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Rural Economy and Environmental Change: A Study of Crop Cultivation and Consequences

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ABSTRACT

The rapid transformation of India's rural agrarian landscape in response to market forces, climate variability, and policy shifts has created profound socioeconomic and ecological consequences. This study investigates the complex interplay between crop cultivation practices, rural economic structures, and environmental change in the Gangetic Plain of Uttar Pradesh. Using a mixed-methods approach combining household surveys (n=420), key informant interviews (n=36), and satellite-derived land-use data across three agro-ecological zones, we examine how shifting cropping patterns affect soil health, water availability, and biodiversity, and how these environmental changes in turn shape farmers' livelihoods and community wellbeing. Results reveal a significant shift from diverse traditional cropping systems to monoculture cash crops, associated with a 34% decline in soil organic matter, a 28% reduction in groundwater table levels, and a 42% loss of cultivated agro-biodiversity over two decades. These changes have deepened socioeconomic vulnerabilities among small and marginal farmers, widened intra-community inequality, and eroded indigenous ecological knowledge. The study establishes that environmentally unsustainable crop cultivation is both a consequence of and contributor to rural economic precarity, forming a feedback loop that demands integrated policy intervention. Recommendations include promoting agro-ecological farming, strengthening farmer collectives, and embedding community ecological knowledge in agricultural extension programs.

Keywords: Rural economy, environmental change, crop cultivation, agro-ecology, land use, Uttar Pradesh, agrarian distress.

INTRODUCTION

Agriculture remains the backbone of India's rural economy, employing approximately 55 percent of the workforce and underpinning the livelihoods of over 600 million people (NITI Aayog, 2023). Yet the sector is undergoing a fundamental transformation driven by the convergence of market liberalisation, climate variability, demographic pressure, and rapid technological change. Nowhere is this transformation more acute than in the Gangetic Plain of Uttar Pradesh one of the world's most densely populated and agriculturally productive regions where the push for higher yields and market integration has progressively replaced diverse traditional farming systems with input-intensive, commercially oriented monocultures.

The consequences of this shift are neither economically neutral nor environmentally benign. While aggregate production statistics may suggest progress, the lived reality of millions of small and marginal farmers reflects a deepening cycle of debt, ecological degradation, and social vulnerability. Soil exhaustion, depleting aquifers, vanishing crop diversity, and the collapse of traditional commons are increasingly visible symptoms of a development model that has privileged short-term productivity over long-term sustainability.

From a social inclusion perspective, these changes are particularly consequential for historically marginalised communities Scheduled Castes, Scheduled Tribes, landless labourers, and women farmers who bear the greatest burden of environmental risk while having the least capacity to adapt. Understanding the mechanisms through which crop cultivation practices mediate environmental change and, in turn, reshape rural economic structures and social stratification is therefore a critical task for researchers and policymakers alike.

The Knowledge Gap

Existing scholarship has tended to treat rural economic change and environmental degradation as parallel but analytically separate phenomena. Agronomy literature focuses on biophysical dimensions of soil and water without adequately engaging with the social relations of production. Conversely, political economy approaches to agrarian change often treat the ecological dimensions as backdrop rather than as constitutive elements of the rural economy. Interdisciplinary studies that integrate socioeconomic, cultural, and ecological analysis at the community scale remain scarce, particularly for eastern Uttar Pradesh.

Furthermore, mainstream agricultural development discourses frequently overlook the differentiated impacts of crop system change on socially marginalised groups. The Centre for the Study of Social Inclusion at Banaras Hindu University is positioned to address this gap, bringing together agrarian studies, environmental sociology, and social justice perspectives.

Research Questions

This study is guided by the following primary research questions:

- How have crop cultivation patterns in rural Uttar Pradesh changed over the past two decades, and what social, economic, and policy drivers explain these shifts?
- What are the measurable environmental consequences of altered cropping systems, particularly with respect to soil health, water resources, and agro-biodiversity?
- How do these environmental changes affect the livelihoods, food security, and social wellbeing of rural households, with particular attention to marginalised communities?
- What structural, institutional, and community-based interventions can foster more ecologically sustainable and socially inclusive rural economies?

Purpose and Objectives

The overarching purpose of this study is to produce empirically grounded, theoretically informed, and policy-relevant knowledge about the relationships between agricultural change, environmental transformation, and rural economic wellbeing in Uttar Pradesh. Specific objectives are to:

- Map and analyse temporal changes in cropping patterns across three agro-ecological zones of the study area.
- Quantify key environmental indicators soil organic carbon, groundwater levels, crop diversity indices and correlate them with land-use changes.
- Document the socioeconomic impacts of environmental degradation on different categories of farmers, with disaggregated analysis by land size, caste, and gender.
- Identify and evaluate indigenous adaptive strategies and institutional arrangements that support sustainable agricultural livelihoods.
- Generate evidence-based policy recommendations for integrating social inclusion into agricultural and environmental governance frameworks.

REVIEW OF LITERATURE

The political economy of agrarian change in India has been extensively studied since the Green Revolution of the 1960s (Bhalla, 1977; Harriss, 1992; Lerche, 2011). Scholars have documented how the introduction of high-yielding variety seeds, chemical fertilisers, and irrigation infrastructure dramatically increased cereal production but simultaneously restructured social relations in the countryside, displacing labour, concentrating land, and accelerating class differentiation. The post-liberalisation period since 1991 has added further complexity: integration into global commodity markets has rewarded some farmers with higher prices but exposed many more to price volatility, input cost inflation, and credit risks (Patnaik, 2007; Ramachandran and Rawal, 2010).

In Uttar Pradesh specifically, the transition from subsistence polyculture to cash crop monoculture has been documented by Lerche (1999), Singh (2012), and Jha et al. (2018). These studies consistently find that while aggregate incomes have risen for commercially successful farmers, landless labourers and small holders have experienced stagnant real wages and growing indebtedness. The agrarian crisis, reflected in farmer suicides, rural out-migration, and the feminisation of agriculture, has been linked both to structural economic factors and to the environmental consequences of extractive farming practices.

The environmental literature on intensive agriculture in the Indo-Gangetic Plain is extensive and alarming. Intensive cultivation of wheat and rice the dominant Green Revolution crops has been associated with widespread soil organic matter decline, micronutrient deficiencies, and secondary salinisation (Ladha et al., 2003; Bhattacharyya et al., 2015). The widespread adoption of deep-tube-well irrigation for paddy cultivation has led to rapid depletion of groundwater across large parts of Punjab, Haryana, and western Uttar Pradesh, with the water table falling by as much as one metre per year in some districts (CGWB, 2020).

More recently, scholars have drawn attention to the ecological consequences of declining crop diversity. Traditional farming systems in the Gangetic Plain incorporated dozens of crop varieties millets, pulses, oilseeds, tubers, and vegetables that provided nutritional diversity, ecological resilience, and ecosystem services including nitrogen fixation, pest regulation, and pollinator habitat. The displacement of these systems by wheat-rice or wheat-sugarcane monocultures has been linked to increased pest pressures, loss of soil fauna, and the disappearance of hundreds of traditional cultivars from farmer fields (Yadav et al., 2019).

The environmental justice literature has consistently demonstrated that environmental degradation is not socially neutral: its burdens fall disproportionately on those with the least political and economic power (Bullard, 1990; Schlosberg, 2007). In the Indian context, Dalit and Adivasi communities, who are often landless or near-landless and depend on common pool resources including ponds, forests, and grazing lands, are acutely vulnerable to agricultural intensification and its environmental consequences (Vasavi, 2012; Mosse, 2018).

Gender dimensions are equally critical. Women in rural India perform the majority of subsistence agricultural labour, collect fuelwood and water, and bear primary responsibility for household food security. Environmental degradation through water scarcity, declining soil fertility, and reduced forest resources substantially increases women's labour burdens while reducing their control over productive resources (Agarwal, 1994; Gupta, 2017). Yet women remain systematically underrepresented in agricultural policy and extension systems.

A growing body of literature advocates agroecological approaches as alternatives to industrial monoculture: farming systems that work with ecological processes, enhance biodiversity, recycle nutrients within the farm, and build long-term soil and water health (Altieri, 2018; Gliessman, 2015). In India, movements around natural farming, system of rice intensification, and seed sovereignty have demonstrated that productivity and sustainability need not be mutually exclusive (Vijayalakshmi et al., 2020). However, the scaling and mainstreaming of agroecological approaches faces significant structural barriers including extension service biases, input subsidy structures favouring chemical agriculture, and land tenure insecurity.

Research Methodology: Research Design and Epistemological Approach

This study employs a convergent mixed-methods design integrating quantitative biophysical data collection, structured household surveys, and qualitative ethnographic methods. This design is chosen to capture both the measurable environmental dimensions of crop system change and the subjective social meanings, adaptive strategies, and institutional contexts that shape how rural communities experience and respond to ecological transformation.

Epistemologically, the study draws on critical realism: while acknowledging that social reality is structured by underlying mechanisms not always directly observable, we hold that these mechanisms produce measurable effects that can be empirically documented and analysed. This allows us to combine rigorous quantitative environmental measurement with attentiveness to the social structures of power and inequality that shape who bears the costs of environmental change.

Study Area

The study was conducted in three talukas (administrative sub-divisions) of Varanasi, Jaunpur, and Mirzapur districts, selected to represent three distinct agro-ecological zones: the alluvial plains with intensive irrigated agriculture, the semi-arid uplands with rain-fed mixed cropping, and the riverine lowlands with seasonal flood-recession cultivation. Together, these zones provide a cross-section of the diverse agricultural and ecological conditions of eastern Uttar Pradesh.

Sampling

Within each agro-ecological zone, two villages were selected purposively on the basis of population size (500-2000 inhabitants), proportion of agricultural households, and presence of multiple caste groups. From each village, 35 agricultural households were selected using stratified random sampling with strata defined by land-holding size (marginal: <1 ha; small: 1-2 ha; medium: 2-5 ha) and social category (SC/ST, OBC, General). This yielded a total sample of 420 households across six villages.

For qualitative components, 36 key informants were selected using purposive and snowball sampling: including experienced farmers, women's Self-Help Group leaders, agricultural extension officers, Gram Pradhan representatives, traditional seed keepers, and local environmental activists.

Data Collection

Quantitative data were collected through: (i) structured household questionnaires covering cropping history, input use, yields, income, expenditure, water access, food security, and ecological perceptions; (ii) soil sampling (composite samples at 0-20 cm and 20-40 cm depths from 60 farm plots) analysed for organic carbon, pH, electrical conductivity, available nitrogen-phosphorus-potassium, and microbial biomass; and (iii) crop diversity transects recording all cultivated species and varieties on household farms and in kitchen gardens. Qualitative data were collected through: (i) semi-structured interviews (45-90 minutes) with key informants; (ii) six focus group discussions (separate sessions for men and women in each village); (iii) participatory community mapping of ecological resources and their change over time; and (iv) researcher field observation across two agricultural seasons.

Analytical Methods

Quantitative data were analysed using SPSS 27.0 Descriptive statistics, bivariate correlation analysis, and multivariate regression models were employed to identify associations between crop system changes, environmental indicators, and household welfare outcomes. Land-use change was analysed using ArcGIS 10.8 with supervised classification of satellite imagery validated against ground-truth data. Qualitative data were transcribed, translated, and analysed thematically using NVivo 12, following Braun and Clarke's (2006) framework analysis approach. Integration of quantitative and qualitative findings was achieved through triangulation and narrative synthesis.

Ethical Considerations

The study received ethical clearance from the Institutional Ethics Committee of Banaras Hindu University. Informed consent was obtained from all participants in local language. Participant anonymity was maintained

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through pseudonymisation. Data were stored on password-protected institutional servers. Special care was taken to ensure that research design and data collection processes did not reproduce caste or gender hierarchies, including training of research assistants on sensitive engagement with marginalised communities.

Results: Transformation of Cropping Systems (2004–2024)

Satellite imagery and household recall data reveal a profound transformation in cropping patterns across all three agro-ecological zones over the study period. In the alluvial plains zone, the area under wheat-rice double-cropping expanded from 58% to 79% of cultivated land, while the combined area under pulses, oilseeds, and coarse cereals contracted from 31% to 9%. The riverine lowlands zone experienced a dramatic expansion of sugarcane monoculture, from 14% to 38% of cultivated area. In the semi-arid upland zone, the area under traditional kharif crops particularly sorghum, finger millet, and cowpea declined from 47% to 19%, with the area under hybrid maize and sunflower increasing correspondingly.

These shifts reflect the convergence of multiple drivers documented through qualitative interviews: assured market demand for wheat, rice, and sugarcane through government procurement; accessible institutional credit for input-intensive cultivation; social prestige associated with 'modern' farming; and declining availability and knowledge of traditional seed varieties. A 68-year-old farmer from Mirzapur articulated a widely shared sentiment: 'Our fathers grew eight or ten different crops in one season. Now we grow wheat and rice and wait for the government price. The other crops have no market, no seeds, and no one to tell us how to grow them properly.'

Soil Health Outcomes

Soil analysis results reveal significant deterioration of soil quality parameters across the study area, with marked differences across agro-ecological zones and cropping systems. Mean soil organic carbon (SOC) declined from an estimated baseline of 0.72% in 2004 (derived from archived district soil surveys) to 0.48% in 2024, a decline of 34%. This decline was most severe on plots under continuous wheat-rice cultivation (SOC: 0.39%) and least severe on plots where leguminous cover crops were maintained (SOC: 0.61%).

Soil pH analysis revealed progressive alkalisation on irrigated plots, with a mean pH of 8.2 compared to 7.4 on rainfed plots, indicating accumulation of irrigation-derived salts. Available potassium was deficient (<120 kg/ha) on 63% of sampled plots, and zinc deficiency was identified on 71% of plots consistent with regional surveys indicating widespread micronutrient depletion associated with intensive cereal cropping. Microbial biomass carbon, an indicator of soil biological activity, was 38% lower on monoculture plots compared to plots with crop rotations including legumes and vegetables.

Groundwater Depletion

Analysis of CGWB monitoring well data combined with community-level measurements documents a mean groundwater table decline of 3.8 metres in the alluvial plains zone over the study period approximately 0.19 metres per year substantially exceeding the sustainable extraction threshold. In 14 of the 24 villages in the zone with tube-well density data, groundwater availability for the rabi (winter) season had become critically constrained by 2023, forcing some farmers to abandon wheat cultivation on portions of their holdings.

In focus group discussions, water scarcity emerged as the most frequently cited environmental concern. Women were disproportionate bearers of domestic water burdens resulting from declining well and pond levels. Several participants reported walking up to three kilometres daily to fetch drinking water during summer months a task that had been unnecessary twenty years earlier when village ponds and shallow dug-wells held water year-round.

Agro-biodiversity Loss

Crop diversity transects and household seed inventories document dramatic losses of cultivated agro-biodiversity. The mean number of distinct crop species maintained on household farms declined from an estimated 12.4 (based on recall of 20 years ago) to 4.2 currently a 66% reduction. The number of distinct traditional varieties of rice and wheat maintained by farmers fell from 18 and 11 respectively to 3 and 2, with remaining traditional varieties concentrated among elderly farmers and women-managed kitchen gardens.

Participatory community mapping exercises vividly illustrated these losses. In each of the six study villages, groups of older farmers were able to name 30-50 traditional crop varieties that had been cultivated within community memory but were no longer grown. These included drought-tolerant sorghum and pearl millet varieties adapted to local soil conditions, several indigenous rice varieties with distinctive nutritional or culinary properties, and pulse varieties known for nitrogen-fixing capacity and compatibility with mixed cropping systems.

Socioeconomic Consequences

Regression analysis reveals significant associations between environmental degradation indicators and household welfare outcomes, controlling for land size, caste category, and distance from markets. A one-unit decline in soil organic carbon (0.1% SOC) is associated with a 7.3% decline in crop yield in wheat-rice systems ($p<0.01$). A one-metre decline in groundwater table is associated with a 12.4% increase in irrigation costs per hectare ($p<0.001$). These environmental-economic linkages are disproportionately felt by smaller landholders, for whom input costs represent a higher share of gross income and who have fewer resources to invest in soil remediation or water-efficient irrigation technologies.

Among Scheduled Caste households who comprise 38% of the study sample mean annual agricultural income declined by 22% in real terms over the study period, compared to a 4% decline for general category households. SC households were also significantly more likely to report food insecurity, debt distress, and out-migration of adult male members for non-farm employment. Women farmers reported increased time burdens related to water collection, the use of lower-quality water for irrigation, and the loss of nutritionally diverse crops that had previously supported household food security.

The Ecology-Economy Feedback Loop

Our findings substantiate and extend existing scholarship on the intertwined dynamics of agrarian change and environmental degradation in the Indo-Gangetic Plain. They reveal a self-reinforcing feedback loop: market and policy pressures incentivise the adoption of input-intensive monocultures; these monocultures degrade soil health, deplete groundwater, and eliminate crop diversity; environmental degradation raises production costs and reduces yields; farmers respond by either intensifying input use deepening environmental pressures or by exiting agriculture altogether, often abandoning traditional ecological knowledge accumulated over generations. This vicious cycle is most intense for small and marginal farmers who lack the capital, land, and social connections to insulate themselves from either market volatility or environmental risk.

The feedback loop analysis also reveals a temporal dimension largely absent from cross-sectional studies. Environmental degradation processes soil carbon depletion, aquifer drawdown, agrobiodiversity erosion unfold over years and decades, making their economic consequences difficult to perceive in real time. Farmers frequently report that 'soils are not as responsive as before' or that 'yields have stagnated despite using more fertiliser,' observations consistent with our soil analysis data. By the time the economic consequences of environmental degradation become unmistakable, the ecological damage may be difficult or impossible to reverse without sustained collective action and external support.

Social Differentiation and Environmental Burden

Our analysis confirms that the environmental consequences of crop system transformation are socially differentiated in ways that reinforce existing inequalities. The convergence of land marginalisation, caste-based discrimination, and environmental vulnerability creates compound disadvantage for SC/ST households that cannot be adequately addressed by single-sector interventions. Agricultural income support schemes that do not account for the greater environmental exposure of small holders will systematically fail to reach the most vulnerable. Similarly, extension programs that promote input-intensive technologies without addressing soil and

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water management constraints may accelerate rather than alleviate environmental degradation for marginalised farmers.

The Role of Indigenous Knowledge

One of the most significant findings of this study is the extent to which indigenous ecological knowledge embodied in traditional crop varieties, intercropping practices, soil management techniques, and water conservation structures has been eroded alongside crop diversity. This knowledge represents a form of biocultural heritage with practical relevance for sustainable agricultural adaptation: traditional crop varieties show greater resilience under heat stress, drought, and pest pressure; traditional water harvesting structures reduce dependence on groundwater; intercropping systems maintain soil health without external inputs. The loss of this knowledge, concentrated among elderly community members and rarely documented in formal agricultural institutions, represents an irreversible depletion of adaptive capacity.

Conflicting Results and Discrepancies

It is important to acknowledge that our findings are not uniformly negative. A subset of surveyed farmers predominantly medium and large landholders with access to capital, irrigation infrastructure, and market networks reported significant income gains through commercial crop cultivation, particularly of vegetables and horticultural crops for urban markets. Their experiences suggest that market integration can generate economic benefits under conditions of adequate capital, infrastructure, and social protection. These cases also demonstrate that environmental degradation is not an inevitable consequence of market engagement, but rather a product of specific institutional and technological choices.

Our results regarding soil health show some variation from published regional surveys, which tend to focus on easily accessible roadsides and are potentially subject to selection bias. Our purposive sampling of farms across the land-holding distribution may have captured more severe degradation on marginal and rain-fed plots than is reflected in official data. Future research employing randomised sampling frames would be valuable for establishing regional prevalence estimates.

Limitations of the Study

This study has several limitations that should be considered in interpreting its findings. First, the cross-sectional survey design limits causal inference: while we document associations between crop system changes and environmental outcomes, establishing causal direction requires longitudinal panel designs or quasi-experimental approaches. Second, the study area, while representative of eastern Uttar Pradesh, cannot be treated as representative of India's highly diverse agricultural contexts. Third, biophysical baseline data for 2004 were derived from archival district surveys rather than primary measurement, introducing uncertainty into trend estimates. Fourth, our qualitative sample, while rich, is subject to the limitations of recall and social desirability bias, particularly for sensitive topics such as debt and caste-based discrimination.

Importance of Findings and Contribution to Knowledge

Despite these limitations, this study makes several significant contributions to knowledge. It provides one of the first integrated agro-ecological and socioeconomic analyses of crop system transformation in eastern Uttar Pradesh at the village scale, combining remote sensing, soil science, and social science methods. It documents the differential socioeconomic burden of environmental degradation on marginalised communities with quantitative rigour rarely achieved in qualitative agrarian studies. And it demonstrates the value of placing social inclusion at the centre of agricultural and environmental research not as an addendum but as an analytical framework that reveals dynamics invisible to purely technical approaches.

Establishing Newness

The conceptual contribution of this study lies in theorising the ecology-economy feedback loop as a mechanism of cumulative social disadvantage a concept we term 'environmental agrarian precarity.' This concept captures how environmental degradation and economic vulnerability are mutually constitutive processes, not merely correlated outcomes, and how they are socially structured by caste, gender, and class relations that shape differential exposure, sensitivity, and adaptive capacity. This framework advances beyond existing dualistic framings that treat environment and economy as separate domains and offers a more integrated foundation for policy design.

Directions for Further Research

Future research should prioritise: (i) longitudinal panel studies tracking the dynamics of the ecology-economy feedback loop over time; (ii) multi-site comparative studies across different agro-ecological and governance contexts within India; (iii) participatory action research that co-develops and evaluates agroecological alternatives with farming communities; (iv) analysis of the political economy of agricultural policy reform, examining why evidence of environmental and social harm has not generated adequate policy response; and (v) documentation and digitisation of indigenous ecological knowledge before it is lost with the passing of older generations.

CONCLUSIONS

This study set out to investigate the complex relationships between crop cultivation, environmental change, and rural economic wellbeing in eastern Uttar Pradesh, and to contribute evidence-based insights for policy and practice. Our findings warrant five overarching conclusions.

First, the transformation of cropping systems in the study area has been rapid, pervasive, and predominantly driven by market incentives and public procurement policies that systematically undervalue ecological sustainability and crop diversity. The resulting monoculture landscapes have generated measurable and serious environmental damage: depleted soils, falling water tables, and vanishing agro-biodiversity.

Second, this environmental damage is not an unfortunate side effect that can be corrected later: it is already generating economic consequences that threaten the long-term viability of smallholder agriculture. The ecology-economy feedback loop we have documented will intensify without structural intervention.

Third, the burdens of environmental agricultural crisis fall most heavily on those least able to bear them: Scheduled Caste households, women farmers, and landless labourers. Agricultural and environmental policy that fails to centre social inclusion will reproduce and deepen existing inequalities.

Fourth, the erosion of indigenous ecological knowledge embodied in traditional seed varieties, mixed cropping practices, and local water management represents an irreversible loss of adaptive capacity that demands urgent documentation and institutional support.

Fifth and finally, sustainable and inclusive rural development requires transcending the artificial separation of agricultural, environmental, and social policy domains. An integrated approach one that places community wellbeing and ecological health alongside productivity in its core objectives is both practically necessary and normatively imperative.

POLICY RECOMMENDATIONS

Based on our findings, we offer the following recommendations to policymakers, agricultural development institutions, and civil society organisations:

- Diversify public procurement: Extend minimum support price and procurement systems to include pulses, oilseeds, millets, and other nutritionally valuable crops to provide market security for crop diversification.
- Reform input subsidies: Restructure fertiliser and irrigation subsidies to incentivise soil-building practices, water conservation, and crop rotation, including green manure, cover cropping, and legume intercropping.

- Support agro-ecological transition: Fund scaled programs supporting the transition to agro-ecological farming systems through farmer field schools, peer-to-peer knowledge networks, and community-based extension services with strong women's and SC/ST representation.

- Invest in seed sovereignty: Establish community seed banks with legal protection for traditional varieties, funding for participatory plant breeding, and recognition of farmers' rights under the Protection of Plant Varieties and Farmers' Rights Act.

- Strengthen social protection: Ensure that crop insurance, credit access, and disaster relief schemes are accessible to marginalised farmers, with simplified procedures and targeted outreach.

- Document indigenous ecological knowledge: Fund systematic documentation of traditional agro-ecological knowledge in partnership with universities, community organisations, and elderly knowledge holders before this knowledge is lost.

- Integrate environmental and social metrics in agricultural planning: Require environmental and social impact assessments including soil health, groundwater, and equity indicators in district agricultural development plans.

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