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Advances in Crop Cutting Experiments for Yield Estimation: Insights from Gram Cultivation in North-West Rajasthan: A Review

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ABSTRACT

In the arid expanses of North-West Rajasthan, gram (chickpea) sustains smallholder farmers amid harsh climates and poor soils. Accurate yield estimation, critical for planning and insurance, has historically relied on Crop Cutting Experiments (CCE), but traditional methods are labour-intensive and error-prone. This article explores recent advances in CCE, focusing on gram cultivation in districts like Bikaner and Jodhpur. Innovations such as satellite imagery, machine learning, and drone-based monitoring enhance precision, achieving up to 90% accuracy in yield predictions. Frontline demonstrations show yield increases of 18-35% through improved varieties and practices. By integrating real-time data collection and AI-driven models, these methods reduce bias and expedite results, vital for timely interventions under schemes like Pradhan Mantri Fasal Bima Yojana. We review 20 studies, analyse yield data from 2020-2024 showing steady growth despite climatic challenges, and discuss implications for sustainable agriculture. Enhanced CCE empowers farmers with reliable forecasts, improving food security and economic stability in a region where agriculture is a gamble against nature. Suggestions include policy support for tech adoption and farmer training to bridge digital divides, ensuring these advances translate into tangible benefits for Rajasthan's pulse growers.

Key words: Chickpea yield, Crop cutting experiments, Gram cultivation, Machine learning, North-west rajasthan, Precision agriculture, Yield estimation.

Crop cutting experiments (CCE) remain the backbone of official crop yield estimation in India, particularly for policy formulation, crop insurance settlement and food security planning. In arid and semi-arid regions such as North-West Rajasthan-characterized by low rainfall (200-400 mm annually), sandy soils and high climatic variability-the reliability of traditional CCE methods is frequently compromised by sampling bias, delayed execution and human errors. Gram (*Cicer arietinum* L.), a major *rabi* pulse crop that sustains smallholder livelihoods in districts such as Bikaner, Jaisalmer and Jodhpur, is particularly vulnerable to these limitations.

Despite the growing availability of geospatial data, digital platforms and artificial intelligence (AI)-based analytical tools, conventional CCE practices in arid regions have remained largely manual and labour-intensive. Existing studies often document technological advancements in isolation, with limited synthesis focused specifically on pulse crops under arid agro-climatic conditions. This reveals a critical research gap regarding the systematic integration of remote sensing, machine learning and digital data collection tools with CCE for gram yield estimation in North-West Rajasthan.

The present review addresses this gap by critically examining recent methodological innovations in CCE and assessing their applicability to gram cultivation in arid environments. The objectives of this review are threefold:

(i) To synthesize recent advancements in CCE methodologies relevant to pulse crops.

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(ii) To evaluate the role of remote sensing, machine learning and digital tools in improving yield estimation accuracy.

(iii) To analyse region-specific implications for gram cultivation in North-West Rajasthan.

By thematically integrating empirical findings from multiple studies, this article contributes a region-focused perspective to the precision agriculture literature, highlighting how hybrid CCE approaches can enhance yield reliability, policy responsiveness and farmer resilience in resource-constrained arid systems.

Review of literature

Review methodology

This review synthesizes findings from 20 peer-reviewed articles, government reports and institutional studies

published between 1991 and 2024. Studies were selected based on their relevance to crop cutting experiments, yield estimation methodologies, remote sensing applications and gram or pulse cultivation in arid and semi-arid regions. Emphasis was placed on empirical studies demonstrating methodological innovation or region-specific application. Findings were thematically analysed to identify converging evidence and methodological trends.

Theme 1: Conventional CCE and sampling challenges

Early studies established CCE as a statistically robust method for yield estimation through randomized plot harvesting (Ahmad *et al*., 2021). However, in heterogeneous landscapes such as Rajasthan, conventional square plots often introduce edge effects and sampling bias, particularly under mixed cropping systems (Mahajan, 2001). Historical surveys also highlighted systematic underestimation in remote arid districts due to logistical constraints (NSSO, 1991).

Theme 2: Remote sensing and geospatial integration

Recent studies demonstrate that integrating satellite imagery with CCE enhances spatial representativeness and reduces sampling errors by 10-20% (Reddy, 2022). SAR and optical data have proven effective in identifying gram acreage prior to harvest, enabling targeted CCE deployment in vast arid zones (Directorate of Economics and Statistics, 2021).

Theme 3: Machine learning and predictive modelling

Machine learning models, particularly random forest and hybrid DSSAT-CROPGRO frameworks, outperform traditional statistical approaches by incorporating weather, soil and management variables. Studies in semi-arid Rajasthan report prediction accuracies exceeding 85% when CCE data are used for model calibration (Chandrasekhar and Reddy, 2024; Singh and Kumar, 2023).

Theme 4: Digital data collection and participatory approaches

Mobile-based CCE data collection platforms have significantly reduced transcription errors and processing delays (MoAFW, 2022). Participatory demonstrations and GPS-enabled plot marking further reduce yield variance and improve farmer confidence in official estimates (Singh, 2013; Singh, 2023). These hybrid approaches indicate a transition from purely manual CCE to digitally augmented systems suitable for arid pulse cultivation.

Analysis of secondary yield data from 2020-2024 indicates a gradual increase in gram productivity in North-West Rajasthan, with average yields rising from approximately 1050 kg/ha in 2020-21 to 1222 kg/ha in 2023-24. Frontline demonstrations incorporating GPS-assisted CCE and improved grain varieties recorded yield gains of 17% to 35% compared with traditional farmer practices. Machine learning-assisted yield estimation models achieved prediction accuracies of 80-90% when calibrated with CCE data, significantly reducing estimation errors observed in conventional methods.

The findings demonstrate that technology-enabled CCE significantly outperforms traditional manual approaches in terms of accuracy, timeliness and operational efficiency. Conventional CCE methods, while statistically sound, often suffer from delayed execution, limited spatial coverage and human-induced bias-constraints that are particularly pronounced in arid regions with fragmented landholdings.

In contrast, hybrid approaches combining satellite imagery, machine learning and digital data collection enable early yield forecasting and reduce dependence on extensive field labour. However, these innovations are not without limitations. High initial costs, limited digital literacy among smallholder farmers and uneven access to internet connectivity pose significant barriers to large-scale adoption. Moreover, machine learning models may introduce bias if trained on incomplete or regionally unrepresentative datasets.

Scalability remains a key challenge. While pilot projects in districts like Bikaner and Jodhpur demonstrate success, replication across resource-poor settings requires institutional support, standardized protocols and sustained capacity building. Addressing these challenges is essential to ensure that technological advancements in CCE translate into equitable benefits for smallholder farmers rather than widening existing digital divides.

Suggestions

To maximize the impact of advanced Crop Cutting Experiments (CCE) for gram yield estimation in North-West Rajasthan, a strategic approach is essential. First, expand farmer training through Krishi Vigyan Kendras, focusing on digital tools such as mobile apps for CCE data entry and for interpreting satellite imagery. Workshops supported by NGOs could use demo plots to demonstrate 20% accuracy gains from GPS-guided sampling (Ministry of Agriculture and Farmers Welfare, 2022). Subsidize affordable tools-low-cost drones or smartphones with yield apps-targeting women farmers who manage post-harvest tasks.

Policy-wise, integrate hybrid CCE into PMFBY, mandating AI-verified yield data to streamline insurance payouts, reducing disputes by 25% (Singh, 2024). Establish regional data hubs in Bikaner and Jodhpur, linking CCE results to SMS-based yield alerts, potentially boosting gram yields by 15-25% through timely sowing advice (Kumar and Sharma, 2024). Public-private partnerships with agrotech firms can pilot AI-driven CCE and offer tax incentives for arid-specific innovations.

Research should focus on localized models, funding universities like Swami Keshwanand Rajasthan Agricultural University to develop gram-specific algorithms incorporating soil microbes (Singh and Kumar, 2023). Explore blockchain to enable transparent CCE data and build market trust. Promote sustainable intercropping with nitrogen-fixing plants, monitored *via* CCE, to reduce fertilizer use by 30% (Food and Agriculture Organization, 2018). Form farmer

cooperatives for shared drone access, cutting costs and use radio campaigns to build trust in tech. Annual audits will refine these efforts, potentially raising incomes by 20-40% and securing food supplies.

CONCLUSION

The transformation of crop cutting experiments (CCE) for gram yield estimation in North-West Rajasthan marks a pivotal shift toward resilient agriculture. From labour-intensive plot sampling, CCE has evolved into a tech-driven tool, integrating satellite imagery, AI and mobile data to deliver precise yield forecasts. These advances address critical challenges: unpredictable yields due to drought, delays in insurance payouts and inefficiencies in manual methods. In a region where grain sustains both diets and economies, such innovations are game-changers. Studies show yield increases of 15-35% through frontline demonstrations, with data from 2020-2024 confirming steady growth despite climatic setbacks.

For farmers in Bikaner or Barmer, enhanced CCE means actionable insights-knowing when to irrigate or switch varieties-reducing risks in a climate-stressed landscape. Drone-mapped plots cut costs by 30%, while machine learning flags yield dips early, enabling timely interventions. This isn't just about numbers; it's about empowering marginalized farmers with data-driven decisions, boosting food security and incomes. The potential is vast: a networked system in which CCE data informs policy in real time could transform Rajasthan's pulse sector. Challenges like tech access persist, but the path forward is clear-sustained investment in hybrid CCE will strengthen gram cultivation, turning arid challenges into opportunities for sustainable growth and regional prosperity.

Conflict of interest

All authors declare that they have no conflicts of interest.

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