Policy Research Journal
ISSN (E): 3006-7030 ISSN (P) : 3006-7022 Volume 3, Issue 4, 2025

ECONOMIC ISSUES IN ASIAN RICE-WHEAT CROPPING SYSTEMS

Shamroza Ejaz[*1], Muhammad Abubakar*[2], Muhammad Subhan[*3], Zubair Ahmed[4], Awais Akram[5], Faizan Ayyub[6], Babar Khan[7], Muhammad Khizar Hayat[8], Ghulam Moeen Ud Din[9], Muhammad Zeeshan Khan[10]

[*1]*Department of Botany, Faculty of Applied Biology, Bahauddin Zakariya University, Multan, Pakistan.*
[2,*3,4,5,6,7,9,10]*Department of Agronomy, Faculty of Agriculture, University of Agriculture, Faisalabad, Pakistan.*
[8]*Department of Agronomy, Faculty of Agriculture, University of Agriculture, Faisalabad, Pakistan, Department of Field Crops, Faculty of Agriculture, Sakarya University of Applied Science, Sakarya, Turkey*

[*1]shamrozaejaz@gmail.com, [*2]bakar.swl@gmail.com, [*3]msubhanuaf225@gmail.com

[8]https://orcid.org/0009-0005-4998-7138

DOI: https://doi.org/10.5281/zenodo.15254402

Keywords
Rice-Wheat, Economic Challenges, Resources Conservation, Food Security, Environmental Stability, Global Demand.

Article History
Received on 12 March 2025
Accepted on 12 April 2025
Published on 21 April 2025

Corresponding Author: *
Shamroza Ejaz[*1]
Muhammad Abubakar*[2]
Muhammad Subhan[*3]

Abstract
The rice-wheat cropping system (RWCS) is a cornerstone of agriculture and food security in South Asia, spanning approximately 13.5 million hectares across India, Pakistan, Bangladesh, and Nepal, and feeding over 3.1 billion people. Despite its critical role, RWCS faces significant sustainability and economic challenges including stagnant yields, soil degradation, water scarcity, pollution, and climate change impacts. Traditional practices such as puddling and excessive fertilizer use have contributed to soil health decline and increased greenhouse gas emissions. Socioeconomic factors, rising input costs, and labor shortages further threaten profitability and productivity. Research highlights the potential of resource-conserving technologies (RCTs) such as zero tillage, direct-seeded rice, crop residue management, and conservation agriculture (CA) to improve yields, reduce environmental footprints, and enhance economic returns. For example, long-term studies show CA systems surpass conventional tillage in productivity and net returns after initial adaptation periods. Crop diversification with legumes and maize, improved irrigation management, and integrated nutrient management are also promising strategies to enhance system resilience and sustainability. However, barriers such as farmer hesitancy, small landholdings, and limited access to technology hinder widespread adoption. Addressing these challenges requires integrated, site-specific approaches that consider socio-economic and agro-ecological conditions. Innovations like dry-seeded rice, precision irrigation, and agronomic biofortification offer additional avenues to improve resource use efficiency and food security. Overall, sustainable intensification and policy support are essential to maintain the RWCS's vital role in regional food security while conserving natural resources and mitigating climate risks.

INTRODUCTION

Agriculture is the backbone of Asian countries economy and rice wheat cropping system is the backbone of agriculture. The collective agricultural area of India, Pakistan, Bangladesh, and Nepal under this system is approximately 13.5 million hectares (Mahajan & Gupta, 2009). Global cereal demand is rising, requiring increased rice production. Rice-wheat cropping systems (RWCS), crucial in Asia, face sustainability concerns due to stagnant yields. Improved varieties and management boosted yields, but socioeconomic factors now need assessment for future productivity (Prasad, 2005). The RWCS, vital in northwest India, faces sustainability threats like soil depletion, water scarcity, and pollution. Solutions include sustainable intensification technologies, precision management, and policy changes. Stakeholder awareness is crucial for addressing these challenges and ensuring continued productivity (Dhanda et al., 2022). Nepal's long-standing rice-wheat system faces sustainability challenges: plateauing yields, agrochemical impacts, resource depletion, and biodiversity loss. Climate change exacerbates these issues. Conservation agriculture and sustainable intensification offer potential solutions, but further research is needed to address socio-economic factors (Lamsal & Khadka, 2019). Nepal's rice-wheat system, vital for livelihoods, faces sustainability issues due to traditional practices. Conservation agriculture, including minimal tillage and crop rotation, offers solutions. Despite proven benefits, limited research and farmer hesitancy hinder its widespread adoption, crucial for future sustainability (Pandeya et al., 2021).

The rice-wheat cropping system, feeding over 3.1 billion people, faces sustainability challenges due to traditional practices like puddling and excessive fertilizer use, leading to soil degradation and increased emissions. Replacing this vital system is impractical; instead, researchers advocate for cost-effective, eco-friendly technologies to ensure food and environmental security in South Asia (Hossain et al., 2021). The IGP's rice-wheat system, vital for food security, faces declining yield growth and sustainability issues like soil degradation and water scarcity. The RWCS in the IGP, vital for India's food security since the 1970s, faces challenges like soil degradation and water depletion. Production has stagnated. Resource-conserving technologies (RCTs) like zero-tillage and crop residue management are crucial for sustainable productivity, addressing environmental and economic risks while ensuring food security (Debangshi & Ghosh, 2022; Ladha et al., 2007).

South Asia's cereal-dominated agriculture, feeding 20% of the world, faces stagnating productivity. Yield growth has slowed significantly since the Green Revolution's peak, leading to higher food prices. Substantial yield gaps, ranging from 14-77% across cereals, persist. Soil fatigue and declining productivity are major challenges. Crop residue management and conservation agriculture are crucial for sustainable cereal production and soil health in the Indo-Gangetic Plains (Kumar et al., 2019). The 24 Mha Asian rice-wheat system faces sustainability threats like soil degradation and water scarcity. Resource-conservation technologies, including no-till wheat and direct-seeded rice, offer solutions, but are site-specific. Strategies like seed priming, carbon trading, legume inclusion, and biological weed control are also vital. Irrigation management and residue utilization through biogas or biochar production are key. Agronomic biofortification can address malnutrition (Nawaz et al., 2019). The 26 Mha Asian rice-wheat system, crucial for food security, faces challenges like low yields due to nutrient and water mismanagement. Research aims to optimize practices, addressing soil, pest, and disease issues. Strategies include improved cultivars, mechanization, and integrated nutrient management. Innovative approaches like reduced tillage and raised beds are needed for sustainable productivity (Timsina & Connor, 2001). Rice residue burning in India's RWCS causes pollution and nutrient loss. In-field residue management offers a sustainable alternative. Residue retention impacts pests, especially weeds, reducing herbicide needs and improving soil health. Conservation tillage alters weed dynamics. Long-term studies are crucial for integrated weed management using rice residue (Kaur et al., 2021).

South Asia's 12-million-hectare rice-wheat rotation faces declining productivity. Surveys reveal system problems like poor wheat growth and late planting. Sustainability concerns include soil nutrient depletion and increased pest/weed pressures, threatening long-term yields (Fujisaka et al., 1994). The labor, water, and energy-intensive South Asian rice-wheat system faces declining profitability and sustainability. Resource-conserving technologies like zero tillage and direct seeding are recommended, but require site-specific implementation. Integrated approaches, considering soil and climate, are crucial. Understanding and addressing all related issues is essential for successful conservation agriculture and sustainable RWCS (Bhatt et al., 2016). The labor, water and energy-intensive South Asian rice-wheat system faces declining profitability and sustainability. Resource-conserving technologies and integrated approaches, considering soil and climate, are crucial. Understanding and addressing all related issues is essential for successful conservation agriculture and sustainable RWCS (Ullah et al., 2021). Climatic vulnerabilities and natural hazards severely threaten global crop productivity, especially the rice-wheat system impacting millions. Drought, floods, and temperature changes reduce yields, increasing food insecurity. Conservation agriculture emerges as a sustainable solution, improving water productivity, soil health, and mitigating climate change effects, crucial for Pakistan's future food security (Ali et al., 2023). Being the main crops of the area, it provides food to billions of people while ensuring food security in the area. The system is currently facing many economic challenges that threaten its sustainability and productivity. The purpose of this project would be to identify and analyze the economic principles contributing to these challenges and will suggest some solutions.

How to Address these challenges:

To address these economic challenges, researchers and policymakers are exploring sustainable intensification strategies, diversification of crops, and improved resource management practices. Wheat is vital for Asian food security, but growing demand and climate change threaten production. Asia, a potential production hub, faces increasing consumption and now has more importing than exporting countries. This chapter analyzes trends in area, production, and trade, highlighting challenges and research priorities to enhance efficiency and sustainability for achieving zero hunger goals (Sendhil et al., 2022). Nepal's rice-wheat system, vital but understudied for sustainability, faces ecological and climate change impacts. Yield growth is slow, below 1.5%. Agrochemical use and resource depletion are concerns. Hybrid rice threatens local varieties. Socio-economic factors also play a role. Conservation agriculture and sustainable intensification are proposed for resilience (Lamsal & Khadka, 2019).

RWCS, vital for India's food security, faces declining productivity. Crop diversification with legumes, maize, and other crops offers a sustainable solution, improving productivity and resource use. The intensive rice-wheat system in the Indo-Gangetic Plains faces groundwater depletion, pollution, and stagnant yields. Solutions include direct-seeded rice, crop diversification with maize and legumes, and conservation tillage. Genotype development, weed control, and farmer training are crucial for transitioning to sustainable, resource-efficient cropping systems (Khedwal et al., 2023). In Bangladesh's Level Barind Tract, a study compared existing and improved cropping systems. Replacing T. Boro rice with potato, cucumber, and T. Aus significantly increased system productivity and profitability. The improved system yielded 49% more, with double the net return. While protein and energy output slightly decreased, crop diversification enhanced sustainability and food security, reducing groundwater depletion from intensive irrigation (Alam et al., 2021).

The extensive rice-wheat cropping system in the IGP, vital for South Asia, faces sustainability challenges: resource depletion, soil degradation, and climate change impacts. Integrated approaches are needed to improve livelihoods. Resource conservation technologies, like direct-seeded rice and precision irrigation, can enhance water and land productivity. Carbon and water footprints must be assessed. Tailored packages, considering farmers' socio-economic and geological conditions, are crucial. Understanding residual moisture effects on intercropping is also vital. Scientists must advocate for context-specific solutions to ensure sustainable productivity and improved livelihoods (Bhatt et al., 2019). Surveys across Sub-Saharan Africa, South Asia, and East Asia revealed significant yield gaps in major food crops. Rice had the smallest gap, sorghum and legumes the largest. Key constraints include fertilizer issues, drought, pests, weeds, and soil degradation. Socio-economic factors also play a role, highlighting the need for targeted agricultural research and development (Waddington et al., 2010).

Previous research on the economic issues of the Rice-Wheat Cropping System (RWCS) highlights several challenges that threaten its sustainability and productivity. Increased costs for inputs such as fertilizers, labor, and energy have escalated production expenses, affecting farm profitability. A long-term study in the Eastern IGP evaluated conservation agriculture (CA) versus conventional tillage (CT) in a rice-wheat system. Initially, CT rice yields were higher, but CA yields surpassed CT after six years. Wheat yields were consistently higher in CA. Overall system productivity and net returns were greater in CA from the second year. CA's benefits emerged after 2-3 years of adaptation. CA systems proved agronomically and economically superior, offering a sustainable pathway to improve productivity, income, and food security for smallholder farmers in the region (Jat et al., 2014).

A study investigated that the impact of fertilizer combinations on rice-wheat cropping systems across six Indian states. Results showed that NP fertilization significantly increased rice and wheat yields. NPK application boosted overall system productivity, with Amritsar and Katni showing the highest gains. Balanced NPK use increased productivity 245% over control. Partial factor productivity of nitrogen, phosphorus, and potassium improved with combined applications. Rice exhibited higher agronomic use efficiency of nitrogen and phosphorus than wheat. Economically, NPK+Zn yielded the highest net returns, though marginal returns varied, with nitrogen alone showing the highest (Panwar et al., 2018). A four-year study in the eastern Indo-Gangetic Plains compared tillage and crop establishment methods in a rice-wheat-greengram rotation. Zero-tillage and direct-seeded rice systems showed comparable or improved yields to conventional methods, with reduced water use and lower global warming potential. Conservation agriculture-based systems increased net returns and energy productivity. These emerging technologies offer a sustainable alternative, potentially driving a second green revolution through further refinement and local expansion (Mishra et al., 2021).

Traditional tillage in South Asia's rice-wheat systems involves puddling for rice and dry plowing for wheat, often delaying planting and reducing yields. Late wheat planting, particularly, causes significant yield losses. To address these issues, research explores zero- and reduced-tillage for wheat, including surface seeding, zero-tillage, rotavator-based reduced-tillage, and bed planting. For rice, efforts focus on dry-seeded rice to eliminate puddling, alongside mechanical transplanting and direct seeding on puddled soils. These innovations aim to improve timeliness, plant stands, reduce costs, and enhance soil health (Hobbs, 2021). A 7-year study on the Indo-Gangetic Plains evaluated rice-wheat systems. Conventional puddled transplanting yielded the highest rice (7.81-8.10 Mg ha−1), with T2 (alternate wetting-drying) showing a 25% water saving. Zero-tillage wheat yielded 18% more. T2 and zero-tillage on flat beds (T5) had the highest net returns (~1225 US$). T5's sustainability is promising, but rice yields need improvement for wider adoption (Gathala et al., 2011).

Direct seeded rice (DSR) faces weed challenges, but integrated management can mitigate them. A three-year study in the IGP showed that initially, DSR had higher weed density than puddled transplanted rice (PTPR), but this reversed over time. DSR with residue or cover crops reduced weed dry matter. DSR yields matched or exceeded PTPR. Herbicide combinations, like pendimethalin followed by bispyribac–Na, effectively controlled diverse weeds. Cover crops and residue retention also aided weed suppression, offering sustainable DSR weed management solutions (Jat et al., 2019). Intensive farming degrades soil health, necessitating sustainable practices. Conservation agriculture (CA), with reduced tillage and residue retention, offers benefits but has low adoption in South Asia, particularly the IGP, where residue burning is a major issue. CA is favored in rice-wheat systems to overcome sowing delays. Challenges include small landholdings, limited technology access, and traditional mindsets. Despite diverse agro-ecologies, CA adoption is crucial for food security and environmental sustainability in rapidly growing South Asia (Somasundaram et al., 2020).

Over-reliance on groundwater for irrigation has led to severe depletion, threatening long-term sustainability. Per capita water availability is projected to decline significantly, exacerbating water scarcity issues. Contrary to popular belief, water deficit, not just groundwater withdrawal for rice, drives water table decline in Punjab's rice-wheat system. Wheat, despite needing less irrigation, shows a higher water deficit due to evapotranspiration exceeding rainfall. Thus, reducing wheat's evapotranspiration is crucial alongside improving rice irrigation practices (Jalota et al., 2018).

North-west India's rice-wheat systems face groundwater depletion. Modeling showed switching to short-duration rice reduces water use, but lowers yield. Mung bean increases yield but significantly raises water consumption. Developing high-yielding, short-duration rice is crucial for sustainable yields and groundwater conservation. Mung bean inclusion is not recommended due to high water use (Humphreys & Gaydon, 2015). North-west India's rice-wheat system faces groundwater depletion and sustainability issues. Modeling showed conservation agriculture (CA) reduced irrigation by 390 mm but only slightly decreased evapotranspiration (ET). Maximum rice equivalent yield (14.6 t ha-1) occurred with long-duration rice, but ET reduction required short-duration varieties, lowering yields by 1.8 t ha^{-1}. A three-crop CA system with mung bean offered flexibility and ET reduction. Developing higher-yielding short-duration rice is crucial, alongside field trials and hydrological studies to determine sustainable ET levels (Balwinder-Singh et al., 2015).

Practices like crop residue burning contribute to air pollution and greenhouse gas emissions, impacting environmental quality. Agriculture accounts for a significant portion of India's greenhouse gas emissions, with rice cultivation being a major contributor. The IGP's rice-wheat system, crucial for food security, faces declining yields and sustainability risks. Resource-conserving technologies like zero tillage, direct seeding, water efficiency, residue management, and crop diversification are needed to enhance productivity, conserve resources, and increase farmer profitability (Kakraliya et al., 2018). Industrial waste compost, combined with fertilizers and microbes, significantly boosted rice-wheat yields, energy output, and carbon sequestration. Optimal combinations increased water productivity and reduced footprints. This approach offers a sustainable food-energy-water-carbon-economic model, enhancing productivity and environmental benefits (Meena et al., 2023). To improve sustainability in Bihar's rice-wheat systems, short-duration legumes were introduced. Farm DESIGN modeling assessed impacts on smallholders. Legumes enhanced soil health but showed profit trade-offs. Resource-rich farms benefited most. Some farms saw no gains. Innovation impact varies by farm type, highlighting the need for tailored solutions (Toorop et al., 2020).

Economic Challenges of RWCS

The rice-wheat cropping system (RWCS) in Asia, particularly in South Asia, faces significant economic and environmental challenges due to resource scarcity and opportunity costs. A critical issue is the overuse of water resources, leading to declining groundwater levels. Below is an explanation of the key challenges, supported by data, tables, and graphs.

Table 1: Average variable cost of cultivation and labor use in the rice–wheat cropping system in Haryana India in rice under dry direct seeded rice-zero-till wheat in comparison with puddled transplant rice-conventional till wheat.

Sr. No.	Operations	Cost in US Dollars per Hectors	
		Dry Direct Seeded Rice-Zero-Till Wheat	Puddled Transplant Rice-Conventional-Till Wheat
1	Preparatory tillage operations	56	81
2	Seedling Stand and Establishment	55	113
3	Irrigational operations	96	125
4	Weed Management Operations	53	15
5	Total variable cost of cultivation	**448**	**555**
6	Labor cost used per (No. of hectors)	56	81

(Yadav et al., 2021).

Policy Research Journal
ISSN (E): 3006-7030 **ISSN (P) :** 3006-7022 Volume 3, Issue 4, 2025

Table 2: Groundwater Depletion in Punjab and Haryana (2003–2020)

Year	Groundwater Depletion (Billion Cubic Meters)	Annual Decline Rate (Meters)
2003	Baseline	-
2010	~21 BCM lost	~0.49 m/year (Punjab)
2015	~40 BCM lost	~0.5â€ "1 m/year (Haryana)
2020	~64.6 BCM lost	~8â€ "10% decline overall

(Source: Massive Groundwater Loss: Punjab & Haryana Deplete 64.6 Billion Cubic Meters in 17 Years | Gurgaon News - Times of India and Accelerating rate of groundwater depletion in Punjab, worries farmers and experts (https://india.mongabay.com/)

Table 3: Groundwater Depletion in Punjab and Haryana

Sr. No.	*Year*	*Groundwater Depth (meters)*
1	2000	10
2	2005	12
3	2010	15
4	2015	18
5	2020	22

Source: Emerging Issues and Potential Opportunities in the Rice–Wheat Cropping System of North-Western India and (Dhanda et al., 2022).

Graph 1: Groundwater Depletion in Punjab and Haryana (2003–2020)

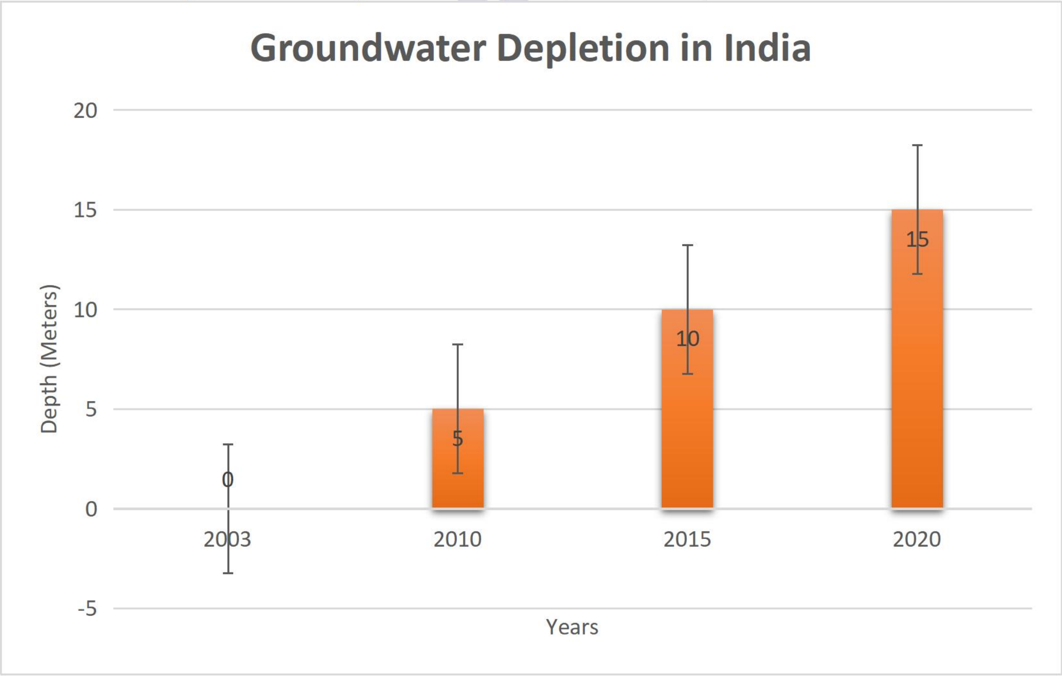


Table 4: Groundwater Depletion in India.

Sr. No.;	Key Findings	Demonstration
1	Cumulative Loss	Punjab and Haryana collectively lost 64.6 BCM of groundwater between 2003 and 2020, equivalent to filling approximately 25 million Olympic-sized swimming pools.
2	Decline Rate	Groundwater levels fell by 8–10% in Punjab and Haryana during this period, with an annual decline rate of ~0.49 meters/year in Punjab.
3	Overexploitation	Groundwater extraction exceeded sustainable limits: **Punjab:** Extraction at 166% of extractable resources, with irrigation accounting for 26.69 BCM annually. **Haryana:** Extraction at 134%, with overexploited blocks making up 61% of the state.

Source: this data is taken and modified in the form of a table from Gurgaon News - Times of India, India-Mongabay and Chandigarh News - Times of India.

Diminishing Marginal Returns: Soil Depletion and Its Impact on Yields

The law of diminishing marginal returns is a fundamental concept in economics that describes what happens when you increase one input of production while keeping other inputs constant. Soil depletion, caused by intensive agricultural practices, is a key factor contributing to diminishing marginal returns in crop production. As soil fertility declines, the additional yield gained from increased inputs (e.g., fertilizers, water) diminishes, leading to reduced productivity and higher environmental costs.

Equation:

The foundation is the production function, which shows the relationship between inputs and outputs. A simplified form is:

$$Q = f\{L, K\}$$

Where:

Q = Output, L = Labor (variable input) and K = Capital (fixed input).

This function tells us how much output (Q) we can produce with different combinations of labor (L) and capital (K).

The marginal product of labor (MPL) is the change in output resulting from a one-unit change in labor, holding capital constant.

$$MPL = \frac{\Delta Q}{\Delta L}$$

Where:

ΔQ = Change in output and ΔL = Change in labor

Production Cost Analysis of Rice in South Asia: 2000 vs. 2020

The production costs of rice in South Asia have undergone significant changes between 2000 and 2020, influenced by factors such as rising input costs, technological advancements, and policy interventions. Below is a comparative analysis of these costs, supported by tables and graphs.

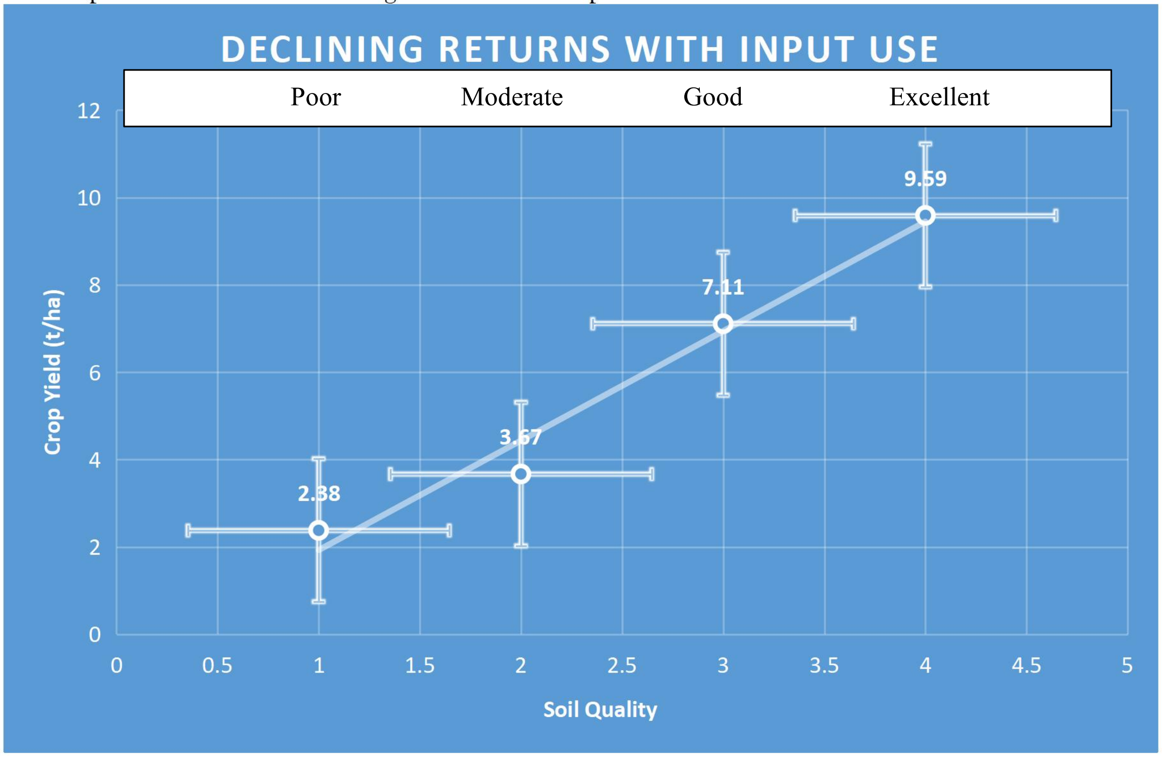
Table 5: Rice Production Costs in South Asia (2000 vs. 2020).

Input Costs (USD/ha)	2000	2020
Seeds	$20–$50	$50–$100
Fertilizers	$50–$100	$150–$300
Pesticides	$20–$50	$50–$100
Labor	$50–$100	$150–$300
Total	$200–$400	$600–$1,000

Source: A Report from the Economic Research Service Southeast Asia's Rice Surplus 2012 and USDA, Economic Research Service calculations based on Food and Agriculture Organization of the United Nations FAOSTAT data.

Soil depletion refers to the loss of essential nutrients (e.g., nitrogen, phosphorus, potassium) and organic matter due to over-cultivation, erosion, and poor management practices. Degraded soils lose their ability to retain water and nutrients, leading to reduced crop productivity. For example: High-quality soils can yield up to 9.59 t/ha, while degraded soils on marginal lands produce only 2.38–4.50 t/ha. Globally, up to 1% of topsoil is lost annually due to erosion, further reducing yields (Mosier et al., 2021). As soil fertility declines, farmers must increase inputs like fertilizers and irrigation to maintain yields. However, the additional cost often outweighs the marginal gains in production. Intensive farming on degraded lands leads to a feedback loop of declining productivity and rising input costs, making agriculture less profitable over time (Gomiero, 2016).

Graph 2: Comparison between Declining Returns with Input Use



Source: (Mosier et al., 2021).

Market Dynamics and Price Instability: Impact on Rice-Wheat Cropping System (RWCS)

Global trade and price fluctuations significantly affect the Rice-Wheat Cropping System (RWCS), influencing production costs, profitability, and sustainability. Below is a discussion on how these dynamics impact RWCS, supported by tables and graphs.

1. Global Trade and Price Fluctuations

Tariffs and trade agreements can alter the competitiveness of RWCS crops in global markets. For example, U.S. tariffs on Chinese imports could indirectly affect Indian rice and wheat exports by altering global supply chains and prices are demonstrated by Dr. Carlos Mera and Oran van Dort in December 2024 on Rabobank. Fluctuations in global commodity prices impact input costs (e.g., fertilizers, energy) and output prices for rice and wheat. Rising fertilizer costs, driven by energy prices, can increase production expenses, while stable or declining crop prices reduce profitability.

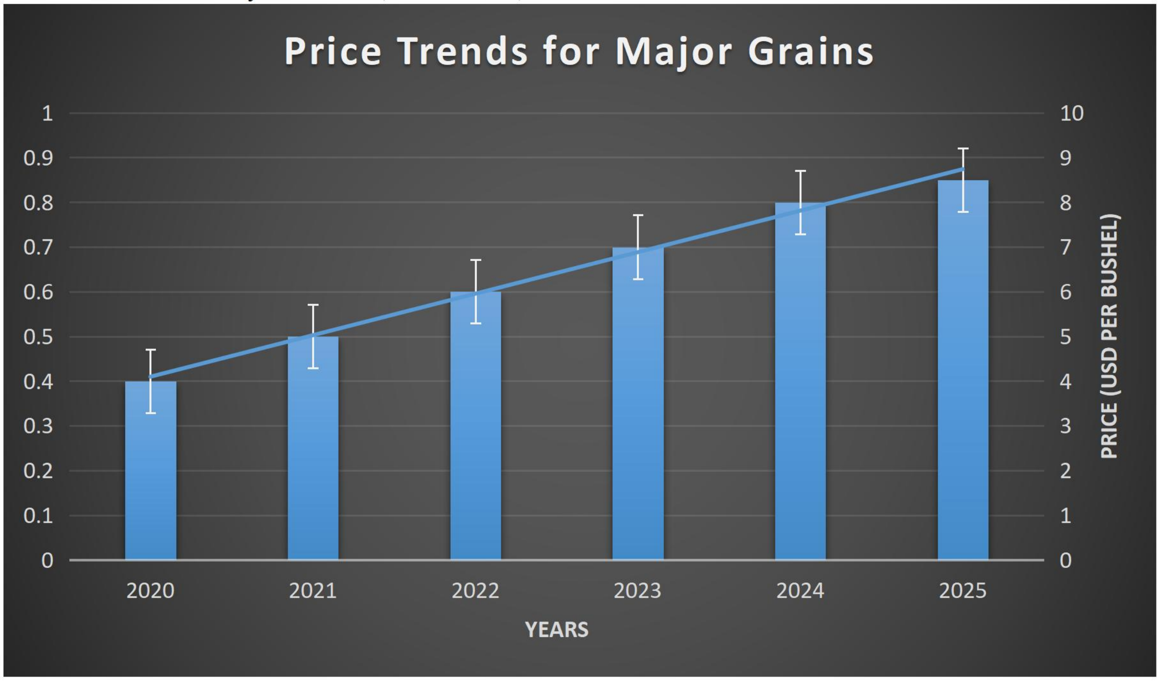
ISSN (E): 3006-7030 ISSN (P) : 3006-7022 Volume 3, Issue 4, 2025

Table 6: Impact of Global Trade and Price Fluctuations on RWCS

Factor	Impact on RWCS
Tariffs and Trade Policies	Alters export competitiveness and profitability.
Price Volatility	Increases input costs, reduces output prices, affecting profitability.
Global Demand	Influences crop prices and production decisions.

(Source: Five key commodity trends to watch for in 2025 | Oxford Economics).

Graph: Price Trends for Major Grains (2020–2025)



This graph illustrates the volatility in grain prices over recent years, with wheat prices expected to remain high in 2025 due to supply constraints (Source: Farm-Raise Commodity Price Forecast 2024 & 2025 and Miller Magazine 2025).

Farmers in RWCS regions face reduced profitability due to rising input costs and fluctuating output prices. This can lead to decreased investment in sustainable practices and increased reliance on subsidies. Price instability discourages long-term investments in soil health and water conservation, exacerbating environmental challenges like groundwater depletion and soil degradation (source: The Commodity Markets Outlook in eight charts - World Bank Blogs 2025). Global trade dynamics and price fluctuations significantly impact the economic viability and sustainability of RWCS. To mitigate these effects, policymakers and farmers must adopt strategies like diversification, efficient irrigation systems, and market risk management tools to ensure the long-term resilience of these critical cropping systems.

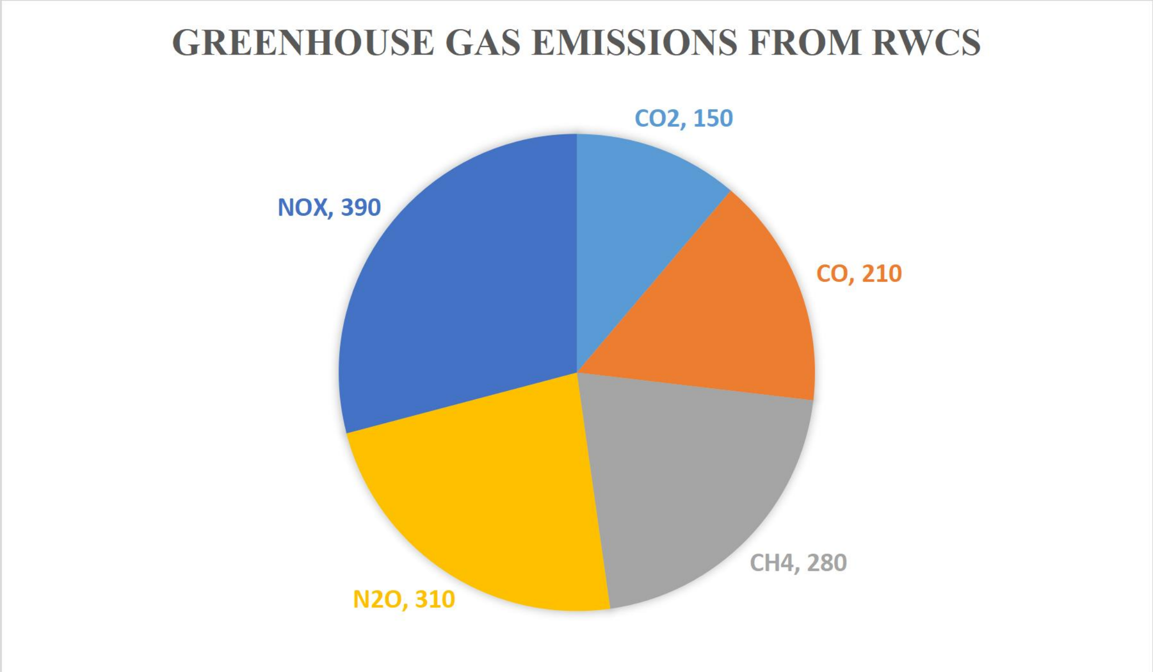
Environmental Costs of Rice-Wheat Cropping System (RWCS): Externalities and Economic Burden

The Rice-Wheat Cropping System (RWCS) in South Asia, particularly in India, faces significant environmental challenges that impose substantial economic burdens. Key externalities include methane emissions from rice cultivation, residue burning, and nutrient imbalances. Below is an explanation of these issues, supported by data and visual representations.

Rice cultivation is a major source of methane (CH_4), contributing approximately 20% of global CH_4 emissions. The warming potential of CH_4 is 25–30 times greater than carbon dioxide (CO_2) over a 100-year time frame. The economic cost of CH_4 emissions can be substantial, as they contribute to climate change impacts such as increased frequency of extreme weather events, which can damage crops and infrastructure (Ullah et al., 2021). In northwest India, about 2 million farmers burn 23 million metric tons of rice residue annually, causing severe air pollution. This practice emits significant amounts of CO_2, CO, CH_4, NO_x, and SO_2. Air pollution from residue burning leads to premature mortality and severe health issues, imposing a significant economic burden on healthcare systems. Intensive cultivation in RWCS leads to nutrient depletion, necessitating increased fertilizer use. This not only increases production costs but also contributes to nitrous oxide (N_2O) emissions, further exacerbating climate change. Continuous monoculture practices and residue burning degrade soil organic carbon, reducing fertility and water retention capacity (Dhanda et al., 2022).

Table 7: Economic Burden of Environmental Externalities in RWCS

Externality	Economic Impact
Methane Emissions	Contributes to climate change impacts, damaging crops and infrastructure.
Residue Burning	Increases healthcare costs due to air pollution-related health issues.
Nutrient Imbalances	Raises production costs through increased fertilizer use.



Unit: Greenhouse Gas Emissions Tg (Teragrams of CO_2 equivalent).

This graph illustrates the composition of greenhouse gas emissions from RWCS, highlighting methane as a significant contributor.

The Rice-Wheat Cropping System (RWCS) is a significant source of greenhouse gas (GHG) emissions, primarily due to methane (CH_4) from rice cultivation and nitrous oxide (N_2O) from fertilizer use in both crops. Below is a graphical representation of these emissions, highlighting their contribution to the overall carbon footprint. Rice cultivation accounts for substantial CH_4 emissions, contributing significantly to the global warming potential (GWP) of RWCS. The carbon footprint of rice is higher than that of wheat, with an average of 6.34 t CO_2-eq/ha for rice compared to 1.41 t CO_2-eq/ha for wheat in Punjab, India (Ranguwal et al., 2022). N_2O emissions are relatively low but potent due to their high GWP, particularly from wheat cultivation.

Table 8: Greenhouse Gas Emissions from RWCS

Sr. No.,	Greenhouse Gas	Emissions (Tg CO_2-eq)
1	Methane (CH_4)	~88.5 Tg (from rice)
2	Nitrous Oxide (N_2O)	~0.02 Tg (from rice), ~0.017 Tg (from wheat)
3	Carbon Dioxide (CO_2)	~72.9 Tg (from rice), ~43.2 Tg (from wheat)

The environmental costs associated with RWCS, including methane emissions and residue burning, impose a substantial economic burden. Addressing these externalities requires adopting sustainable practices like direct-seeded rice, controlled-release fertilizers, and efficient residue management to mitigate environmental impacts while ensuring long-term agricultural sustainability.

Cost-Benefit Analysis (CBA) and Its Application to Rice-Wheat Cropping System (RWCS)

Cost-Benefit Analysis (CBA) is a systematic approach used to evaluate the financial and economic viability of projects or interventions by comparing their costs and benefits. In the context of the Rice-Wheat Cropping System (RWCS), CBA helps assess the profitability of adopting best practices, technologies, or policies that enhance sustainability and productivity. CBA involves quantifying the expected costs and benefits of a project or intervention to determine whether it is worthwhile. Identify costs and benefits, quantify them in monetary terms, compare them over time using discount rates, and calculate indicators like Net Present Value (NPV) or Internal Rate of Return (IRR).

Improved crop yields, enhanced water efficiency, reduced environmental impacts (e.g., methane emissions), and increased farmer income. Initial investment in new technologies or practices (e.g., laser land leveling, precision irrigation), training costs, and potential short-term yield reductions during transition. CBA is a valuable tool for evaluating the economic viability of interventions in RWCS. By systematically assessing costs and benefits, policymakers and farmers can make informed decisions about adopting sustainable practices that enhance productivity while reducing environmental impacts.

Policy Evaluation: Assessing Existing Policies in Agriculture

Policy evaluation is a critical process for assessing the effectiveness and impact of existing agricultural policies. It involves systematic analysis to determine whether policies achieve their intended objectives and to identify areas for improvement. Below is a discussion on how existing policies are assessed, supported by references from international papers.

1. Methodologies Used in Policy Evaluation

- **Quantitative and Qualitative Approaches**: Evaluations often combine quantitative methods (e.g., econometric models, cost-benefit analysis) with qualitative approaches (e.g., stakeholder interviews, case studies) to provide a comprehensive view of policy impacts.

- **Theory-Based Approaches**: Theories of Change (ToC) and contribution analysis are used to understand how policies influence outcomes and to assess causality in complex policy environments (Đurić et al., 2023).

2. International Frameworks for Policy Evaluation

- **OECD Monitoring and Evaluation**: The OECD annually monitors and evaluates agricultural policies across 54 countries, using indicators to assess policy support and its impact on the sector (Source: Agricultural Policy Monitoring and Evaluation 2024 | OECD).

- **European Commission's Common Monitoring and Evaluation Framework (CMEF):** This framework evaluates the Common Agricultural Policy (CAP) by assessing its implementation, results, and impacts, ensuring transparency and accountability (Source: Common monitoring and evaluation framework https://agriculture.ec.europa.eu/).

3. Challenges in Policy Evaluation

- **Complexity and Causality**: Evaluating policy impacts is challenging due to the complexity of policy environments and the difficulty in attributing outcomes to specific interventions (FAO, 2021).

- **Long-Term Nature**: Policy changes often have slow and incremental effects, requiring long-term monitoring and evaluation strategies (FAO, 2021).

Policy evaluation in agriculture involves a range of methodologies and frameworks to assess the effectiveness of existing policies. By leveraging these tools, policymakers can refine policies to better address agricultural challenges and enhance sector sustainability.

RECOMMENDATIONS & POLICY SUGGESTIONS:

Based on the provided document, the following policy recommendations are crucial for addressing the economic and environmental challenges facing the Rice-Wheat Cropping System (RWCS) in Asia:

1. **Promote Sustainable Intensification:** Encourage the adoption of resource-conserving technologies (RCTs) like zero-tillage, direct-seeded rice (DSR), and laser land leveling through subsidies, training programs, and awareness campaigns. These technologies improve water use efficiency, reduce soil degradation, and lower production costs. Provide financial incentives for farmers transitioning to these methods.

2. **Incentivize Crop Diversification:** Offer subsidies and market access support for alternative crops such as legumes, maize, and oilseeds. Crop diversification improves soil health, reduces reliance on rice and wheat monoculture, and enhances nutritional diversity. Research and extension services should promote crop rotations and intercropping systems.

3. **Residue Management:** Impose stricter regulations on residue burning and provide subsidies for in-situ residue management technologies like mulching and composting. Facilitate the adoption of machinery for residue incorporation into the soil.

4. **Groundwater Regulation:** Implement policies to regulate groundwater extraction, such as tiered pricing for electricity used in irrigation. Promote water-efficient irrigation techniques and invest in rainwater harvesting infrastructure.

5. **Invest in Research and Development:** Allocate funding for research on developing high-yielding, short-duration rice varieties that require less water. Support research on integrated weed management strategies for DSR and climate-resilient crop varieties.

6. **Strengthen Extension Services:** Empower extension services to disseminate information on sustainable agricultural practices, provide training to farmers, and facilitate access to credit and technology.

CONCLUSION:

The rice-wheat cropping system (RWCS), a crucial component of Asian agriculture and a vital food source for over 3 billion people, faces a complex web of interconnected economic and environmental challenges that threaten its long-term sustainability. Characterized by plateauing yields, escalating input costs, resource depletion, and environmental degradation, the RWCS requires urgent and multifaceted interventions. Key challenges include soil fatigue, water scarcity, groundwater depletion exacerbated by traditional practices like puddling, and air pollution from burning 23 million tons of rice residue annually in areas like northwest India. Addressing these challenges demands a shift towards sustainable intensification through the adoption of resource-conserving technologies (RCTs) like zero-tillage, direct-seeded rice (DSR), and precision irrigation. Crop diversification with legumes and maize offers a pathway to improved soil health and reduced dependence on monoculture. Context-specific solutions, coupled with supportive policies, are essential for successful implementation. While conventional agriculture has provided benefits, a more sustainable pathway includes conservation agriculture. Developing high-yielding, short-duration rice varieties and effective residue management techniques will further enhance the system's resilience. Integrated approaches that consider socio-economic factors and empower farmers through training and access to technology are essential to ensuring food security and improving livelihoods. The RWCS's future hinges on balancing productivity with environmental stewardship, guaranteeing its vital role in Asian food systems for generations to come.

REFERENCES:

Alam, M. J., Al-Mahmud, A.-., Islam, M. A., Hossain, M. F., Ali, M. A., Dessoky, E. S., El-Hallous, E. I., Hassan, M. M., Begum, N., & Hossain, A. (2021). Crop diversification in rice–based cropping systems improves the system productivity, profitability and sustainability. *Sustainability*, *13*(11), 6288.

Ali, S., Zahid, A., Fatima, A., Aziz, M., Maqsood, H., Shezhad, A., Younas, S., & Bushra. (2023). Conservation Agriculture a Sustainable Approach for Disaster Risk Reduction in Rice Wheat Cropping System of Pakistan. In *Disaster Risk Reduction in Agriculture* (pp. 311-333). Springer.

Balwinder-Singh, B.-S., Humphreys, E., Gaydon, D., & Sudhir-Yadav, S.-Y. (2015). Options for increasing the productivity of the rice-wheat system of north west India while reducing groundwater depletion. Part 2. Is conservation agriculture the answer?

Bhatt, R., Kaur, R., & Ghosh, A. (2019). Strategies to practice climate-smart agriculture to improve the livelihoods under the rice-wheat cropping system in South Asia. *Sustainable management of soil and environment*, 29-71.

Bhatt, R., Kukal, S. S., Busari, M. A., Arora, S., & Yadav, M. (2016). Sustainability issues on rice–wheat cropping system. *International Soil and Water Conservation Research*, *4*(1), 64-74.

Debangshi, U., & Ghosh, P. (2022). Rice wheat cropping systems-constraints and strategies: a review. *Plant Archives (09725210)*, *22*(1).

Dhanda, S., Yadav, A., Yadav, D. B., & Chauhan, B. S. (2022). Emerging issues and potential opportunities in the rice–wheat cropping system of North-Western India. *Frontiers in Plant Science*, *13*, 832683.

Đurić, K., Lukač Bulatović, M., Tomaš Simin, M., & Glavaš-Trbić, D. (2023). Monitoring and Evaluation as a Mechanism for Agricultural Policy Management.

Filippi, P., Jones, E. J., Ginns, B. J., Whelan, B. M., Roth, G. W., & Bishop, T. F. (2019). Mapping the depth-to-soil pH constraint, and the relationship with cotton and grain yield at the within-field scale. *Agronomy*, *9*(5), 251.

Fujisaka, S., Harrington, L., & Hobbs, P. (1994). Rice-wheat in South Asia: systems and long-term priorities established through diagnostic research. *Agricultural Systems*, *46*(2), 169-187.

Gathala, M. K., Ladha, J., Kumar, V., Saharawat, Y. S., Kumar, V., Sharma, P. K., Sharma, S., & Pathak, H. (2011). Tillage and crop establishment affects sustainability of South Asian rice–wheat system. *Agronomy Journal*, *103*(4), 961-971.

Gomiero, T. (2016). Soil degradation, land scarcity and food security: Reviewing a complex challenge. *Sustainability*, *8*(3), 281.

Hobbs, P. (2021). Tillage and crop establishment in South Asian rice-wheat systems: Present practices and future options. In *The Rice-Wheat Cropping System of South Asia* (pp. 1-22). CRC Press.

Hossain, A., Bhatt, R., Sarkar, S., Barman, M., Majumder, D., Saha, S., Islam, M. T., Maitra, S., & Meena, R. S. (2021). Cost-effective and eco-friendly agricultural technologies in rice-wheat cropping systems for food and environmental security. *Sustainable intensification for agroecosystem services and management*, 69-96.

Humphreys, E., & Gaydon, D. (2015). Options for increasing the productivity of the rice–wheat system of north-west India while reducing groundwater depletion. Part 1. Rice variety duration, sowing date and inclusion of mungbean. *Field Crops Research*, *173*, 68-80.

Jalota, S., Jain, A., & Vashisht, B. (2018). Minimize water deficit in wheat crop to ameliorate groundwater decline in rice-wheat cropping system. *Agricultural Water Management*, *208*, 261-267.

Jat, R. K., Sapkota, T. B., Singh, R. G., Jat, M. L., Kumar, M., & Gupta, R. K. (2014). Seven years of conservation agriculture in a rice–wheat rotation of Eastern Gangetic Plains of South Asia: yield trends and economic profitability. *Field Crops Research*, *164*, 199-210.

Jat, R. K., Singh, R. G., Gupta, R. K., Gill, G., Chauhan, B. S., & Pooniya, V. (2019). Tillage, crop establishment, residue management and herbicide applications for effective weed control in direct seeded rice of eastern Indo–Gangetic Plains of South Asia. *Crop Protection*, *123*, 12-20.

Kakraliya, S., Kumar, S., Kakraliya, S., Choudhary, K., & Singh, L. (2018). Remedial options for the sustainability of rice-wheat cropping system. *J Pharmacogn Phytochem*, *7*(2), 163-171.

Kaur, R., Kaur, S., Deol, J. S., Sharma, R., Kaur, T., Brar, A. S., & Choudhary, O. P. (2021). Soil properties and weed dynamics in wheat as affected by rice residue management in the rice–wheat cropping system in south Asia: A review. *Plants*, *10*(5), 953.

Khedwal, R. S., Chaudhary, A., Sindhu, V. K., Yadav, D. B., Kumar, N., Chhokar, R. S., Poonia, T. M., Kumar, Y., & Dahiya, S. (2023). Challenges and technological interventions in rice–wheat system for resilient food–water–energy-environment nexus in North-western Indo-Gangetic Plains: A review. *Cereal Research Communications*, *51*(4), 785-807.

Kumar, R., Saurabh, K., Kumawat, N., Mishra, J., Hans, H., Krishna, B., Meena, R. S., Krishna Jha, B., Upadhyay, P. K., & Hazra, K. (2019). Conservation agriculture: perspectives on soil and environmental management in Indo-Gangetic plains of South Asia. *Sustainable management of soil and environment*, 123-168.

Ladha, J., Pathak, H., & Gupta, R. (2007). Sustainability of the rice-wheat cropping system: issues, constraints, and remedial options. *Journal of Crop Improvement*, *19*(1-2), 125-136.

Lamsal, S., & Khadka, R. (2019). Rice-wheat cropping system in Nepal: issues concerning sustainability. *Int. J. Environ. Agric. Biotechnol*, *5*(6), 1913-1922.

Mahajan, A., & Gupta, R. (2009). The rice–wheat cropping system. *Integrated Nutrient Management (INM) in a Sustainable Rice-Wheat Cropping System.(Springer, Dordrecht, pp. 109–117, 2009).*

Meena, R. S., Pradhan, G., Kumar, S., & Lal, R. (2023). Using industrial wastes for rice-wheat cropping and food-energy-carbon-water-economic nexus to the sustainable food system. *Renewable and Sustainable Energy Reviews*, *187*, 113756.

Mishra, J., Poonia, S., Kumar, R., Dubey, R., Kumar, V., Mondal, S., Dwivedi, S., Rao, K., Kumar, R., & Tamta, M. (2021). An impact of agronomic practices of sustainable rice-wheat crop intensification on food security, economic adaptability, and environmental mitigation across eastern Indo-Gangetic Plains. *Field Crops Research*, *267*, 108164.

Mosier, S., Córdova, S. C., & Robertson, G. P. (2021). Restoring soil fertility on degraded lands to meet food, fuel, and climate security needs via perennialization. *Frontiers in Sustainable Food Systems*, *5*, 706142.

Nawaz, A., Farooq, M., Nadeem, F., Siddique, K. H., & Lal, R. (2019). Rice–wheat cropping systems in South Asia: issues, options and opportunities. *Crop and Pasture Science*, *70*(5), 395-427.

Pandeya, S., Shresthab, S., Bhattaraib, R., & Sharmaa, A. (2021). Role of Conservation Agriculture in Sustainability of Rice-Wheat Cropping System In Nepal. *Reviews in Food and Agriculture (RFNA)*, *2*(2), 76-82.

Panwar, A., Shamim, M., Babu, S., Ravishankar, N., Prusty, A. K., Alam, N., Singh, D., Bindhu, J., Kaur, J., & Dashora, L. (2018). Enhancement in productivity, nutrients use efficiency, and economics of rice-wheat cropping systems in India through farmer's participatory approach. *Sustainability*, *11*(1), 122.

Prasad, R. (2005). Rice–wheat cropping systems. *Advances in agronomy*, *86*, 255-339.

Ranguwal, S., Sidana, B. K., & Kumar, S. (2022). Carbon footprints of rice-wheat cultivation across farm size categories: Evidence from Punjab in India. *Journal of Cereal Research*, *14*(Spl2).

Sainju, U. M., & Liptzin, D. (2022). Relating soil chemical properties to other soil properties and dryland crop production. *Frontiers in Environmental Science*, *10*, 1005114.

Sendhil, R., Kumari, B., Khandoker, S., Jalali, S., Acharya, K. K., Gopalareddy, K., Singh, G. P., & Joshi, A. K. (2022). Wheat in Asia: trends, challenges and research priorities. In *New horizons in wheat and barley research: global trends, breeding and quality enhancement* (pp. 33-61). Springer.

Somasundaram, J., Sinha, N., Dalal, R. C., Lal, R., Mohanty, M., Naorem, A., Hati, K., Chaudhary, R., Biswas, A., & Patra, A. (2020). No-till farming and conservation agriculture in South Asia–issues, challenges, prospects and benefits. *Critical Reviews in Plant Sciences*, *39*(3), 236-279.

Timsina, J., & Connor, D. J. (2001). Productivity and management of rice–wheat cropping systems: issues and challenges. *Field Crops Research*, 69(2), 93-132.

Toorop, R. A., Lopez-Ridaura, S., Bijarniya, D., Kalawantawanit, E., Jat, R. K., Prusty, A. K., Jat, M. L., & Groot, J. C. (2020). Farm-level exploration of economic and environmental impacts of sustainable intensification of rice-wheat cropping systems in the Eastern Indo-Gangetic plains. *European Journal of Agronomy*, *121*, 126157.

Ullah, A., Nawaz, A., Farooq, M., & Siddique, K. H. (2021). Agricultural innovation and sustainable development: A case study of rice–wheat cropping systems in South Asia. *Sustainability*, *13*(4), 1965.

Waddington, S. R., Li, X., Dixon, J., Hyman, G., & De Vicente, M. C. (2010). Getting the focus right: production constraints for six major food crops in Asian and African farming systems. *Food Security*, *2*, 27-48.

Yadav, D. B., Yadav, A., Vats, A. K., Gill, G., & Malik, R. K. (2021). Direct seeded rice in sequence with zero-tillage wheat in north-western India: addressing system-based sustainability issues. *SN Applied Sciences*, *3*(11), 844.