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Drone-enabled precision spraying as a pathway to resource-efficient and climate-resilient cotton farming: Evidence from Pakistan

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Abstract

Agrochemical overuse in smallholder farming systems is a critical driver of soil degradation, greenhouse gas emissions, and ecosystem disruption, undermining the long-term resilience of agro-ecosystems in the Global South. Precision drone spraying offers a technology-driven pathway to reduce agrochemical inputs, improve yields, and strengthen the economic viability of smallholder farms. Yet rigorous field-level evidence on the resource-efficiency gains and economic returns of drone adoption remains scarce in South Asia. This study addresses that gap by quantifying the input-use efficiency and economic outcomes of agricultural drone adoption among cotton farmers in Multan district, Punjab, Pakistan.

Primary data were collected from 292 cotton farmers using commercial drone-spraying services. A three-stage benefit-cost analysis (BCA) captured per-acre changes in fertiliser, pesticide, and labour inputs, along with yield and revenue outcomes before and after drone adoption. Paired-sample t-tests assessed the statistical significance of all pre-post differences.

Results reveal significant and measurable resource-efficiency gains. Precision GPS-guided spraying reduced per-acre fertiliser expenditure by 3,780 PKR (USD 14) and pesticide expenditure by 4,290 PKR (USD 16), directly reflecting reduced agrochemical loads on the agro-ecosystem. Labor costs fell by 3,025 PKR (USD 12) per acre. Collectively, total per-acre input costs declined by 4,985 PKR (USD 24; t = 25.89, $p < 0.001$). Simultaneously, cotton yield increased by 156 maunds (6.18 metric tons) per acre (t = 23.75, $p < 0.001$), and per-acre revenue rose by 45,210 PKR (t = 23.75, $p < 0.001$). The benefit-cost ratio improved from 5.27 before adoption to 7.12 after adoption, a statistically significant net gain of 1.85 (t = 17.93, $p < 0.001$). Improved crop quality (N = 61), cost-effectiveness (N = 48), and reduced environmental impact (N = 15) were the most frequently reported benefits.

These findings demonstrate that precision drone spraying functions as a multi-functional agro-ecosystem intervention: it reduces agrochemical pressure, strengthens farm-level economic resilience, and enhances production efficiency, precisely the convergence demanded by climate-adaptive agriculture. The study offers actionable evidence for policymakers, agribusiness actors, and development organisations seeking scalable, resource-efficient farming solutions for smallholder systems in climate-vulnerable regions.

Keywords: Agricultural drones, agrochemical reduction, benefit-cost analysis, climate-resilient farming, input-use efficiency, precision agriculture, smallholder farmers

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