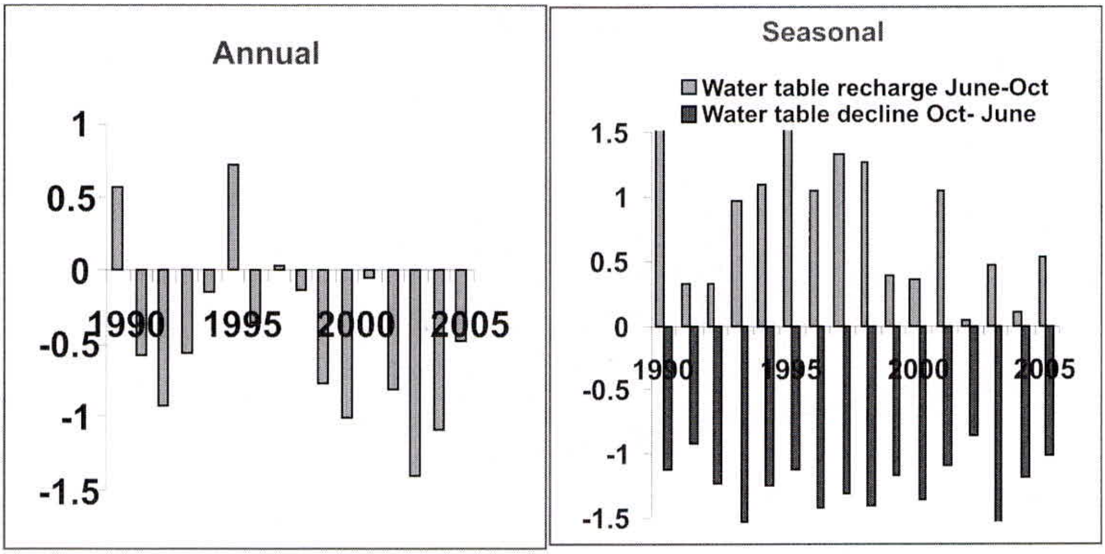

Figure1. Annual and seasonal water table rise / fall (m) during 1990-2005 (Source: Minhas et al., 2010)

with low ET crops. In the *kharif,* rice may be replaced with basmati, maize and pulses; while in the *rabi,* wheat may be replaced with raya and gram. Sugarcane has greater ET than rice-wheat together (Table 1) and would be a poor diversification option. Similarly, sunflower would be a poor replacement for wheat. Cultivation of short-duration and hybrid- rice varieties has a potential in water saving as short- and medium-duration varieties use 15-20 % less water than long-duration varieties like PR-118 and Pusa 44. In addition, pricing and marketing of alternative options have a role in crop diversification.

Optimizing (trans) planting time

Another practice is shifting planting time of crops to coincide their growing cycle with period of low atmospheric demand to reduce unproductive E component of ET. Time-trends of the deficits between rainfall and pan evaporation in Punjab indicate that crops growing during hot and dry months of April to June will have greater irrigation needs due to high evaporative demand and little rainfall. This concept has implications for increasing water productivity in rice and spring sunflower. Field and simulation studies have demonstrated that shifting transplanting of rice from the month of May to beyond mid- June caused a substantial saving in ET and irrigation with little reduction in crop yields (Table 2) (Arora, 2006; Jalota *et al.*, 2009). In this regard, introduction of a regulation by the state Government- Preservation of sub-soil water Act- in 2009 is a step in right direction. The December-planted sunflower gave greater yield than January- or February- planted crop, and required 100 – 230 mm less water (Sekhon *et al.*, 2001).

Enhancing irrigation efficiency

Irrigation efficiency can be enhanced at different spatial scales. The conveyance losses due to seepage in the canal network from water heads until the fields can be reduced by lining water courses and channels. At a field scale, proper land levelling, optimum plot size, and improved irrigation scheduling and methods are quite helpful. Sidhu *et al.*, (2007) observed that laser levelling of land saved 25-30 % irrigation water by improved application. This practice also helped in increasing crop yields by improving the efficiency of applied fertilizers and pesticides. Check basin is the most practiced method of irrigation. Based upon soil texture, slope and stream size, the basin sizes and cut-off ratios have been standardized. Plot sizes of 250 m^2 in coarse-textured and 500 m^2 in medium to fine textured soils has been found to be optimal for wheat (Singh *et al.*, 2008). Furrow irrigation in wide row crops like cotton saved 100-150 mm of irrigation water without any adverse effect on cotton yield (Aujla *et al.*, 1991). Micro-irrigation systems, like drip and mini-sprinkler, have a potential in irrigation saving in high value vegetable and horticultural crops as water application is targeted to root-zone (Saini and Singh, 2006).

Improved irrigation timing implies that water should be applied before any yield- or quality-reducing water stress builds. Irrigations scheduled to wheat based on the ratio of fixed depth of irrigation water (IW) to cumulative pan evaporation since previous irrigation (PAN-E minus rainfall) saved 2 irrigations compared to 5-6 irrigations at fixed growth stages without a significant loss in yield (Table 3)(Prihar *et al.*, 1976). It is a deficit- irrigation approach that promotes use of profile-stored water by inducing deeper rooting. This concept has been used in irrigation timing to different crops. In rice, it has been shown that higher yield can be maintained by irrigating at 2 d- interval after soaking-in of previous irrigation following 2 weeks of ponding after transplanting (Table 4) (Sandhu *et al.*, 1980). Kukal *et al.* (2005) observed that irrigating rice based on soil water tension of 1600 + 200 mm used less water without any yield loss.

Straw mulching

Use of surplus crop residues as mulching during summer conserves water by decreasing soil water evaporation, reduces soil temperature and controls weeds. A review on straw mulching benefits documents enhancement of yield in field and vegetable crops like sugarcane, maize, soybean, sunflower, potato and tomato (Jalota *et al.*, 2007) and an irrigation saving in 70- 300 mm water by reducing soil water evaporation (E) component of ET (Table 5) (Jalota and Arora, 2002). Straw mulching is more economical under low rainfall / irrigation regimes.

Judicious tillage

In rice-wheat culture, the two component crops have contrasting edaphic requirements. Rice is transplanted in puddled soil that is kept submerged for a part of the growing season, while wheat flourishes in well drained upland conditions. Puddling coarse-textured soils in rice reduces percolation loss. Studies have shown that puddling of a sandy loam soil twice reduced percolation by 50 % of that in un-puddled soil (Singh *et al.*, 2001) without any yield loss, and increased water productivity. This practice of repeated puddling may induce the development of a plough pan at 0.15-0.20 m depth. Deep tillage of sandy soils and soils having plough pans with a chisel (0.30-0.40 m deep) improved yield in maize, wheat, mustard and sunflower through better rooting that help in greater mining of stored water (Table 6) (Gajri *et al.*, 2002). Tillage gains are more on coarse-textured soils and under low rainfall / irrigation regimes.

Resource conservation technologies

Emerging resource conservation technologies (RCT's) like zero-tillage (with or without crop residues), bed planting of crops and direct-seeded rice (DSR) have a scope in irrigation saving and reducing energy needs. Zero-till wheat after rice is the most adopted RCT in Indo-gangetic plains. In a review (Erenstein and Laxmi, 2008), it has been documented that zero-till wheat (primarily in the absence of residues) after rice generates benefit through a combination of yield effect (5-7 % gain due to more timely planting) and a cost-saving effect (tillage saving). This practice saves irrigation due to faster flow across non-tilled fields. Recent developments of planting zero-till wheat with surface retention of residues (with machine like Happy seeder) has additional gain of reducing soil water evaporation by 30 % during the growing season through mulching effects.

Bed planting helps in irrigation saving by reducing wetted area compared to flat sown crops. It is gaining popularity in vegetable crops. Studies have shown that planting potato on both sides of narrow beds (0.55 m wide) increased tuber yield and saved irrigation compared to ridge planting (Sidhu *et al.*, 2005). This practice is also successful in overcoming aeration stress in crops like wheat and soybean, more so in low permeability soils. The DSR has a potential in saving irrigation by avoiding puddling, transplanting and ponding of water in rice culture. There may be some yield loss, but water productivity is likely to be more in DSR. In a recent study, although the yield of DSR was less than that of transplanted crop by 1.3 t ha^{-1}, but it led to 15 % greater water productivity due to reduced less ET (Table 7) (Choudhury *et al.*, 2007).

Managing poor quality groundwater

In south-west region, poor quality groundwater can be used in conjunction with good quality surface waters. Bajwa and Josan (1989) observed that alternate irrigations with canal and sodic waters to a rice-wheat system continuously gave the same yield as irrigation with canal water alone (Table 8). The groundwater with high sodicity needs to be supplemented with amendments. In a long-term study, Choudhary *et al.* (2004) observed that use of farmyard manure and gypsum with sodic waters in sugarcane yielded close to that with good quality surface water (Table 9).

SUMMING-UP

It is summed up that field-scale technologies reduce groundwater use resulting in irrigation and energy saving. Most of the resource conserving technologies like laser land leveling, bed / ridge planting and improved irrigation scheduling, cause irrigation saving by improved application efficiency that reduces percolation component with little effect on ET. For example, irrigation timing to rice using tensiometer caused an irrigation saving of 30% compared to 2-d interval scheduling, but with no saving in ET (Jalota *et al.*, 2009). A part of irrigation saving may be translated to ET saving with interventions like diversification to shorter duration crops / cultivars, shift in planting time and straw mulching in crops. For example, a shift in transplanting time of rice from May 15 to June 15 caused an ET saving of 100-140 mm (Minhas *et al.*, 2010). This distinction of irrigation saving is helpful as only ET saving component influences groundwater levels (Humphreys *et al.*, 2010; Prihar *et al.*, 2010).

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