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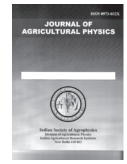

Review Article

Field Water Saving as Influenced by Crops and Management Interventions – A Review

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ABSTRACT

Water in agriculture is saved by reducing irrigation water applied to the crops and/or used by the plants as evapotranspiration (ET) by a number of water saving technologies. A review of the literature and its critical analysis reveals that though irrigation water saving management interventions save irrigation water yet there is some reduction in the yield. The yield reduction with the saving of one cm irrigation water is 26, 37, 52, 9, and 25 kg ha^{-1} in rice, wheat, maize, cotton, and chickpea crops, respectively. Likewise in corresponding crops saving of one cm of ET reduces yield by 55, 97, 188, 31, and 71 kg ha^{-1}. There is no reduction in the yield in case the irrigation water saving interventions are concomitant with mulching, tillage, and application of additional nitrogen. It warrants that while assessing the water saving by any water saving technology due consideration should be given to yield reduction and ensuing profit or loss which has been overlooked so far. In this study, the ratio of fiscal gain calculated from irrigation water saved to loss through yield reduction is higher in rice (2.0) followed by maize (1.2), chickpea (1.0), cotton (0.9), and wheat (0.5).

Key words: Management interventions, Irrigation water saving, Evapotranspiration saving, Yield loss, Fiscal profitability

Introduction

For understanding water saving, the knowledge of sources and sinks as well as recycle of water is a prerequisite. In agriculture, the water received from sources (precipitation or groundwater withdrawal) is used to irrigate crops. A part of that is used by the crop to meet evapotranspiration (ET) demand and is lost as transpiration (T) from plants and evaporation from soil (E) to the atmosphere a sink, from where it cannot be reused. The remaining part drains to surface and subsurface storages and other sinks such as aquifers, inland seas, and oceans which maybe sink or source depending upon the condition of the water. If water gets deteriorated and is of poor quality then water storage in the subsurface will act as a sink, and if that is of good quality and is fit for reuse, it is a source. So any reduction in water that leads to those sinks from where it cannot be reused is called water saving. With groundwater becoming a major source of irrigation supporting 63% of irrigated areas and with 90% of groundwater withdrawal being used for irrigation, the over-exploitation of aquifers is becoming a serious risk in India (Sikka, 2021). In Punjab state rice wheat is a major cropping system, and about 90% of irrigation water requirement is constituted by the groundwater which has resulted in over-exploitation of aquifers in 117 blocks out of 153 (CGWB, 2022) and a speedy water table decline To sustain this cropping system and arrest water table decline (0.49 m in the year) it is imperative to understand thoroughly the purpose of water saving and role of different water saving techniques.

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In agriculture water is saved for two purposes (i) decreasing groundwater draft and (ii) preventing /ameliorating water table decline. Groundwater draft is decreased by applying less irrigation as a result of reducing water conveyance losses, proper application at the surface, and distribution in the soil profile by the management interventions such as laser leveling, optimum plot size, appropriate method and scheduling of irrigation, etc. The reduction of irrigation water via decreasing groundwater draft is called dry or apparent water saving (Seckler, 1996; Zwart and Bastiaanssen, 2004) as it may be recycled within the basin (unless it is polluted). In reality, the reduction of irrigation water is not water saving, however, it lowers the cost of production of crops, saves energy, and reduces carbon emission. It is estimated that pumping that causes one meter fall in water level contributes19 kg carbon ha^{-1} emission (Kaur *et al*., 2016). Reduction in evapotranspiration (ET) through crop diversification i.e. replacing high ET crops with relatively low, synchronizing crop period with lower evaporative demand by shifting planting time, adopting shorter duration variety, adopting micro/subsurface irrigation, and using crop residue as mulch results in as real water saving, which ameliorates water table decline (Jalota *et al*., 2018).

Methodology

Based on the research work pertaining to field water saving at Punjab Agricultural University and elsewhere, the effects of different factors and management interventions on water saving in different crops were analyzed. From its critical review, it becomes apparent that irrigation water and ET savings cause yield decline, which vary with the factors like crops, cultivars, soil texture, climate change, as well as management practices such as date trans /planting, irrigation scheduling, crop residue mulching, and crop establishment method. In this study irrigation water and ET savings were analyzed in conjunction with the yield reduction as affected by these factors and managements. Fiscal gain from irrigation water saving and loss from yield reduction was computed. The fiscal gain is the saving of energy and subsequently its cost corresponding to the irrigation water saved. The energy to lift was worked out using Equation 1.

$$E = \frac{mgh}{Time_{cf} \times Pumping_{efficiency}} \quad (1)$$

Where E is the energy required in kWh, m is the mass of water in kg, g is the acceleration due to gravity in Newton (9.8 m s^{-2}), h is the height of water lifting in m, $Time_{cf}$ is the time conversion factor (3.6 × 10^2). Pumping efficiency was taken as 50%. In equation 1, to convert 1 mm water to mass in kg per hectare a factor of 10 is also put in. The fiscal gain was calculated as the cost of irrigation water saved using the prevailing charges of electricity (i.e. Rs 5.0/kWh for the first 100 units, Rs 6.6/kWh for 100 500 units, and Rs 7.2/kWh above 500 units). The loss was calculated as the cost of yield reduction using the minimum support price of the crop (MSP).

Techniques for saving irrigation water

Irrigation water

Before reaching the water to crops for use in the field from distributaries or tube-wells, it has to follow different courses of action i.e. conveyance (carrying of irrigation water from the source (distributaries and tubewells) to point of application (cropped area), distribution (passing on of irrigation water on the soil surface and in the profile during its application in the plot and use by plants. The Water use is water (from irrigation + rain + capillary rise) used/ consumed by the plant (or cropped area) as evapotranspiration. Since the water for irrigation is scarce and the generation of new water supplies is less, therefore, in agriculture emphasis should be laid on saving irrigation water (whatsoever available), and using it ably by increasing its efficiency at each course of action so that the cost of production is reduced. Irrigation water is saved/or conserved by reducing water losses at different courses of action as follows:

Reducing conveyance loss

The average water conveyance losses from unlined canals, branches and distributaries, and water courses are 8, 17, and 20 percent respectively of the water released from the reservoir (Singh, 1978). During conveyance, it is lost through seepage from the main canal, branches, distributaries, minors, water courses, and field channels. Water from distributaries or tube wells is generally conveyed in main and farm channels to the fields through open earthen channels. Though open earthen channels are made depending upon the infiltration ability of soil controlled by texture in such a way that flow velocity is not erosive (or is within permissible limits) (Table 1) yet a huge amount of water (20-40%) is lost on its way through evaporation and seepage processes from the point of source to the point of its use.

Table 1. Recommended side slope (horizontal to vertical) and permissible flow velocity of the earthen channel as influenced by texture

Soil texture	Side slope	Permissible velocity, m sec^{-1}
Clay	1:1	1.00
Silt loam and loam	1.5:1	0.75
Sandy loam	2:1	0.60
Loamy sand and sand	3:1	0.45
Very coarse sand	4:1	–

Source: Katyal and Verma (1976)

Such channels (open earthen) are vulnerable to erosion, breaches, damage by rodents, and weed infestation as well as high evaporative demand. Water lost by seepage is not only wasted, as not used by the crop but also causes water logging and soil salinization. To reduce seepage losses opened channels are lined with concrete and bricks and stones or other sources like polyethylene, clay, bitumen etc. These lined open channels are less vulnerable to erosion, breaches, damage by rodents, and weed infestation. By lining the canal network, the water is saved by reducing seepage loss to the tune of 10-15% (Gulati and Narda, 1981). Similarly, the losses to the extent of 8, 28, and 15 percent can be reduced at distributaries, channel, and field channel levels through their lining (*pucca channel*) or shifting to an underground conveyance system. Lining may reduce 80-85% seeof page losses (Malhotra, 1980). The conveyance losses can be further reduced by using an underground pipeline water system. The underground pipeline water distribution system is a unique water conveying system at different points in the farm and it frees 2 4% area which earlier covered underwater channels (Michael, 1978). The freed area can be used for growing crops, thus expecting to have better land productivity too with underground pipelines. In most of irrigation projects, 60–70% of irrigation water is lost during conveyance and application. Such losses of water though can be saved by using an underground pipeline system, however, it is not adopted by farmers due to ignorance, unawareness, and unwillingness to divert from old open channels (where the water is actually seen) and the complex operation of earthing up while fitting pipes in the field as well as the selection of the most appropriate diameter of underground pipeline. However, the governments are popularizing it by providing subsidies.

Reducing application losses

Irrigation water can also be saved by selecting the proper method for its application in the field. The best method is that which fulfills the objectives of (i) water is distributed uniformly over the field as per crop needs (ii) maximum water is stored in the root zone for plant use (iii) soil transport or loss is negligible (iv) crop growth is favorably affected (v) technique used is economically sound and adaptable at the farm. Generally, irrigation water in the fields is applied by different methods i.e. border, furrow, drip, and, sprinkler. The irrigation water can be saved by the following methods i.e.

a) Selecting the proper plot size or number of strips in the unit area in relation to soil type, field slopes, and stream size as given in Table 2.

b) Replacing border irrigation with furrow methods of irrigation in wide-row crops like cotton, sunflower, and maize. In cotton compared to flooding, irrigation to each furrow, alternate furrow and pair crop row saved irrigation water (Aujla *et al*., 1991). The saving of irrigation water was 103 mm in the furrow, 171 mm in the alternate furrow, and 160 mm in pair row crop methods. The corresponding yield increased by 200 kg ha^{-1} (each furrow), decreased by 600 kg ha^{-1} (alternate furrow), and increased by 500 kg ha^{-1} (a pair crop row).

c) Using pressurized irrigation systems (drip and sprinkler) in crops, orchards, and vegetables where small and frequent irrigations are to be

Table 2. Recommended plot sizes under different soil types, slopes, and discharge in one acre length

Soil type	Average slope (%)	Number of border strips (Kiara) per acre		
		Tube-well delivery size		Mogha discharge
		3″- 4″ (7.5 10 lps*)	6″ (20 lps)	(30 lps)
Light	0.3	16	10	7
Medium	0.4	10	5	4
Heavy	0.15	8	4	3

*lps – litres per second

Source: Package of Practices for Crops of Punjab - Rabi 2021-22, PAU, Ludhiana

applied. Drip, sprinkler, and subsurface irrigation methods, also known as micro irrigation techniques, save irrigation water as less amount of water is applied. The drip system saves water by targeting water application to the root zone only rather than the entire field and by reducing both unproductive water losses from soil like evaporation (E) and deep drainage (D). It also saves total irrigation water requirements by cutting conveyance losses up to 50% as it uses less space at the surface. In wheat crop, drip irrigation compared to the conventional method saved 170 mm of irrigation water, but the yield was decreased by 262 kg ha^{-1} (Dar *et al*., 2017). In the cotton saving of irrigation water by drip compared to conventional was 100 mm and yield increase of 1710 kg ha^{-1}; compared to furrow irrigation water saved was 400 mm with a yield increase of 390 kg ha^{-1}, however in furrow sprinkler, irrigation water saved was 217 mm, but the yield was less by 767 kg ha^{-1} (Radin *et al*., 1992). In Sugarcane drip saved 395 mm of irrigation water and increased yield by 205 kg ha^{-1} (Singh *et al*., 2015). In potatoes, drip irrigation saved 41 mm of irrigation water and increased yield by 7900 kg ha^{-1} (Brar *et al*., 2019); saved irrigation water by 115 mm and increased yield by 2330 kg ha^{-1} (Ati *et al*., 2012); saved 172 mm irrigation water and increased 2880 kg ha^{-1} yield (Jha *et al*., 2017). The overall water savings with drip systems ranged between 50 70% in the majority of fruits and vegetables compared with surface irrigation systems (Saini and Singh, 2006). The drip irrigation system not only saves water, but improves irrigation water productivity too by (i) improving the nutrient use efficiency as it provides fertilizer to the water through a network of valves, pipes, tubing, and emitters (ii) cutting off the spreading of diseases from one plant to another mainly in orchards. However, the common obstacle to shifting from traditional basin to localized drip irrigation system is the investment cost of farm equipment which is not affordable by small and marginal farmers. Though the government has introduced subsidies to the extent of 75%, still the drip system does not seem affordable for low/medium value crops. The drip system has the main drawback that very small water holes drip often clog and needs a good filtration system. Sprinkler irrigation system irrigates the field crops by sprinkling the water at a rate lesser than the infiltration rate of the soil for having maximum water as well as nutrient use efficiency. The effectiveness of a sprinkler irrigation system depends on several factors like soil texture, environmental factors, measured plant height, stem size of plants, and weight of plants, etc. Sprinklers save irrigation by reducing drainage losses. Compared to furrow irrigation sprinklers in cotton saved 217 mm irrigation water, but reduced yield (lint+seed) by 767 kg ha^{-1} (Cetin and Bilgel, 2002). Amongst the drip and sprinkler irrigation methods, the drip irrigation system could provide better performance than the sprinkler irrigation system (Keeratiurai, 2013) as (i) it provides higher land productivity for the same planting areas and quantity of water (ii) plants received regularly water on specific site i.e., at roots (iii) it can cover a variety of plants and soil in all areas. Automation based on soil moisture sensor irrigation scheduling in drip irrigation systems has significantly improved irrigation efficiency (Sidhu *et al*., 2021). An automated irrigation system helped to save water by up to 90% compared to the traditional method (Gutiérrez *et al.,* 2013; Pramanik *et al.,* 2022).

d) *Laser leveling:* On uneven topography of land more irrigation water is required as the movement of the water at the soil surface is slow and water is distributed non-uniformly. Under such conditions, laser leveler levels all the dukes and dikes cause uniform distribution of irrigation water on a large area within a shorter period of time, and avoids the plants to suffer from both excess and limited supply of irrigation water. Laser leveling saves irrigation water to the tune of 76 mm (21%) in wheat (Kahlown *et al*., 2006); 50 100 mm (17 30%) in wheat, and 100 150 mm (5 8%) in rice (Jat *et al*., 2006) which is due to increased water application efficiency and reduced deep drainage. Saving irrigation water in crops by laser leveling also increases crop yield. Such irrigation water saving and increase in yield are more if a total cropping system is taken. For instance, rice laser leveling compared to conventional tillage saved 240 mm irrigation water and increased yield by 740 kg ha^{-1} (Jat *et al*., 2009); in wheat irrigation water saved was 35 mm and increased yield by 695 kg ha^{-1}; in rice-wheat system irrigation water saved was 280 mm and increased yield by 730 kg ha^{-1} (Jat *et al*., 2009). In another study water conserved was 1098 mm but, there was a reduction in yield by 400 kg ha^{-1} (Jat *et al*., 2011). Water saving by laser leveling is also influenced by site conditions, irrigation system design, and water management practices. In canal irrigated areas, it is useful to reduce the rate of water table rise and thus the amount of water logging and secondary salinization. Also, the water saved by reduced irrigation requirements will make more canal water available for other uses. However, laser leveling is of no use to reduce water depletion and groundwater decline where groundwater is used for irrigation. The amount of irrigation water saving is controlled by the laser index (mean deviation between desired elevation to actual elevation) (Tyagi, 1984) which is influenced by soil type, depth to the water table, and duration of irrigation, depending on irrigation flow rates in relation to field size. Precision laser land leveling compared to conventional tillage not only saves irrigation water but saves power (electricity) too by lessening the time of pumping to irrigate the field especially when irrigation groundwater is to be applied. It also improves crop stand and yield, saves costly inputs like fertilizers, and reduces labor costs. In addition to large reductions in irrigation amount and higher yields, laser leveling has many other benefits including an increase in the cultivable area and greater efficiency of machinery operations and inputs (due to reduced overlap of machinery passes and reduced "misses") (Jat *et al*., 2006), but it cannot be denied that a lot of energy is required by laser leveler to level the field.

Proper irrigation scheduling

Irrigation scheduling to crops is usually aimed at eliminating over or under-irrigation and ensuring optimum yields with high water productivity. Under ample water supplies, irrigation is applied before the build-up of yield or quality reducing water stress. Different schedules are used to reduce irrigation water input in different crops. For instance, in puddle transplanted rice (PTR) if irrigation is scheduled based 2 days drainage interval compared to continuous flooding irrigation water saving is 1410 mm, and yield reduction is 459 kg ha^{-1} (Singh *et al*., 1996); irrigation water saving is 650 mm and yield reduction is 130 kg ha^{-1} (Sandhu *et al*., 1980). In general, alternate wetting and drying scheduling irrigation is at 2 days interval after soaking-in of previous irrigation saved about one third of irrigation water. Further increasing the irrigation interval to 5 days saved irrigation water 527 mm with a yield reduction of 650 kg ha^{-1} (Brar *et al*., 2015); to 4 or 5 days during the reproductive phase caused additional water saving of 150 200 mm without yield loss (Aujla *et al*., 1984; Uppal *et al*., 1991). Compared to 2 days drainage period irrigation based on soil matric potential of 16 20 kPa using tensiometers saved irrigation water of 460 mm with a yield reduction of 30 kg ha^{-1} (Kukal *et al*., 2005); saved irrigation water of 675 mm with yield reduction of 352 kg ha^{-1} (Jalota *et al*., 2009); saved irrigation water of 770 mm with yield reduction of 130 kg ha^{-1} (Sandhu *et al*., 2012); saved irrigation water of 134 mm with yield reduction of 600 kg ha^{-1} (Vashisht *et al*., 2015). In lieu of PTR, direct seeded rice (DSR) has been advocated in the heavy textured soils where the inherent percolation rate is low and there is no need of puddling operation to cut down percolation. Like PTR, in DSR too scheduling irrigation based on alternate wetting and drying and soil moisture suction (30 kPa) saved 262 mm irrigation with a yield reduction of 1600 kg ha^{-1} than continuous flooding (Sudhir-Yadav *et al*., 2011). Irrigation water saving in DSR with alternate wetting and drying irrigation schedule was 33-53% albeit there were higher reduced seepage and runoff losses under DSR coupled with increased deep drainage under clay loam soils. However, the saving of irrigation water in DSR is one third to one half than in PTR owing to decreased average crop duration in the later (Akhgari and Kaviani, 2011).

For upland crops, a simple concept that takes into account the effects of evaporative demand and rainfall for the timing of irrigation application to crops was put forward in the ’70s (Prihar *et al*., 1974; Cheema and Kaul, 1974). This approach of scheduling irrigation to wheat based on irrigation water (IW) to cumulative open pan evaporation (PAN-E) ratios of 0.90 saved 125 205 mm irrigation water compared to 5 6 irrigations applied at fixed growth stages with yield reduction of 81 203 kg ha^{-1} (Prihar *et al*., 1976; Jalota *et al*., 1985; Vashisht *et al*., 2019). Further reducing four post sowing irrigation water based on IW/Pan-E = 0.90 (300 mm) to one irrigation at crown root initiation (75 mm) saved 225 mm of water with a yield reduction of 217 kg ha^{-1} (Jalota *et al.*, 2006). In maize shifting irrigation schedule from IW/Pan E =1.2 to 0.9 and 0.6 saved 75 and 225 mm irrigation water with yield reduction of 600 and 1370 kg ha^{-1}, respectively (Singh *et al.*, 2015). In soybean partial irrigation (withholding irrigation of 70 mm at pod filling) compared to full irrigation (three irrigations of 70 mm each) saved 140 mm of irrigation water with a yield reduction of 2960 kg ha^{-1} (Arora *et al.*, 2011). After thorough testing, a time table for scheduling irrigation to wheat in relation to sowing time was released for adoption by the farmers. Because of its convenience and easier adoption, this technique has been extended on a large scale in the country to develop water economizing irrigation schedules for other crops. The optimal IW/PAN E ratios are 1.0 for maize and soybean, 0.4 for groundnut and cotton, 0.9 for wheat and barley, 1.0 for sugarcane and winter maize, 1.5 for autumn potato, 2.0 for spring potato, 1.2 for berseem, 0.4 for gram, and 0.4 0.6 for lentil under adequate water supplies (Prihar and Sandhu, 1987). With the ever-increasing scarcity of irrigation water, it is likely that full irrigation would have to be replaced with deficit irrigation targeted to periods that coincide with the sensitive stages of the crop’s life. Thus efforts have also been made to compute crop sensitivity to water stress by relating yield with ET or T. The water-sensitive growth stages for different crops have been defined. As water deficits mainly damage the crops during meiosis of pollen mother-cells or around anthesis, thereby, flowering to grain formation in wheat (Jalota *et al*., 1985; Arora *et al*., 1987; Jalota *et al*., 2006); flowering to boll formation in cotton; pod setting and grain filling in chickpea (Jalota *et al.,* 2006); silking and teselling in maize; pod formation and pod filling in soybean; anthesis to achene filling in sunflower are found to be the most sensitive growth stages.

Crop establishment

Permanent beds are generally recommended to save irrigation water as irrigation is applied to the lesser area (in furrows only) keeping the raised bed un irrigated (Buttar *et al*., 2006; Jat *et al*., 2009; Singh *et al*., 2010; Brar *et al*., 2011). The beds are effective for saving irrigation water at the initial stages only, but year after year the effectiveness is decreased because of decreased movement of water from furrow to beds resulting from the compactness of the side due to natural aging of the beds and during reshaping and sowing of wheat operations (Kukal *et al*., 2008, 2010). Moreover, the surface area of these beds is more (about 25%) which absorbs more radiant energy and increases evaporation losses, and irrigation needs ultimately. So it is not effective in saving irrigation water.

Rice crop is generally established by the methods such as transplanted puddle (TPR), direct seeded rice (DSR), wet seeded, dry seeded, raised beds, and system rice intensification (SRI). Dry and wet seasoned DSR rice saved 1487 and 710 mm irrigation water with yield reduction of 650 and 290 kg ha^{-1} than the TPR (Cabangon *et al*., 2002). Wet seeded, dry seeded, and raised beds rice saved 141, 530, and 732 mm irrigation water with yield reduction of 1090, 1270, and 2000 kg ha^{-1} compared to TPR (Choudhary *et al*., 2007). DSR and SIR saved 352 and 169 mm of irrigation water with a reduction of yield of 1485 and 425 kg ha^{-1}, respectively compared to PTR (Sagar *et al*., 2017). In DSR conventional tilled and bedded rice saved 230 and 440 mm irrigation water with yield reduction of 950 and 2550 kg ha^{-1}, respectively than the PTR (Jat *et al*., 2009). Wheat bed planting saved 68 mm of irrigation water without a reduction in yield (Buttar *et al*., 2006).

Short-duration crop cultivars

Short-duration cultivars require less frequency and total amount of irrigation water as these stay for relatively shorter periods in the field than long duration to complete their life cycle. Irrigation water requirement is decreased all the way through decreasing evapo-/transpiration needs and deep drainage losses. Short duration rice cultivar (RH 257, 90 days from transplanting to harvest) saved 100 mm irrigation water with a yield reduction of 182 kg ha^{-1} compared to long duration (PR 118, 110 days from transplanting to harvest) on loamy sand soil (Jalota *et al*., 2009); saved 90mm irrigation water and yield increase of 300 kg ha^{-1}compared to PAU 201 on sandy loam (Vashisht *et al*., 2015); saved 135 mm irrigation water with yield increase of 1350 kg ha^{-1} (Arora *et al*., 2018). Reports also there showing that RH 257 saved 100, 333, and 40 mm of irrigation water with a yield increase of 167,133 and 300 kg ha^{-1} compared to PR118, PR113, and PR115 (Mahajan *et al*., 2009). Averaged over six years of experimentation, in wheat PBW 550 saved 2 mm of irrigation water and 69 mm of ET with a yield reduction of 239 kg ha^{-1} compared to PBW 343 (Vashisht *et al*., 2019).

Date of Transplanting (DOT)

The date of transplanting in rice is very important for saving irrigation water. Irrigation water requirement is more if it is transplanted during a period of higher evaporative demand accompanied by less rainfall. On the contrary, if rice is transplanted during the period of relatively lower evaporative demand accompanied by rainfall less water is required to sustain yield. The amount of irrigation water saved by shifting the transplanting date varies with variety, soil type, and irrigation schedule. For instance, shifting the transplanting date from May 16 to May 31 and June 16 saved 320 and 590 mm of irrigation water with a yield reduction of 329 and an increase of 532 kg ha^{-1}, respectively on sandy loam soil (Singh *et al*., 1996); from May 20 to July 10 saved 40 mm water with yield reduction of 720 kg ha^{-1} (Gill *et al*., 1990); from June 15 to July 5 in varieties of different durations on medium textured soils water saving was 80 mm with reduction in yield 1900 kg ha^{-1} in PR113 (112 days from transplanting to maturity), 40 mm with reduction in yield 1300 kg ha^{-1} in PR115 (95 days from transplanting to maturity), 60 mm with reduction in yield 1800 kg ha^{-1} in RH 257 (90 days from transplanting to maturity) and 310 mm with reduction in yield 100 kg ha^{-1} in PAU 201 (114 days from transplanting to maturity) (Mahajan *et al*., 2009). Similarly by shifting the transplanting date from 25 May to 25 June on coarser soil water saving was 260 mm in long-duration cultivars (PR118) and 230 mm in short duration (HR 257) of day duration (Jalota *et al*., 2009); from June 5 to July 5 saved 140 mm with the increase in yield 1300 kg ha^{-1} in variety PR118, and saved 114 mm irrigation water with a yield increase of 1800 kg ha^{-1} in HR 257 (Vashisht *et al.*, 2015). Irrigation water requirements were least with 5 July transplanting, the date which resulted in the greatest rainfall interception and relatively low ET during the cropping season. Delaying transplanting to mid-June or later provided more favorable temperatures (reduced heat stress) and reduced risk of rain during flowering (Chahal *et al*., 2007). Later rice planting also widens the window between wheat harvest and rice planting and thus increases the ability to include a third crop, such as a short-duration pulse, in the RW system. Though some yield loss has been reported, ultimately water productivity increased because of greater saving of irrigation water. Keeping this in mind Punjab government implemented the law to go for nursery sowing after 20 May and transplantation of nursery into the field only after 20 June. Any farmers violating this law are punished by disking their sown nursery back into the soil from 2018.

In irrigated wheat recommended optimum sowing date is staggered from mid-October to mid

December depending upon the preceding kharif crop (maize, rice, cotton, etc.). In irrigated wheat compared to October 20, sowing of wheat on November 5 saved 80 mm irrigation water with a yield reduction of 162 kg ha^{-1}; on November 20 saved 80 mm water with a yield reduction of 244 kg ha^{-1} (Vashisht *et al*., 2019). Similarly, the sowing of wheat on November 25 compared to October 25 saved 80 mm of irrigation water with a yield reduction of 700 kg ha^{-1} (Singh *et al*., 2019). In dry land sowing of wheat on November 15 and December 31 compared to November 1 reduced yield by 309 and 466 kg ha^{-1}, respectively (Jalota *et al*., 2010); sowing on November 15 and December 15 compared to October 15 reduced yield by 128 and 224 kg ha^{-1}, respectively (Vashisht *et al*., 2013).

Mulching

Crop residue mulching is a practice of keeping the crop residue of the previous crop on the soil surface. The mulching saves irrigation water by restricting evaporative losses because of a decrease in radiant energy reaching the soil to cause phase change from liquid water to the gaseous phase, a decrease of the vapor pressure difference between soil and ambient air, and finally decrease in vapor lifting capacity of the air (Jalota and Prihar, 1998). Jalota *et al*. (2007) reported that straw mulching saves irrigation in crops, but saving is more in fodder crops or crops that have their life cycle longer under high evaporative demand (Table 3). In non flooded rice mulching @ 5 t ha^{-1} saved 216 mm irrigation water and increased yield by 1977 kg ha^{-1} (Qin *et al*., 2006). Mulching in maize @ 6 t ha^{-1} saved 22 mm ET and increased 536 kg ha^{-1} yield (Kaur and Arora, 2019); increased 261 kg ha^{-1} yield of soybean at the same level of irrigation (Arora *et al*., 2011).

The effect of mulch is modified with the type of tillage. The effect is more in conventional tillage than deep tillage. Recently a technique of sowing of wheat with Happy seeder after the rice has been developed. The seeder allowed the sowing of wheat crop in the standing paddy stubbles, and with this, there is no need to remove the rice stubbles outside the field, and secondly, rice residues act like mulch which decreases the evaporation losses to the tune of 45% (Sidhu *et al*., 2009) and decreases the amount of water used per irrigation by which there is no need for pre-sowing irrigation and ultimately causes around 30% saving in irrigation water (Singh *et al*., 2008).

Table 3. Irrigation water saving and yield augmentation by straw mulching in different crops

Crop	Yield increase (t ha^{-1})	Irrigation water saving (mm)
Maize fodder	7.5	150
Soybean	0.4	–
Sorghum fodder	7.2	230
Mentha	0.7	320
Sugarcane	4.3	400
Potato	3.9	120
Moong	0.1	70
Winter maize	1.0	230
Maize rain–fed	1.1	–
Maize irrigated, Loamy sand	1.9	–
Maize irrigated, Sandy loam	0.4	–
Sunflower, Loamy sand	0.4	–
Sunflower Sandy loam	0.2	–

Source: Jalota *et al*. (2007)

Crop diversification

Replacement of crops having high irrigation/ET requirements with those having low irrigation/ET can help to save water and reduce the withdrawal of groundwater. In Punjab, the large-scale adoption of the rice-wheat system has been a major factor in the over-exploitation of groundwater. In *kharif,* rice may be replaced with maize, pulses, and oilseeds; whereas in *rabi*, wheat may be replaced with raya and chickpea. Diversification of one million hectares of land each under wheat and rice (as suggested by the Johl Committee) would result in substantial savings of irrigation water required and water consumed as ET by the crops. For example, diversification of one million hectare area under rice to pulses (100%) only and pulses (50%) and maize (50%) together would save irrigation water by 1.22 m ha-m, and 1.20 m ha-m (Table 4). The corresponding ET saving is 0.20 m ha- m and 0.165 m ha-m.

Similarly, diversification of 1 m ha of land under wheat with 100% oil seeds only and 50% oil seeds

Table 4. Water savings by diversifying a 1 m ha area each under rice and wheat to alternate crops in Punjab

Options of diversification	Irrigation water saving (m ha-m)	ET saving (m ha-m)
In Rice		
Pulses (100%)	1.22	0.20
Pulses (50%) + Maize (50%)	1.20	0.165
In Wheat		
Oil seeds (100%)	0.12	0.12
Oil seeds (50%) + chickpea (50%)	0.12	0.10
Oil seeds (50%) + Winter maize (50%)	zero	Zero

Table 5. Yield reduction, irrigation water and evapotranspiration saving and profit/loss ratio in different crops

Crop	IW saving (mm)	Yield reduction (kg ha^{-1})	ET saving (mm)	Yield reduction (kg ha^{-1})	MSP (Rs kg^{-1})	Loss due to yield reduction (Rs)	Gain due to IW saving (Rs)	Gain/ loss ratio
Rice	323	824	79	432	18.88	15557	30534	2.0
Wheat	103	380	50	480	19.25	7315	3778	0.5
Maize	134	703	39	725	18.50	13006	15147	1.2
cotton	132	120	51	158	55.15	6618	5931	0.9
Chickpea	105	267	36	257	48.75	13016	13383	1.0

and 50% chickpea together can save irrigation water by 0.12 m ha-m each. The corresponding ET saving is 0.12 m ha- m and 0.10 m ha- m of water. However, diversification with 0.5 m ha with oil seeds and 0.5 m ha with winter maize would result in no saving of irrigation water and ET.

Economic aspect

The economic aspect was worked out as a ratio of monetary gain (due to the cost of irrigation water saved)/monetary loss (due to yield reduction). Averaged over management interventions related to irrigation water saving (such as shifting irrigation regime from higher to lower, trans-/planting date from higher to lower evaporative demand, cultivar from longer duration to shorter) the worked out irrigation water saving is 323 mm in rice, 103 mm in wheat, 134 mm in maize, 120 mm in cotton and 105 mm in chickpea with corresponding reduction in yield as 824 kg ha^{-1} in rice, 380 kg ha^{-1} in wheat, 703 kg ha^{-1} in maize, 132 kg ha^{-1} in cotton and 267 kg ha^{-1} in chickpea (Table 5).

Similarly saving in evapotranspiration is 79 mm in rice, 50 mm in wheat, 39 mm in maize and 51 in cotton, and 36 mm in chickpea and the corresponding reduction in yield is 432, 480, 725, 158, and 257 kg ha^{-1} respectively. By and large, the reduction in yield with saving of one cm of irrigation water is 26, 37, 52, 9 and 25 kg in rice, wheat, maize, cotton and chickpea crops. Likewise with saving of one cm of ET corresponding yield reduction is 55, 97, 188, 31 and 71 kg, respectively. It illustrates that saving of 1 cm of ET results in more yield reduction than equal amount of irrigation water saving. But if the irrigation water saving technologies are concomitant to the interventions like mulching, tillage and application of additional nitrogen or laser leveling there is no yield reduction rather there is increased yield (Jalota *et al*., 2007; Arora *et al*., 2011; Kaur and Arora, 2019) due to congenial soil environment for root growth and more nutrient and water uptake (Li *et al.,* 2008; Ram *et al.,* 2013). In this study the ratio of fiscal profit computed from saving of irrigation water to loss through reduction in yield is higher in rice (2.0) followed by maize (1.2), chickpea (1.0) in cotton (0.9) and wheat (0.5).

Conclusion

With the introduction of high yielding varieties and growing these on large area, the requirement of the irrigation has increased in the past. But at present water resources are scarce and alarming. Consequently water management research has been diverted to sustain the crop yields with lesser amounts of irrigation water and saving it. In this direction a number of water saving management interventions like shifting date of trans-/planting, method and schedule of irrigation, crop establishment method, short duration cultivars, mulching, tillage etc. have been tried for saving of irrigation water and evapotranspiration which show that the magnitude of irrigation water and/or evapotranspiration saved vary with above said management interventions as well as the factors like crop, soil texture and climate change. The present analysis concludes that while advocating irrigation water saving management technology it is important to consider the magnitude of reduction in crop yield too, which has been overlooked so far. Only that management intervention should be recommended which is profitable having higher ratio of fiscal gain by irrigation water saving to fiscal loss by yield reduction.

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