# Resource conservation techniques for mitigating the water scarcity problem in the Punjab, India - a review

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***Abstract:** Water is declining at an alarming rate in the central district of Punjab because of 1.3 Mha-m additional withdrawal of water from the ground and mainly it is used for the rice crop which is not a traditional crop of the region. Puddling, seepage and percolation losses are the main sources of water loss from the rice based cropping systems in the Indo-Gangetic plains (IGPs) and a number of Resource Conservation Technologies (RCTs) has been recommended for water saving but the real water saving techniques are those which hinders the water from going into those sink from where it cannot be reused (Evaporation, E) and divert greater fraction of water of ET toward transpiration, T which is desired as greater transpiration greater the inflow of water and nutrients which ultimately increase the grain yield with the lesser consumption of irrigation water as interval in between two irrigation increased, which further increases the water productivity. This paper focuses on the point that among different RCTs, short duration crop varieties and delaying transplanting time is the real water saving techniques for the regions where water table is already declining down, however other RCTs may be suitable for the regions facing water logging problems as these cut down the drainage losses and these energy saving rather than water saving techniques.*

***Keywords:** Rice, Water saving, RCTs, Puddling, IGPs, Evapotranspiration*

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Rice is one of the most important staple foods for more than half of the world's population (IRRI, 2006) and influences the livelihoods and economies of several billion people. In 2010, approximately 154 million ha were harvested worldwide, of which 137 million ha (88% of the global rice harvested) were in Asia – of which 48 million ha (31% of the global rice harvested) were harvested in Southeast Asia alone (FAOSTAT, 2012). The greatest levels of productivity are found for irrigated rice, which is the most intensified production system, where more than one crop is grown per year and yields are high – 12.5 tonnes/ha/year compared with 2.5 tonnes/ha/year for rainfed rice. In Asia, more than 80% of the developed freshwater resources are used for irrigation purposes; about half of which is used for rice production. The global demand for water in agriculture will increase over time with increasing population, rising incomes, and changes in dietary preferences. Increasing demands for water by industrial and urban users, and water for the environment will intensify competition. At the same time, water scarcity is increasing in several important agricultural areas. India -The largest groundwater user in the world (230 $km^3$ $yr^{-1}$), more than a quarter of the global total water use (Tyagi et al.,2012). NASA's gravity mapping satellite "GRACE" tracks the local gravity filed of an area on the assumption that if we remove much of ground water, there is a loss of mass which further resulted in the decrease of the gravity. Recent reports of the satellite showed that in North India about in an area of 440,000 $km^2$ ground water declined at an alarming rate of 1 ft $year^{-1}$ which further resulted in the loss of 4 cm loss of raw ground water or 18 $km^3$ $year^{-1}$ (Soni, 2012). In Punjab, particularly in the central Punjab, the water table is declining at an alarming rate because of increase in the rice cultivated area from 6% (1960) to 60% (2012). Further it is reported that to produce 1kg of rice we have to give about 4000 lts of water. Because of ensured MRP and government policies, it looks difficult to reduce the are of paddy, though efforts are there. For mitigating the upcoming problem of the water scarcity, a no of RCTS are recommended in the region. But further there is a need to look into them as all of them are not fully suitable for entire Punjab as in the central parts water is declining down whereas in the South-Western areas the water table is high and is of poor quality and farmers have to use canal water for irrigating their cropos. Thus there is a need to look into detail that these RCTs are site specific and work accordingly. Now we discuss these RCTs one by one and then discuss their site specific performance and look into detail that whether all or some RCTs are suitable for mitigating the problem of water scarcity in the central and South-Western Punjab

**A. <u>Role of Laser leveler in water saving:</u>** Flood irrigation is most adopted practice in rice-wheat cropping system in the IGP because of which a significant amount of water lost (10-25%) because of uneven fields (Kahlown et al, 2002) which further results in poor resource use efficiency (Jat et al, 2006a) (Table 1). Frequent dikes and ditches in the fields always results in lower water productivity as uneven fields results in uneven distribution of the irrigation water, thus more water used for producing fixed amounts of grains. According to Jat et al (2006a) laser leveling results in improved crop stand because of uniform distribution of water along with improved crop productivity and lower labour requirement. LL improved the farm income by improving system productivity to 7% and by saving irrigation water upto 14% in rice and upto 13% in wheat (Jat et al, 2009). Thus laser leveller saves a substantial amount of water as it levelled all the ups and downs in the soil surface for the quick movement of irrigation water in the plot which further resulted in the uniform plant growth and higher yields (Pal, 2005) (Table 2). Though it saves the amount of irrigation water, but the thing is that it cut off the drainage water (which is a must for recharging the water table) and that is not required in the central Punjab, where water table is declining down at an alarming rate. Thus laser levelling may be effective in the areas where there is the problem of water logging viz. South-Western Punjab but for the central Punjab, Laser levelling is not “Real water saving technology”.

**Table 1 Effect of land leveling on the yield and water productivity**

| Land leveling | Yield (t ha$^{-1}$) | | |
|---|---|---|---|
| | Rice | Wheat | Rice-Wheat |
| Laser | 6.42 | 4.70 | 11.10 (6.0%) |
| Traditional | 6.15 | 4.32 | 10.47 |
| | Input water productivity (kg grain m$^{-3}$ water) | | |
| Laser | 0.30 | 1.13 | 0.43 (16.2%) |
| Traditional | 0.25 | 0.95 | 0.37 |

(Jat *et al.*, 2009)

**Table 2 Effect of land leveling on grain yield and water productivity of rice**

| Treatments | Grain yield (kg ha$^{-1}$) | Total water use (m$^3$ ha$^{-1}$) | Water productivity (kg m$^{-3}$) |
|---|---|---|---|
| Laser Leveled+ NPK | 6300 | 6916 | 0.91 *(68.5%)* |
| Traditionally Leveled + NPK | 4950 | 9130 | 0.54 *(22.7%)* |
| Traditional Leveled + no-NPK | 3940 | 9120 | 0.44 |

(Pal., 2005)

**B. <u>Role of Direct seeded rice (DSR) in water saving</u>:** As reported by many scientists that puddling deteiorates the soil structure by churning the soil into individual particles and finally results into the foirmataion of the "*Plough Pan*" which further creates the problem for the succeeding wheat crop by causing proper aeration problem (Kukal and Aggarwal, 2003a). Ways must be found to decrease water use in rice production. Irrigated rice in Asia is typically transplanted into puddled paddy fields. Land preparation consists of soaking followed by plowing and harrowing of saturated soil. After crop establishment, the fields are kept submerged with 5 cm—10 cm of water. Because of the water used for wet land preparation and the large losses by seepage, percolation, and evaporation when the soil is submerged, the production of lowland rice requires much water. Amoung DSR, Dry seeding is probably the oldest method of crop establishment and resulted in higher yields (Gangwar et al, 2008; Chaudhary et al, 2007) (Table 3 & 4). Historical accounts of rice cultivation in Asia indicate that during its early period of domestication, rice used to be dry sown in a mixture with other crops that were established under the shifting cultivation system (Grigg 1974). Studies in Indo-Gangetic Plains (IGP) have shown that the performance of DSR can vary from location to location within a country. For example, in the north-western IGP, there is a tendency of a yield penalty with DSR (Gathala *et al* 2011, Jat *et al* 2009). A possible reason for this differential performance in northwestern versus eastern IGP is lower annual rainfall in the former (400–750 mm) while in Bihar and Nepal DSR seems to be quite effective as there soil type is heavy viz. clay loam which does not allowed the water to infiltrate quickly. Secondly rainfall is quite high and frequent which further favors the DSR. Further it was reported that the total seepage and percolation was higher in the puddle transplanted system is high as compared to the other systems system viz. dry seeded and wet seeded rice. Thus DSR is site specific and found to a success where soil type is heavy while in light textured soils DSR is not so effective and finally DSR performance is increased as clay content in the soil is increased. Though it saves the amount of irrigation water, but the thing is that it cut off the drainage water (which is a must for recharging the water table) and that is not required in the central Punjab, where water table is declining down at an alarming rate. Thus DSR may be effective in the areas where there is the problem of water logging viz. South-Western Punjab but for the central Punjab, DSR is not " Real water saving technology" as it never cuts off the evaporation losses but cut off the drainage water.

**Table 3 Water productivity WP (g grain kg water$^{-1}$) of rice under different establishment methods**

| Establishment methods | Yield (t ha$^{-1}$) | WP $_{ET}$ (Kg m-3) | WP$_{IR}$ (Kg m-3) |
|---|---|---|---|
| Transplanted puddled rice | 5.5 | 0.70 | 0.34 |
| Wet seeded flat plots | 4.0 | 0.56 | 0.27 |
| Dry seeded flat plots | 4.2 | 0.76 | 0.40 |
| Raised bed plots | 3.2 | 0.68 | 0.35 |

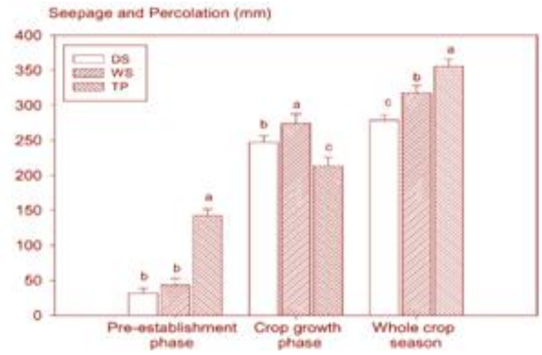
(Choudhary *et al.*, 2007)

**Table 4 System productivity (tha$^{-1}$) under different establishment methods of rice**

| Establishment methods | Rice – wheat | Rice-chickpea | Rice-Indian mustard |
|---|---|---|---|
| Direct-seeding (Un-puddled) | 15.20 | 13.88 | 13.58 |
| Mechanical transplanting (Puddled) | 14.06 | 12.12 | 12.22 |
| Manual transplanting (Puddled) | 13.75 | 11.76 | 11.84 |
| CD (P=0.05) | 0.70 | 0.76 | 0.58 |

(Gangwar *et al.*, 2008)

**Fig 1 Seepage and percolation in dry-seeded (DS), wet-seeded (WS) and transplanted (TP) rice**




(Cabangon *et al.*, 2002)

**C. <u>Role of Permanent beds in water saving:</u>** Bed Planting is also known to be a very important RCT for saving water upto 20-30%, has been first tried for wheat on the pattern of Mexico and later for rice (Singh et al., 2005). Beds solved of the problem of aeration stress in wheat particularly in the heavy less permeable soils. It also reduces the lodging due to lesser water in wheat colm and increase in thickness of basal internodes. Beds seems to improve water productivity as water use efficiency is always higher in furrows than in the flood irrigation and furthermore N recovery can be increased for both rice and wheat by banding N into the soil between two rows on the bed . On the contrary, higher water use efficiency (WUE) was observed in bed planted crops (Brar *et al* 2011) although with time (Table 5), the irrigation water productivity on permanent beds decreased as side slopes of the permanent beds were compacted due to tractor-tyre pressure during repeated re-shaping and sowing of wheat and to natural aging of the beds (Kukal *et al* 2008) (Table 6) (Fig. 2).

Further Kukal et al (2008) reported that compaction of the side slopes of the beds during repeated reshaping increases the bulk density of the side slopes and due to natural aging of the beds, which further hinders the proliferation of the rhizosphere in the 0-15 cm, but this problem could be handled by using narrow tyres. Rice grain yields decreased by 19% in 2004, 45% in 2005 and 59% in 2006 from 4.64 t ha$^{-1}$ in 2003. Root mass density in at 0–15 cm the middle of the fresh beds was 59% higher than on the permanent beds. Thus, fresh beds seems to work effectively but their efficiency decreased as they got old because on increased bulk density.

**Table 5 Performance of bed planted wheat over CT and ZT**

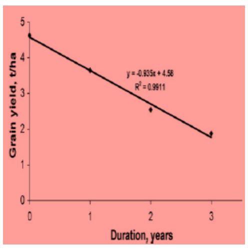
| Establishment method in wheat | Water productivity (g m$^{-3}$) | | |
|---|---|---|---|
| | Direct seeded basmati rice | Transplanted basmati rice | Mean |
| Conventional sown wheat | 384.21 | 366.5 | 375.4 |
| Bed planted wheat | 388.0 | 366.4 | 377.2 |
| Zero till wheat | 374.6 | 359.4 | 367.0 |
| Mean | 382.3 | 364.1 | |

(Brar *et al*., 2011)

**Table 6 Higher bulk density on side slopes of permanent beds tends to lower yields**

| Soil Depth (cm) | Fresh beds | Permanent beds |
|---|---|---|
| 0-5 | 2.078$^a$ | 1.209$^b$ |
| 5-10 | 1.524$^a$ | 0.957$^b$ |
| 10-15 | 0.359$^a$ | 0.320$^b$ |
| 15-20 | 0.149$^a$ | 0.141$^a$ |
| 20-25 | 0.041$^a$ | 0.063$^a$ |
| 25-30 | 0.036$^a$ | 0.043$^a$ |
| ***0-30*** | ***0.698*** | ***0.456*** |

Root mass density (mg cm$^{-3}$) of rice




(Kukal *et al*. 2008)

**Fig 2 Rice root growth pattern on permanent bed**

Permanent beds | Fresh raised beds | Compaction of side slopes

(Kukal *et al*. 2008)

## D. Role of Tensiomters in water saving:

Changing global climatic patterns coupled with declining surface and ground water resources (Hira 2009) have put agriculture on the back foot. Annually, we are extracting >13 Lakh ha-m of additional water from the ground which further decline the water table. In these conditions application of irrigation water as and when required is very important in improving the water productivity. Thus, tensiometers which works on the principles of soil matric potential (a force with which water is held in the soil matrix) helps us to apply water as and when required (Fig 3). Work done by Bhatt and Sharma (2010) showed that during the years from 2006-2010, the water saving varies from 11.1 to 30.7% with almost similar yields as it avoids unnecessary supply of water and helps us to apply water as and when required in right quantity. Performance of tensiometers is not site specific as in case of the DSR as tensiometers measured the soil water tension and show the irrigation need when it is required. Hence in sandy soil it may show more number of irrigations while in heavy textured it may show requirement of less number of irrigations as macro-pores of light textured soil are not able to hold water at a higher suction while micro-pores of heavy textured soil could hold water upto a higher level of suction. Though it saves the amount of irrigation water, but the thing is that it cut off the drainage water (which is a must for recharging the water table) and that is not required in the central Punjab, where water table is declining down at an alarming rate. Thus tensiometers may be effective in the areas where there is the problem of water logging viz. South-Western Punjab but for the central Punjab, Laser levelling is not "Real water saving technology".

**Fig 3 Soil spec Front view (a), rear view (b) and in action measuring soil water tension (c)**


(a) (b) (c)

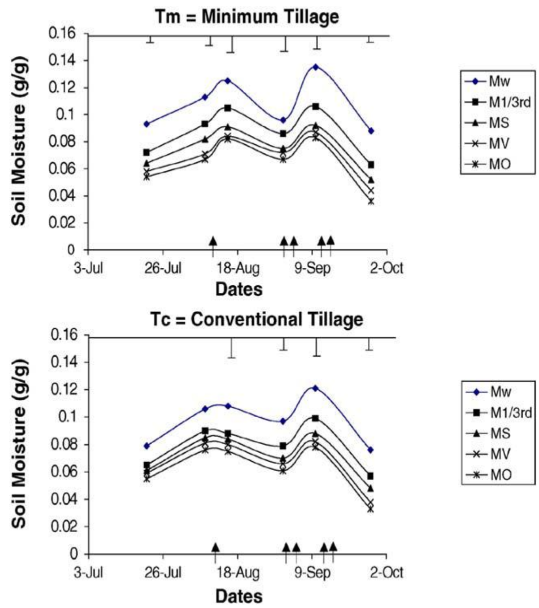
**E. <u>Role of Zero tillage in water saving</u>:** Zero tillage (ZT) is also known as zero-till, no till and direct drilling (Erenstein et al.,2008b). The prevailing ZT technology in the IGP uses a tractor drawn zero-till-seed drill to seed wheat directly into unplowed fields with a single pass of the tractor and the crop residue of previous crop is there and will act as a mulch which further helps in reducing the evaporation and thus in decreasing the total number of irrigation. (Singh et al, 2011; Singh et al, 2008, Bhatt and Khera, 2006) (Fig 4 & 5).

**Fig 4 Happy Seeder for Zero Tilled wheat to improve water productivity**

Direct drilling of wheat into rice residues with combo + Happy seeder

Turbo happy seeder with seed row left relatively exposed– Advantage for sowing wheat into rice stubbles

**Fig 5 Soil surface moisture content as affected by different levels of tillage and modes of mulch application.**




By three ways ZT separated from related systems of rice-wheat establishment methods as firstly, ZT is typically only applied to the wheat crop in the double-cropped system, with the subsequent rice crop still intensively tilled. Secondly, ZT wheat after rice does not necessarily entail an increased reliance on herbicide, reflecting that paddy rice fields are relatively weed free at harvest time and lastly ZT wheat does not necessarily imply the retention of crop residues as mulch. Further, in ZT system along with higher moisture content water amount applied is higher as water took more time to reach to other end of the plot, finally resulted in lower water productivity as compared to the conventional system during the first year as weed pressure is also higher in the ZT plots which decreased the grain yields.

**F. Role of mechanical transplanting in water saving:**

Mechanical transplanting into zero tilled plots (zero tilled transplanted) has been shown to be a promising technology for establishing rice in Haryana with large energy and labour saving and regular plant spacing (Malik and Yadav 2008, Sharma *et al* 2005). This is particularly beneficial in view of increasing labour scarcity in the state of Punjab because of National Rural Employment Guarantee Act (2007) which promises 100-d paid work to people from villages (Anonymous 2011). However, whether zero till transplanting results in water or energy saving in comparison with the puddle transplanted rice in not established yet. There are few studies comparing the water use in the puddle and unpuddled transplanted rice. Singh *et al* (2001) observed that in a sandy loam soil, puddled transplanted rice (PTR) used 125 mm less irrigation water than transplanted rice in untilled soil. There is insufficient data on the components of water balance in zero tilled transplanted rice and it's water productivity. Moreover, the above studies while reporting the irrigation water saving do so in comparison to the farmer's practice of irrigation scheduling, who in general have a tendency of over-applying irrigation water amounts. Finally, mechanical transplanting the need of the hour while further there is a need to train the farmers regarding growing of mat type nursery and operating of these transplanters.

**G. Crop diversification towards water saving:**

Rice wheat is the most adopted cropping system in the IGP but on the long run it leads to the degradation of the soil health and decline of the water table as rice is the water guzzling crop and requires almost submerged conditions. Scientists are busy in finding out some way to divert some area from the paddy to other lesser water requiring crops. In Indian Punjab area under rice is 2.6 M ha from last few decades and we required around 4.3 M ha-m of water annually to successfully cultivate this without any stress but we had 3.0 M ha-m of water annually from all the sources viz. dams and rains, thus we have to withdraw 1.3 M ha-m of water to fulfill our needs this put an adverse effect on the underground water table (Jain and Kumar, 2007). According to Johl committee report, 2002 we must have to divert at least 1.0 M ha area from the rice, then our water requirement is as per our supply (Table 8). From rice we could move to Basmati rice, maize and pulses and in rabi wheat could be replaced with raya and chickpea for their lesser ET requirements. (Table 7)

**Table 7 Diversification for improving Water productivity**

| Annual loss of water (mm) including fallow periods | | | | |
|---|---|---|---|---|
| Cropping System | Medium textured soils | | Coarse texture soils | |
| | ET | Deep drainage | ET | Deep drainage |
| Rice – wheat | 1130 | 810 | 960 | 770 |
| Maize – wheat | 1080 | 410 | 890 | 650 |
| Cotton – wheat | 1340 | 280 | 1210 | 500 |
| Sugarcane | 1360 | 210 | 1340 | 550 |

(Jalota and Aroa, 2002)

**H. Date of transplanting for water saving:**

Date of transplanting has a marked effect in improving the water productivity because in the early transplantation of paddy during May – air is dried and thus ET requirement is much higher, much of supplied water is lost via evaporation from the soil and lesser water is partitioned toward. Therefore we have to apply frequent irrigations to optimize the production for supplying more water to plant to transpire. Whereas in case of delaying DOT upto or beyond 25$^{th}$ of June, rains are there, air is humid and not able to lift much of applied water therefore interval between two successive

**Table 8 Water saving by diversifying 1.0 M-ha area from rice-wheat to other crops**

| Suggested crops | Replaced crop | Total ET-Based saving (M ha-m) |
|---|---|---|
| Pulses (1.0 M ha) | Rice | 0.15 |
| Pulses (0.5Mha) + Maize (0.5 M ha) | | 0.135 |
| Basmati rice (1.0 M ha) | | 0.10 |
| Oil seeds (10 M ha) | Wheat | 0.10 |
| Oiol seeds (0.5 M ha) + Gram (0.5 M ha) | | 0.08 |

(Minhas et al., 2010)

irrigations increased, which ultimately increased the water productivity. Jalota et al., 2009 (Table 9), Singh et al., 2001 shown that shifting of DOT of rice from a period of high to low evaporative demand increases the water productivity due to irrigation saving. Simulation studies shown that shifting of DOT of rice from 16$^{th}$ of May to 16$^{th}$ of June decreased ET by 100-140 mm and a further delay to 1$^{st}$ July caused an additional saving of 50mm (Arora, 2006) which mean shifting DOT in first case could save 0.30 M ha-m of water whereas sfiting upto 1$^{st}$ of July causes additional ET saving of about 0.12 M ha-m. Therefore, shifting DOT upto 25$^{th}$ of June could lead to substantial increase in the water productivity and every effort made to popularize this fact through different KVKs but farmers again go for early transplanting (48% area still transplanted before 15th of June) .Timsena et al, 2008 showed the greater wheat productivity between Oct 25 and Nov. 10 (Table 10). For the central Punjab, this RCT is the "Real water saving" RCT as it cuts off the evaporation loss of water without cutting off drainage loss down the profile which further recharge the water table.

**Table 9 Effect of transplanting date and variety on yield and water requirements of rice**

| Transplanting date | Irrigation water (mm) | Grain yield (t ha$^{-1}$) | Irrigation water (mm) | Grain yield (t ha$^{-1}$) |
|---|---|---|---|---|
| | PR-118 *(155-160 days)* | | RH-257 *(110-120 days)* | |
| 25 May | 2530 | 7.5 | 2350 | 6.8 |
| 10 June | 2420 | 6.6 | 2310 | 7.3 |
| *25 June* | *2270* | *7.1* | *2120* | *7.5* |
| Mean | 2407 | 7.1 | 2260 | 7.2 |

(Jalota *et al.*, 2009)

**Table 10 Effect of date of sowing of wheat on Water productivity (g grain kg irrigation$^{-1}$)**

| Treatments | Irrigation (mm) | Grain yield (t ha$^{-1}$) | Crop water productivity (g grain kg ET$^{-1}$) | Irrigation water productivity (g grain kg irrigation$^{-1}$) |
|---|---|---|---|---|
| Oct. 10 | 257 | 4.73 | 1.5 | 1.9 |
| Oct. 25 | 284 | 5.93 | 1.7 | 2.2 |
| Nov. 10 | 279 | 6.25 | 1.7 | 2.4 |
| Nov. 25 | 289 | 6.03 | 1.6 | 2.2 |
| Dec. 10 | 277 | 5.69 | 1.6 | 2.1 |
| Dec.25 | 281 | 5.25 | 1.5 | 1.9 |
| Jan. 25 | 289 | 4.96 | 1.4 | 1.8 |

(Timsina *et al.*, 2008)

**General discussion:**

Though a number of RCTs have been recommended in the region for saving the irrigation water and for improving the water productivity but most of these technologies are concentrating on saving the applied water which further decreased the drained water (Drainage water is very important for recharging the underground water table which could be further used). Decreasing the applied water is infact not desired in the regions where water table is already declining down viz. NE Punjab, where already water table is declining at an alarming rate. Thus in these regions, we must applied water to get it drained and recharge the underground water table to which farmers could again used.

In fact, there is a difference in between water saving techniques (laser leveller, bed planting, soil matric based irrigation, mulching and zero tillage) and real water saving techniques (delaying the date of transplanting and short duration rice cultivators). Real water saving techniques are those techniques which will not allowed the water to go into that sink from which that cannot be reused as these technique decreased the duration of crop in the field and thus evaporation, the unproductive loss of water (Humphreys et al, 2010). Thus, the water saving techniques may be assigned as electricity saving technique as it saved the electricity which we may used to pump the additional water and these may be useful in the SW districts of the region as those regions are already suffering from the problem of water logging and salinity. But, as far as central parts of the regions are concerned, we have to focus on the real water saving techniques so that unproductive loss of water (evaporation loss) can be minimized. Thus applicability and suitability of the different RCTs are both location and situation specific.

**Conclusion:**

There exist strategies and practices that could be implemented at farm level for improving the water productivity in the region. The Water under the ground is declining down at an alarming rate which must be arrested through the different recommended RCTs. But, these RCTs have promising role that may be highly useful for the south-western districts of Punjab which are already suffering from the problem of water logging as these cut off the drainage water which is a must for recharging the underground water table. Thus for the central Punjab where water table is declining down at an alarming rate, RCTs reducing the evaporation losses viz. delayed transplanting and short duration rice varieties coupled with crop diversification will serve the purpose and is known as **real water saving technologies** to increase the water productivity in the region.

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