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Cropping *Kharif* Fallows to Enhance *Rabi* Chickpea Productivity and Cropping Intensity in Rainfed Deep Vertisols: A Comprehensive Review

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ABSTRACT

Rainfed deep Vertisols in semi-arid regions of India are traditionally left fallow during the *kharif* season to conserve soil moisture for *rabi* crops, particularly chickpea (*Cicer arietinum* L.). While this practice ensures residual moisture availability, it significantly limits cropping intensity, land productivity and resource use efficiency. Recent agronomic research has demonstrated the feasibility of cropping *kharif* fallows with short-duration, low-water-demand crops such as green gram, foxtail millet, sesame and cowpea. These crops can be harvested before the onset of *rabi* season, leaving sufficient residual moisture for chickpea establishment. Moreover, strategic interventions in land configuration, nutrient management and integrated pest control have enabled successful *kharif* cropping in Vertisols, mitigating risks associated with waterlogging and poor soil aeration. This review synthesizes multidisciplinary research on *kharif* crop-chickpea systems, comparing them with conventional fallow-chickpea rotations across agronomic, economic and ecological metrics. Evidence from long-term trials and farmer participatory research reveals that intensified systems improve chickpea equivalent yields, enhance soil carbon sequestration, suppress pest and disease cycles and contribute to climate resilience. Integrated nutrient and residue management further supports soil health and microbial activity, while diversified cropping systems offer better profitability and livelihood security. Across Vertisol regions, inclusion of *kharif* crops increased chickpea equivalent yield by 22-33% and soil organic carbon by 18-21% compared with traditional fallow-chickpea system, while also improving yield stability and farm profitability. The paper also identifies key research gaps and policy interventions needed to scale sustainable *kharif* cropping in Vertisol landscapes. By integrating agronomic innovations with ecological and socioeconomic perspectives, this review provides a comprehensive framework for advancing chickpea-based systems and promoting sustainable intensification in rainfed agriculture.

Key words: Chickpea, Cropping intensity, *Kharif* cropping, Rainfed agriculture, Sustainable intensification, Vertisols.

Rainfed agriculture in India occupies nearly 60% of the net sown area and supports the livelihoods of millions of smallholder farmers (Venkateswarlu and Prasad, 2012). Within this domain, deep Vertisols-characterized by high clay content, slow permeability and pronounced shrink-swell behavior-are a dominant soil group in semi-arid regions such as central and southern India. These soils are agriculturally significant but pose unique challenges during the monsoon season due to water logging, poor aeration and crust formation. Consequently, the conventional practice in Vertisol regions has been to leave the land fallow during the *kharif* season, conserving soil moisture for *rabi* crops, particularly chickpea (*Cicer arietinum* L.), which is highly sensitive to terminal drought and soil moisture deficits (Vittal *et al*., 2005; Sharma, 2001).

The fallow-*rabi* chickpea system, while agronomically conservative, restricts cropping intensity and underutilizes the *kharif* rainfall. This practice results in low land use efficiency, reduced annual productivity and missed opportunities for ecological benefits such as nutrient cycling and carbon sequestration. With increasing pressure on land resources, climate variability and the need for sustainable intensification, researchers began to explore the feasibility of cropping *kharif* fallows with short-duration, low-water-demand crops. These include green gram

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(*Vigna radiata*), foxtail millet (*Setaria italica*), sesame (*Sesamum indicum*) and cowpea (*Vigna unguiculata*), which can be harvested before the onset of *rabi* season, leaving sufficient residual moisture for chickpea establishment (Munirathnam and Kumar, 2021; Prabhakar *et al*., 2022). The transition from fallow to *kharif* cropping in Vertisols is supported by agronomic innovations such as broad-bed and furrow (BBF) land configuration, improved drainage systems and integrated nutrient and pest management. These systems not only enhance land use efficiency but also contribute to soil health, carbon sequestration and ecological resilience (Salahin *et al*., 2021; Kumari *et al*., 2024). Moreover, the inclusion of legumes and cover crops during *kharif* improves biological nitrogen fixation, microbial activity and soil structure-factors critical for sustaining chickpea productivity. Studies have shown that *kharif* crop-chickpea systems outperform traditional fallow-chickpea rotations across multiple metrics, including chickpea equivalent yield, sustainability yield index (SYI), net returns and soil organic carbon levels (Wani, 2003; Ghosh *et al*., 2014; Kumar *et al*., 2023).

In addition to agronomic benefits, *kharif* cropping offers ecological and socio-economic advantages. Diversified cropping systems suppress pest and disease cycles that often intensify in monoculture fallow-*rabi* systems. Crop residues from *kharif* legumes and cereals enhance soil organic matter and improve water retention. Economically, farmers benefit from an additional harvest, reduced input costs per unit yield and improved resilience to climate shocks. Region-specific studies, such as those conducted in Andhra Pradesh and Karnataka, have demonstrated that *kharif* cropping does not compromise chickpea yields and, in many cases, enhances overall system productivity (Raghuwanshi *et al*., 2024).

Despite these promising outcomes, adoption of kharif cropping in Vertisols remains limited due to perceived risks, lack of access to suitable crop varieties, inadequate drainage infrastructure and limited extension support. Addressing these barriers requires a combination of research, policy interventions and farmer engagement. Breeding efforts must focus on short-duration, waterlogging-tolerant *kharif* crops and chickpea varieties adapted to post-*kharif* conditions. Agronomic packages should be tailored to local soil and climate conditions and institutional support must facilitate access to inputs, credit and markets.

This review synthesizes multidisciplinary research on cropping *kharif* fallows to enhance *rabi* chickpea productivity and system sustainability. A systematic literature survey was conducted covering peer-reviewed journal articles, long-term experiments, ICAR and ICRISAT research reports and cluster front line demonstrations published primarily between 2000 and 2025. Studies were included if they addressed rainfed Vertisols, evaluated *kharif*-chickpea sequences and reported agronomic, ecological or socio-economic outcomes.

By integrating agronomic, ecological and policy perspectives, the review aims to provide a comprehensive framework for researchers, extension professionals and policymakers to reimagine *kharif* cropping in Vertisols-not as a risk, but as a strategic opportunity for climate-resilient agriculture. A schematic map showing the distribution of Vertisols in India is provided in Fig 1 (Mandal *et al*., 2013).

To synthesize the interactions, among *kharif* cropping, soil-water processes in Vertisols, *rabi* chickpea performance and broader sustainability outcomes, a conceptual framework is presented (Fig 2). The framework illustrates how short-duration *kharif* crops, supported by appropriate land configuration and nutrient management can mitigate Vertisol constraints, enhance residual soil moisture and soil health and ultimately improve productivity and resilience of chickpea-based rainfed systems.

Cropping systems and dominant crops

Cropping systems in deep Vertisols of semi-arid India have traditionally revolved around a fallow–*rabi* chickpea rotation, primarily to conserve soil moisture and avoid waterlogging during the monsoon season. However, this practice significantly limits cropping intensity and land productivity. A long-term (15 year) experiment at ICRISAT demonstrated that cropping during the rainy season is technically feasible and the grain productivity of double cropped sorghum + chickpea and black gram + sorghum sequential systems were higher than their conventional counterparts with rainy season fallow, *i.e.* fallow + post-rainy sorghum and fallow + post-rainy chickpea (Rao *et al*., 2015). Recent research has demonstrated the feasibility and benefits of introducing short-duration *kharif* crops prior to chickpea, thereby enhancing system productivity, soil health and economic returns (Prabhakar *et al*., 2022; Munirathnam and Kumar, 2021). The selection of *kharif* crops suitable for Vertisols hinges on their ability to tolerate intermittent water logging,

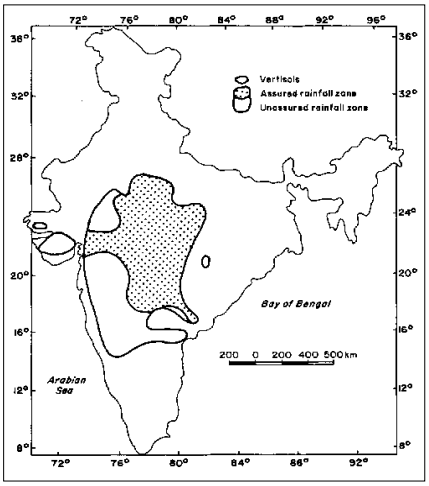


Fig 1: Schematic map showing Vertisols distribution in India under assured and unassured rainfall zones.

mature early and leave sufficient residual moisture for *rabi* chickpea. The most promising crops include green gram (Patil *et al*., 2022), foxtail millet (Munirathnam and Kumar, 2021; Jyotsna *et al*., 2023), maize (Venkatesh *et al*., 2023) and sesame (Shahana *et al*., 2022).

Regional variations in cropping systems

Cropping systems on Vertisols in India exhibit pronounced regional variation driven by differences in rainfall regime, soil moisture dynamics and market orientation across agro-climatic zones. In central India, particularly in Madhya Pradesh and Maharashtra, soybean-chickpea and pigeon pea-chickpea sequences dominate rainfed Vertisol agriculture, reflecting both climatic suitability and strong market demand for pulses. In these regions, the broad-bed and furrow (BBF) land configuration has been widely adopted to alleviate seasonal waterlogging, improve surface drainage and enhance root aeration, resulting in improved crop establishment and yield stability under monsoon rainfall conditions (Prasad *et al*., 2023; Jadav *et al*., 2022). In the southern Vertisol zones of Karnataka and the erstwhile Andhra Pradesh region, cotton and pigeon pea-based systems are prevalent, often practiced as intercropping with millets or short-duration legumes to spread risk and optimize resource use. Here, conservation agriculture practices such as reduced tillage, residue retention and diversified cropping are increasingly promoted to mitigate climate variability, conserve soil moisture and sustain productivity under semi-arid conditions (Jat, 2012; Kassam *et al*., 2019). Eastern Vertisol pockets in Chhattisgarh and parts of Odisha are characterized by maize- and sorghum-based systems, traditionally constrained by excess moisture and suboptimal drainage during the kharif season. Recent research and development efforts emphasize diversification through the integration of pulses and oilseeds to improve system resilience, soil fertility and farm income, supported by improved land shaping and location-specific nutrient management strategies (ICAR-CRIDA, 2016; ICAR, 2020).

Recent field experiments conducted at RARS, Nandyal and other regional stations have shown that *kharif* crop-chickpea systems outperform fallow-chickpea rotations across multiple agronomic and economic metrics. The inclusion of *kharif* crops improves chickpea equivalent yield (CEY), sustainability yield index (SYI) and soil organic carbon (SOC) levels (Table 1) (Munirathnam and Kumar, 2021).

These systems enhance nutrient cycling, suppress weeds and pests and improve soil structure through root biomass and residue incorporation. Notably, green gram-chickpea systems recorded the highest production use efficiency and SYI, attributed to biological nitrogen fixation and improved soil carbon status (Prabhakar *et al*., 2022).

Relative to the traditional fallow-chickpea system, *kharif*-based cropping systems resulted in a 22-33% increase in chickpea equivalent yield, with the highest improvement observed under green gram-chickpea followed by cowpea-chickpea and foxtail millet-chickpea systems (Table 1).

Higher system productivity translated into substantially greater net returns, ranging from Rs. 39,000 to 42,000/ha under *kharif* -based systems compared with Rs. 28,000/ha under fallow-chickpea (Table 1).

Scope for introducing preceding *kharif* crops

The rationale for leaving land fallow in *kharif* is soil moisture conservation. However, several studies have shown that early-maturing crops (60-70 days) can utilize the early monsoon rainfall without adversely affecting *rabi* chickpea yields (Chaudhary *et al*., 2020). Short-duration pulses such as mungbean (*Vigna radiata*), urdbean (*Vigna mungo*) and cowpea (*Vigna unguiculata*) are well suited to rainfed *kharif* systems due to their low water requirement, early maturity and capacity for biological nitrogen fixation, which enhances soil fertility and benefits succeeding crops

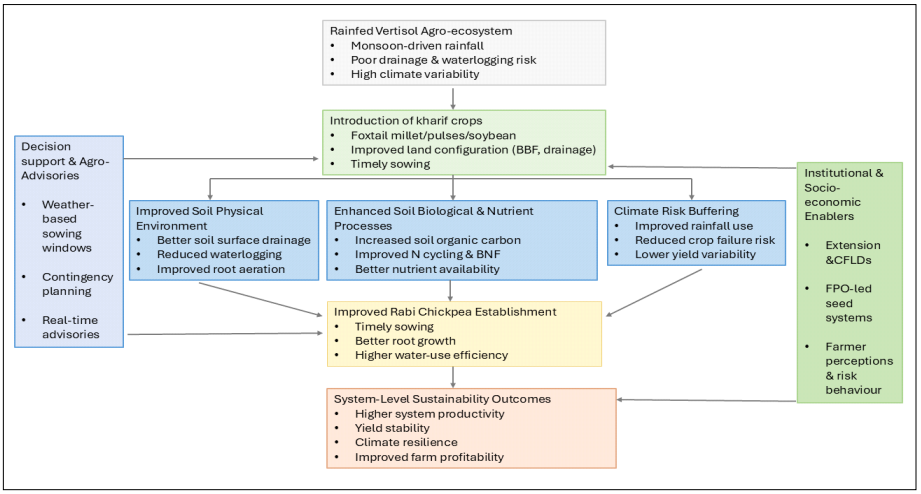


Fig 2: Conceptual framework illustrating *kharif* crop introduction in deep Vertisols and its interactions with soil-water processes, *rabi* chickpea performance and sustainability pathways under rainfed conditions.

(Singh and Praharaj, 2011; Kermah *et al.,* 2018). In addition, drought-tolerant cereals such as sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*) have been widely evaluated for their adaptability to semi-arid rainfed environments and their role in crop diversification and system intensification (Bandyopadhyay *et al*., 2017).

Soil and water management

Land configuration plays a pivotal role in mitigating waterlogging and improving root zone aeration. Among the most effective techniques is the Broad-Bed and Furrow (BBF) system, which elevates planting beds and channels excess water into furrows (Khambalkar *et al*., 2014). Studies conducted in Madhya Pradesh and Andhra Pradesh have shown that BBF improves chickpea establishment following *kharif* crops by enhancing infiltration and reducing crust formation (Prabhakar *et al*., 2022). Other configurations include raised beds, which facilitate drainage and reduce compaction; Contour bunding, which conserves moisture and minimizes runoff; and Graded furrows, which direct water flow and prevent stagnation (Autkar *et al*., 2006; Verma *et al*., 2017).

Techniques such as mulching with crop residues, cover cropping and ridge-furrow planting have proven effective in retaining soil moisture and improving infiltration rates. Mulching reduces evaporation and moderates soil temperature. Cover crops like cowpea and green gram enhance soil structure and microbial activity. Ridge-furrow systems optimize water distribution and root zone moisture.

Effective drainage is essential for *kharif* cropping in Vertisols. Poorly drained soils lead to anaerobic conditions, root diseases and delayed sowing. Strategies include: Surface drainage channels to remove excess water. Early sowing before peak monsoon to avoid saturation. Subsurface drainage (where feasible) to improve aeration and reduce waterlogging risk.

Kharif cropping improves several physical properties of Vertisols like aggregate stability, increases due to root biomass and residue incorporation; Bulk density, which decreases, enhancing root penetration; and Porosity and infiltration improve, facilitating moisture retention for *rabi* crops.

Nutrient management

Kharif legumes such as green gram/cowpea/soybean contribute to biological nitrogen fixation, enriching the soil with available nitrogen for the succeeding chickpea crop. (Patil *et al*., 2022; Shah *et al*., 2025). Cereals like foxtail millet and oilseeds like sesame mobilize phosphorus and micronutrients from deeper soil layers, improving nutrient availability in the rhizosphere. The residual effects of these crops are particularly beneficial in Vertisols, where nutrient stratification and poor mobility can limit uptake. Field studies in Andhra Pradesh and Maharashtra have shown that cropping *kharif* fallows with green gram or foxtail millet leads to higher chickpea yields and improved nutrient use efficiency compared to fallow-chickpea systems (Prabhakar *et al*., 2022; Munirathnam and Kumar, 2021). Sidhu *et al*. (2003) reported that mung bean residue incorporation increased subsequent maize crop yield by 39%.

Integrated nutrient management (INM) combines organic amendments, biofertilizers and inorganic fertilizers to optimize nutrient availability and sustain soil health. In Vertisols, INM has proven effective in maintaining productivity under intensive cropping systems (Wu and Ma, 2015). Gabhane *et al*. (2022) reported that application of 50% recommended nitrogen dose (RDN) through farmyard manure (FYM) or gliricidia, combined with 50% RDN and full doses of phosphorus and potassium through inorganic sources, significantly improved crop yields and soil fertility under cotton + green gram intercropping in Vertisols. Similar approaches can be adapted for *kharif*-chickpea systems to balance nutrient inputs and reduce dependency on chemical fertilizers. Key INM components include Organic amendments like FYM, compost and green manures improve soil structure, water retention and microbial activity; Biofertilizers such as Rhizobium, phosphate-solubilizing bacteria (PSB) and mycorrhizae enhance nutrient uptake and root development and Balanced fertilization, based on soil testing, tailored nutrient doses prevent deficiencies and optimize crop response.

Residue incorporation from *kharif* crops contributes to soil organic carbon, improves cation exchange capacity and supports microbial biomass (Ladha *et al*., 2022). Legume residues, in particular, decompose rapidly (Jibat *et al*., 2014) and release nutrients synchronously with chickpea demand. Residue retention also enhances soil aggregation and reduces erosion, which is critical in Vertisols prone to surface sealing and runoff (Page *et al*., 2019). Conservation tillage combined with residue management has shown positive effects on nutrient availability (Jayaraman *et al*., 2021) and chickpea performance (Karuna *et al*., 2024).

Micronutrient deficiencies-especially of zinc (Zn), boron (B) and sulfur (S)-are increasingly reported in intensively

Table 1: Comparative performance of cropping systems in deep vertisols.

Cropping system	Chickpea equivalent yield (kg/ha)	SYI	Net returns (Rs/ha)	Soil organic carbon (%)
Fallow → Chickpea	1800	0.52	28000	0.38
Green gram → Chickpea	2400	0.68	42000	0.45
Foxtail Millet → Chickpea	2200	0.64	39000	0.43
Cowpea → Chickpea	2300	0.66	41000	0.44

*SYI: Sustainability yield index.

cultivated vertisols (Palmer *et al*., 2023). Site-specific nutrient management (SSNM) trials in Chhattisgarh identified nitrogen, phosphorus and sulfur as the most limiting nutrients, followed by Zn and B (Sushma and Sao, 2018).

Pest and disease dynamics

Kharif cropping introduces plant diversity that interferes with pest life cycles and reduces host continuity (Han-ming *et al*., 2019). In fallow systems, soil-borne pathogens such as *Fusarium oxysporum sp. ciceri* (causing Fusarium wilt) and *Rhizoctonia bataticola* (causing dry root rot) tend to accumulate due to the absence of crop rotation, leading to severe yield losses, while collar rot (*Sclerotium rolfsii*) and wet root rot (*Rhizoctonia solani*) also thrive in monocropped or fallow-chickpea fields and foliar diseases such as Ascochyta blight (*Ascochyta rabiei*), Botrytis gray mold (*Botrytis cinerea*), anthracnose (*Colletotrichum* spp.) and Sclerotinia stem rot (*Sclerotinia sclerotiorum*) spread more rapidly in monoculture systems. Also, insect pests, particularly the pod borer (*Helicoverpa armigera*), are more destructive in fallow chickpea fields where natural predator populations are scarce and cutworms and bruchids also show higher prevalence in monocropped systems, while weeds in fallow land act as alternate hosts, sustaining pest populations and exacerbating the problem, making fallow chickpea highly vulnerable to biotic stress (Saravanan and Amanath, 2025). Whereas in *kharif* cropping-chickpea system reduces pest pressure by breaking insect life cycles, thereby lowering pod borer outbreaks. Pande *et al*. (2012) observed that chickpea grown after cereals or pulses experiences lower disease incidence compared to chickpea grown after fallow. In addition, *Fusarium* wilt incidence was significantly reduced in sorghum/maize-chickpea compared to fallow (Priyanka and Yogita, 2022). Furthermore, research studies indicated that rice-fallow chickpea systems in the Indo-Gangetic plains suffered from higher pest and disease pressure compared to rotational systems (Hedayetullah, 2023).

The comparative analysis of cropping systems reveals that fallow chickpea has high pest and disease pressure, with key issues including *fusarium* wilt, root rots and pod borer outbreaks, while chickpea after foxtail millet, maize, or jowar shows low pest and disease pressure. In conclusion, fallow-chickpea systems are more vulnerable to pests and diseases due to pathogen buildup and uninterrupted pest cycles, while rotational cropping with foxtail millet, maize, jowar and pulses significantly reduces pest and disease incidence. Furthermore, integrated pest management strategies are essential to sustain chickpea productivity in diverse agro-ecological zones, with evidence from multiple studies confirming that non-fallow systems consistently outperform fallow systems in terms of pest and disease management, soil health and yield stability.

Yield gaps and productivity trends

Multiple studies across central and southern India have demonstrated that *kharif* crop-chickpea systems consistently outperform traditional fallow-chickpea rotations. Chickpea yields remain stable or improve when preceded by green gram, foxtail millet, or cowpea, provided appropriate land configuration and moisture conservation practices are followed (Munirathnam and Kumar, 2021). Cluster Frontline Demonstrations (CFLDs) conducted in Vertisol regions have shown that improved *kharif* management leads to higher chickpea equivalent yields (CEY) and better sustainability yield index (SYI). For instance, green gram-chickpea systems recorded CEY values of 2400-2600 kg/ha, compared to 1800 kg/ha in fallow-chickpea systems (Mohan *et al*., 2019). Yield gaps are defined as the difference between potential and actual yields under farmer-managed conditions. Similar trends were observed in Andhra Pradesh and Karnataka, where *kharif* cropping improved soil moisture and nutrient availability for chickpea.

Long-term trials conducted by ICRISAT and CRIDA over 5-7 years have shown that *kharif* cropping enhances system resilience and stabilizes chickpea yields under variable rainfall conditions. These systems also improve soil health indicators such as organic carbon, microbial biomass and aggregate stability.

Economic and efficiency gains

Beyond yield, *kharif* cropping improves economic returns and input use efficiency. Studies show that net returns in *kharif*–chickpea systems are 30-50% higher than in fallow-chickpea systems, due to additional *kharif* harvest and improved chickpea performance (Saila and Kumar, 2009; Meena *et al*., 2021). Land use efficiency (LUE) also improves, as the same land supports two crops per year instead of one (Jat *et al*., 2011; Dhaka *et al*., 2025a). This intensification contributes to better livelihood outcomes and reduces per-unit production costs.

Carbon sequestration and sustainability

Vertisols are known for their high clay content and capacity to stabilize organic carbon (Smith *et al*., 2015; Jadhav *et al*., 2024), but their SOC levels decline rapidly under continuous monoculture and residue removal (Jha *et al*., 2020). Inclusion of *kharif* crops-especially legumes like green gram and cowpea-contributes to both labile and stable carbon pools through root biomass and leaf litter (Rai *et al*., 2023; Singh and Singh, 2025). Studies from Akola and Bhopal have shown that conservation tillage combined with *kharif* cropping increases total carbon input by 30-40% over conventional fallow systems. A long-term study by Raghuwanshi *et al*. (2024) in central India revealed that *kharif* cropping under no-tillage conditions significantly improved SOC, aggregate stability and soil penetration resistance. Soybean-chickpea and maize-gram systems recorded higher carbon sequestration rates (Anupama *et al*., 2025) compared to fallow-chickpea rotations.

Sustainability in cropping systems is commonly assessed using integrative indicators such as the Sustainability Yield Index (SYI) (Wanjari *et al*., 2004), which

reflects yield stability over time; land use efficiency (LUE), which captures productivity per unit area and time (Marcello *et al*., 2022) and carbon footprint reduction, which indicates net mitigation of greenhouse gas emissions (Xing and Wang, 2024). Across these indicators, *kharif*-chickpea cropping systems consistently outperform the traditional fallow-chickpea system, demonstrating both higher productivity and greater system resilience (Salakinkop, 2024). Among the evaluated systems, green gram-chickpea recorded particularly high sustainability performance, with SYI values reaching 0.68 and LUE improvements of 35-40%. These gains are largely attributed to enhanced biomass inputs, improved soil cover and reduced tillage intensity during the *kharif* season, which collectively contribute to better resource-use efficiency and soil health (Prabhakar *et al*., 2022).

Kharif cropping enhances climate resilience in rainfed Vertisol systems by buffering rainfall variability through improved soil infiltration and water retention (Kamboj *et al*., 2025; Sawant *et al*., 2025), reducing erosion *via* continuous ground cover and root-mediated soil stabilization and enhancing on-farm biodiversity through crop diversification and microbial enrichment. Beyond these physical and biological functions, *kharif*-based systems support a range of ecosystem services, including improved nutrient cycling, enhanced pollinator habitat and suppression of pest and disease pressures (Desalegn and Abate, 2021; Mwila *et al*., 2021). The adoption of conservation agriculture practices-particularly residue retention and reduced tillage-further strengthens these benefits by improving soil structure, moderating soil temperature and increasing system resilience to climatic stress (Jayaraman *et al*., 2021). Collectively, these processes contribute to greater carbon sequestration and overall system sustainability in Vertisols, as reflected in higher soil organic carbon levels, reduced erosion risk and improved productivity over time (Singh *et al*., 2025) (Table 2).

Policy and socioeconomic dimensions

Access to quality inputs-such as seeds of short-duration *kharif* crops, biofertilizers and land configuration implements-is essential for system intensification. Government schemes like the National Food Security Mission (NFSM) and Rashtriya Krishi Vikas Yojana (RKVY) have supported pulses and oilseeds through seed minikits, demonstrations and training. However, these programmes often focus on *rabi* crops, with limited emphasis on *kharif* diversification. Credit access remains a barrier, especially for smallholders in Vertisol regions. Seasonal cash flow constraints and lack of collateral limit investment in *kharif* cropping. Strengthening institutional credit and promoting self-help groups (SHGs) and Farmer Producer Organizations (FPOs) can improve input adoption and reduce financial risk. Market access for *kharif* crops is uneven. While chickpea benefits from Minimum Support Price (MSP) and procurement mechanisms, *kharif* millets, pulses and oilseeds often lack assured markets. This discourages farmers from investing in *kharif* cropping despite its agronomic benefits. Developing value chains for green gram, sesame and foxtail millet-including aggregation, processing and branding-can enhance profitability. FPOs play a critical role in linking producers to buyers, negotiating prices and reducing transaction costs. Digital platforms and e-NAM (National Agriculture Market) offer additional avenues for market integration (Chand *et al*., 2016; Singh *et al*., 2021; Chauhan and Rathore, 2025). *Kharif* cropping increases labor demand, particularly during land preparation, sowing and harvesting. This has implications for household labor allocation and gender roles. Studies in Karnataka and Maharashtra show that women contribute significantly to *kharif* operations, especially in weeding and harvesting, yet often lack decision-making power and access to training (Ekatpure, 2011; Sunitha *et al*., 2018).

Knowledge gaps and risk perceptions hinder *kharif* cropping in Vertisols. Many farmers associate *kharif* cultivation with waterlogging, crop failure and reduced chickpea yields. Participatory extension approaches-such as Farmer Field Schools (FFS), on-farm trials and ICT-based advisories-can address these concerns and build confidence. ICRISAT's watershed-based interventions have demonstrated that community engagement and localized training improve adoption of *kharif* cropping and conservation practices. Integrating agronomic recommendations with socioeconomic realities ensures relevance and scalability.

Scaling *kharif* cropping in deep Vertisols requires a shift from *rabi*-centric support toward year-round system intensification. Policy incentives such as MSP, crop insurance and targeted input support can reduce risk and promote *kharif* diversification, while investments in drainage infrastructure and land configuration tools are

Table 2: Carbon sequestration and sustainability metrics in vertisol cropping system.

Cropping system	SOC (%)	Carbon input (ton/ha)	SYI	LUE (%)	Erosion risk
Fallow-chickpea	0.38	2.36	0.52	48	High
Green gram-chickpea	0.45	3.10	0.68	65	Low
Foxtail millet-chickpea	0.43	2.90	0.64	60	Moderate
Cowpea-chickpea	0.46	3.20	0.66	63	Low

*SOC: Soil organic carbon; SYI: Sustainability yield index; LUE: Land use efficiency.

Table 3: Socio-economic factors influencing *kharif* cropping adoption in vertisols.

Factor	Influence on adoption	Current status	Recommended intervention
Input subsidies	High	Limited for *kharif*	Expand to include *kharif* pulses
Credit access	Moderate	Constrained for smallholders	Promote SHGs and FPO credit models
Market linkages	High	Weak for *kharif* crops	Develop value chains and MSP support
Labor availability	Moderate	Gendered and seasonal	Mechanization and gender training
Extension services	High	Patchy and reactive	Strengthen participatory models

*SHG: Self help group; FPO: Farmers producers organization; MSP: Minimum support price.

essential to overcome waterlogging constraints. Strengthening Farmer Producer Organizations (FPOs) can improve access to inputs and markets and gender-sensitive extension approaches are crucial given women's significant role in *kharif* operations (Birthal *et al*., 2015). Together, these measures can transform *kharif* cropping from a perceived risk into a viable pathway for sustainable intensification and livelihood enhancement. The adoption of *kharif* cropping in vertisols is strongly shaped by socio-economic and institutional factors, which are summarized in Table 3.

Future directions and research gaps

Despite growing evidence supporting *kharif* cropping in deep vertisols, several research and implementation gaps remain that limit widespread adoption and long-term sustainability. Addressing these gaps requires a multi-disciplinary approach that integrates agronomy, soil science, climate resilience, socio-economics and policy innovation. One of the most critical needs is the development of short-duration, waterlogging-tolerant *kharif* crops that can mature before *rabi* sowing while withstanding early monsoon stress. For chickpea, breeding efforts must focus on varieties adapted to post-*kharif* conditions, with improved root architecture, drought tolerance and disease resistance. ICRISAT's work on Vertisols has emphasized the importance of matching genotype to micro-environment, especially in double cropping systems. Participatory varietal selection (PVS) and decentralized trials can accelerate adoption of region-specific cultivars.

Although *kharif* cropping has been shown to improve soil organic carbon (SOC) in vertisols, its long-term impacts on carbon sequestration, nutrient cycling and soil microbial dynamics remain insufficiently quantified. Addressing this gap requires the development of standardized soil health indicators applicable across Vertisol regions, along with robust carbon budgeting models that compare different *kharif-rabi* cropping sequences. In addition, advanced microbial profiling is needed to better understand the biological regulation of pests and diseases and their interactions with soil carbon dynamics. These assessments should be embedded within long-term conservation agriculture trials to evaluate trade-offs among tillage intensity, residue retention and carbon stabilization. Concurrently, climate variability-particularly erratic monsoon onset, intra-seasonal dry spells and extreme rainfall events-poses significant risks to *kharif* cropping, underscoring the need for integrated climate risk assessment and adaptive agronomic strategies to enhance system resilience.

Future research should focus on agro-climatic zoning to refine *kharif* crop suitability in Vertisols and on developing decision support tools for optimizing sowing windows, crop choice and contingency planning under delayed monsoon or excess rainfall conditions. Recent ICAR agro-advisories for farmers (2025) highlight the importance of localized, real-time, weather-based agro-advisory systems to support adaptive decision-making in rainfed systems. Equally critical is a deeper assessment of the economic viability of *kharif*-chickpea systems, including cost–benefit analysis of land configuration and drainage practices, risk-return modeling under rainfall and price variability and behavioral studies on farmer perceptions and risk aversion. Evidence from cluster frontline demonstrations suggests that adoption is strongly influenced by perceived profitability and extension support, underscoring the need for similar evaluations in vertisol regions. Scaling *kharif* cropping will therefore require institutional innovations beyond demonstrations, including landscape-level drainage planning, FPO-led seed systems, digital extension platforms and adaptation of watershed-based approaches for *kharif*-chickpea systems with strong policy and community support.

CONCLUSION

Cropping *kharif* fallows in deep Vertisols represents a transformative opportunity for enhancing *rabi* chickpea productivity, improving land use efficiency and advancing sustainable intensification in rainfed agriculture. Traditionally fallowed to conserve moisture, Vertisols have long been underutilized during the monsoon season due to concerns over waterlogging and operational constraints. However, recent agronomic innovations-such as broad-bed furrow land configuration, short-duration *kharif* crops, integrated nutrient and pest management and conservation agriculture-have demonstrated that *kharif* cropping is not only feasible but highly beneficial.

Evidence from long-term trials, participatory research and field demonstrations confirms that *kharif* crop-

metrics. These systems enhance soil organic carbon, suppress pest and disease cycles, improve nutrient cycling and contribute to climate resilience. Moreover, they offer higher chickpea equivalent yields, better sustainability yield indices and increased profitability for smallholder farmers.

Despite these advantages, adoption remains constrained by limited access to inputs, inadequate drainage infrastructure, market uncertainties and risk perceptions. Addressing these challenges requires targeted breeding programs, robust soil health monitoring, climate-adaptive agronomy and inclusive policy frameworks. Institutional innovations-such as FPO-led seed systems, digital extension platforms and watershed-based scaling models-can accelerate uptake and ensure equitable benefits.

This review underscores the need to reframe *kharif* cropping in Vertisols not as a risk, but as a strategic pathway toward resilient, productive and sustainable chickpea-based systems. With coordinated research, policy support and farmer engagement, *kharif* cropping can become a potential cornerstone of climate-smart agriculture in India's rainfed heartlands.

Conflict of interest

The authors here by declare that there are no conflicts of interest.

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