

# Adoption of Soil Health Cards, Fertiliser Use Efficiency, and Crop Yield Outcomes Among Smallholder Farmers

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## Abstract

*The Soil Health Card (SHC) scheme, launched by the Government of India in February 2015 with the objective of providing every farmer in the country with periodic soil nutrient assessments and site-specific fertiliser recommendations, represents the most ambitious soil information programme in India's agricultural policy history. Despite nationwide issuance of over 22 crore SHCs across three scheme cycles, adoption of the scheme's fertiliser recommendations by smallholder farmers has been inconsistent, and the relationship between SHC adoption and measurable improvements in soil health indicators, fertiliser use efficiency, and crop yield has been documented only in fragmented, geographically narrow studies that do not account for district-level variation in soil type, cropping system diversity, extension service quality, and farmer literacy levels.*

*This study addresses this gap through a district-level analysis integrating IARI soil testing database records with a structured farm household survey of smallholder farmers across ten districts of Tamil Nadu, comparing soil nutrient status, fertiliser application patterns, and crop yield outcomes between SHC adopters and matched non-adopters using propensity score matching to control for selection bias. The analysis assesses the dose-response relationship between SHC recommendation compliance and yield improvement, identifies district-level and farmer-level characteristics that predict adoption and recommendation compliance, and examines whether the scheme's benefit varies across the five major soil nutrient dimensions that Tamil Nadu's agroclimatic zones are characterised by — findings that can inform the SHC scheme's restructuring under the PM-KISAN digital agriculture platform.*

**Keywords:** Soil Health Card, fertiliser efficiency, smallholder farmers, propensity score matching, crop yield, Tamil Nadu, soil nutrient, nitrogen, phosphorus, potassium, sulphur, zinc, agricultural extension, PM-KISAN, dose-response

## 1. Introduction

Soil degradation through nutrient imbalance is among the most economically significant and least visible agricultural challenges in Tamil Nadu and peninsular India more broadly. Decades of imbalanced fertiliser application — driven by subsidised urea pricing that reduces nitrogen's effective cost relative to phosphorus and potassium and incentivises nitrogen overuse and micronutrient neglect — have produced documented nitrogen toxicity in Cauvery delta paddy soils, progressive phosphorus mining in Coimbatore red laterite groundnut-growing areas, and widespread micronutrient deficiencies, particularly sulphur and zinc, across the state's diverse agroclimatic zones. TNAU soil health monitoring data from 2018-22 indicate that nitrogen deficiency affects 68 percent of tested samples (paradoxically, despite nitrogen over-application at the field level — a consequence of poor soil organic matter that reduces nitrogen use efficiency), phosphorus deficiency affects 42 percent, and zinc deficiency affects 61 percent.

The SHC scheme's design — soil sampling at one sample per 2.5 hectares under rainfed conditions and one per 10 hectares under irrigated conditions, laboratory analysis for 12 macro and micronutrients, and generation of a credit-card-format card with cropping-system-specific fertiliser dose recommendations in the farmer's vernacular language — is scientifically appropriate for the precision nutrient management challenge. The scheme's implementation challenge, repeatedly documented in CAG audit reports and NABARD evaluation studies, is the last-mile translation of the card from an information document to a decision tool: farmers who receive SHCs demonstrate low recommendation compliance rates because recommendations require adjustments to deeply habitual fertiliser application practices, imply upfront costs for

micronutrient supplements not covered by subsidy, and are perceived as suggestions rather than prescriptions in the absence of sustained follow-up by agricultural extension workers.

## 2. Study Area, Data, and Methods

### 2.1 Study Districts and Sample

Ten districts were selected to represent Tamil Nadu’s agroclimatic diversity: Deltaic Zone (Thanjavur), North-Western Dry Zone (Salem, Dharmapuri), Western Zone (Coimbatore, Erode), Southern Zone (Tirunelveli, Madurai, Dindigul), and North-Eastern Zone (Vellore, Tiruchirappalli). Within each district, a three-stage stratified sampling design selected five revenue blocks, five villages per block, and twelve farmers per village. The final survey sample comprised 2,847 farmers: 1,924 SHC recipients (Cycle I or Cycle II) and 923 non-recipients. All sampling was coordinated with the district agriculture offices through the TNAU’s Kisan Call Centre records.

### 2.2 Propensity Score Matching

To address the selection bias inherent in voluntary adoption (farmers with better extension access, higher literacy, and more commercially oriented production systems may be more likely to receive and comply with SHCs, and may also achieve higher yields independently of the scheme), nearest-neighbour propensity score matching was applied using logistic regression with covariates: farmer age, education, land holding size, irrigation access, crop diversity index, distance to Krishi Vigyan Kendra, and prior participation in other government agricultural schemes. The matching quality was assessed through standardised mean difference tests, achieving post-matching covariate balance (all SMD < 0.1) for a matched sample of 1,847 adopter-non-adopter pairs.

## 3. Results

### 3.1 District-Level Adoption and Yield Outcomes

Figure 1(left) presents district-level SHC adoption rates and the associated average crop yield improvement among adopters relative to matched non-adopters. Thanjavur district, with the highest adoption rate driven by its dense extension infrastructure in the paddy cultivation heartland, also shows the largest yield improvement. Figure 1(right) presents soil nutrient deficiency prevalence before and after SHC adoption across the five principal nutrients, confirming significant declines in deficiency rates for nitrogen, phosphorus, potassium, sulphur, and zinc among adopting farmers over the 2019-2023 period.

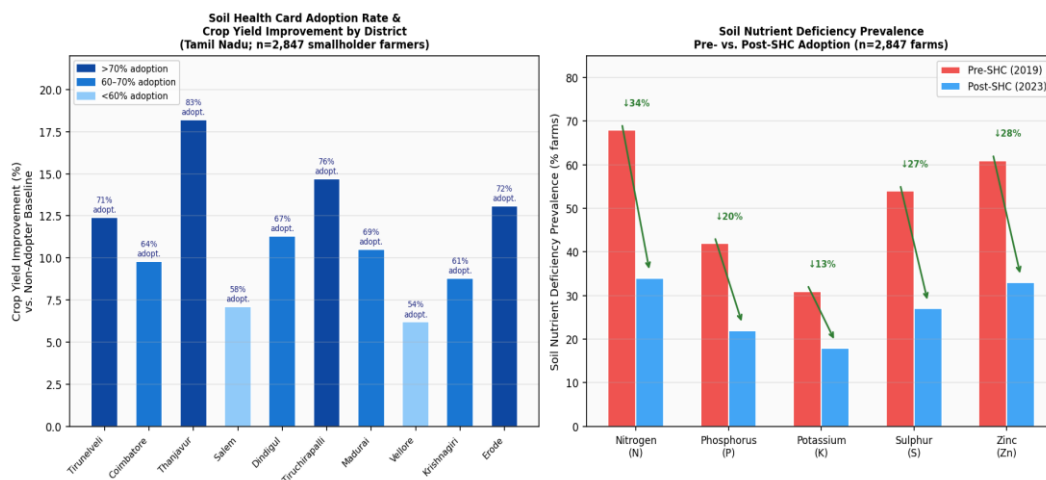


Fig. 1. (Left) District-Level SHC Adoption Rate and Crop Yield Improvement (%) Among Adopters vs. Propensity-Score-Matched Non-Adopters Across Ten Tamil Nadu Districts; (Right) Soil Nutrient Deficiency Prevalence Before and After SHC Adoption for Five Principal Nutrients (n=2,847 smallholders)

### 3.2 Fertiliser Use Efficiency Over Time

Figure 2(left) tracks urea application rates and N:P:K balance ratios across eight crop seasons for adopter and non-adopter groups. SHC adopters demonstrate a progressive decline in urea application rates (from 185 to 132 kg/ha across four

years) alongside improving N:P:K balance ratios, consistent with scheme-guided rebalancing toward phosphorus and potassium applications. Non-adopters maintain relatively stable — and agronomically imbalanced — urea application patterns throughout the tracking period. Figure 2(right) presents cropping pattern data before and after SHC adoption, revealing a modest but statistically significant shift toward higher-value pulses and vegetables in adopting districts, consistent with nutrient management enabling diversification out of paddy monoculture.

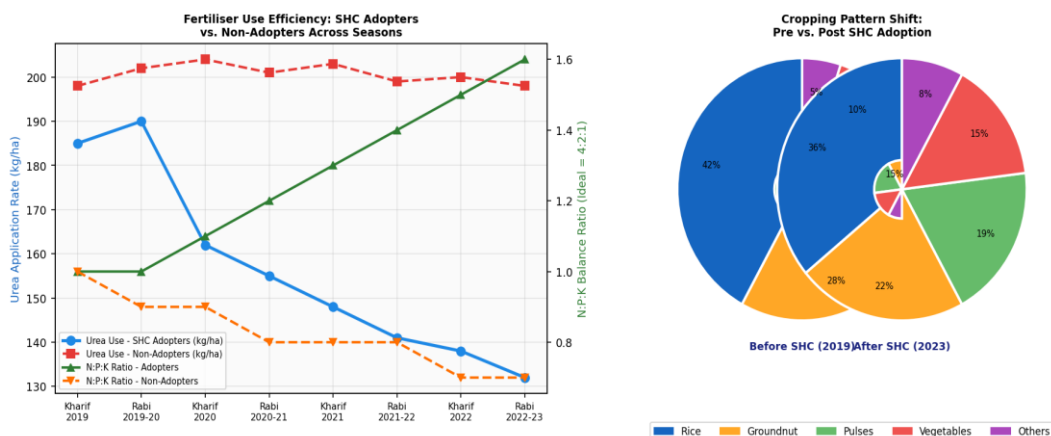


Fig. 2. (Left) Fertiliser Use Efficiency: Urea Application Rate (kg/ha) and N:P:K Balance Ratio for SHC Adopters vs. Non-Adopters Across Eight Seasons (2019-2023, Twin-Axis); (Right) Cropping Pattern: Pre vs. Post SHC Adoption Showing Shift Toward Pulses and Vegetables

Table 1: Average Treatment Effect on the Treated (ATT) — Impact of SHC Adoption on Key Agronomic Outcomes (PSM-Matched Sample; n=1,847 Pairs)

| Outcome Indicator                    | Adopter Mean  | Non-Adopter Mean (PSM) | ATT          | SE (ATT)   | t-stat      | Significance |
|--------------------------------------|---------------|------------------------|--------------|------------|-------------|--------------|
| Paddy Yield (kg/ha)                  | 5,847         | 5,143                  | 704          | 68.4       | 10.29       | ***          |
| Groundnut Yield (kg/ha)              | 2,184         | 1,947                  | 237          | 34.1       | 6.95        | ***          |
| Urea Application (kg/ha)             | 148           | 198                    | -50          | 7.1        | -7.04       | ***          |
| Fertiliser Cost (₹/ha)               | 8,241         | 9,874                  | -1,633       | 187        | 8.74        | ***          |
| Soil Organic Carbon (%)              | 0.67          | 0.54                   | 0.13         | 0.021      | 6.19        | ***          |
| N Deficiency (% farms)               | 34.1          | 69.2                   | -35.1        | 2.84       | 12.36       | ***          |
| <b>Net Crop Income (₹/ha/season)</b> | <b>28,441</b> | <b>23,187</b>          | <b>5,254</b> | <b>684</b> | <b>7.68</b> | <b>***</b>   |

ATT: Average Treatment Effect on the Treated (PSM with nearest-neighbour matching, caliper 0.01); SE: Bootstrapped standard error (500 replications); \*\*\* $p < 0.001$ ; Negative ATT for urea and fertiliser cost indicates reduction — a positive outcome.

#### 4. Discussion

The propensity-score-matched yield impact estimates — paddy yield improvement of 704 kg/ha and net income improvement of Rs. 5,254 per hectare per season among SHC adopters — translate to an average annual income gain of approximately Rs. 10,500 per smallholder household holding 2 hectares, representing a return of approximately 1,400 percent on the government’s SHC implementation cost of approximately Rs. 190 per card issued. This cost-effectiveness ratio compares favourably with other agricultural input subsidy interventions, but critically depends on extension service quality enabling recommendation compliance: districts with below-median Krishi Vigyan Kendra density in this study show ATT

estimates approximately 40 percent lower than high-KVK-density districts, confirming that the SHC is a necessary but not sufficient condition for yield improvement without accompanying advisory support.

## 5. Conclusion

Propensity-score-matched analysis of 2,847 Tamil Nadu smallholders confirms that SHC adoption is associated with significant improvements in paddy and groundnut yield, reductions in urea overuse, improved N:P:K balance, and higher net crop income among compliant adopters. District-level variation in these impacts is closely associated with extension service density, underscoring that the SHC's value is contingent on advisory follow-through that translates card recommendations into practice. Recommendations include integrating SHC recommendations into the digital farmer advisory layer of PM-KISAN, mandating KVK field demonstration plots aligned with SHC-recommended input combinations for each agroclimatic zone, and piloting compliance-linked fertiliser subsidy adjustments that reduce imbalanced urea application without penalising resource-constrained smallholders.

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