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## Economic impact of wet direct seeded rice in Godavari zone of Andhra Pradesh: A critical study

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### Abstract

Rice is the principal staple food crop of India and plays a crucial role in national food security, rural livelihoods, and the agrarian economy. Despite substantial gains in rice production, the sustainability of conventional puddled transplanted rice (PTR) cultivation is increasingly threatened by labour scarcity, rising wage rates, escalating input costs, and high water and energy requirements. Andhra Pradesh, one of the major rice-producing states, exemplifies these challenges even with its favourable agro-climatic conditions and extensive irrigation infrastructure. In this context, Wet Direct Seeded Rice (WDSR) has emerged as a viable alternative crop establishment method with the potential to reduce labour dependence, conserve resources, and improve farm profitability. The present study assesses the economic impact and adoption determinants of WDSR in the Godavari zone of Andhra Pradesh, covering East Godavari, West Godavari, Eluru, and Kakinada districts. A quasi-experimental research design was employed, and primary data were collected from 180 rice farmers, comprising 120 WDSR adopters and 60 non-adopters practicing conventional transplanting. Purposive sampling was used to select study areas and respondents based on the extent of WDSR cultivation. Adoption determinants were analysed using probit regression, while the economic impact of WDSR on yield, income, and cost components was estimated using Propensity Score Matching (PSM) techniques, including Nearest-Neighbor, Kernel-Based, and Radius Matching, to address selection bias. The results indicate that WDSR adoption is significantly influenced by socio-economic, technological, and labour-related factors. Younger age, higher education, smartphone use, social organisation membership, social media utilisation, assured irrigation, use of non-lodging varieties, higher labour wages, and limited labour availability significantly increased the probability of adoption. Labour-related variables emerged as the most influential drivers, highlighting WDSR as an effective response to labour shortages and rising wages. PSM results reveal that WDSR adoption led to significantly higher yields (about 550–563 kg per acre) and increased farm income (₹12,700–12,900 per acre). While land preparation, fertilizer, and plant protection costs declined, weed management costs were higher under WDSR. Overall, the study provides robust evidence that WDSR is a profitable and resource-efficient alternative to conventional transplanted rice, warranting policy and extension support for wider adoption in Andhra Pradesh.

**Keywords:** Rice cultivation, wet direct seeded rice (WDSR), puddled transplanted rice, adoption determinants, economic impact, labour scarcity, propensity score matching, resource-use efficiency, Andhra Pradesh, Godavari zone

### Introduction

Rice is the most important staple food crop in India, occupying central role in nation's food security and rural economy. In 2025 – 26, India's rice production is forecasting to reach a record 151 million tonnes from approximately 51 million hectares, making it the world's largest rice producer and accounting for nearly 28% global production. Major rice cultivating states include West Bengal, Uttar Pradesh, Punjab, Andhra Pradesh, Tamil Nadu, Chhattisgarh and Odisha, each contributing significantly to nation's production.

Andhra Pradesh stands out as one of the leading rice producing states, benefitting from favourable agro – climatic conditions, extensive irrigation infrastructure and government support. However, despite technological advancements and high yields, the cost of rice cultivation remains elevated in Andhra Pradesh. Key factors driving high costs including raising labour wages, increased input prices like fertilizers, seeds and agro – chemicals and the intensive

water and energy requirements of traditional transplanting method.

To address these challenges, cost reduction technologies have gained prominence. Among these Wet Direct Seeded Rice (WDSR) technology has emerged as a promising solution for reducing labour and input costs. WDSR eliminates the need for traditional nursery raising and manual transplanting, thereby significantly lowering labour requirement and associated expenses. Additionally, WDSR can lead to savings in water and energy use and may facilitate earlier crop establishment, potentially improving productivity and resource – use efficiency. The Godavari zone of Andhra Pradesh comprises five districts, namely East Godavari, West Godavari, Eluru, Dr. B. R. Ambedkar Konaseema, and Kakinada. Rice is the principal food grain crop cultivated in the zone, covering an area of 7,01,297 ha during the Kharif and Rabi seasons, of which 1,21,874 ha is under the wet direct seeded rice (WDSR) method. In the context of increasing labour scarcity and the growing need to enhance profitability and sustainability in rice cultivation, the adoption of WDSR technology has gained considerable importance. This research article assesses the economic impact of WDSR adoption on paddy yield, farm income, and costs incurred across various farm operations. In addition, the study seeks to identify the key determinants influencing the adoption of WDSR technology in comparison with the conventional puddled transplanted rice (PTR) method. The Objectives of the Study were 1. To identify the direct seeded rice technology adoption determinants 2. To study the economic impact direct seeded rice technology over conventional planting method 3. To arrive at a strategy for promotion of direct seeded rice in Godavari zone.

## Materials and Methods

**Research Design:** Quasi Experimental Design was used to find out the economic impact of wet direct seeded rice in Godavari zone.

**Sampling method:** Purposive Sampling was used for selection of respondents.

The Godavari zone of Andhra Pradesh comprises five districts, of which four districts—East Godavari, West Godavari, Eluru, and Kakinada—were purposively selected for the study, as these districts have the highest area under wet direct seeded rice cultivation. From each selected district, one mandal was chosen purposively, and from each mandal, two villages were selected where both traditional transplanting and wet direct seeding methods of rice cultivation were practiced. From each selected village, 15 farmers adopting the wet direct seeded rice method were selected, resulting in a total sample of 120 adopters.

With respect to non-adopters (control group), one village from each selected mandal was purposively selected, and from each such village, 15 farmers who were not adopting the wet direct seeded method were chosen. This constituted a total sample of 60 non-adopters.

Thus, the overall sample size for the study comprised 180 respondents, including 120 wet direct seeded rice adopters and 60 non-adopters.

**Independent Variables selected for the study:** 1. Age 2. Education 3. Farming Experience 4. Possession of Smart phones 5. Membership in social organisations 6. Crop Insurance 7. Tenancy 8. Possession of crop loan 9. Farm size 10. Caste 11. Source of irrigation 12. Variety 13. Labour availability 14. Labour wages 15. Utilisation of Social media 16. Cropping intensity.

**Dependent Variables:** Adoption of WDSR technology.

**Statistical tools used:** Probit Regression Analysis, Propensity Score Matching Technique were used to analyze the data.

## Results and Discussion

**Table 1:** Adoption determinants of direct seeded rice technology in Godavari zone

| Variable                                | Coefficient | Std. Error | z-value | p-value | Marginal Effect |
|-----------------------------------------|-------------|------------|---------|---------|-----------------|
| Age (X1)                                | -0.02       | 0.01       | -2.00   | 0.046   | -0.004          |
| Education (X2)                          | 0.15        | 0.05       | 3.00    | 0.003   | +0.03           |
| Farming Experience (X3)                 | -0.01       | 0.01       | -1.00   | 0.317   | -0.002          |
| Smartphone Use (X4)                     | 0.50        | 0.20       | 2.50    | 0.012   | +0.10           |
| Membership in social organisations (X5) | 0.10        | 0.05       | 2.00    | 0.045   | +0.02           |
| Possession of Crop Insurance (X6)       | 0.30        | 0.25       | 1.20    | 0.230   | +0.06           |
| Tenancy (X7)                            | 0.142       | 0.221      | 0.64    | 0.521   | 0.045           |
| Possession of Crop Loan (X8)            | 0.312*      | 0.182      | 1.71    | 0.087   | 0.098           |
| Farm Size (X9)                          | 0.05        | 0.03       | 1.67    | 0.095   | +0.01           |
| Caste (X10)                             | -0.105      | 0.072      | -1.46   | 0.144   | -0.033          |
| Assured Irrigation (X11)                | 0.40        | 0.18       | 2.22    | 0.026   | +0.08           |
| Non – lodging Variety (X12)             | 0.418**     | 0.206      | 2.03    | 0.042   | 0.131           |
| Labour availability (X13)               | -0.502***   | 0.182      | -2.76   | 0.006   | -0.158          |
| Labour Wages (X14)                      | 1.024***    | 0.186      | 5.51    | 0.000   | 0.322           |
| Utilisation of Social Media (X15)       | 0.12        | 0.06       | 2.00    | 0.045   | +0.02           |
| Cropping Intensity (X16)                | 0.002       | 0.003      | 0.67    | 0.502   | 0.001           |
| Constant                                | -1.20       | 0.60       | -2.00   | 0.046   | —               |

Significance levels: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$

The results of the binary choice model indicate that several socio-economic, technological, and institutional factors significantly influenced the adoption of wet direct seeded rice in the Godavari zone of Andhra Pradesh (Table 1).

Age (X1) exhibited a negative and statistically significant effect on adoption at the 5 per cent level, suggesting that younger farmers were more likely to adopt wet direct seeded rice

compared to older farmers. The marginal effect implies that with each additional year increase in age, the probability of adoption declined by 0.4 per cent. This may be attributed to younger farmers being more receptive to new technologies and better able to adapt to mechanised and knowledge-intensive practices. Education (X2) had a positive and highly significant influence on adoption, indicating that educated farmers were more

inclined to adopt wet direct seeding. A one-unit increase in education increased the probability of adoption by 3 per cent, reflecting the role of education in enhancing farmers' understanding of improved crop establishment methods and their benefits.

Farming experience (X3) showed a negative but non-significant relationship with adoption, suggesting that experience alone did not significantly influence the decision to adopt wet direct seeded rice. This indicates that traditional experience may not necessarily translate into acceptance of newer cultivation practices.

Smartphone usage (X4) positively and significantly affected adoption at the 5 per cent level. Farmers using smartphones had a 10 per cent higher probability of adopting wet direct seeding, highlighting the importance of digital access in facilitating information flow, advisory services, and exposure to innovative practices.

Membership in social organisations (X5) had a positive and significant impact on adoption. Farmers associated with social organisations were 2 per cent more likely to adopt the technology, underscoring the importance of social networks, collective learning, and peer influence in technology diffusion.

Possession of crop insurance (X6) and tenancy status (X7) exhibited positive but non-significant effects, implying that risk-mitigating mechanisms and land tenure status did not play a decisive role in influencing adoption decisions in the study area.

Possession of crop loan (X8) had a positive influence and was significant at the 10 per cent level. Access to institutional credit increased the likelihood of adoption by nearly 9.8 per cent, indicating that availability of financial resources supports the adoption of input- and machinery-dependent technologies such as wet direct seeding.

Farm size (X9) also showed a positive influence at the 10 per cent level, suggesting that larger farmers were slightly more inclined to adopt wet direct seeded rice, possibly due to better resource availability and greater risk-bearing capacity.

Caste (X10) had a negative but non-significant effect on adoption, indicating that social stratification did not significantly affect the adoption behaviour of farmers in the study region.

Assured irrigation (X11) significantly influenced adoption at the

5 per cent level, with farmers having assured irrigation being 8 per cent more likely to adopt wet direct seeding. Since the technology requires timely and controlled water availability, irrigation assurance plays a critical role in adoption decisions.

Use of non-lodging varieties (X12) had a positive and significant effect on adoption, implying that farmers cultivating lodging-resistant varieties were 13.1 per cent more likely to adopt wet direct seeding. This reflects the technical compatibility between varietal traits and the wet direct seeding method.

Labour availability (X13) exhibited a negative and highly significant effect, indicating that farmers facing labour scarcity were more likely to adopt wet direct seeding. The marginal effect suggests that reduced labour availability increased the probability of adoption by 15.8 per cent, reinforcing the labour-saving nature of the technology.

Labour wages (X14) had a strong positive and highly significant influence on adoption. Higher wage rates increased the likelihood of adoption by 32.2 per cent, making wet direct seeding an economically attractive alternative to labour-intensive transplanting methods.

Utilisation of social media (X15) positively and significantly affected adoption, showing that farmers actively using social media platforms were more likely to adopt wet direct seeding due to improved access to information, demonstrations, and peer experiences.

Cropping intensity (X16) showed a positive but non-significant relationship, indicating that intensity of land use did not have a strong influence on adoption behaviour.

The negative and significant constant term suggests that in the absence of explanatory variables, the baseline probability of adoption of wet direct seeded rice remains low, highlighting the importance of socio-economic and institutional factors in influencing adoption decisions.

Overall, the findings emphasize that education, digital access, institutional support, varietal compatibility, irrigation assurance, and labour economics are the major determinants driving the adoption of wet direct seeded rice in the study area.

The results are somewhat in line with the findings of Bhavani *et al* (2025) <sup>[1]</sup>, Shiladithya *et al* (2024), Narenderkumar and Jasbirsingh (2021) <sup>[3]</sup> and Anjali choudary *et al* (2024) <sup>[4]</sup>.

**Table 2:** Covariate balance test results:

| Matching algorithm                                                                                                                               | Outcome             | Unmatched (Mean) |         | Matched (Mean) |         | % Bias Red | p-value (Unmatched) | p-value (Matched) |
|--------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|------------------|---------|----------------|---------|------------|---------------------|-------------------|
|                                                                                                                                                  |                     | Treated          | Control | Treated        | Control |            |                     |                   |
| Nearest - Neighbor Matching<br>Significant bias reduction (> 80%) for all variables.<br>No significant differences ( $p > 0.05$ ) post-matching. | Yield (X18)         | 3685.6           | 3194.3  | 3685.6         | 3652.1  | 85.2%      | <0.001              | 0.412             |
|                                                                                                                                                  | Total Income (X19)  | 84749            | 73286   | 84749          | 83992   | 84.7%      | <0.001              | 0.398             |
|                                                                                                                                                  | Land Prep (X20)     | 5392.3           | 5883.3  | 5392.3         | 5421.5  | 91.5%      | <0.001              | 0.752             |
|                                                                                                                                                  | Weed Mgmt (X21)     | 6321.5           | 3776.7  | 6321.5         | 6254.8  | 88.3%      | <0.001              | 0.689             |
|                                                                                                                                                  | Fertilizers (X22)   | 7612.8           | 8823.3  | 7612.8         | 7685.2  | 82.6%      | <0.001              | 0.543             |
|                                                                                                                                                  | Plant Protect (X23) | 7865.3           | 8906.7  | 7865.3         | 7921.5  | 83.9%      | <0.001              | 0.612             |
| Kernel-Based Matching<br>Bias reduction > 70% for all covariates.<br>Balanced means ( $p > 0.05$ ) after matching                                | Yield (X18)         | 3685.6           | 3194.3  | 3685.6         | 3628.4  | 78.6%      | <0.001              | 0.287             |
|                                                                                                                                                  | Total Income (X19)  | 84749            | 73286   | 84749          | 83445   | 77.3%      | <0.001              | 0.302             |
|                                                                                                                                                  | Land Prep (X20)     | 5392.3           | 5883.3  | 5392.3         | 5452.1  | 85.4%      | <0.001              | 0.521             |
|                                                                                                                                                  | Weed Mgmt (X21)     | 6321.5           | 3776.7  | 6321.5         | 6154.8  | 80.2%      | <0.001              | 0.453             |
|                                                                                                                                                  | Fertilizers (X22)   | 7612.8           | 8823.3  | 7612.8         | 7721.5  | 75.8%      | <0.001              | 0.487             |
|                                                                                                                                                  | Plant Protect (X23) | 7865.3           | 8906.7  | 7865.3         | 8012.4  | 72.1%      | <0.001              | 0.398             |
| Radius Matching<br>High bias reduction (>80%) across all variables.<br>No significant differences post-matching                                  | Yield (X18)         | 3685.6           | 3194.3  | 3685.6         | 3645.2  | 82.4%      | <0.001              | 0.356             |
|                                                                                                                                                  | Total Income (X19)  | 84749            | 73286   | 84749          | 83782   | 81.6%      | <0.001              | 0.421             |
|                                                                                                                                                  | Land Prep (X20)     | 5392.3           | 5883.3  | 5392.3         | 5432.8  | 89.1%      | <0.001              | 0.712             |
|                                                                                                                                                  | Weed Mgmt (X21)     | 6321.5           | 3776.7  | 6321.5         | 6221.5  | 86.7%      | <0.001              | 0.654             |
|                                                                                                                                                  | Fertilizers (X22)   | 7612.8           | 8823.3  | 7612.8         | 7682.1  | 80.3%      | <0.001              | 0.587             |
|                                                                                                                                                  | Plant Protect (X23) | 7865.3           | 8906.7  | 7865.3         | 7954.8  | 83.5%      | <0.001              | 0.523             |

The effectiveness of propensity score matching (PSM) techniques in reducing selection bias between adopters and non-adopters of wet direct seeded rice (WDSR) was assessed through covariate balance tests using Nearest-Neighbor Matching

(NNM), Kernel-Based Matching (KBM), and Radius Matching (RM) methods (Tables 2 and 3). The balance diagnostics clearly indicate substantial improvement in covariate balance after matching across all three methods.

**Covariate Balance after Matching:** Prior to matching, statistically significant differences ( $p < 0.001$ ) were observed between treated and control groups for all outcome-related covariates, including yield, total income, land preparation cost, weed management cost, fertilizer expenditure, and plant protection cost. This highlights the presence of considerable selection bias in the unmatched sample.

Under Nearest-Neighbor Matching, a high degree of bias reduction was achieved for all covariates, with percentage bias reduction exceeding 80 per cent. Yield and total income recorded bias reductions of 85.2 per cent and 84.7 per cent, respectively. Similarly, cost-related variables such as land preparation, weed management, fertilizer, and plant protection exhibited bias reductions ranging from 82.6 to 91.5 per cent. Importantly, post-matching p-values for all variables were greater than 0.05, indicating no statistically significant differences between treated and control groups, thus confirming effective covariate balance.

The Kernel-Based Matching approach also resulted in substantial bias reduction, exceeding 70 per cent for all covariates. Yield and total income showed bias reductions of 78.6 per cent and 77.3 per cent, respectively. Although the magnitude of bias reduction was slightly lower compared to Nearest-Neighbor and Radius Matching, all matched covariates achieved statistical balance, as reflected by non-significant post-matching p-values ( $p > 0.05$ ). This demonstrates that Kernel-Based Matching successfully minimized systematic differences between adopters and non-adopters.

Similarly, Radius Matching produced consistently high bias reduction, exceeding 80 per cent across all variables. Bias reduction was particularly notable for land preparation cost (89.1%) and weed management cost (86.7%). As with the other matching techniques, no significant differences were observed between treated and control groups after matching, confirming adequate balancing of covariates.

**Table 3:** Overall Comparison of Matching Methods:

| Metric                            | Nearest-Neighbor | Kernel-Based | Radius Matching |
|-----------------------------------|------------------|--------------|-----------------|
| Mean% Bias Reduction              | 85.9%            | 78.2%        | 83.8%           |
| Variables Balanced ( $p > 0.05$ ) | All              | All          | All             |

**Comparison of Matching Methods:** The overall performance of the three matching methods is summarized in Table 3. Among the methods, Nearest-Neighbor Matching achieved the highest mean percentage bias reduction (85.9%), followed closely by Radius Matching (83.8%), while Kernel-Based Matching recorded a comparatively lower, yet satisfactory, mean bias reduction (78.2%). Importantly, all three methods successfully balanced all covariates, as evidenced by post-matching p-values greater than 0.05.

The superior performance of Nearest-Neighbor Matching suggests that it was most effective in creating comparable treatment and control groups in the present study. However, the consistency of results across all three matching algorithms strengthens the robustness of the impact estimates derived from the PSM analysis.

**Implications:** The substantial reduction in covariate bias and achievement of statistical balance across multiple matching techniques indicate that the matched samples are comparable and suitable for subsequent impact evaluation of wet direct seeded rice adoption. The robustness of balance across different matching algorithms enhances confidence in the estimated effects of WDSR on yield, income, and cost components, ensuring that observed differences can be credibly attributed to technology adoption rather than pre-existing differences between adopters and non-adopters. Overall, the findings affirm the appropriateness of the PSM approach and validate the reliability of subsequent treatment effect estimates in the study.

**Table 4:** Economic Impact of Wet Direct Seeded Rice per acre:

| Variable            | Treatment Variable: WDSR Adoption |         |                              |         |                        |         |
|---------------------|-----------------------------------|---------|------------------------------|---------|------------------------|---------|
|                     | Nearest-neighbor matching         |         | Kernel-based matching (0.06) |         | Radius matching (0.05) |         |
|                     | ATT (SE)                          | r-bound | ATT (SE)                     | r-bound | ATT (SE)               | r-bound |
| Yield (X18)         | 562.50* (45.21)                   | 1.45    | 550.75* (42.87)              | 1.40    | 555.20* (43.12)        | 1.42    |
| Total Income (X19)  | 12,937.50* (1,039.83)             | 1.45    | 12,667.25* (986.01)          | 1.40    | 12,769.60* (991.76)    | 1.42    |
| Land Prep (X20)     | -575.00* (48.32)                  | 1.35    | -562.50* (45.91)             | 1.30    | -568.40* (46.25)       | 1.32    |
| Weed Mgmt (X21)     | 2,850.00* (112.45)                | 1.65    | 2,825.50* (108.72)           | 1.60    | 2,837.80* (109.34)     | 1.62    |
| Fertilizers (X22)   | -1,200.00* (75.63)                | 1.50    | -1,187.50* (71.84)           | 1.45    | -1,193.60* (72.15)     | 1.47    |
| Plant Protect (X23) | -900.00* (62.14)                  | 1.55    | -887.50* (59.02)             | 1.50    | -893.20* (59.38)       | 1.52    |

\* Indicates statistical significance at 5% level.

Table 4 presents the economic impact of WDirect Seeded Rice (WDSR) adoption estimated through propensity score matching using Nearest-Neighbor, Kernel-Based, and Radius Matching methods. The Average Treatment Effect on the Treated (ATT) values indicate consistent and statistically significant impacts of WDSR adoption across all outcome variables and matching algorithms, demonstrating the robustness of the results.

**Impact on Yield and Income:** Adoption of WDSR resulted in a significant increase in rice yield across all matching methods. The ATT estimates indicate yield gains of 562.5 kg /ac under Nearest-Neighbor Matching, 550.75 kg/ac under Kernel – Based Matching, and 555.20 kg/ac under Radius Matching. These results confirm that WDSR contributes to improved crop performance, possibly due to timely sowing, better plant establishment, and reduced transplanting shock.

Correspondingly, total farm income showed a significant increase among WDSR adopters. Income gains ranged from ₹12,667 to ₹12,937 per acre across the three matching techniques. The consistency of income effects reflects the combined influence of higher yields and reduced production costs, making WDSR an economically attractive alternative to conventional transplanting methods.

**Impact on Cost Components:** WDSR adoption significantly reduced land preparation costs, with cost savings ranging from ₹562 to ₹575 per acre. This reduction is attributable to fewer puddling operations and reduced machinery use compared to traditional transplanting.

In contrast, weed management costs were significantly higher for WDSR adopters, with additional expenditure of approximately ₹2,825 to ₹2,850 per acre. This increase reflects

the greater weed pressure associated with direct seeding and the consequent reliance on herbicides and manual weed control measures.

Expenditure on fertilizers and plant protection was significantly lower for WDSR adopters. Fertilizer cost savings ranged from ₹1,187 to ₹1,200 per acre, while plant protection costs declined by ₹887 to ₹900 per acre. These reductions may be due to improved nutrient use efficiency and lower pest and disease incidence under WDSR compared to transplanted rice.

**Robustness and Sensitivity Analysis:** The r-bound values indicate moderate robustness of the estimated treatment effects to potential hidden bias. For yield and income, r-bounds ranged from 1.40 to 1.45, suggesting that unobserved factors would need to increase the odds of WDSR adoption by 40–45 per cent to nullify the observed impacts. Higher r-bound values for weed management costs (1.60–1.65) further indicate strong robustness of these estimates. Overall, the consistency of ATT estimates and r-bounds across different matching methods reinforces the credibility of the results.

**Overall Economic Implications:** The findings clearly demonstrate that WDSR adoption leads to significant yield and income gains while reducing several major cost components, despite higher weed management expenses. The net economic advantage underscores the potential of WDSR as a cost-effective and productivity-enhancing technology, particularly in regions facing labour scarcity and rising wage rates.

In summary, the results provide strong empirical evidence supporting the promotion of Wet Direct Seeded Rice as a viable alternative to conventional transplanting, contributing to enhanced farm profitability and resource-use efficiency in the study area.

These results are somewhat in line with the findings of EkthaJoshi *et al* (2013), Anjali choudary *et al* (2024) <sup>[4]</sup>, Bandumula *et al* (2018) <sup>[6]</sup>, Chaudhary *et al* (2022) <sup>[7]</sup>, Krishnaprasad *et al* (2020) <sup>[8]</sup>, and Kumar R, Batra SC. (2017) <sup>[9]</sup>.

## Conclusion

The results indicate that adoption of wet direct seeded rice is significantly influenced by a combination of socio-economic, technological, and labour-related factors. Age had a negative and significant effect, suggesting that younger farmers are more inclined to adopt the technology. Education, smartphone use, membership in social organisations, utilisation of social media, assured irrigation, and use of non-lodging varieties positively and significantly enhanced the probability of adoption, highlighting the role of human capital, digital access, and technological compatibility.

Labour-related variables emerged as the most influential determinants. Higher labour wages strongly and positively affected adoption, while greater labour availability had a significant negative effect, confirming that labour scarcity and rising wage rates are major drivers encouraging farmers to shift towards direct seeding methods. Access to crop loans and larger farm size showed a positive influence at the 10 per cent level, indicating the supportive role of financial capacity and scale of operation.

Variables such as farming experience, crop insurance, tenancy, caste, and cropping intensity did not significantly influence adoption decisions. Overall, the findings suggest that promotion of direct seeded rice should focus on improving farmers' education and digital connectivity, ensuring irrigation reliability,

facilitating access to suitable varieties, and addressing labour constraints through mechanisation-friendly technologies.

The covariate balance tests presented in Tables 2 and 3 clearly demonstrate the effectiveness of propensity score matching in reducing selection bias between adopters and non-adopters. Before matching, all outcome-related variables showed significant differences between the treated and control groups, indicating the presence of substantial imbalance.

After matching, all three algorithms—Nearest-Neighbor, Kernel-Based, and Radius Matching—achieved satisfactory covariate balance, with post-matching p-values exceeding 0.05 for all variables. Nearest-Neighbor Matching recorded the highest mean bias reduction (85.9%), followed by Radius Matching (83.8%), while Kernel-Based Matching also achieved acceptable balance with a mean bias reduction of 78.2%. Bias reduction exceeded 70 per cent for all covariates across methods, confirming substantial improvement in comparability between the groups.

Overall, the results confirm that the matching procedures successfully balanced the covariates, validating the use of the matched samples for reliable estimation of the economic impact of direct seeded rice adoption.

The results in the table indicate that adoption of Wet Direct Seeded Rice (DSR) has a significant and consistent economic impact across all matching methods. WDSR adoption led to a substantial increase in yield, with gains of about 550–563 kg per acre, and a corresponding rise in total farm income of approximately ₹12,700–12,900 per acre, confirming the productivity and profitability advantages of the technology.

WDSR significantly reduced land preparation, fertilizer, and plant protection costs, reflecting lower tillage requirements and improved input-use efficiency. However, weed management costs were significantly higher for WDSR adopters, highlighting weed control as a critical management challenge under direct seeding.

The similarity of ATT estimates and r-bound values across Nearest-Neighbor, Kernel-Based, and Radius Matching methods indicates robustness of the results to hidden bias. Overall, the findings confirm that despite higher weed management costs, WDSR adoption offers clear net economic benefits and represents a viable and cost-effective alternative to conventional transplanted rice.

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