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# Water Management in Conservation Agriculture

*Siya Aryashree Sangramsingh, Dr. Anshuman Nayak and Dr. Ipsita Kar
College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India
*Corresponding Author's email: siyaaryashree@gmail.com

Every drop of water that reaches an agricultural field does not necessarily reach the crop. A part may be lost through runoff, evaporation or inefficient irrigation, making the management of water as important as its availability. Conservation agriculture offers a different approach by treating soil as a living reservoir capable of receiving, storing and supplying water to crops more efficiently. With minimum soil disturbance, protective soil cover and diversified cropping, the system can improve infiltration, reduce evaporation and help maintain moisture in the crop root zone. Evidence from South Asia indicates that improved conservation-oriented soil and water management can save approximately 50–300 mm of water annually, while zero tillage combined with residue retention has improved water-use efficiency by an average of 12.6% across a large regional assessment. The significance of water management in conservation agriculture therefore lies not simply in using less water, but in reducing avoidable losses and obtaining greater productivity from the water already available. As rainfall becomes more uncertain and irrigation resources increasingly limited, managing water through healthier and better-protected soils may become one of the most important foundations of sustainable agriculture.

**Keywords:** Conservation agriculture, water management, water conservation, irrigation scheduling, soil moisture conservation, water productivity, rice–wheat system, sustainable agriculture.

## Introduction

Water is one of the most critical resources for sustainable agricultural production. Increasing demand for food, growing competition for water from non-agricultural sectors and climate variability are placing increasing pressure on agricultural water resources. In India, the net sown area was about 139.0 million ha and the net irrigated area about 82.4 million ha in 2023–24, indicating the major role of irrigation in supporting crop production. The intensive rice–wheat cropping system, particularly in the Indo-Gangetic Plains, has placed considerable pressure on groundwater resources because of its high irrigation requirement. Rice is especially water demanding, with approximately 2500 L of water required to produce 1 kg of rice under conventional production conditions. Therefore, the emphasis in agricultural water management has shifted from simply maximizing yield per unit area to increasing water productivity, i.e., obtaining greater crop production from each unit of water used. Conservation agriculture offers an important approach to achieving efficient water use by improving soil-water conservation, reducing avoidable water losses and increasing the efficiency of irrigation. Hence, efficient water management under conservation agriculture is essential for conserving scarce water resources while maintaining crop productivity and ensuring the sustainability of agricultural production.

# Recent Advances in Water Management under Conservation Agriculture

## Laser Land Levelling


**Fig.1: Tractor-operated laser land levelling.**

Laser land levelling is a precision land-management technology used to obtain a highly uniform field surface with the help of a laser-guided system. A laser transmitter establishes a reference plane, while a laser receiver fitted to the land-levelling equipment detects variations in field elevation and automatically controls the scraper blade. This produces a level field with minimum variation in elevation, allowing irrigation water to spread more uniformly throughout the field. It is particularly useful in irrigated conservation agriculture systems where efficient and uniform application of limited water is essential. Uniform land levelling reduces excessive water accumulation in lower portions of the field and inadequate irrigation in higher portions. It can therefore reduce runoff, deep percolation and unnecessary irrigation, while improving crop establishment and water-use efficiency. Laser land levelling is especially important in rice–wheat systems of the Indo-Gangetic Plains, where groundwater depletion has increased the need for efficient irrigation practices. Laser-levelled fields can substantially reduce irrigation requirements compared with conventionally levelled fields. Laser land levelling also works effectively in combination with other conservation agriculture practices such as zero tillage, residue retention and efficient irrigation systems. By improving the uniformity of water distribution, it helps crops utilize applied water more effectively and increases water productivity. Thus, laser land levelling is an important precision water-management technology for reducing water wastage and promoting sustainable agricultural production.

## Permanent Raised Beds

Permanent raised-bed planting involves growing crops on raised beds that are maintained over successive seasons, with irrigation water supplied through the furrows between the beds. Unlike conventional flat planting, the crop root zone remains elevated, while the furrows provide controlled pathways for irrigation and drainage. Under conservation agriculture, permanent beds can be maintained with minimum soil disturbance and combined with zero tillage and crop-residue retention, thereby improving soil structure and conserving moisture. Permanent raised beds can reduce the amount of irrigation water required because water is applied mainly through the furrows rather than flooding the entire field. Permanent raised beds can save up to 29.2% irrigation water in the maize–wheat system compared with zero-tilled flat planting, along with about 24.5% higher water productivity. Raised-bed wheat can reduce irrigation amount or irrigation time by around 30–40% while maintaining similar or higher yields than conventional flat planting. The system also improves infiltration, reduces unnecessary waterlogging and provides better aeration of the crop root zone. When combined with residue retention, permanent raised beds help conserve soil moisture and improve overall resource-use efficiency. Therefore, permanent raised beds offer an effective approach for increasing water productivity while supporting the principles of conservation agriculture.

## Non-Puddled Transplanted Rice

Non-puddled transplanted rice is a water-saving rice establishment method in which rice seedlings are transplanted without puddling the soil. Unlike conventional puddled transplanted rice, the field is not repeatedly tilled under saturated conditions to create a puddled layer. This reduces the large quantity of water required for land preparation and helps maintain better soil structure for the succeeding crop. It is therefore particularly suitable for conservation-agriculture-based rice–wheat systems, where maintaining soil physical condition and reducing water use are important. The major water-saving advantage comes from avoiding the pre-transplanting puddling operations, which require considerable amounts of irrigation water. Non-puddled establishment also reduces excessive soil disturbance and can improve the infiltration and movement of water through the soil profile. In rice-based systems, this can be combined with efficient irrigation practices such as alternate wetting and drying to further reduce irrigation requirements. Avoiding conventional puddling can substantially reduce water inputs while maintaining productive rice yields when appropriate varieties, planting methods and irrigation management are used. The importance of this approach is particularly high in the rice–wheat system because a non-puddled rice field provides a more favourable soil condition for the following wheat crop than a heavily puddled field. It also reduces the time and energy required for land preparation. Thus, non-puddled transplanted rice conserves water at the crop-establishment stage while reducing soil disturbance and improving the overall resource-use efficiency of the rice–wheat system. Water savings of approximately 20–30% or more can be achieved, depending on soil type, irrigation practice and the method used for conventional comparison.

**Direct-Seeded Rice (Smart Seeding Method)**

Direct-seeded rice (DSR) is a water-saving method of rice establishment in which seeds are sown directly into the field instead of raising seedlings in a nursery and transplanting them into puddled soil. It is an important conservation-agriculture approach because it eliminates the water-intensive operations of nursery raising, puddling and transplanting. The field is therefore not kept continuously flooded, and irrigation is applied according to crop requirement. This substantially reduces water input while also saving labour, fuel and time. The magnitude of water saving under DSR can be considerable. DSR can reduce water use by 25–30% compared with flooded transplanted rice in north-western India. Water use under direct-seeded/aerobic rice could be approximately 60% lower than under conventional lowland rice (Kumar & Ladha, 2011). Although yields in some situations were 20–30% lower than flooded lowland rice, the reduction in water use was much greater, resulting in 1.6–1.9 times higher total water productivity and approximately two-fold higher net returns to water use. Water productivity can increase by 20–40% under aerobic cultivation compared with flooded conditions. DSR also allows more timely establishment of the following wheat crop because the prolonged puddling and transplanting operations are avoided. However, effective weed management, suitable varieties, proper seed placement and precise irrigation scheduling are essential for maintaining productivity. Thus, direct-seeded rice provides an important pathway for reducing irrigation demand while increasing the amount of rice produced per unit of water under conservation agriculture.

**Zero Tillage**

Zero tillage is a conservation agriculture practice in which crops are sown directly into the soil without conventional ploughing and intensive seed-bed preparation. It minimizes soil disturbance, reduces the time and energy required for land preparation, and helps conserve soil moisture. In rice–wheat systems, zero tillage is particularly useful for establishing wheat soon after rice harvest, when wet soil conditions can make conventional land preparation difficult and delay sowing by 10–15 days. Zero tillage can reduce irrigation water requirement by about 15–30% compared with conventional tillage and may increase wheat yield by 5–7%, mainly due to timely sowing. It can also save approximately 1.0 million litres of irrigation water and 98 L of diesel per hectare. When combined with crop-residue retention, it further improves soil-moisture conservation and reduces evaporation losses. Thus, zero tillage helps improve water-use efficiency while reducing tillage operations, energy consumption and delays in crop establishment. Wheat in the rice–wheat system is a major example of its successful application under conservation agriculture.

**Fig. 2: Zero-tillage crop establishment.**

## Surface Mulching

Surface mulching is the practice of covering the soil surface with crop residues or other suitable materials to reduce direct exposure of the soil to solar radiation and atmospheric conditions. In conservation agriculture, crop-residue mulches such as rice straw, wheat straw, maize stover, sugarcane trash and other retained plant residues are commonly used. Organic materials such as leaves, grass and compost can also serve as surface mulch. The protective layer reduces soil evaporation, improves infiltration and helps maintain favourable soil-moisture conditions for crop growth. Soil evaporation can account for approximately one-third of crop evapotranspiration (ET), although it makes little direct contribution to crop production. Therefore, reducing unnecessary evaporation through mulching can improve water productivity. Rice-straw mulching in zero-tilled wheat reduced total system soil evaporation by about 45 mm (Gupta et al., 2021). Residue retention also improves moisture conservation deeper in the soil profile; in one study, soil-moisture conservation up to 90 cm depth after maize harvest was 108% higher under conservation agriculture than under conventional agriculture. The effectiveness of mulching depends on the type and quantity of residue, its distribution over the soil surface and the prevailing climatic conditions. Besides conserving water, surface mulch moderates soil temperature, reduces runoff and erosion, suppresses weeds and contributes organic matter as it decomposes. Thus, retention of crop residues as surface mulch is an important conservation-agriculture practice for reducing soil-water losses and improving water-use efficiency.

## Alternate Wetting and Drying (AWD)

Alternate wetting and drying (AWD) is a water-saving irrigation technique mainly used in rice in which the field is not maintained under continuous flooding. Instead, irrigation is applied after the ponded water disappears and the soil is allowed to undergo a controlled drying period before the next irrigation. This reduces unnecessary standing water and encourages the rice crop to use both irrigation water and stored soil moisture more efficiently. AWD is therefore an important alternative to continuous flooding for improving irrigation water productivity in conservation-based rice production.

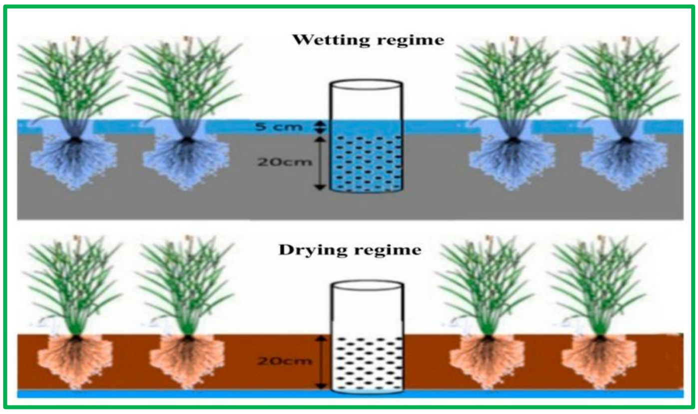


**Fig. 3: Wetting and drying regimes under AWD.**

**Fig. 4: Field implementation of AWD in rice.**

Under suitable soil and crop conditions, AWD can substantially reduce irrigation requirements without causing a significant reduction in yield. After the disappearance of ponded water, irrigating rice at approximately 2-day intervals can maintain higher yields while saving considerable irrigation water compared with continuous flooding.The principle is to allow the soil to dry to a safe level but avoid severe water stress, particularly during sensitive crop-growth stages. Soil moisture or water level in the field can be monitored to decide when irrigation is required. AWD can be further combined with direct-seeded rice, residue retention and precise land levelling to increase its water-saving potential. By reducing the duration and amount of standing water, it can also decrease losses through evaporation and percolation and improve the productivity of irrigation water. Thus, AWD shifts rice cultivation from the traditional practice of continuous flooding towards controlled and need-based irrigation, making it an important strategy for sustainable water management under conservation agriculture.

**Drip Irrigation**

Drip irrigation is a highly efficient method of irrigation in which water is delivered slowly and directly to the crop root zone through emitters fitted on surface or subsurface pipelines. It may be used as surface drip irrigation (SDI) or sub-surface drip irrigation (SSDI). Unlike conventional flood irrigation, the entire field does not need to be flooded, which reduces unnecessary wetting, evaporation and deep percolation. Under conservation agriculture, drip irrigation can be combined with zero tillage, residue retention and permanent beds to further improve water-use efficiency. Drip irrigation has considerably higher application efficiency than conventional surface irrigation. Its conveyance efficiency can approach 100%, while application efficiency is generally about 70–90%, compared with approximately 40–70% conveyance efficiency and 60–70% application efficiency under basin irrigation. Because water is supplied close to the root zone, irrigation can be matched more closely with crop demand. Drip irrigation can substantially improve yield and water productivity in crops such as cotton, sugarcane, soybean, maize and wheat. The water-saving potential is particularly significant in rice–wheat systems. Drip irrigation in wheat can save 24–43% irrigation water, depending on the irrigation regime, while increasing wheat yield by 16–28%. Irrigation water productivity under surface drip irrigation was 0.85–0.90 kg $m^{-3}$ in direct-seeded rice, compared with 0.42–0.52 kg $m^{-3}$ under flood irrigation (Sharda et al., 2017). When combined with conservation agriculture and residue retention, sub-surface drip irrigation can save 48–53% irrigation water in rice and 42–53% in wheat compared with conventional flood irrigation. Drip irrigation therefore reduces water losses while allowing more precise application of irrigation to the crop root zone. Its integration with conservation agriculture can substantially improve water productivity, crop productivity and sustainability of irrigated farming, particularly in regions facing groundwater depletion and increasing water scarcity.

## Conclusion

Efficient water management is essential for sustaining agricultural production under increasing water scarcity and climate variability. Conservation agriculture provides several complementary approaches for reducing water losses and improving water productivity, including laser land levelling, permanent raised beds, non-puddled and direct-seeded rice, zero tillage, surface mulching, alternate wetting and drying and drip irrigation. These practices help conserve soil moisture, reduce unnecessary irrigation, improve the efficiency of water application and maintain crop productivity with fewer inputs. Their combined adoption can be particularly beneficial in water-intensive cropping systems such as rice–wheat, where groundwater depletion is a major concern. Thus, integrating conservation agriculture with efficient water-management technologies can help achieve higher crop production per unit of water while improving the long-term sustainability and resilience of agricultural systems.

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