A PUBLICATION OF MOTHERHOOD UNIVERSITY, ROORKEE
(Recognized by the UGC with the right to award degrees u/s 22(1) of the UGC act 1956
and established under Uttarakhand Government Act No. 05 of 2015)

Motherhood International Journal of Multidisciplinary
Research & Development
A Peer Reviewed Refereed International Research Journal
Volume I, Issue III, February 2017, pp. 40-54
ONLINE ISSN-2456-2831

Conservation Agriculture based Water Management Technologies for Sustainable Rice Production

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Abstract

Rice (Oryza sativa), the staple food of half of the population of the world, is an important target for water use reduction because of its greater input water requirement than other crops. This is especially the case of India and particularly fornorth west Indo-Gangetic Plains (IGP) of India, where the production of rice and wheat is critical for food security of India. Here, overuse of ground water is amajor threat to the sustainability of the traditional system of puddled transplanted rice (PTR) production (Humphreys et al., 2010).

Keywords: Agriculture, crops, food security.

Ground water Scenario

Declining in ground water level of most of irrigated rice based system is one the major challenge for rice production. The increase in depth of ground water may be started from early 1970 of major RW growing area of Indo-gangetic plain of India. (Ambast et al., 2006; Hira, 2009; Rodell et al., 2009). The increase in depth has accelerated alarmingly in some areas in recent years; for example, in parts of Ludhiana District in central Punjab, the rate of change increased from about 0.2 m/yr during 1973–2001 to about 1 m/yr during 2000–2006 (Fig. 1) (Humphreys et al 2010).. A similar trend was reported in Kurukshetra in Haryana (Sharma et al., 2008a). In 2009, 103 out of 138 administrative blocks were overexploited in Punjab, while 55 out of 108 blocks were overexploited in Haryana (http://cgwb.gov.in/gw_profiles/ st_Haryana.htm).

Using satellite-based estimates of ground water depletion Rodell et al. (2009) found that groundwater is being depleted at a mean rateof 4.0 _ 1.0 cm/yr across the states of Rajasthan, Punjab, Haryana, andwestern Uttar Pradesh. Over a period of 6 years (August 2002–October2008) with close to normal rainfall, they estimated that the volume ofgroundwater had declined by 109 km3 (109 _ 109 m3), double the capacityof India's largest surface reservoir. The maximum rates of groundwaterdepletion appeared to be centred on Haryana and western Uttar Pradesh. The main focuses should be given on increasing rice production while maintaining/improving ground water level. The real water saving could not achieve until and unless evapotranspiration (ET) is checked. Therefore, it is need of the time to check the water demand of rice wisely by adopting new improved tested agricultural technologies.

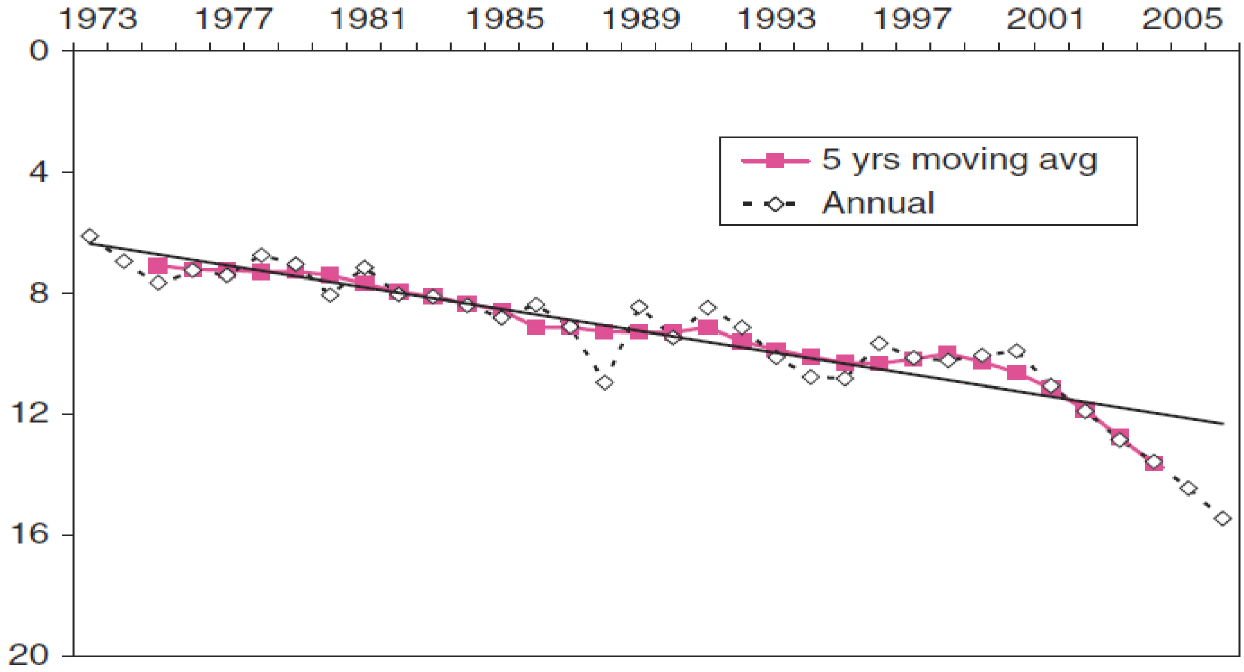

Fig 1: Depth to the water table in June in Gujjarwal, Ludhiana District, Punjab, India, 1973–2005 (data source: Groundwater Cell, Punjab Department of Agriculture).

Water requirement of rice and water management practices

Irrigated rice which is major source of production is generally grown in two seasons:with supplementary irrigation in the wet season and is entirely reliant on irrigation in the dry season. The irrigation water demand of rice also depends upon several factors such as soil type, establishment method, cultivars and water management options.

Irrigated lowland rice is grown under floodedconditions. Mostly, rice is first raised in a separateseedbed and subsequently transplanted into therice field when the seedlings are 2–3 weeks old.Rice can also be established by direct wet seeding(broadcasting pre-germinated seeds onto wet soil)or direct dry seeding (broadcasting dry seeds ontodry or moist soil) in the main field.After crop establishment, the main field is usuallykept continuously flooded as this helps controllingweeds and pests. Before crop establishment, themain field is prepared under wet conditions. Thiswet land preparation consists of soaking, plowing, and puddling (i.e., harrowing or rotavating under shallow submerged conditions). Puddling is doneto control weeds, to reduce soil permeability, andto ease transplanting.

The daily consumptive use of rice varies from 6-10 mm and total water requirement ranges from 1100 to 1250 mm depending upon the agro climatic situation, duration of variety and characteristics of the soils.The water requirement of paddy crop can be divided under stage wise and operation wise as follows:

a) **Stage-wise water requirement for paddy:**

Sl. No.	Stage of Growth	Water requirement	Percentage of total water requirement
1.	Nursery	40	3.22
2.	Main field Preparation	200	16.12
3.	Planting to panicle initiation	458	37.00
4.	Panicle initiation to flowering	417	33.66
5.	Flowering to maturity	125	10.00

b) **Operation wise water requirement of paddy :**

Sl. No.	Operation	Water requirement
1.	Nursery	40
2.	Land Preparation	200
3.	Field Irrigation	1000
Total		1240

Existing irrigation scheduling of India

However, several water saving technologies are developed and promoted by extension worker to the farmers, these are not popular till date. For taking example of Northern and Eastern India:In both the part,canal water and deep borewell are major source of irrigation, The irrigation by bore well depends upon the availability of electricity. Hence whenever electricity is available, farmer irrigate the rice field without considering requirement of irrigation. However, Eastern India is mostly rainfed, all though in some places both canal and bore well facility is available but it is mostly community based and irrigation method is field to field. The bore well owner charges fixed amount for irrigation of rice during entire season. Therefore, in both the scenario adoption of water saving irrigation technologies is one of the challenges as most of these technologies saves substantial amount of water without any yield penalty.

Future challenges and Water Scarcity

Rice production in Asia needs to be increased to feed a growing population whereas water for irrigation is getting scarcer.Rapidpopulation growth and multiple competing demands for water(i.e., drinking, industrial uses) have contributed to irrigation waterscarcity in many Asian developing countries, including the India (Pingali et al., 1997; Van der Hoek et al., 2000; Tabbalet al., 2002). Tuong and Bouman (2003)estimated that, by 2025,about 2 million ha of Asia’s irrigated dry-season rice and 13 millionha of its irrigated wet-season rice will experience physicalwater scarcity. However, as population continues to rise in Asia,more irrigation water may be needed to increase total food productionand meet growing food demand in the future (Rosegrant andRingler, 1998).Irrigated rice production requires large amounts of water,with 1 kg of rice grain requiring 2500 L of water (Bouman 2009). Major challenges in this situation are to:

(i) save water
(ii) increase water productivity and
(iii) produce more rice with less water

Conservation Agriculture for irrigation water management

The conservation agriculture had potential to counter theseproblems. Conservation agriculture aims to increase crop production while reducing the cost of production, sustainable soil fertility and conserving water. The three basic component of conservation agriculture are:

(1) zero or minimum tillage (2) residue retention and (3) crop diversification. All the components have potential to save substantial amount of irrigation water.

Minimal tillage reduces volume and velocity of surface runoff, leading to reduction in soil erosion and nutrient loss; incorporation of crop residues enhances soil water availability, reduces evaporation loss1–3, improves infiltration by restricting surface runoff and reduces surface sealing from raindrop impact3. Crop diversification reduces the risk of crop failure and is recognized as a cost-effective solution to build resilience into agricultural production system4,5. Diversification also brings stability in soil fertility through cultivating legumes with cereals in rotation or intercropping system 6,7.

Recent studies have reported that CA improved crop productivity by 20–120% and water productivity by 10– 40% (refs 8–12). On farm trials showed8 that the CA not only improved the crop yield, but also generated higher gross returns compared to farmers' practice. However, other studies reported no improvement or at some cases negative effects on crop yield by adopting such techniques13,14. For A generalargument is that in addition to CA, appropriate farming practices such as timely planting, balanced nutrient management, crop protection and weed management are necessary to improve crop productivity.

Land Preparation

Land preparation lays the foundation for the whole cropping season and it is important in any situation to "get the basics right." Especially are field channels, land leveling, and tillage operations (puddling, and bund preparation and maintenance) are important for good water management.

Tillage operations

Rice is traditionally grown by transplanting in which puddling is the prerequisite. Puddling requires lots of water and due to intensive tillage most of water lost through percolation and seepage. However, thorough puddling results in a good compactedplow sole that reduces permeability and percolationrates throughout the crop growing period. The effect of puddling varies on the basis of soil properties. Puddling has negative effect in coarse textured soil where as it is very efficient in clay textured soil. Continuous puddling adversely affects production of succeeding crop especially maize and wheat. Therefore it is need of time to avoid puddling with resource conservation technologies. It can not only save substantial amount of water require for puddling but also improves soil physio chemical and biological properties.

Field Channels

Many irrigation systems have no fieldchannels (or drainage channels)and water flows from one field into the otherthrough breaches in the bunds. This is called "plot-to-plot" irrigation. The amount of water flowingin and out of a rice field cannot be controlled andfield-specific water management is not possible.This means that farmers may not be able to draintheir fields before harvest because water keepsflowing in from other fields. Also, they may not beable to have water flowing in if upstream farmersretain water in their fields or let their fields dryout to prepare for harvest. Moreover, a number oftechnologies to cope with water scarcity requiregood water control for individual fields. Finally, the water that continuously flowsthrough rice fields may remove valuable (fertilizer) nutrients. Constructing separate channels to conveywater to and from each field (or to a small groupof fields) greatly improves the individual control ofwater and is the recommended practice in any typeof irrigation system.

Land leveling

Laser-assisted precision land leveling considered as a precursor technology for RCTs has been reported to improve crop yields and input-use efficiency including water and nutrients (Jat et al., 2006a). In the IGP, flood irrigation is acommon practice in the RW system wherein a significant amount (10–25%) of irrigation water is lost during application on the farm because of poor management and uneven fields (Kahlown et al., 2002) that lead to lower crop yields, higher irrigation costs and poor resource-use efficiency (Jat et al., 2006a). Traditionally leveled fields have frequent dikes and ditches within the fields and field slopes vary from 1 to 3 degrees in transects I and II (Pakistan Punjab, Indian Punjab, Haryana and Western Uttar Pradesh) to 3 to 5 degrees in transects IV and V of the IGP (Jat et al., 2006a). PLL has been shown to improve water management and it saves up to 50% of irrigation water (Rickman, 2002; Jat et al., 2006a). Other benefits of laser land leveling include improved crop stand and cropproductivity (up to 30%) and reduced labour requirement for w eding from 21 to 5 d ha_1 in rice (Rickman et al., 1998; Jat et al., 2006a). Kahlown et al. (2002) reported that PLL improved the performance of RW and water productivity in non-puddled soil with ZT surface seeding and seeding on permanent beds compared with conventional-tillage.Jat et al (2009) reported Laser land leveller improved RW system productivity by 7.4 % in year 2 as compared to traditional land levelling. Total water saving under laser leveller verses traditional levelling in rice 12 to 14 %.

Bund Preparation and maintenance

Good bunds are a prerequisite to limit seepageand underbund flows (Tuong et al 1994). To limitseepage losses, bunds should be well compactedand any cracks or rat holes should be plasteredwith mud at the beginning of the crop season.Make bunds high enough (at least 20 cm) to avoidoverbund flow during heavy rainfall. Small leveesof 5–10-cm height in the bunds can be used to keepponded water depth at that height. If more waterneeds to be stored, it is relatively simple to closethese levees.

Crop Residue management

Keeping the soil covered is one of component of CA and important for converging soil moisture.Crop residue is one of the most important conservation tillage factors for improving soil's physical, chemical and biological properties. Residue helps reduce surface runoff and soil loss, conserving soil moisture and improving soil microorganism populations, soil organic matter content, and soil hydraulic/ physical properties. The effectiveness of residue is linked to the soil topography and soil slope, as well as other factors that affect the sustainability of the residue on the soil surface. Relatively flat fields can be protected against water erosion with 12 to 20 percent residue cover. Fields with steeper or longer slopes require at least 50 to 60 percent residue cover. The amount of residue to be left on the field depends on the site and the percentage of coverage that is agreed upon while preparing the conservation plan with the Natural Resources Conservation Service.

Crop Establishment

Minimizing the turn-around time between landsoaking for wet land preparation and transplantingreduces the period when no crop is presentand when outflows of water from the field do notcontribute to production. Especially in large-scaleirrigation systems with plot-to-plot irrigation, waterlosses during the turn -around time can be very high.

Farmers raise seedlings in part oftheir main field.Because of a lack of tertiary fieldchannels, the whole main field is soaked when theseedbed is prepared and remains flooded duringthe entire duration of the seedbed.With field channels, water can bedelivered to the individual seedbeds separately andthe main field does not need to be flooded. Commonseedbeds, either communal or privately managed, can be located strategically close to irrigation canalsand be irrigated as one block.

With direct seeding, the crop starts growingand using water from the moment of establishmentonward. Direct dry seeding can also increasethe effective use of rainfall and reduce irrigationneeds. However, dryseeding with subsequent flooding is possible onlyin heavy (clayey) soils with low permeability andpoor internal drainage.

Direct seeded rice

Direct seeding of rice is one of the old practice in which farmers broadcast the seed in prepared field. However due to low yield potential and weed problem this practice is not widlyadoped by the farmers. However, in resource conservation technologies with improved weed management practices farmer can grow rice while saving resource without or higher yield as compared to transplanted rice. Two type of DSR is now a days getting popular wet and dry.Both Dry- and Wet-DSR have the potential to reduce water and labor use compared with CT-TPR.

Tabbal et al. (2002) in their on-farm studies in the Philippines observed on average 67–104 mm (11–18%) of savings in irrigation water in Wet-DSR compared with CT-TPR when irrigation application criteria was same for both establishment methods. Cabangon et al. (2002) in the Muda region of Malaysia found that irrigation water application in Dry-DSR was about 200 mm (40%) less than that in CTTPR. Similarly, 10–50% savings in water have been claimed with Dry- DSR compared with CT-TPR from India when irrigation application criteria after crop establishment (CE) were either the appearance of hairline cracks or tensiometer-based (_20 kPa at 20-cm depth) (Bhushan et al., 2007; Jat et al., 2009; Sudhir-Yadav et al., 2011a,b).

Raised Beds

In the system of raised beds,rice is grown on beds that are separated by furrowsthrough which irrigation water is coursed. In irrigationengineering terms, the system of raised beds iscomparable with “furrow irrigation.” Irrigation isintermittent and the soil of the beds is dominantlyin aerobic conditions; hence, the system can beconsidered an aerobic rice system (this is differentfrom the use of beds in heavy soils to maintainsaturated soil conditions). In general,furrow irrigation is more water efficient than flashflooding(depending on soil type, field dimensions,and slope of the land), and furrow irrigation shouldhold promise for aerobic rice.Rice can be transplanted or direct-seeded onthe beds.

So far, the raised-bed system has mostlybeen tested with current lowland rice varieties, andyield gains can be expected when suitable aerobicvarieties are developed/used.

Tractor-pulled equipmenthas been developed that shapes the beds anddrills seed (sometimes together with fertilizers) inone operation.

Among the suggested benefits of raised bedsare improved water-use and nutrient-use efficiency,improved water management, higher yields,and—when the operations are mechanized—reducedlabor requirements and improved seedingand weeding practices (Connor et al 2003, Hobbsand Gupta 2003).

Selection of cultivar

Selection of cultivars can also play an important role in water saving. Now a day, several drought tolerant cultivars (Sahbhagidhan, DRR 42 &44) have been developed by different research institutes. Also short duration cultivars had potential to produce higher yield with minimum water requirement. Although, the selection of cultivar is depends upon several other biotic and abiotic factors.

Alternate wetting and drying

Several water-saving technologies and practices havebeen developed to help farmers cope with water scarcity inirrigated environments. These include saturated soil culture,aerobic rice, and alternate wetting and drying (AWD) etc. These watersavingtechnologies are mostly aimed at reducing unproductivelosses of water due to seepage, percolation, andevaporation, thereby increasing the productivity of totalwater inputs from rainfall and irrigation. Despite these water saving technologies, there are several best water management practices to minimize the water losses and reduce the water requirement.

Soil texture

Although selection of crop should be based on soil texture. But commonly it is not happening. Whereas, several other factors play role in selection; mainly selection of crop are market driven. However, different types of soils have different type of water holding capacity such as sandy soil requires frequent irrigation. Whereas, clay soil holds water for longer duration however once clay soil dries develop wide crack in which the water requirement of soil increases dramatically. Hence, water saving technologies should be adopted keeping in consideration of the soil texture.

The way to deal with reduced (irrigation orrain) water inflows to rice fields is to reduce thenonproductive outflows by seepage, percolation, orevaporation, while maintaining transpiration flows(as these contribute to crop growth). This can bedone at land preparation, at crop establishment, andduring the actual crop growth period.

Alternate Wetting and Drying

In Alternate Wetting and Drying (AWD), irrigationwater is applied to obtain flooded conditions after acertain number of days have passed after the disappearanceof ponded water. The number of days ofnon-flooded soil in AWD before irrigation is appliedcan vary from 1 day to more than 10 days.Experimenting with AWD in lowland riceareas with *heavy soils and shallow groundwater*tables in China and the Philippines, Cabangonet al (2004), Belder et al (2004), Lampayan et al(2005), and Tabbal et al (2002) reported that total(irrigation and rainfall) water inputs decreased byaround 15–30% without a significant impact onyield. In all these cases, groundwater depths werevery shallow (between 10 and 40 cm), and pondedwater depths almost never dropped below the rootzone during the drying periods , thus turningAWD effectively into a kind of near-saturatedsoil culture. Even without ponded water, plant rootsstill had access to “hidden” water in the root zone. More water can be saved and waterproductivity further increased by prolonging theperiods of dry soil and imposing a slight droughtstress on the plants, but this usually comes at theexpense of yield loss (Bouman and Tuong 2001).

AWD is recommended to be followed by using field water tube (perforated upto 6 inches from one end) of 15 inches depth. The field water tubes are installed on the ground from the perforated side with the removal of soil from the inside of the tube. Farmers have to follow the irrigation scheduling by observing the water level inside the tube. The threshold of 6 inch (15 cm) is called “Safe AWD” as thiswill not cause any yield decline since the roots of therice plants will still be able to take up water from thesaturated soil and the perched water in the root zone.In Safe AWD, the following rules should beobserved. In AWD irrigation can be used from a few daysafter transplanting (or a 10-cm-tall crop after directseeding) till first heading. In the period of first heading to 1 week after flowering, field is to be flooded with5-cm depth. After that, during grain filling and ripening,AWD can be applied again. When many weeds are present inthe early stages of crop growth, the implementationof AWD can be postponed for 2–3 weeks until weedshave been suppressed by the ponded water. Under SafeAWD, no special N management regime is needed andlocal recommendations as for flooded rice can be used (Belder et al 2004). Fertilizer N should be applied preferably on thedry soil just before irrigation is applied.

AWD is a technology that has been widely tested andpromoted in several countries in Asia, especially thePhilippines, China, Vietnam, and Bangladesh.The following potential benefits of AWD have been made it popular in some Asian countries: improved rooting system, reducedlodging (because of a better root system), periodicsoil aeration, and better control of some diseasessuch as golden snail. On the other hand, there is appearance of weed growth if proper weed control measures are not taken.

Micro irrigation systems

Micro irrigation systems such as drip, sprinkler is known for water saving and gaining importance particularly vegetable and horticultural crops. But these technologies have potential to reduce substantial amount of irrigation water. These systems reduce mainly seepage and percolation loss of water. Surface and subsurface drip irrigation and sparkler are also tested in rice but till now it limited to the research experimental plots. Robin et al (2014) reported that feasibility of rice growing by using drip and sprinkler irrigation with substantial amount of water saving. Despite the lots of water saving and other benefit from micro irrigation its adoption to the farmer in rice depends on both initial cost of system, operational maintenance of system and scientific and well tested irrigation scheduling.

System of Rice Intensification

System of Rice Intensification (SRI), an integratedcrop management technology developed by theJesuit priest Father Henri de Laulanie in Madagascar(Stoop et al 2002). AWD is the major water management practice of SRI in which water is applied on observing hairline cracks. No continuous flooding during the cropgrowth period, applying small amounts ofwater regularly or alternating wet and dryfield conditions to maintain a mixof aerobic and anaerobic soil conditions. After flowering, a thin layer of water shouldbe kept on the field, although some farmersfind alternate wetting and drying of fields throughout the crop cycle to be feasible andeven beneficial.

Challenges of irrigation water management

The uptake of innovativetechnologies is not only depend of effectiveness but several other following striving factor involves

1. Change in farmer’s attitude toward the existing conventional practice is a daunting challenge as a most of farmers are not ready to adopt new innovative technologies. Some

farmer's are well acquainted with existing conventional practice and also having some religious believe. So for adoption continuously frontline demonstration will be needed.

2. Land holding: Most of farmers having small to marginal land holding and this land holding is only source of income so deviation from conventional to conservation agriculture require assurance or it should be step wise.
3. Residue management: Although residue retention on soil is key component of CA. But it can be difficult. As crop residue is also used as revenue generation source.In dry area, it is impossible to grow a dry season crop due to unviability of irrigation; residue is a major source of animal feed in rain fed ecology. However, in irrigated ecosystem where Rice-wheat cropping system is prevailing. Rice residue is a major problem and mostly farmer burn the residue.

Conclusion

Although having several benefits, conservation agriculture as a whole or CA based water management practices and water saving technologies are still not popular or widely adopted. The availability of irrigation source and level of groundwater varies from locations to locations. In most part of the countries people are still not aware of increasing water scarcity and need of judicious water management. So this is the need of the time to make mass awareness about water scarcity, judicious water management, role of water saving technologies and best management practices. Situation specific technology should be generated participatory and there is need for change in policy level. Strong decisions should be taken in the policy level by the decision makers for restricting water use and for the adoption of best water management practices among farmers.

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