Chronicle of Bioresource Management 2026, 10(2): 042-045

Chronicle of Bioresource Management
An International E-magazine

June, 2026 **Popular Article**

DOI: HTTPS://DOI.ORG/10.23910/3.2026.7167

Non-Puddled Transplanted Rice (NPTR): Prospects and Challenges

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Abstract

Conventional rice cultivation in South Asia is heavily dependent on Puddled Transplanted Rice (PTR), a method that is increasingly unsustainable due to its massive water, energy, and labour requirements. While Direct Seeded Rice (DSR) offers a low-water alternative, it is plagued by poor crop stands, yield penalties, and uncontrollable weed flushes. Non-Puddled Transplanted Rice (NPTR) emerges as a strategic technical compromise, bypassing the germination risks of DSR while avoiding the structural soil damage of TPR. This article evaluates the physiological and soil-mechanical conditions necessary for NPTR success. We identify that soil texture, specifically Saturated Hydraulic Conductivity (Ksat) and seedling age (25–30 days) are the primary determinants of yield stability. By maintaining Saturated Soil Culture (SSC), NPTR can reduce the "Water" footprint and preserve soil health for succeeding crops, provided that specific challenges regarding nitrogen volatilization and iron chlorosis are addressed through precision management.

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Citation: Vijayakumar, 2026. Non-Puddled Transplanted Rice (NPTR): Prospects and Challenges. Chronicle of Bioresource Management 10(2), 042-045. HTTPS://DOI.ORG/10.23910/3.2026.7167.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

Keywords:

Paddy, rice, crop establishment, puddling

Article History

Article ID: CBM7167

Received on 03rd May 2026

Received in revised form on 13th June 2026

Accepted in final form on 25th June 2026

1. Introduction

Rice is the staple food for millions, yet its conventional production method, Puddled Transplanted Rice (PTR), faces an existential crisis. The practice of puddling, churning soil in standing water is fraught with environmental and economic drawbacks. It demands exorbitant amounts of water and energy for pumping, contributes significantly to Greenhouse Gas (GHG) emissions (specifically methane), and requires intensive manual labour during the transplanting phase. Furthermore, puddling destroys soil aggregates and creates a restrictive "hard-pan," which leads to poor drainage and delayed sowing of succeeding crops like wheat, ultimately reducing total system productivity.

While Direct Seeded Rice (DSR) has been proposed to mitigate these issues, it is burdened by significant agronomic constraints. DSR frequently suffers from a yield penalty compared to TPR, often attributed to poor crop stand and uneven germination. Furthermore, DSR management is complicated by multiple flushes of weeds that emerge throughout the season, alongside physiological issues like iron chlorosis in aerobic soils. Non-Puddled

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Transplanted Rice (NPTR) serves as a strategic middle ground. By transplanting established seedlings into a well-tilled but non-puddled field, usually maintained under Saturated Soil Culture (SSC), NPTR attempts to bypass the germination hurdles of DSR while avoiding the ecological damage of puddling. Move this sentence to end of the next sentence. So that this sentence will be end of the introduction.

NPTR cultivation is evaluated as a critical alternative to conventional PTR in India and Asia, driven by the need to address labour shortages, water scarcity, and soil degradation. However, the scope of NPTR lies in its ability to maintain or enhance yields while significantly reducing the environmental and economic "footprints" of rice production.

2. Scope and Productivity Potential

Study in Haryana, India, demonstrated that mechanized NPTR can produce 3%–11% higher grain yields compared to CPTR across various cultivars including HKR47 and PR114 (Kamboj et al., 2014). Additionally, by eliminating puddling, NPTR prevents the formation of a "hard pan" in the soil. This facilitates better root growth for subsequent upland crops in the rotation, such as wheat or lentils, improving overall system productivity (Kamboj et al., 2014). Moreover, NPTR can reduce irrigation water requirements by 22% to 28% and fuel consumption for tillage by 50%–70% compared to conventional methods (Hossen et al., 2018). Furthermore, the shift to NPTR is a significant lever for climate-smart agriculture in Asia. Life cycle assessments indicate that NPTR can save 35% of net GHG emissions compared to conventional practice (Alam, 2020). By reducing the period and intensity of soil anaerobic conditions, NPTR lowers methane emissions. While DSR is also effective, NPTR avoids the significant yield penalties (up to 11%) sometimes seen in DSR (Reddy et al., 2025).

3. Comparative Advantages: Is NPTR Better than DSR?

NPTR outperforms DSR in three critical dimensions namely weed management, water efficiency, and soil health.

(i) NPTR offers superior weed management. In DSR, weeds and rice germinate simultaneously, often resulting in weeds outnumbering and outgrowing the crop. NPTR provides a "head start" by utilizing 25-to-30-day-old seedlings. These taller seedlings offer a spatial advantage and achieve canopy closure faster. This shading effect suppresses sunlight-dependent weed seeds (such as *Echinochloa*) before they can emerge, effectively managing the "multiple flushes" that plague DSR.

(ii) Water Savings: While dry DSR is more water-efficient in theory, NPTR significantly outperforms wet DSR. Puddling in wet DSR demands massive water inputs for land preparation. NPTR eliminates puddling entirely, though success depends on maintaining field capacity. If the soil is not perfectly saturated during transplanting, it can shrink away from the roots, creating lethal air gaps. A "glistening" wet surface rather than standing water is required to ensure firm soil-to-root contact.

(iii) Preserved Soil Health: Unlike TPR, NPTR preserves soil aggregates, benefiting subsequent crops like wheat or legumes. While non-puddled soils exhibit higher surface bulk density, the absence of a restrictive "hard-pan" allows for better root penetration for following rotation crops.

4. Adoption Barriers: The "Quiet Killers" of NPTR

Despite its theoretical benefits, NPTR adoption is hindered by three major constraints:

(i) Labour Intensity: Manual transplanting remains the most expensive and labour-demanding phase. Many farmers prefer the weed-suppressing "safety" of puddled soil if they are already committed to high labour costs.

(ii) Mechanical Limitations: Existing mechanical transplanters are engineered for "muck" (puddled slurry). In the firmer, non-puddled soil of NPTR, mechanical "fingers" often fail to grip the soil or inadvertently damage the seedlings.

(iii) Absence of a Hard-Pan: Puddling creates an impervious layer that holds water. Without this barrier, water percolates rapidly in light-textured soils, leading to prohibitive irrigation costs unless the soil has naturally high clay content.

5. Success Factors: When Does NPTR Work?

The viability of NPTR is governed by the Saturated Hydraulic Conductivity (Ksat) of the soil and the physiological maturity of the seedlings.

(i) Soil Type and Preparation: High clay content (e.g., Vertisols) is the "Gold Standard" for NPTR. These soils exhibit "self-sealing" properties. As they wet, the clay expands to naturally restrict drainage. Conversely, NPTR usually fails in sandy soils where water "gallops" through the profile, requiring irrigation every 24 hours and increasing the Blue Water Footprint. Furthermore, NPTR requires a fine tilth and precision laser leveling to prevent air pockets around roots and ensure uniform moisture distribution.

(ii) The Crucial Role of Seedling Age: In NPTR, seedling age is more critical than in PTR because the firmer soil is less forgiving than slurry. Young Seedlings (<20 days): These are too tender and susceptible to mechanical damage. Their soft roots often fail to penetrate the firmer soil, leading to high "transplant shock" or lodging. Ideal Seedlings (25–30 days): These possess lignified (woody) bases and higher carbohydrate reserves. They have the "pushing power" (root penetration potential) required for non-puddled environments. Old Seedlings (>40 days): While robust, their primary root systems begin to senesce (age), which can cause stunting and poor tillering.

6. Critical Technical Constraints

Nutrient Dynamics and Iron Chlorosis: Nutrient management in NPTR is more complex than in TPR due to fluctuating aerobic and anaerobic states.

(i) Nitrogen (N) Loss: In NPTR, the absence of a compacted soil "hard pan" and the maintenance of more aerobic soil conditions significantly alter nitrogen and micronutrient dynamics. Frequent Nitri-Denitrification cycles occur as soil oscillates between wet and dry. This leads to N being lost as N_2O gas, typically requiring 10-15% more N than TPR, applied in smaller, more frequent doses. Iron (Fe) Availability: Puddling induces a "reduced" state that converts Ferric iron (Fe^{3+}) to the plant-available Ferrous state (Fe^{2+}). In the more "oxidized" aerobic environment of NPTR, iron remains in the Fe^{3+} state. In neutral or alkaline soils, this frequently results in iron chlorosis (yellowing of leaves).

Table 1: Seedling Age Performance in NPTR

Seedling Age	Survival Rate	Weed Competition	Recovery Time	Recommendation
Young (15-20 days)	Low (Fragile)	Poor	Long (7-10 days)	No
Ideal (25-30 days)	High	Good	Short (3-5 days)	Yes (Best Choice)
Old (>40 days)	Medium (Stunted)	Excellent	Medium	Only if necessary

(ii) Initial Mortality: In TPR, the slurry "hugs" the roots, ensuring 100% contact. In NPTR, the soil is an aggregate of solids. Failure to keep the soil perfectly saturated for the first seven days post-transplant can result in total crop failure due to moisture-related transplant shock.

7. Needed intervention for popularizing NPTR

To promote NPTR, a combination of technical, economic, and extension-based interventions is required. These solutions focus on overcoming the primary barriers to adoption, such as increased weed pressure, the need for specialized mechanization, and technical knowledge gaps.

7.1. Technical interventions

The transition to NPTR necessitates precise management techniques to ensure yield stability.

(i) Laser Land Leveling (LLL): This is a critical prerequisite for NPTR. LLL can save approximately 30% of irrigation water and improve yields by 4% compared to un-leveled puddled fields by ensuring uniform water distribution (Bhatt et al., 2021).

(ii) Integrated Weed Management (IWM): Because non-puddled soils do not benefit from the weed-suppressing "smothering" effect of puddling, sequential herbicide applications are necessary. Effective protocols include pre-emergence followed by post-emergence herbicides are essential. However, in place where manual weeding is feasible, then sequential herbicide application is not required. Only one herbicide application, either pre or post emergence application is sufficient.

(iii) Nutrient Management: Unlike puddled systems where standing water and a semi-impermeable layer restrict downward movement, NPTR soils typically exhibit higher infiltration rates, which increases the risk of N leaching, particularly of nitrate (NO_3^-). To mitigate these losses and align nutrient availability with the crop's physiological needs, a higher frequency of split applications (typically 4 splits) is essential (Vijayakumar et al., 2023). Furthermore, the higher redox potential in unpuddled soils can lead to iron (Fe) chlorosis, as iron remains in the less soluble ferric (Fe^{3+}) state rather than the plant-available ferrous (Fe^{2+}) state common in flooded soils. This often necessitates prophylactic foliar sprays of ferrous sulphate to prevent significant biomass and yield reductions.

(iv) Mat-Type Nurseries: Successful mechanized NPTR requires “mat-type” nurseries where seedlings are grown on thin layers of soil and manure over plastic sheets. This allows the mechanical transplanter to pick seedlings effectively, which is essential for maintaining optimum plant density.

7.2. Socio-economic and institutional solutions

Addressing the capital intensity of mechanization is vital for smallholder adoption.

(i) Custom Hiring Centers (CHCs): Government-supported CHCs allow small and marginal farmers to access costly machinery like mechanical transplanters and Versatile Multi-crop Planters (VMP) on a rental basis, reducing the need for individual capital investment.

(ii) Subsidies and Incentives: Schemes like the Sub-Mission on Agricultural Mechanization (SMAM) in India provide financial assistance for purchasing specialized equipment. Expanding these initiatives to specifically target NPTR-compliant machinery is a key policy lever.

(iii) Carbon Credits and Payments for Ecosystem Services: Since NPTR reduces methane emissions by approximately 35%, integrating these farmers into carbon markets can provide additional income, incentivizing the shift away from puddled systems.

7.3. Extension and policy frameworks

Scaling the technology requires robust knowledge dissemination and regional coordination.

(i) Participatory Research and Demonstrations: Establishing large-scale “cluster demonstrations” on farmers’ fields is one of the most effective ways to build trust. Exposure visits allow farmers to see the yield parity and labour-saving benefits of NPTR firsthand.

(ii) Policy Realignment: Realigning regional water and electricity subsidies to favour water-saving technologies like NPTR can accelerate adoption. In areas with high pre-monsoon showers (like Eastern India), NPTR is often a more viable “climate-smart” option than DSR because it avoids the risks of poor germination in heavy rains.

8. Conclusion

NPTR offers a promising path toward sustainable rice production by mitigating the structural damage caused by puddling. By utilizing 28-day-old seedlings, farmers can create a “biological window” where the rice canopy dominates weeds naturally. This will reduces the “Grey Water Footprint” by lowering herbicide dependency over DSR. However, for NPTR to be successful, it must be targeted to heavy-textured soils and managed with precision regarding seedling maturity, irrigation, and nitrogen application.

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