

Root zone irrigation in cereal based systems to address the groundwater crisis in North-West India

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Conventional cultivation practices (flood irrigation) of rice-wheat (RW) consumes substantial amount of irrigation water for crop production. There has been a steady decline in groundwater table in most of the RW domain area of North-West (NW) India. Looking to the constraints of water shortages, ICAR-CSSRI evaluated site specific water management (SSWM) based root zone irrigation (RZI) under cereal (rice-wheat/maize-wheat (MW) based) systems. RZI saved water (by ~50%) and improved yields (by 10-20%) by eliminating surface water evaporation with similar management practices over flood irrigation. RZI in RW system also increased the crop productivity and farm profitability while saving 72% of irrigation water with CA-based management practices compared to flood irrigation in farmers' practice (FP). The MW system recorded ~20% higher productivity, 49% higher profitability and saved 85% of irrigation water compared to conventional flood irrigated RW system. Scheduling of fertilizer N through RZI (fertigation) in the rice/maize-wheat systems saved 20% of N in each crop and increased N use efficiency by 47%.

Keywords: Ground water, Indo-Gangetic plains, Maize-Wheat system, Rice-Wheat system, Root zone irrigation, Site specific water management, Subsurface drip irrigation

TO grow more food for ever-increasing population under a changing climate, radical changes are needed in agricultural use of available water. Nowhere is this more obvious than India, where a growing demand for food combined with climate change is putting serious pressure on groundwater resources, especially in the populous Indo-Gangetic Plains. This area (5 M ha) in the country's north-west is the most important production area for India's two staple cereals: rice and wheat. Inefficient flood-based irrigation and climate change are putting enormous stress on the region's groundwater supplies. Furthermore, by 2050, the share of water for agriculture use will be less than 50% of total water from the present share of 70%. Rice being a water guzzling crop, consumes significant amount (about 50%) of total irrigation water. Since the early 1970s (Green Revolution era), there

has been a steady decline in groundwater table in most of the RW domain area of North-West (NW) India which has now accelerated rapidly in central Punjab and parts of Haryana in India.

In NW India, conventional cultivation practices in RW system consumes huge quantities of water and energy, is labour-intensive, and can deteriorate soil health. Over use of nitrogen-based fertilizers (>175 kg/ha in Punjab and Haryana) can pollute waterways (> 5 ppm nitrate in groundwater in some parts of NW India) and emit harmful greenhouse gases (GHGs) that cause climate change. Furthermore, crop residue burning also wastes a precious resource and farmers are forced to apply one more irrigation (10 Lakh liters/ha) to fields to compensate the soil moisture lost during the burning.

Conventional cultivation practices (flood irrigation) of rice-wheat (RW)

consumes 2,000-2,500 mm of irrigation water for crop production. If sustainable measures are not taken soon to ensure sustainable use of groundwater, the IGP of NW India may soon experience decline in crop productivity and farm profitability, and shortages of potable water leading to extensive socio-economic stresses. The adoption of surface drip irrigation has always remained cumbersome process of anchoring laterals at the beginning and removing after every crop due to field operations. To eliminate this hurdle and looking to the constraints of water shortages in future, it is imperative that we focus on developing alternative and remunerative approaches for increasing water productivity in the 'Green Corridors' of NW India. Therefore site-specific water management (SSWM) based RZI/SDI was evaluated first time in the

country under cereal (rice/maize based) systems approach for irrigation water saving, higher water use efficiency and water productivity.

Site of experiment

The root zone irrigation (RZI) was evaluated at strategic research platform of ICAR-Central Soil Salinity Research Institute (CSSRI), Karnal, Haryana to optimize the precision water and nitrogen management options using RZI in rice-wheat (RW) and maize-wheat (MW) cropping system. The mains and sub-mains were laid out at depth of 100 cm, while lateral at 20 cm using tractor operated drip laying machine. The laterals were spaced at 67.5 cm in both rice and maize based systems. Each dripline served 3 rows (67.5 cm) of rice, wheat and mungbean and 1 row of maize crop. The emitters were in-line type having a capacity of 2.0 L/h at a pressure of 135 kPa and spaced at 30 cm. The operating pressure for drip irrigation was maintained between 1.5 to 2.0 kg cm⁻². For fertigation, a Venturi injector was used and the suction was created due to the pressure differences between upstream and downstream. In the rice, maize and wheat crops, irrigation was applied on the basis of tensiometer readings (soil moisture potential; SMP) installed at 15 cm soil depth between the laterals and/or crop rows. The values of SMP used for RZI were -20 to -30 kPa in rice, -40 to -50 kPa in wheat and -50 kPa in maize. The investment costs of a SDI system is normally INR 2,50,000/ha. Normal life expectancy of RZI is 15 years. With good maintenance and high water quality the system can be used even up to 20 years. Cost of drip irrigation system was calculated after considering 80% subsidy provided by the Govt. of India on the actual cost.

Root zone irrigation (RZI)/ subsurface drip irrigation (SDI)

Root zone irrigation (RZI) is a SSWM technology in which water is applied directly to the root zone of the crop or below the soil surface (as opposed to surface irrigation) and it has a similar design as a surface drip



Root zone irrigation/subsurface drip irrigation in wheat crop.

irrigation system except it is buried below the soil surface. RZI involves below ground pipes that deliver precise doses of water and fertilizer directly to the plant's root zone, avoiding evaporation from the soil. Existing options of surface drip irrigation was there but it was limited to the wider row crops and tress only, which offers an efficient alternative to traditional flood irrigation in vegetable and horticulture crops. The RZI system limits irrigation water loss, prevents weed growth, reduces labour cost, and allows normal cultural practices. Fertigation through drip irrigation system reduces the N-volatilization and leaching losses thereby improving the nutrient use efficiency. A RZI system was designed that can work for both rice and maize crops with no modifications between rotations with respect to the laterals distances.

Management scenario of cropping system

Conventional rice of North-West (NW) India is manually transplanted under well-pulverized puddled fields followed by continuous submergence (5 ± 2 cm) for 1 month. Flood irrigated puddled transplanted rice (PTR) requires 2,500-3,000 liters of water to produce 1.0 kg of rice, while wheat requires 600-800 and maize 300-450 liters of water for the same. Furthermore, traditional practices of growing these crops contribute greatly to the high irrigation water, energy and labour costs resulting in lower water productivity and farm profitability. Indian agriculture facing a major challenge in RW system of NW India due to faster depletion of groundwater table, stagnating or declining productivity growth, degrading soil health and environmental quality via crop



Maize crop with RZI/SDI system under CA-based management practices.

Table 1. System productivity, irrigation water use and its efficiency (IWUE), net profit and partial factor productivity on nitrogen (PFP_N) under different scenarios (2 yrs' mean)

Scenario	Crop Rotation	Tillage	Water management	Productivity (Mg/ha)	Irrigation water use (mm/ha)	Net profit (₹/ha)	IWUE (kg grain/m ³)	PFP _N (kg grain/kg N applied)
I	Rice-Wheat- Fallow	CT-CT	FI	13.36	2320	124171	0.58	41.125
II	Rice-Wheat-Mungbean	ZT-ZT-ZT	FI	14.02	2000	142592	0.7	45.245
III	Maize-Wheat- Mungbean	ZT-ZT-ZT	FI	14.87	1070	160415	2.37	47.165
IV	Rice-Wheat-Mungbean	ZT-ZT-ZT	RZI/SDI	15.33	650	175456	1.42	59.46
V	Maize-Wheat- Mungbean	ZT-ZT-ZT	RZI/SDI	16.00	360	184932	4.46	61.52

CT, conventional tillage; ZT, zero-tillage; FI, flood irrigation; RZI, root zone irrigation; SDI, subsurface drip irrigation.

residue burning. To overcome irrigation water problems of RW system, management of tensiometer based RZI scheduling in combination with conservation agriculture (CA) based management techniques like direct seeded rice, zero-tillage, surface mulch etc. were evaluated for water saving and higher water productivity (WP). In NW India, almost 1.0 million hectare has been covered under partial and full conservation agriculture (CA) based management in rice-wheat system.

Water saving and increase in water use efficiency

The RZI system saved 58 and 96% irrigation water in rice and maize crop, respectively compared with flood irrigation under puddled transplanted rice (189 cm) while the saving of irrigation water over flood irrigation was 53% (20 cm) in wheat and 55% (10 cm) in mungbean. The RZI technology saved 72 and 85% of irrigation water in RW and MW system, respectively with CA-based management practices compared to farmers' practice of residue burning followed by intensive tillage coupled with flood irrigation. On system mean basis, RZI saved 47 (93.6 cm yr⁻¹) and 45% (29 cm yr⁻¹) irrigation water under rice-wheat (RW) and maize-wheat (MW) system integrated with mungbean, respectively compared to flood irrigation system under same management level in silty loam soils of Haryana (Table 1).

With RZI, the irrigation water use efficiency (IWUE) was 0.84 q ha/cm in DSR (direct seeded rice) against the 0.38 q ha/cm in puddled transplanted rice with flood irrigation. While, in maize it was highest (9.61 q ha/cm). Like rice and maize, the higher IWUE (151%)

of wheat was observed with RZI compared to flood irrigation (1.33 q ha- cm⁻¹). On cropping system basis, the highest (4.46 q ha/cm; 669%) IWUE was recorded with MW-mungbean along with RZI and lowest (0.58 q ha/cm) with Farmers' practice in silty loam soils.

Productivity and profitability

The wheat yield increased by 11% with RZI compared to flood system in RW and MW system. The crop productivity and farm profitability of RW-mungbean system increased by ~11 and 29%, respectively while saving of 72% of irrigation water under RZI system compared to farmers' practice (FP) of flood irrigation system. However, in MW-mungbean ~20% higher productivity, 49% higher profitability was recorded with 85% saving in irrigation water under RZI system compared to flood RW system.

Nitrogen (N) and energy saving and productivity:

The RZI system reduced the fertilizer N requirement by 20% (30 kg N/ha) under each crop of rice, wheat and maize crops and on system basis. On system basis, RW and MW systems recorded 45 and 50% higher partial factor productivity of N (PFP_N) with RZI compared to CT flood. The RZI system in rice, maize and wheat improved the PFP_N by 20, 33 and 46% respectively, to that of flood irrigation (Table 1).

The RZI saved 38 and 55% of energy input in rice and maize systems respectively. The energy use efficiency (EUE) and energy productivity (EP) was improved by almost 300 and 64% with RZI under rice and maize, respectively compared to flood rice (4.6 MJ/ha and 0.15 kg/

MJ). However, with wheat it was increased by ~75% (5.47 MJ/ha and 0.23 kg/MJ) compared to flood irrigated wheat. The RZI improved the EUE by 61% and EP by 75.0% in rice based systems with RZI compared to flood irrigation under farmers; practice (EUE 4.9 MJ/ha and EP 0.18 kg/MJ). Similarly in maize- based system, EUE and EP was increased by 148 and 169% with RZI compared to flood irrigation, respectively.

SUMMARY

The RZI/SDI system combined with conservation agriculture (CA) approaches like zero till, retaining residues on soil surface and dry seeding requires 40-50% less irrigation water than flood irrigation for rice and wheat with the same or higher amount of yields, and would still be cost-effective for farmers. As well, it was found that both rice and wheat needed 20% less nitrogen-based fertilizer (urea) under a subsurface drip fertigation system which could improve ecosystem health and cut greenhouse gas emissions (GHGs). The study demonstrated that this can be accomplished with significant benefits to farmers, saving them input costs and labour. Therefore, for its fast and wider replicability convergence of schemes like 'More Crop Per Drop' with Food security mission, Soil health mission, Doubling farmers' income by 2022 and Sustainable agriculture mission is required to harvest the better fruits from RZI in RW system.

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