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Advancing agricultural mechanization in India: Challenges, opportunities, and farmer-centric solutions

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Abstract

Agricultural mechanization plays a pivotal role in transforming traditional farming into a more productive, efficient, and sustainable practice. In India, the need for mechanization has intensified due to rising food demand, labor shortages, declining productivity, and the imperative to improve farmers' livelihoods. This study examines the current state of farm mechanization in India, identifying key challenges such as limited farmer awareness, inadequate access to machines, and insufficient land holdings that hinder widespread adoption. Despite agriculture contributing approximately 14% to India's GDP, nearly 48% of the population remains dependent on this sector for their livelihood. Encouragingly, there has been a year-on-year increase in the demand and sales of tractors, power tillers, and other farm equipment indicating a growing recognition of mechanization benefits. This paper discusses the technological advancements, policies, and support systems required to bridge the mechanization gap. It also outlines various farm machinery types currently in use and explores their developmental trends. The findings emphasize the importance of inclusive strategies, such as training programs, subsidy models, and shared equipment access schemes, to accelerate the mechanization process and empower farmers across diverse regions of India.

Keywords: Indian agriculture, farm mechanization, agricultural productivity, labor shortage, sustainable farming, tractor adoption, mechanization challenges, agricultural transformation, rural development

Introduction

Agricultural mechanization, defined as the application of mechanical technology to enhance the efficiency and productivity of farming operations, plays a pivotal role in modernizing Indian agriculture. It encompasses the use of power-driven equipment and machinery in agricultural activities such as tillage, sowing, harvesting, irrigation, and post-harvest handling. This transformation has emerged as a critical intervention to overcome the challenges posed by labor scarcity, low productivity, and increasing food demand in the country (Kienzle *et al.*, 2013; FAO, 2018) ^[24, 15].

Mechanization is not merely about replacing manual labor with machines; it represents a systemic change that uplifts the entire agricultural value chain. It contributes to increasing farm output, reducing the cost of cultivation, enhancing resource-use efficiency, and improving the livelihood of smallholder farmers by alleviating the drudgery associated with traditional farming methods (Pingali, 2007; Van Loon *et al.*, 2020) ^[29, 35]. Moreover, mechanized farming integrates small-scale farmers into modern food systems, creating pathways for rural industrialization and fostering economic resilience.

The historical context of Indian agriculture further illustrates the importance of mechanization. Post-independence India grappled with severe food insecurity, relying heavily on imports to feed its population. The Green Revolution of the 1960s introduced high-yielding seed varieties, chemical inputs, and improved irrigation, which, together with initial steps toward mechanization, helped India attain food self-sufficiency by the early 2000s (Jha *et al.*, 1999) ^[21]. However, with more than 67% of farmers holding land parcels smaller than 1 hectare (Nikhade & Gunaki, 2020) ^[28], widespread adoption of mechanization still faces substantial structural barriers. Presently, the urgency to scale up mechanization is amplified by demographic transitions. As per World Bank estimates (2020), by 2050, only about 25.7% of India's workforce will remain in agriculture, down from 58.2% in 2001.

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Urban migration, aging rural populations, and changing employment patterns necessitate rapid adoption of efficient and less labour-intensive agricultural practices (Islam & Hoque, 2015) ^[19]. The Indian farm mechanization market, valued at ₹320 billion in 2015-16, was projected to reach ₹400 billion by 2019-20, growing at a CAGR of 5.74%, reflecting both increasing demand and government initiatives (Sarkar, 2020).

International organizations have also emphasized mechanization as a key enabler of the Sustainable Development Goals (SDGs). The Food and Agriculture Organization (FAO, 2014a) ^[14] has identified mechanization as a cornerstone of sustainable agricultural intensification and resilience building. Its potential to reduce the environmental footprint of farming through conservation practices like zero-tillage (Aryal *et al.*, 2015) ^[5] and precision land leveling (Aryal *et al.*, 2020) ^[1] has been extensively studied.

Nonetheless, challenges such as small and fragmented landholdings, lack of credit access, limited awareness, and high initial costs continue to hinder widespread mechanization, particularly among marginal farmers (Biggs & Justice, 2011; Ghosh, 2010) ^[8, 16]. As such, innovations in cooperative machinery ownership, government subsidies, and the promotion of mechanization services through rural entrepreneurship models are essential strategies for inclusive agricultural development (Binswanger, 1986; Van den Berg *et al.*, 2007) ^[11, 34].

In conclusion, while agricultural mechanization in India has made significant strides, its full potential remains untapped. A

comprehensive policy and institutional push, accompanied by awareness campaigns and technological innovations tailored to smallholders, is imperative to realize the socio-economic and environmental benefits of mechanization.

Theories of agricultural mechanization

Agriculture has long held a central position in the economic development strategies of South Asian countries. With the advancement of the agricultural sector, mechanization processes have expanded across the entire agricultural value chain. Various theories explain this evolution of mechanization over time, particularly within the context of economic development. Two of the most widely cited theories in this domain are the Induced Innovation Theory and the Theory of Farming Systems Evolution, both of which seek to explain the underlying causes and patterns of farm mechanization.

FAO (2021) highlights global trends in mechanization using the number of tractors as a key indicator. Despite the limitations of this metric such as the omission of tractor size and other machinery types it remains a widely accepted proxy for mechanization due to the central role tractors play in key agricultural activities. These include land preparation, seeding, fertilizing, spraying, irrigation, and even milking operations. Figure 1 (FAO, 2021) presents the increase in tractor use (per 1,000 hectares of arable land) between 1961 and 2009 across world regions, illustrating significant progress, though with varying regional disparities.

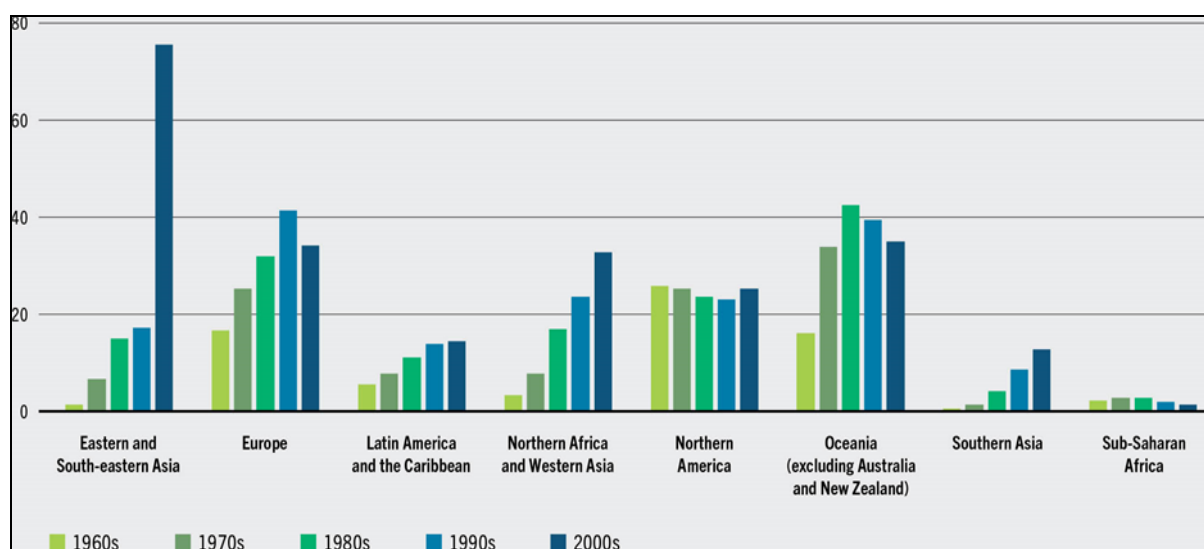


Fig 1: Tractors in use per 1 000 hectares of arable land, FAO, 2021

Role of training in mechanization adoption

Agricultural training plays a critical role in the adoption of mechanized farming techniques. It influences farmers' knowledge, attitudes, and perceptions, which in turn affects their willingness to embrace innovations. Studies have shown that households receiving agricultural training are more likely to adopt machinery such as tractors, tillers, and harvesters than those without such exposure. Training not only raises awareness of the economic and yield-related benefits of mechanization but also empowers farmers to reduce production costs. As Kumar *et al.* (2020) ^[33] observed in Nepal, participation in training significantly enhances the adoption of improved technologies, especially among smallholders in South Asia.

Need for Mechanization in India

Agriculture in India contributes approximately 14% to GDP, yet

employs around 48% of the workforce, reflecting a stark imbalance in labor productivity. This underscores the urgent need for mechanization to boost land productivity, enhance cultivation quality, and address rural labor shortages. Mechanization also plays a key role in reducing poverty, improving food security, and uplifting rural livelihoods.

Farm mechanization can offer both economic and social benefits. Economically, it reduces input costs, increases manpower efficiency, allows for timely operations, enhances crop output, and facilitates diversification. Socially, it reduces physical drudgery especially for women improves workplace safety, and attracts youth to agriculture. Evidence suggests that mechanization leads to 15-20% savings in inputs such as seeds and fertilizers and increases cropping intensity by 5-20%, ultimately improving labor efficiency.

However, a transition is underway. Traditionally, Indian

agriculture relied on cheap, surplus labor. But today, industrial and service sector opportunities, along with rural employment programs like the MGNREGA, are contributing to seasonal labor shortages. This rising labor cost, combined with the projected decline in the agricultural workforce (from 59.1% in 1991 to an estimated 25.7% by 2050), intensifies the demand for mechanized solutions.

Safety concerns further highlight the need for mechanization. A study by ICAR (2004-2007) reported that 34.2% of agricultural accidents involved hand tools, with sickles and spades accounting for nearly half of the injuries. Many of these injuries require extended recovery time, pointing to the urgency of developing safer, mechanized alternatives.

Challenges in the Path of Mechanization

Despite its benefits, the path to widespread mechanization in India is obstructed by several challenges:

1. **Lack of Knowledge and Awareness:** Traditional farming continues to dominate due to low awareness and access to modern technologies. Illiteracy and inadequate training further hinder farmers' ability to operate and maintain machines effectively.
2. **Small Land Holdings:** Approximately 90% of Indian farmers own less than 2 hectares of land, making it impractical to use large machines like combine harvesters. Alterations in cropping patterns to suit machinery often reduce plant density, which smallholders cannot afford.

3. **High Cost and Affordability Issues:** Most smallholders lack the financial capacity to invest in expensive machinery. For example, a 50 HP tractor costs about ₹6 lakhs, with implements adding another ₹2 lakhs. Operational costs, such as fuel (₹70-80/L), further strain farmer budgets. Limited access to credit and risk-averse financial institutions compound the issue.
4. **Inefficiency and Lack of Suitable Machinery:** There is a shortage of efficient, low-cost, multi-functional machinery tailored to India's diverse soils and cropping systems. Complex harvesting requirements such as multiple harvests for cotton pose further design challenges, limiting the effectiveness of mechanization in certain crops.

Government support and mechanization schemes in India

India, despite having only 2.4% of the world's land area and 4% of its water resources, supports 17% of the global population and 15% of livestock. The sector contributes 14% to GDP and 11% to exports, yet mechanization remains limited. Traditional tools still dominate agricultural practices, resulting in low input-use efficiency and high production costs.

Mechanization is crucial for enhancing productivity, reducing drudgery, ensuring timely operations, and addressing labor shortages. Multiple studies (e.g., Singh, 2006; Singh *et al.*, 2011) have shown a strong positive correlation between farm power availability and productivity.

Table 1: Provides all the schemes that connect with mechanization currently operational

S. No.	Name of the Scheme	Origin Year	Objective	Coverage	Benefit
1	Sub Mission on Agricultural Mechanization (SMAM)	2014-15	To increase mechanization among small and marginal farmers and in low farm power availability regions	All states	Financial assistance for machinery, Custom Hiring Centers, Farm Machinery Banks, training, testing & demonstration
2	Promotion of Agricultural Mechanization for In-Situ Management of Crop Residue	2018-19	To reduce air pollution from stubble burning	Punjab, Haryana, Uttar Pradesh, NCT of Delhi	50% subsidy for farmers; 80% project cost support for cooperatives, FPOs for residue management machinery
3	Rashtriya Krishi Vikas Yojana (RKVY) / RAFTAAR	2007-08	Infrastructure for pre- and post-harvest activities	All states contributing their share	100% central assistance till 2014; post-2015: 60:40 (Centre:State), 90:10 (NE/Himalayan), 100% for UTs
4	Pradhan Mantri Krishi Sinchayee Yojana-Per Drop More Crop	2015 (Earlier: 2006, 2010, 2014)	To enhance water-use efficiency through micro irrigation	All states	55% CoI subsidy for small/marginal farmers; 45% for others; shared 60:40 (Centre:State); 90:10 in NE/Himalayas; 100% by Centre in UTs
5	PM-KUSUM	2019	To ensure energy security for farmers	All states	Farmers earn by selling power; 30% subsidy from Centre + 30% from State for solar pumps
6	The Vegetable Initiative for Urban Clusters	2011-12	Address demand & supply of vegetables in urban areas	One city per state (capital or >1 million population)	Financial support for 12 activities
7	Mission for Integrated Development of Horticulture (MIDH)	2014 (Allocations since 2012)	Reduce drudgery via horticultural mechanization	All states	Assistance to grower groups, SHGs for tractors, tillers, land dev., sowing, planting, mulch machines, etc.
8	National Mission on Oil Seeds and Oil Palm	2014-15	Increase oilseed production via mechanization	All states	Financial support for implements as per SMAM norms
9	Bringing Green Revolution to Eastern India	2010-11	Boost rice & wheat production with modern tech	Assam, Bihar, Chhattisgarh, Jharkhand, Odisha, Eastern UP, West Bengal	100% subsidy up to ₹30,000 for shallow tube wells; other benefits under NFSM & SMAM

To address these gaps (Table 1), the Ministry of Agriculture and Farmers Welfare launched the Sub-Mission on Agricultural Mechanization (SMAM) in 2014-15 (Figure 2 & 3).

Key initiatives under SMAM include

- Establishing Custom Hiring Centres (CHCs)
- Developing Farm Machinery Banks (FMBs) and Hi-tech Hubs
- Distributing subsidized machinery
- Promoting awareness through training and demonstrations

These efforts significantly improved farm power availability, from 2.02 kW/ha in 2016-17 to 2.49 kW/ha in 2018-19, alongside increases in cropped area and production.

Objectives of SMAM

- Expand mechanization to small/marginal farmers and underserved regions
- Address economies of scale through CHCs
- Facilitate capacity building and training
- Promote hi-tech equipment hubs
- Ensure testing and certification of machinery

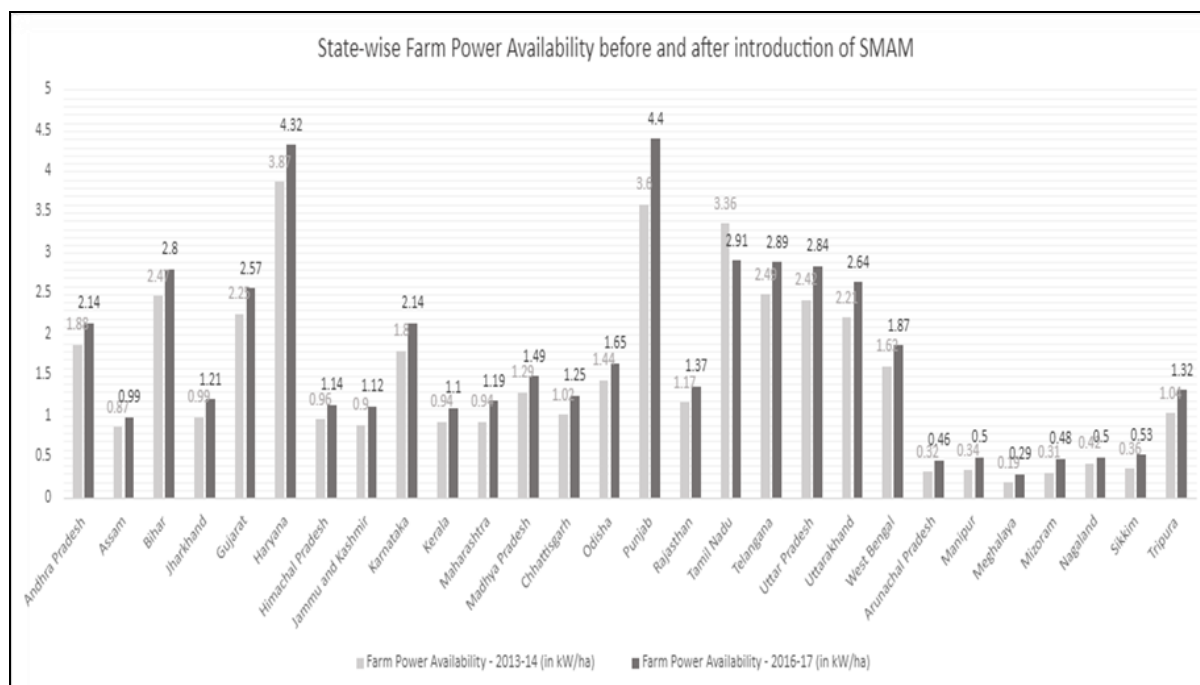


Fig 2: Illustrates state-wise improvements in farm power availability following SMAM's implementation (Ministry of Agriculture and Farmers Welfare, 2023).

Promotion and Strengthening of Agricultural Mechanization through Training, Testing and Demonstration
Demonstration, Training and Distribution of Post Harvest Technology and Management (PHTM)
Financial Assistance for Procurement of Agriculture Machinery and Equipment
Establish Farm Machinery Banks for Custom Hiring
Establish Hi-Tech, High Productive Equipment, Hub for Custom Hiring
Promotion of Farm Mechanization in Selected Villages
Financial Assistance for Promotion of Mechanized Operations/hectare Carried out Through Custom Hiring Centres
Promotion of Farm Machinery and Equipment in North-Eastern/ Region

Fig 3: Components of Sub-Mission on Agricultural Mechanization (SMAM) in India

The progression of mechanization in India has seen a phased transition from traditional to modern equipment, driven by both necessity and policy. Theories such as Hayami and Ruttan's induced innovation suggest that technology evolves in response to factor scarcities labor or land which fits India's push for mechanization in light of rising labor costs and land fragmentation (Zhang *et al.*, 2017) [39].

Technological progression in South Asia began with zero-tillage and conservation agriculture tools like the Turbo Happy Seeder and laser land levelling, which were promoted to address environmental and productivity challenges (Hobbs & Giri, 1997; Sidhu *et al.*, 2015; Aryal *et al.*, 2015) [17, 2, 5]. The adoption of zero-tillage wheat in irrigated plains of South Asia showed notable success due to strong policy and research backing (Erenstein & Farooq, 2009) [13].

In South Asia, countries like India have promoted mechanization through training programs, subsidy schemes, and custom hiring centers (Aryal *et al.*, 2019; Baudron *et al.*, 2015; Mandal, 2014) [3, 7, 25]. These models emerged due to constraints such as small

landholdings and limited capital, which made individual ownership unviable (Diao *et al.*, 2014; Keil *et al.*, 2016) [12, 23]. Government policies and private sector strategies in nations like Thailand and Vietnam further demonstrate how targeted support can enhance mechanization, with lessons relevant to India (Hossen *et al.*, 2020) [18]. Justice and Biggs (2020) [22] highlight the role of small engines and rural machinery markets in expanding access, while Mottaleb *et al.* (2016) [26] show how demographic and socio-economic factors influence machinery adoption in Bangladesh.

Rising wages and structural transformations have also driven mechanization trends across Asia, where larger farms gain comparative advantages (Yamauchi, 2016; Zhang *et al.*, 2014) [37, 38]. In Bangladesh, for instance, machinery services helped overcome labor shortages and increased agricultural productivity (Mottaleb *et al.*, 2017) [27].

In India, agricultural mechanization is further promoted through policy interventions under schemes like SMAM and various ICAR-led initiatives (Nikhade & Gunaki, 2020) [28]. Despite

these, challenges remain in ensuring equitable access to machinery for small and marginal farmers (Aryal *et al.*, 2021)

[4].

Conclusion

Agricultural mechanization in India has evolved from being a tool for large-scale commercial farms to becoming an increasingly essential component for small and marginal farmers. Driven by a combination of demographic shifts, labour shortages, technological advances, and institutional support, mechanization today plays a central role in enhancing productivity, improving input efficiency, and supporting sustainable agricultural practices. Theoretical underpinnings such as Boserup's intensification hypothesis and Schultz's efficiency paradigm remain relevant, especially as rising rural wages and the declining availability of agricultural labour in densely populated economies compel a transition towards machine-supported farming.

Policy frameworks like India's Sub-Mission on Agricultural Mechanization (SMAM) and the promotion of Custom Hiring Centres (CHCs) represent commendable efforts to democratize mechanization. Yet, these need to be complemented by stronger institutional capacity, robust monitoring mechanisms, localized training, and inclusive financing models. Lessons from Bangladesh, where public-private partnerships and targeted subsidies have facilitated remarkable progress in mechanization. Moving forward, mechanization must be seen not just as a technological input but as a transformative force embedded within a broader rural development agenda. Its success lies in integrating precision technologies (e.g., sensor-based systems, IoT), encouraging entrepreneurship in farm services, and ensuring environmental sustainability. A one-size-fits-all approach will not work. Instead, countries must adopt agro-ecology-specific, demand-driven models that are inclusive, climate-resilient, and economically viable.

Agricultural mechanization holds substantial potential to transform the rural economy, reduce drudgery, improve farm productivity, and contribute to climate-resilient agricultural systems in India. Realizing this potential requires a holistic and inclusive approach that not only promotes technological dissemination but also addresses the socio-economic and institutional barriers that constrain its adoption. Future research should focus on evaluating the long-term impacts of mechanization on rural livelihoods, gender equity, and environmental sustainability to inform evidence-based policy making.

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