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Cotton as a sustainable game changer in

rice-wheat system of Indo-Gangetic plains

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Cultivating cotton as an alternative to rice in the rice-wheat cropping system of the Indo-Gangetic Plains emerges as a scientifically sustainable substitute. Studies indicate that cotton exhibits significantly lower water requirements compared to rice, with water-use efficiency ranging from 2.5 to 3.5 kg/m^3 for cotton, as compared to 4.5 to 5.5 kg/m^3 for rice. This reduction in water demand is particularly relevant in an agrarian landscape grappling with water scarcity. Additionally, research highlights the positive impact of cotton on soil health and nutrient management. Cotton's deep root system enhances soil structure, with studies reporting increased soil organic carbon content by approximately 15% in cotton-based rotations compared to continuous rice systems. Furthermore, the introduction of cotton into the cropping cycle disrupts pest and disease cycles associated with monoculture rice, reducing the reliance on chemical inputs. Studies from the Indo-Gangetic Plains report a 20-30% reduction in pesticide usage in diversified cropping systems incorporating cotton. This reduction not only contributes to economic savings for farmers but also aligns with sustainable agriculture practices by mitigating environmental risks associated with excessive chemical use. The adoption of cotton also brings economic benefits, with studies indicating income diversification and enhanced profitability due to reduced input costs. In the face of climate variability, cotton's adaptability to diverse weather conditions positions it as a resilient and sustainable choice in the rice-wheat cropping system of the Indo-Gangetic Plains, offering a comprehensive solution with scientific evidence.

Keywords: Cotton, IGP, Rice-wheat, Sustainable

In India, the most critical challenges for sustainable development currently revolve around the diminishing availability of land and water resources, and the escalating population. Effectively addressing the pressing need to nourish the continuously growing population within the constraints of limited resources stands as the foremost challenge for farmers, scientists, and policymakers. Rice-wheat system (RWCS) is the predominant cropping system in Indo-Gangetic Plains (IGP) occupying an area of about 13.5 m-ha, out of which 10 m-ha is in India contributing significantly to food security. The cultivation of RWCS demands substantial quantities of water, nutrients, and energy, resulting in increased cost of production and greenhouse gas emissions. Additionally, growing apprehensions about yield stagnation or decline, coupled with expanding environmental impacts, have sparked significant debates regarding the sustainability of the RWCS system in South Asia, especially in the northwest IGP. Cotton, Maize, Pigeon pea are viable alternatives to rice in RWCS of N-W IGP. Relative low water requirement, potential productivity and assured high returns makes cotton-wheat system more reliable for improvement of livelihood of farmers.

Sustainability issues related to RWCS

The standing water prevalent in paddy cultivation contribute to greenhouse gas emissions, particularly methane from anaerobic microbial processes (methanogenesis) by methanogenic bacteria during the decomposition of organic matter in waterlogged soils. Additionally, the practice of burning crop residues, a common post-harvest activity in this system, exacerbates air quality issues and poses environmental challenges. The continuous cultivation of rice and wheat in a monoculture format can lead to issues such as soil health degradation, increased vulnerability to pests and diseases, and a higher

demand for water resources, i.e. approximately 1,500 mm of water by rice crop, shift in weed flora and development of herbicidal resistance in crops.

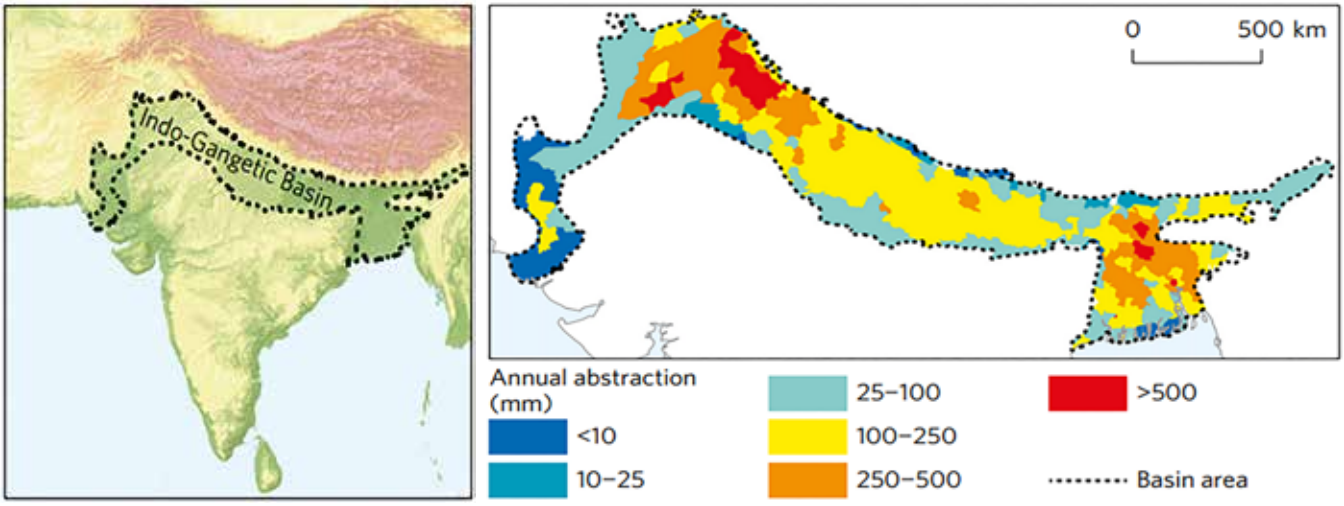
- ***Receding groundwater table***: NASA's GRACE satellite reports a 30 cm annual groundwater depletion across 4,40,000 sq. km in northwest India, equating to a 0.04 m drawdown per year. Around 1,00,000 sq. km of this area is under water-intensive rice cultivation, with 27,800 sq. km in Punjab, 10,800 sq. km in Haryana, 30,000 sq. km in western UP (part of a total 46,000 sq. km in UP), and 1,800 sq. km in Rajasthan.
- ***Water loss***: Deep drainage causes significant loss of approximately 40% of irrigation water in the R–W production systems within the northwest Indo-Gangetic Plains, especially in soils with coarse textures. Water required to produce 1 kg of rice ranges from 800 to 5,000 liters, with an average of 2,500 litres.
- ***Environmental pollution***: Six districts in Punjab contribute 40% of India's annual air quality impacts from crop residue burning due to high population density, agricultural output, and residue-heavy crops. Over 90% of fire-related exposure increase comes from northwest India, with 64% from Punjab, 11% from Haryana, and 5.7% from Uttar Pradesh, a trend steady for 17 years. Thus, the large quantities of rice and wheat residues produced under the R–W system have raised serious environmental complications.
- ***Greenhouse gases emissions (GHGs)***: Decomposition of organic matter and redox potential in soils of wetland contribute to the emissions of the GHGs, viz. CH_4 and N_2O in rice ecosystems. The greenhouse gas intensity of RWS is 0.2 kg CO_2 equivalent kg/grain, which was significantly higher than CWS.
- ***Destruction of soil structure***: Repeated wet tillage in standing water results in crush soil clods, eliminate macro-pores, reduce puddled layer strength and disperse fine clay particles and induces the formation of hardpan with higher soil bulk density that affects root proliferation of succeeding wheat crop.
- ***Herbicidal resistance***: Long-term use of the same herbicide has caused resistance due to strong selection pressure. Continuous application of urea-based herbicides like isoproturon in the rice–wheat system has led to decelopment of herbicide-resistant *Phalaris minor* biotypes in wheat.

Cotton - a viable alternative to rice in RWCS

Cotton, a significant fibre crop,

Cotton plant

is cultivated across India on 13.1 m-ha, encompassing both rainfed and irrigated conditions. Wheat, covering 34.2 m-ha, plays a crucial role in meeting the nutritional needs of the majority of the population. Both of these crops contribute



Annual abstraction of groundwater from Indo-Gangetic plains
Source: Nature Geoscience.

significantly to the livelihoods of a large segment of the Indian population. The introduction of short-duration, early-maturing cotton varieties (Table 1), along with the expansion of irrigation facilities, has facilitated the establishment of a cotton–wheat rotation system in northwestern India. As a result, the cotton–wheat cropping system now spans approximately 3.0 m-ha in the states of Punjab, Haryana, and Rajasthan.

Advantages of CWCS over RWCS

- ***Less greenhouse gases emission*:** Paddy cultivation significantly contributes to methane emissions, by growing cotton as an alternative to rice can reduce the potential GHG emissions.
- ***Higher income*:** Cotton is a cash crop that fetches a higher minimum support price (MSP) of ₹7,121 per quintal, compared to rice, which has an MSP of ₹2,300 for the 2024-2025 season (Table 2).
- ***Fewer input requirement*:** The introduction of Bt cotton has reduced the need for fertilizers and pesticides by breaking pest and disease cycles, along with lowering water usage, resulting in significant cost savings on agricultural inputs in comparision to rice.
- ***Higher water use efficiency (WUE)*:** Cotton requires less water than rice and produces a higher yield per unit of water. The water-use efficiency for cotton ranges from 0.61 to 0.72 kg/m^3, compared to 0.48 kg/m^3 for rice (Table 2).
- ***Improved soil health*:** Cotton maintains more balanced nutrient profile. Deep root system of cotton improves soil structure, aggregate formation and aeration.
- ***Climate resilience*:** Cotton is generally more resilient to certain weather conditions and can be a viable option in areas prone to climate variability.
- ***Reduced environmental pollution*:** Choosing cotton over rice helps farmers reduce the environmental impact of residue burning by using cotton stalks for biofuel and particle board production.

Table 1. Recommended varieties of cotton for Indo-Gangetic Plains of India

Variety	Year of release	Specifications	Suitable for	Released by
Bt-6	2020	30.46 q/ha, moderately resistant to CLCuV	Punjab, Haryana	ICAR- CICR (Central Institute of Cotton Research), Nagpur
CISAA2	2004	40 q/ha, resistant to fusarium wilt	North cotton zone	
CNH 1111	2022	14 q/ha, Jassids tolerant variety	Rainfed areas of Madhya Pradesh, Gujarat	
CSH 3129	2017	22.9 q/ha, tolerant to fungal foliar diseases	Punjab, Haryana, Rajasthan	
CSH 3075	2017	25 q/ha, suitable for high density planting system, tolerant to major biotic stresses		
CISA 310	2010	32-36 q/ha, tolerant to root rot and sucking pests	Irrigated areas of north zone	
Kalyan (CSHH-238)	2007	CICuV resistant, good fibre quality		
Simran (CSHH-243)	2008			
CSHG 1862	2013	GMS based hybrid with good fibre quality	North zone	

Source: CICR, Nagpur

Table 2. Comparision of RWCS and CWCS in terms of equivalent yield, availability of nutrients and resource use efficiency

Particular		Rice- wheat	Cotton-wheat
System productivity (q/ha)		109.60	115.65
Organic carbon (%)		0.27	0.40
Soil secondary nutrients	Soluble Calcium (C mol (+)/kg)	14.45	15.50
	Soluble Magnesium (C mol (+)/kg)	9.80	10.90
	Available Sulphur (mg/kg)	18.46	22.66
Available macronutrients	Phosphorus (kg/ha)	24.11	93.52
	Potassium (kg/ha)	25.77	96.63
Soil micronutrients	Available B (mg/kg)	1.11	1.29
	DTPA-Zn (mg/kg)	0.33	0.40
Water use efficiency (kg/m^3)		4.5 to 5.5	2.5 to 3.5
Net returns (₹/ha)		62,900	1,08,629

SUMMARY

Cotton emerges as a sustainable alternative to rice in the RWCS of N-W IGP. Its lower water requirements boost water-use efficiency, especially in water-scarce areas. Cotton cultivation not only enhances overall soil health but also disrupts pest cycles. This addresses sustainability concerns like receding groundwater, water loss, and environmental pollution. Besides environmental advantages, cotton brings benefits to farmers, including increased income, lower input needs, and enhanced resource use efficiency. The cotton-wheat system stands out for higher productivity and environmental sustainability, offering a holistic solution for farmers in the region.

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