Scale Appropriate Mechanization (SAM): Business Models and Employment Generation in India

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CGIAR SUSTAINABLE FARMING

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1.Introduction

Background and Structural Challenges

Smallholder farming systems across the globe, particularly in developing nations such as India, are confronting an escalating viability crisis. This challenge is largely driven by rising input costs, declining labour-use efficiency, reduced factor productivity, and suboptimal yield realization (Touch et al., 2024; Gorain & Datta, 2025). Both India and Africa exhibit wide agro-ecological diversity with a predominance of rainfed agriculture. The limited availability of time for executing essential field operations constrains by the erratic rainfall situation, often resulting in yield variability and production risk.

To address these constraints, climate-resilient cropping systems based on sustainable intensification practices and technologies are increasingly being recognized as essential. Such systems enable farmers to adapt to projected climate change impacts and manage existing climate variability more effectively. Sustainable intensification represents not only a necessity but also an opportunity for resource-poor farmers in the semi-arid tropics (SAT) regions. However, progress toward this goal is hindered by low levels of farm mechanization. In addition, a decline in both draught animal populations and the availability of agricultural labour partly due to rural to urban migration-has further exacerbated the challenges facing these systems (Mehta et al., 2023).

Given the heterogeneity of agricultural practices and cropping systems across Africa and India, context-specific adaptation and flexibility in technological interventions are crucial to meet the diverse needs of smallholders operating under varying agro-ecological conditions (Roy et al., 2023). Therefore, scale-appropriate mechanization options, designed to align with small and fragmented field sizes and limited resource endowments, are essential for advancing sustainable intensification. Such mechanization approaches can enhance the efficient use of soil, labour, water, nutrients, and energy resources while also delivering broader social benefits such as fostering rural entrepreneurship, increasing farm incomes, and reducing drudgery. Collectively, these interventions contribute significantly to food and nutrition security through the intensification and diversification of cropping systems (Reich et al., 2021; Sidhu et al., 2021).

The ongoing out-migration of the rural workforce to urban areas has led to a sharp rise in agricultural wages, thereby diminishing the productivity and profitability of farm enterprises despite positive overall growth in Indian agriculture. Labour costs frequently constitute over

50 percent of the total variable production expenses for most crops (Foster & Rosenzweig, 2022), making this demographic shift a major threat to economic viability.

This multifaceted situation is further aggravated by several structural challenges, including the impacts of climate change, extreme land fragmentation, and limited access to both labour and capital. A key structural driver shaping India's current mechanization landscape is the steady reduction in average farm holding size. According to the Agricultural Census (2015-16), the average operational holding in India is merely 1.08 hectares (ha), with small and marginal farmers (owning less than 2 ha) comprising majority of the total operational holdings (Table 1).

Table 1. Operational Holdings and Operated Area by Size Group (Agricultural Census 2015-16)

S.No.	Size Group	% holdings of total holdings	Percentage of area operated to total area	Average Operated area per Holding (ha.)
1	Marginal (< 1.00 ha.)	68.45	24.03	0.38
2	Small (1.00–2.00 ha.)	17.62	22.91	1.4
3	Semi – medium (2.00–4.00 ha.)	9.55	23.84	2.69
4	Medium (4.00–10.00 ha.)	3.8	20.16	5.72
5	Large (10.00 ha. & above)	0.57	9.07	17.07
6	Total	100	100	1.08

The small and marginal holdings of less than 2 ha account for 86% of the total operational holdings and 47% of the total operated area. This fragmentation necessitates a shift away from large, conventional machinery.

Trends in Agricultural Mechanization in India

Agricultural mechanization plays a pivotal role in enhancing production efficiency, reducing drudgery, and promoting sustainable intensification. In India, the steady rise in mechanization has been closely linked with improvements in cropping intensity and farm power availability. The cropping intensity has increased from 120% in 1975-76, when the average power availability was 0.36 kW/ha, to 155.4% in 2023-24 with a corresponding rise in farm power availability to 3.126 kW/ha (PIB, 2024). This relationship reflects how access to power and machines directly influences the capacity of farmers to intensify and diversify their production systems.

Table 2. Cropping intensity and power availability on Indian farms for 1975 to 2022

Year	Cropping intensity (%)	Food-grain productivity (t/ha)	Power available (kW/ha)	Power per unit production (kW/t)	Net sown area per tractor (ha)
1975-76	120	0.94	0.432	0.46	**487**
1985-86	127	1.18	0.653	0.55	**174**
1995-96	131	1.5	0.976	0.65	**84**
2005-06	132	1.65	1.535	0.93	**47**
2015-16	141.25	1.8	2.341	1.3	**22**
2021-22	**141.6**	**2.27**	**3.045**	**1.34**	**15**

Table 3: Farm power availability from different sources in India

Power, kW/ha							Total power, kW/ha
Year	Agric. workers	Draught animals	Tractors	Power tillers	Diesel engines	Electric motors	
1971-72	0.045	0.212	0.02	0.001	0.053	0.041	0.372
1981-82	0.051	0.206	0.09	0.002	0.112	0.084	0.545
1991-92	0.065	0.193	0.23	0.003	0.177	0.159	0.827
2001-02	0.079	0.172	0.48	0.006	0.238	0.25	1.225
2011-12	0.1	0.134	0.804	0.012	0.295	0.366	1.711
2021-22	0.082*	0.075	1.932	0.020*	0.368*	0.568*	3.045

Source: Agricultural Mechanization in Asia, Africa, And Latin America 2023 Vol.54 No.2. Adopted from NABARD National Sector Paper on Farm Mechanization, 2025

Over the past four decades, a major transformation has occurred in the composition of farm power sources. The primary sources of power i.e. agricultural workers and draught animals have gradually been replaced by mechanical and electrical sources. Their combined share in total farm power availability declined sharply from 60.8% in 1971-72 to only 10.1% by 2012-13, whereas the share of tractors and electric motors rose from 6.8% to 45.8% and 14.0% to 26.8%, respectively. The expansion of power tillers has also been noteworthy, with annual sales rising from fewer than 18,000 units in 2004-05 to more than 45,000 units in 2016-17 (Rath, 2024). The contribution of tractor power alone increased from 0.007 kW/ha in 1960-61 to 1.03 kW/ha in 2013–14, and projections suggest it may reach 3.74 kW/ha by 2032-33. These developments highlight the progressive mechanization of Indian agriculture, enabling timely operations, reduced labour dependency, and higher productivity (Tiwari et al., 2019).

Parallel to the shift in power sources, the agricultural equipment market has expanded rapidly. The demand for tractors, power tillers, combine harvesters, rotavators, threshers, and rice transplanters has grown significantly, driven by both policy support and farmers' need for enhancing efficiency. Tractors dominate the market, with the 31-37 kW category accounting for 49% of total sales, followed by the 23-30 kW range with 33%, indicating a growing preference for higher horsepower machines suited for custom hiring and multi-purpose field operations. In contrast, the power tiller market remains concentrated in the eastern and southern regions, where smaller landholdings prevail. The overall power tiller density stands at 2.21 units per 1,000 ha of net sown area, reflecting both progress and untapped potential, particularly for smallholder-oriented, scale-appropriate mechanization solutions.

Overall, these trends underline the transformative role of mechanization in Indian agriculture. The transition from traditional to power-driven sources has not only enhanced operational efficiency and crop yields but also opened new pathways for employment diversification, energy optimization, and climate resilience. Continued investment in scale-appropriate machinery, energy-efficient technologies, and region-specific mechanization models will be critical to sustaining this growth and ensuring equitable access for small and marginal farmers.

NCAER has estimated the total requirement of different farm machinery & implements in India, as given in the table below:

Table 4: Number of Equipment Required: Overall and Number per 1,000 hectares

Equipment	Total area under operation (lakh hectare)	Total no. of equipment required for total area	Total no. of equipment required for 1,000 ha area
Harrow (tractor operated) for 60% area/ 100% area	1241 (of 2068.3)	8,73,912	7
Cultivator (tractor operated)	1241	8,73,912	7
Rotavators (tractor operated)	620.5	6,33,140	10

Rotavators (power tiller operated)	206.8	76,60,222	370
Seed-cum-fertilizer drill (tractor operated)	899.4	3,94,468	4
Seed-cum-fertilizer drill (power tiller operated)	599.6	11,75,670	20
Sugarcane planter	48.3	80,500	17
Potato planter	16.9	28,200	17
Self-propelled eight-row paddy transplanter (Ride Type)	219.5	4,98,863	23
			Contd..

Source: NCAER Report, 2023

Table 5: Number of Equipment Required: Overall and Number per 1000 hectares (Contd.)...

Equipment	Total area under operation (lakh hectare)	Total no. of equipment required for total area	Total no. of equipment required for 1,000 ha area
Self-propelled walk-behind type paddy transplanter	219.5	7,31,667	33
Cultivator (tractor operated)	1186.1	5,56,870	4.7
Power tiller operated cultivator /Power weeder	790.8	10,68,589	13.5
Knapsack sprayer-cum-duster (powered)	827.3	11,49,033	14
Tractor-operated sprayer	1186.1	6,89,420	6
Sprayer self-powered high clearance (cotton, sugarcane)	65.2	27,175	4
Vertical conveyor reaper (power tiller operated)	412.5	3,43,758	8
Vertical conveyor reaper (tractor operated)	618.8	3,22,273	5

Multi-crop combine harvester for 60% area/100% area	607.8 (of 1012.9)	79,136/ 1,31,893	1.3
Multi-crop thresher (tractor PTO operated)	975.4	3,38,689	3.4
Paddy thresher	175.6	1,95,111	11
Maize thresher	92.1	76,750	8
Sugarcane harvester	48.3	67,083	14
Potato digger			
a) Tractor operated	11.8	17,312	15
b) Power tiller operated	7.8	46,165	59
Happy Seeder	158	1,97,550	12.5
Stubble shaver + Baler/ stubble shaver + Hay rack + Baler	105.4	1,09,750/ 87,800	10.4/8.3
Wheat straw combine	183.4	6,21,684	34

Source: *National Council of Applied Economic Research (NCAER)*

2.Scale-Appropriate Mechanization (SAM)

The adoption of farm mechanization among the Indian farming community is highly imperative and need of the hour for continuing and sustainable development. The adoption of mechanized solutions in Indian agriculture is being driven by several macroeconomic and inherent factors, including the growing population, urbanization, and surge in agri. exports like tractors, improved flow of agricultural credit, labour migration, and shortages, in addition to the agricultural, social, and economic growth drivers of mechanization. In the contemporary scenario, farm mechanization start-ups, especially those built on the farming as a service model, are rapidly integrating technology with an emphasis on precision agriculture in India. To increase the effectiveness of their equipment and obtain a competitive advantage, most agriculture equipment manufacturers are currently concentrating on integrating various technologies, such as robotics, Global Positioning System (GPS), and navigation systems. This is paving the way for Farm Mechanization 2.0 in Indian agriculture. The average farm power availability for the cultivated areas of the country has also been increased from 0.48 kW/ha (1975-76) to 1.84 kW /ha (2013-14) and 2.49 kW/ha (2018-19), which needs to be increased to 4.0 kW/ha by the end of 2030 to cope up with increasing demand of food grains. The overall farm mechanization level in the country is only 40-45%. This is substantially lower compared to global comparators like China (59.5%), Brazil (75%), and the U.S. (95%).

The above-discussed shift of labour from agriculture to non-agriculture sectors is also impacting farm power availability. The gap must be filled with mechanization. To accomplish farm operation in a timely manner and assure quality, the goal is to increase power availability from the current 2.54 kW/ha to a minimum of 4 kW/ha by 2030. This will call for greater engineering inputs, which will require developments and introduction of high-capacity, precision, reliable and energy-efficient equipment. Looking at the pattern of land holding in India, it may be noted that about 84% of the holdings are below 1 ha. There is a need for special efforts in farm mechanization for these categories of farmers to enhance production and productivity of agriculture. In the existing scenario of land fragmentation and resulting continued shrinkage of average size of operational holdings, percentage of marginal, small and semi-medium operational holdings is likely to increase. Such small holding makes individual ownership of agricultural machinery uneconomic and operationally unviable.

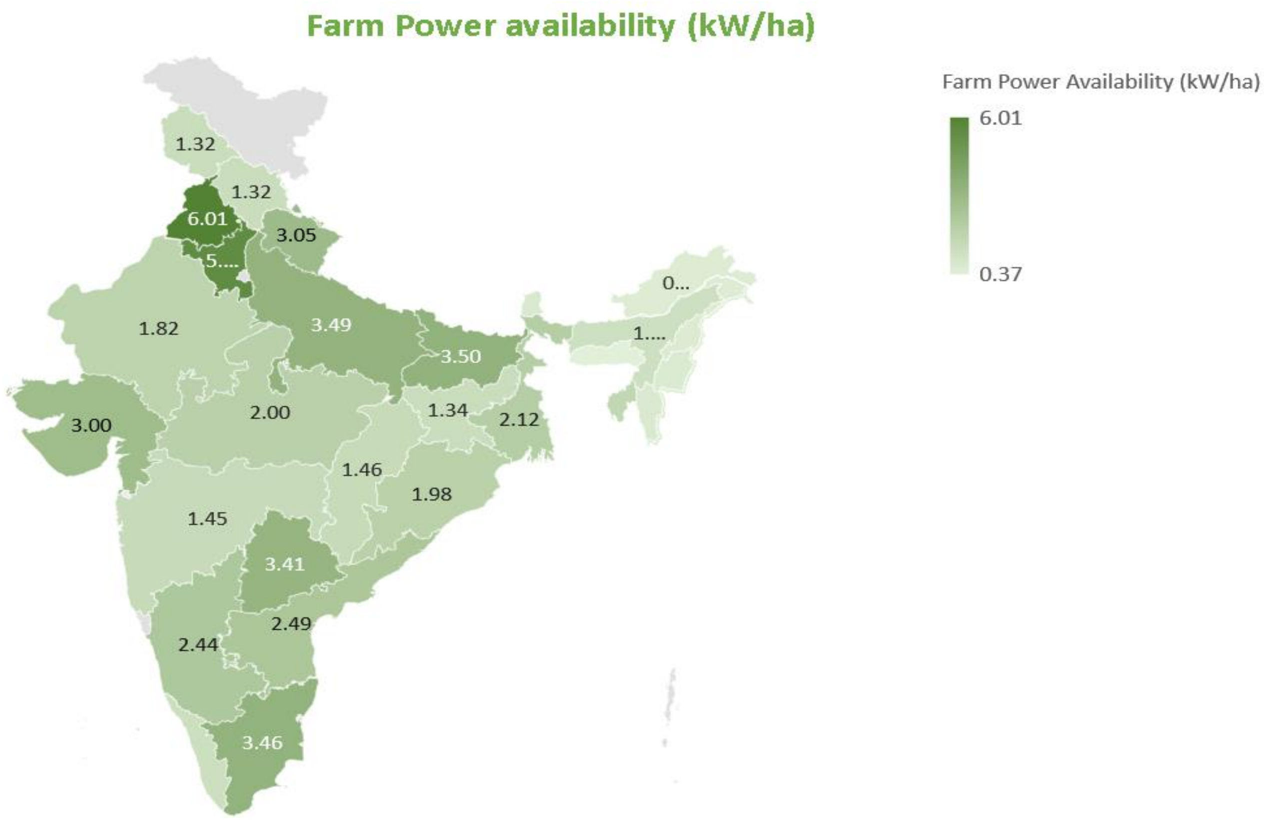


Figure 1: State-Wise Farm Mechanization in India (2018-19)

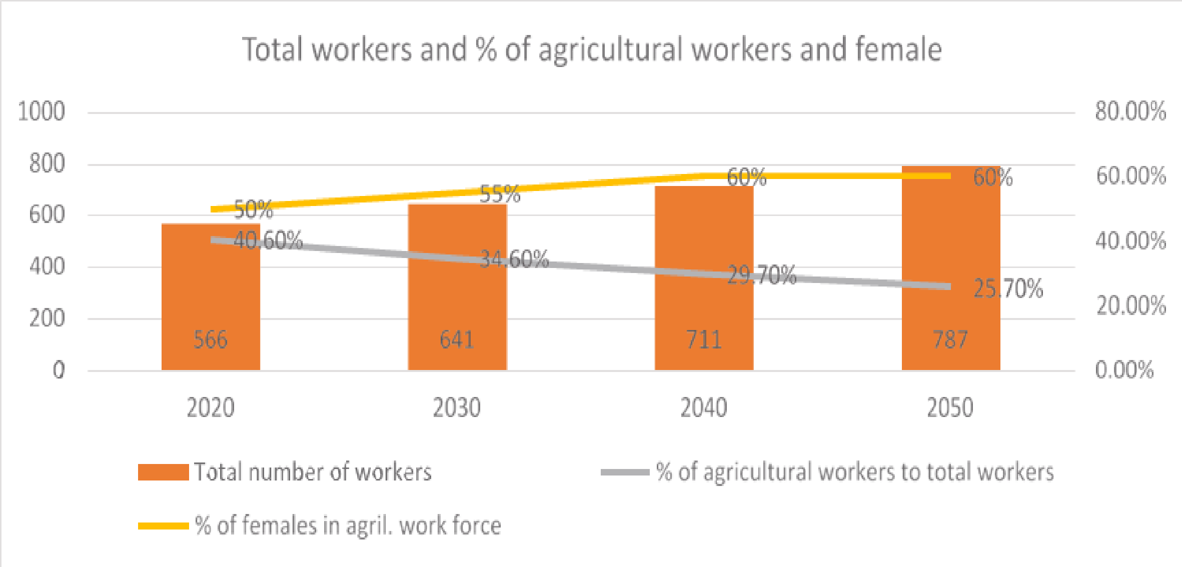


Figure 2: Total workers and percentage of agricultural workers and female

Source: Vision 2050 Document of Central Institute of Agricultural Engineering, Bhopal, 2015

Scale-Appropriate Mechanization (SAM): Definition and Rationale for India

Since the mid-1960s, India's agriculture sector has witnessed remarkable gains in food grain production, largely driven by scientific interventions and policy support. However, the spread of mechanisation—a key enabler of modern, efficient, and resilient farming— has been uneven across regions and farmer categories. This unevenness is particularly distinct for small and marginal farmers, who constitute nearly 85% of India's farming households and often lack access to suitable machinery and finance (NABARD, 2025). The use of appropriate mechanised tools and equipment has the potential to enhance productivity by up to 30% and reduce cultivation costs by around 20%. The adoption of mechanization in Indian agriculture has become an urgent priority for sustaining productivity growth, reducing production risks, and meeting future food demand. India's agricultural system is undergoing rapid structural transformation driven by demographic shifts, labour migration, rising urbanization, changing dietary patterns, and increased global integration. These macroeconomic forces, combined with persistent farm-level constraints, have intensified the demand for efficient and affordable mechanized solutions. However, the prevailing fragmentation of landholdings and the dominance of small and marginal farmers render large-scale machinery unsuitable for most farming households. This reality underscores the need for Scale-Appropriate Mechanization (SAM)-machinery and implements that are technically efficient, economically viable, and operationally compatible with smallholder systems.

SAM refers to the strategic deployment of small, modular, multifunctional, and crop-specific machinery tailored to India's heterogeneous agro-ecological settings and shrinking farm sizes.

Its rationale lies in addressing rising costs of cultivation, labour shortages during peak seasons, and high drudgery associated with manual operations. Evidence demonstrates that SAM significantly improves resource-use efficiency: precision seeders and planters can reduce seed use by 15-20%, fertilizer applicators can save 20-30% of inputs, labour and time requirements decline by 5-30%, cropping intensity increases by 10-15%, and overall productivity rises by 15-20%. These outcomes are particularly relevant for conservation and residue-based cropping systems, where timely and precise operations are fundamental.

The relevance of SAM is further reinforced by the centrality of smallholders in India's food system. Globally, small farms occupy only 24% of agricultural land but contribute nearly 29% of crop output and around 32% of the food supply. Their high land productivity is offset by low labour productivity due to heavy reliance on manual work. Mechanization therefore becomes essential not only to reduce physical drudgery but to enhance labour efficiency and maintain production under conditions of labour scarcity. In India, where 84% of landholdings are below 1 ha, individual ownership of machinery is economically unviable and operationally inefficient. The continued fragmentation of land and increased feminization of agriculture due to male out-migration further heighten the urgency for accessible, labour-saving technologies, including those adapted specifically for women through ergonomic design and supportive government programmes.

India's broader development aspirations-articulated through the Viksit Bharat 2047 vision-make the expansion of mechanization indispensable. By 2047, food demand is projected to double, and demand for high-value commodities may increase three- to four-fold. Meeting this demand requires timely operations and higher input-use efficiency, possible only through widespread adoption of mechanized solutions. At the same time, the average landholding is expected to shrink to approximately 0.6 ha, effectively eliminating the feasibility of individual machine ownership and making service-based models, such as Custom Hiring Centres (CHCs) and Pay-Per-Use platforms, the primary viable pathways for mechanization access. These models also create new opportunities for rural employment, entrepreneurship, and skill development in machine operation, repair, and service management.

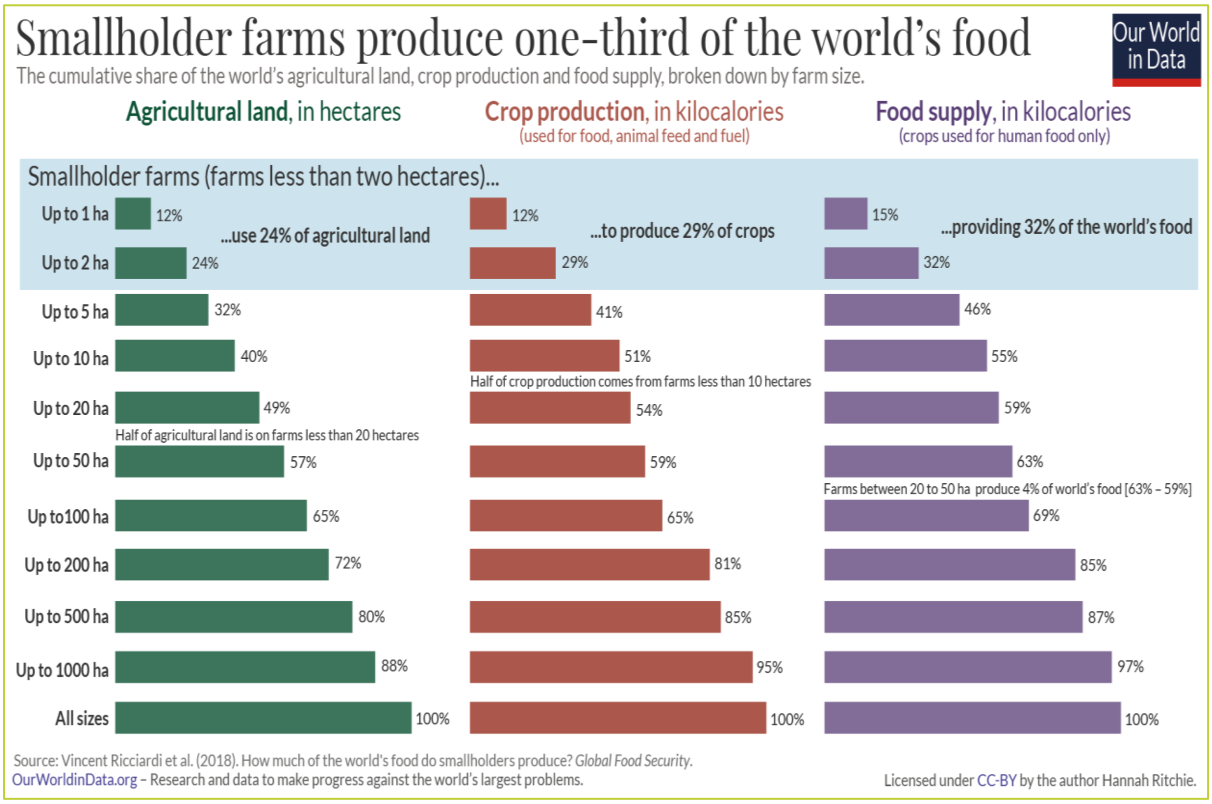
India has already witnessed the emergence of Mechanization 2.0, characterized by the integration of robotics, GPS-enabled equipment, automation, and precision technologies. Start-ups operating under Farming-as-a-Service models are increasingly linking machinery access with data-driven advisory services. These innovations signal a shift toward a more technologically sophisticated agricultural landscape, although their diffusion remains uneven across regions and farm sizes.

Despite these advancements, India's mechanization level remains modest-estimated at 40-45%, far lower than China (59.5%), Brazil (75%), and the United States (95%). Farm power availability has increased from 0.48 kW/ha in the mid-1970s to 2.49 kW/ha in 2018-19, yet it must rise to at least 4.0 kW/ha by 2030 to meet future production requirements. Labour shortages, driven by migration to non-agricultural sectors, further reduce the availability of human and animal power, making mechanization essential to fill the widening power gap. Achieving future farm power targets will require continuous engineering innovation, higher-capacity yet energy-efficient machines, and context-specific technological solutions that align with India's diverse cropping systems.

In this context, SAM represents a scientifically grounded and economically rational framework for modernizing Indian agriculture. It aligns machinery design and service delivery models with structural realities, enhances productivity and sustainability, reduces drudgery, and creates pathways for skilled rural employment. As India moves toward 2047, SAM will be central to bridging the farm power deficit, supporting smallholder competitiveness, and ensuring food and nutrition security in a rapidly changing socio-economic environment.

3. Why Small holder farmers matter in SAM

- Production Share: Smallholder farmers contribute nearly 29% of global crop output (in kilocalories) while operating on only 24% of the world's agricultural land, reflecting their high land productivity despite limited resources.
- Labour Intensity: These farms rely heavily on manual labour, achieving higher yields per hectare but exhibiting lower labour productivity, underscoring the need for mechanization to enhance efficiency.
- Food Supply Contribution: Smallholders provide about 32% of the global food supply, as they devote a larger share of their production to direct human consumption rather than feed or industrial uses.



Classification of agricultural machinery based on various operations

Table 6: Classification of Agricultural Machinery:

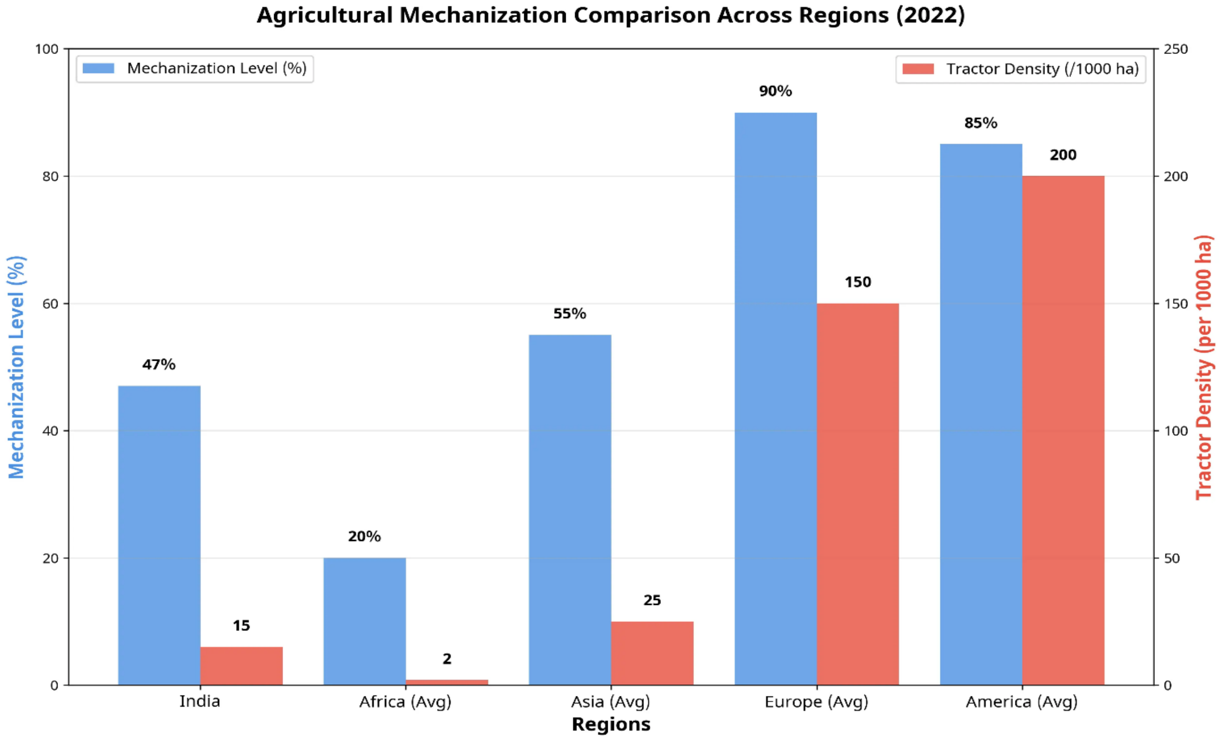
S.No	Category	Example Implements	Primary Function	National Status / Note
1	Land Preparation	Rotavator, MB Plough, Cultivator	Soil inversion & seedbed prep	70% Mechanized (High)
2	Sowing & Planting	Seed Drill, Paddy Transplanter	Precision seed placement	Critical for uniform growth
3	Inter-Culture	Power Weeder, Wheel Hoe	Weed control & soil aeration	<35% Mechanized (Low)
4	Plant Protection	Sprayers, Dusters, Drones	Nutrient & pesticide delivery	Shifting to Drone tech
5	Water Management	Solar/Electric Pumps, Drip	Precision irrigation	Focus on water saving
6	Harvesting	Combine Harvester, Reaper	Cutting & threshing	>60% Mechanized (Cereals)
7	Post-Harvest	Sheller, Grader, Dryer	Quality control & cleaning	Vital for value addition
8	Transport	Tractor Trailer, Trolley	Logistics of produce/inputs	Backbone of farm logistics
9	Power Units	Engines, Motors, Solar Units	Energy for all operations	Cross-cutting power source
10	Smart Machinery	GPS Tractors, IoT Sensors	Precision & automation	Frontier of "SAM 4.0"

4.Mechanization Gap and opportunities

Table 7: Regional disparity and Gap in Farm mechanization

Region / Country	Mechanization Level (%)	Tractor Density (Per 1,000 ha)
America	85%	200
Europe	90%	150
Asia	55%	25
India	47%	15
Africa	20%	2

Source: NABARD, 2018; NACER 2023,



Source: Data compile by authors from multiple sources (FAO, 2022; World Bank)

Mechanization Ecosystem

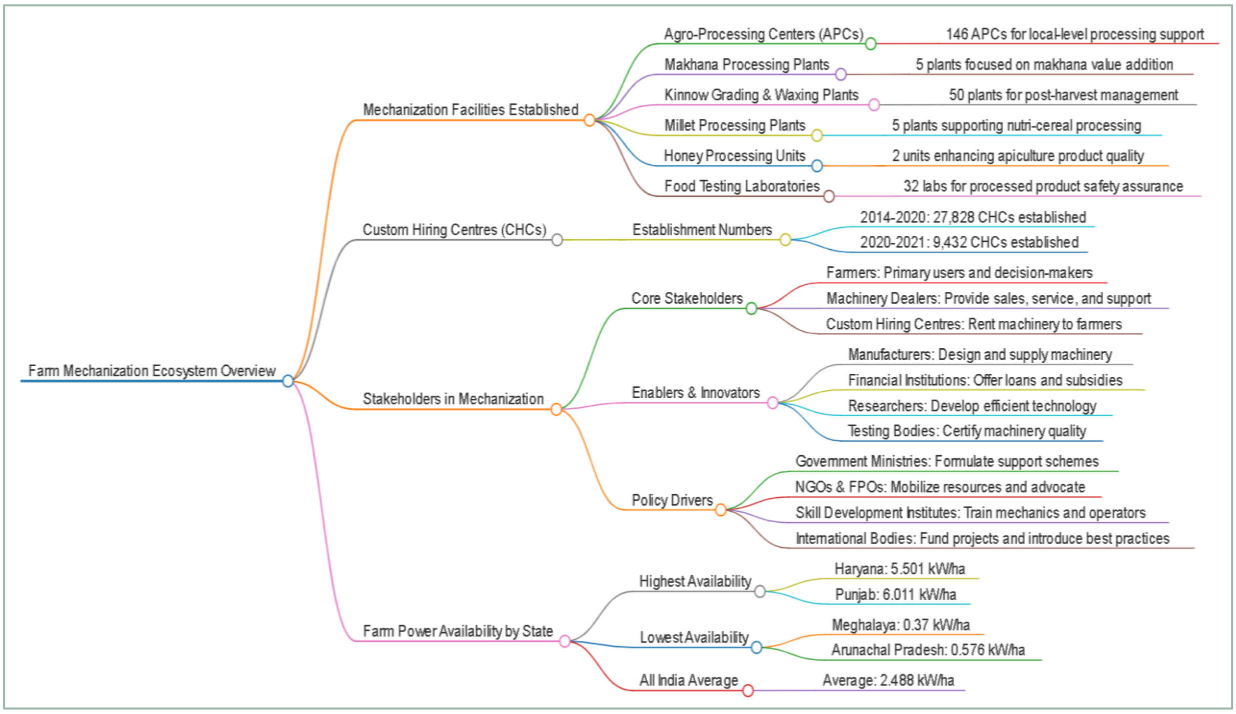


Figure 3: Farm mechanization Ecosystem overview in India

Mechanization is a crucial input for agricultural crop production and one that historically has been neglected in the context of developing countries. Factors that reduce the availability of farm power compromise the ability to cultivate enough land and have long been recognized as a source of poverty, especially in sub-Saharan Africa. Increasing the power supply to agriculture means that more tasks can be completed at the right time and greater areas can be farmed to produce greater quantities of crops while conserving natural resources. Applying new technologies that are environmentally friendly enables farmers to produce crops more efficiently by using less power. Sustainable agricultural mechanization can also contribute significantly to the development of value chains and food systems as it has the potential to render postharvest, processing and marketing activities and functions more efficient, effective and environmentally friendly.

Farm mechanization involves the utilization of engineering and technology in agricultural processes to enhance productivity and efficiency. It encompasses the design, application, and supervision of various mechanical tools for activities such as field production, water management, material handling, storage, and processing. These mechanical aids comprise a range of tools and equipment, including hand tools, animal-drawn implements, power tillers, tractors, engines, and electric motors, as well as processing and hauling machinery. Farm mechanization is crucial for food security, economic growth, environmental sustainability, rural employment, and technological innovation in agriculture.

Mechanization as a Service (MaaS) and it's appropriate scaling to make it affordable, especially for marginal and small farmers, is one of the most effective ways to enhance yield quality and quantity to help farmers multiply returns. It is particularly well-suited to Asia and Africa, which have low to medium levels of mechanization and where food prices of staple crops like maize, rice, and wheat continue to rise despite import growth. MaaS can lower the production costs of staple food and increase local production to lower reliance on imports. Its appropriate adoption can also contribute to the alleviation of hunger.

- It ensures timely preparation of the land in an atmosphere of increasing climate change and uncertainty
- It reduces the costs of production in a world where the cost of labour is constantly rising
- It reduces losses with the help of more efficient pre-harvest, harvest and post-harvest methods
- It increases the market share of smallholders and creates new employment opportunities and diversified livelihoods, making rural employment more attractive
- It cuts costs, increases yields, and conserves natural resources
- It improves the operational efficiency and life cycle of machines
- It increases agricultural productivity and reduces poverty
- It addresses problems related to sustainability and enhances sustainability measures

Studies by the Indian Council of Agricultural Research (ICAR) under the Network Project on Climate Change (NPCC) indicate that in the medium term (2010-2039), food production could reduce by 4.5-9% and in the long term (2070-2099), the production could decrease by nearly 25%. Since agriculture makes up roughly 15% of India's GDP, a 4.5-9% loss of production could translate into a loss of approximately 1.5 GDP per year because of climate change.

A tiny percentage of the approximately 13 crore small, medium, marginal and large farmers in the country have access to modern farm machinery such as backhoes, combine harvesters, cultivators, sprayers, tractors, and mowers that increase farm productivity. With a majority continuing to rely on traditional farming techniques, shared technological interventions and climate-resilient technologies can help farmers make informed decisions and increase their resilience against climate-change shocks.

5. Importance of Farm Mechanization

Food Security

Mechanization enhances agricultural productivity, contributing to increased food production and improved food security for growing populations.

Economic Growth

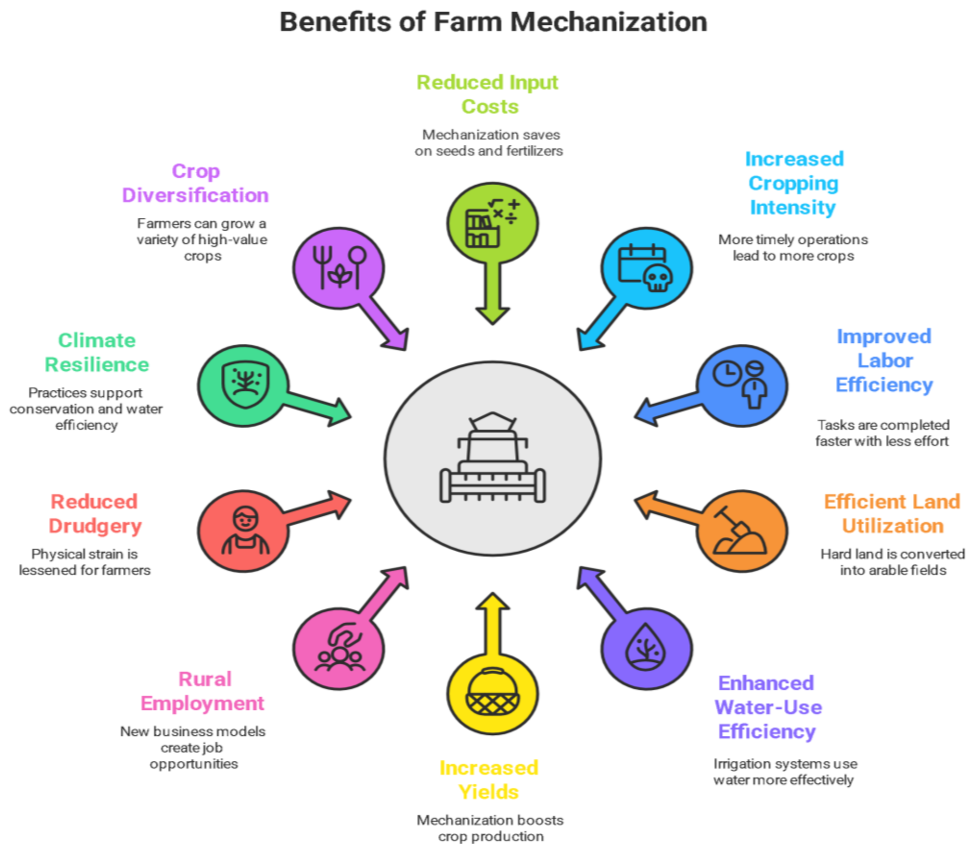
Farm mechanization fosters economic development by improving the efficiency of agriculture, a crucial sector in many economies. Increased agricultural productivity can lead to higher income for farmers and contribute to overall economic growth.

Environmental Sustainability

Modern farm machinery allows for the adoption of sustainable practices, such as precision farming and conservation agriculture. Environmentally friendly practices contribute to soil health, water conservation, and overall sustainability.

Rural Employment Opportunities

While farm mechanization reduces the demand for manual labour in certain tasks, it opens opportunities for skilled employment in machinery operation, maintenance, and repair. This shift can contribute to skill development and create new avenues for rural employment.



Technological Innovation

The adoption of farm mechanization encourages ongoing research and development in agricultural technology. Innovation in machinery design and functionality contributes to the continuous improvement of farming practices, making agriculture more resilient and adaptive to changing conditions.

6.Farm Mechanization in India

India's agricultural sector faces mounting pressure from rising demographic and environmental challenges. With the population projected to reach 1.6 billion by 2048 and global food demand expected to increase by 60% by 2050 (FAO), the country must significantly enhance agricultural productivity despite its constraints of limited arable land, growing water scarcity, and dependence on a highly variable monsoon system. Agriculture continues to support 46.1% of India's population but contributes only 16% to national GDP (Economic Survey 2024–25), reflecting persistent inefficiencies and structural limitations that mechanization could help address. The vulnerability of India's predominantly rainfed agriculture—where only 53% of arable land is irrigated—further underscores the importance of mechanization in ensuring timely farm operations, improving input-use efficiency, and reducing yield losses under climate variability. Lessons from global trends reinforce this imperative: countries such as Canada and the United States have achieved mechanization levels of around 95%, enabling dramatic gains in labour productivity—an American farmer today feeds 144 people, compared to just 26 in 1960—through sustained investments in tractors, harvesters, and precision equipment supported by low-interest credit and subsidy frameworks. France, with 99% mechanization and an agricultural equipment market valued at €6.3 billion, benefits from European Union subsidies that account for nearly half of farmers' income and facilitate high levels of technology adoption. Japan similarly maintains high mechanization intensity, with tractor power availability of around 7 HP per hectare, supported by strong tariff protections and targeted subsidies. These international experiences highlight the critical role of mechanization in enhancing productivity, sustaining rural livelihoods, and ensuring food system resilience—providing a compelling rationale for accelerating mechanization in India, particularly through scale-appropriate solutions that match the needs of its smallholder-dominated farming landscape.

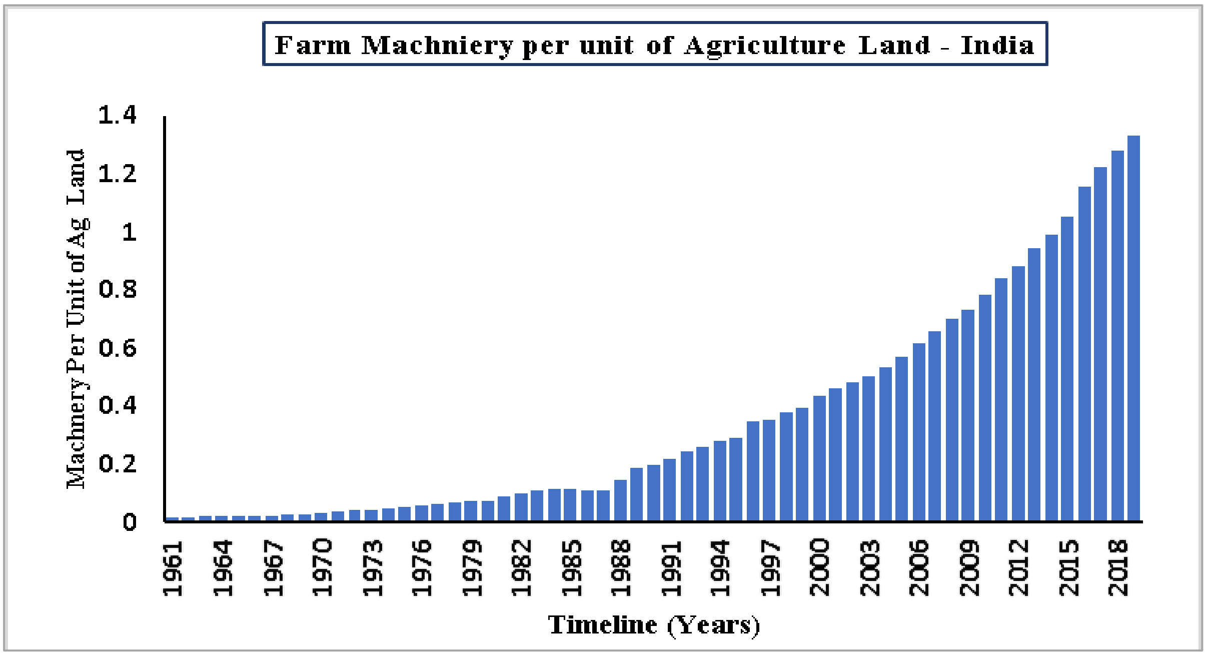


Figure 4: Transition in Farm machinery per unit of agriculture land in India from 1961 to 2019

7. Limitation of Farm Mechanization

- Small land holdings
- Less investing capacity of farmers
- Adequate availability of draft animals
- Lack of suitable farm machines for different operations
- Lack of repair and servicing facilities for machines
- Lack of trained manpower
- Lack of coordination between research organization and manufacturer
- High cost of machines
- Inadequate quality control of machine

Table 8: Tractor Industry Status: Production, Sale and export, 2025

Month	Total Production	Total Sales (Including Exports)	Exports
Jan-25	92648	69770	7847
Feb-25	65996	67751	8954
Mar-25	85500	90679	10733
Apr-25	93369	90280	7441
May-25	97248	99430	8930
June-25	104329	121613	8936
July-25	107417	72797	8477
Aug-25	101943	73199	8877
Sep-25	114500	154417	8237
Oct-25	107089	173635	7490

Source: Tractor and Mechanization Association (TMA) Report, 2025

8.Pattern of Farm Mechanization in India

Farm mechanization patterns show distinct differences across India, shaped by technology availability, landholding size, infrastructure, and policy priorities.

India demonstrates an intermediate level of mechanization, with notable regional and operational variations. Mechanization levels for specific operations reach 70% for seed-bed preparation, around 40% for sowing, and 34% for harvesting, averaging about 45-47% overall farm mechanization nationally. Northern states like Punjab and Haryana lead with power-intensive mechanization (four-wheel tractors, combine harvesters), largely due to subsidized credit and larger farm holdings. Other regions, especially the north-eastern states, lag far behind. Small-scale machinery (small tractors, power tillers) is increasingly adopted to suit fragmented, small-sized plots. Large and medium farmers often serve as service providers for mechanization to smallholders, as seen in developed economies, though diffusion is slower. Mechanization fosters productivity, but equitable, context-appropriate strategies are needed for effective adoption, especially in Africa and India.

9.Farm Mechanization -Business Models in India:

Player-based business models in India

In India, the mechanisation ecosystem has shifted from machine-owning subsidies to a multi-actor, service-oriented economy. The national landscape of mechanisation for large scale is currently organised in four main categories: public, private, collective (non-governmental or non-profit organisations) and individual entrepreneurs. India is now in a transformative phase of mechanisation of agriculture. Farm mechanisation was once linked to the possession of a tractor. Medium-sized and large farms with enough land and capital have benefited greatly from support for the purchase of machinery through grants and agricultural loans. But, because 85 percent of Indian farmers are small and marginal, ownership is often impracticable and economically inefficient. India has moved over the last decade to a service-based mechanisation economy, driven by increasing labour costs and seasonal labour shortages; shrinking agricultural land (on average <1.1 ha); government emphasis on mechanisation at scale, increasing private investment in mechanisation, and the expansion of FPO and rural services models, and digital platforms and rural entrepreneurship. As a result, the Indian mechanical engineering industry is combining: Increasing labour costs and seasonal labour shortages shrinking of agricultural land (average < 1.1 ha) Government's focus on mechanisation at scale and rural business models Increasing private investment in mechanisation services Increasing FPO and rural services sectors Mechanisation is now seen as an enabler, not a hindrance. As a result, the Indian mechanical engineering industry is combining:

Public

The Government of India anchors mechanization through the Sub-Mission on Agricultural Mechanization (SMAM), launched in 2014 under the Ministry of Agriculture and Farmers' Welfare (MoAFW). SMAM focuses on promoting mechanization of the agriculture sector at large scale through funding of custom hiring centres (CHCs) and agricultural machinery bank managed by panchayats, cooperatives, Farmer Producer Organizations (FPOs). These centres pool equipment such as tractors, power tillers, seed drills, transplanters, harvesters, and other modern machinery, and lease it to smallholders for a fee.

Typical Project Cost-Sharing:

- 40–80% government subsidy (depending on the beneficiary type and region),
- 10–40% contribution from the beneficiary.
- The remainder is covered by an institutional loan.

These centres improve the timeliness of field operations, reduce labour, increase the intensity of cultivation and allow equal access to mechanization for small and marginal farmers. Challenges such as underutilization, weak maintenance systems, and lack of trained operators continue to be encountered. To address these problems, states such as Odisha, Madhya Pradesh, Tamil Nadu, and Uttar Pradesh have implemented digital booking portals with GPS tagging and e-payment systems to increase transparency and efficiency.

The public sector has a key role to play in promoting mechanization of agriculture through subsidies, research, and training programmes, ensuring the inclusion of small and marginal farmers.

10. Government Initiatives in Agricultural Mechanization

Subsidies and Grants

The Indian government offers financial support to farmers to buy machinery and set up Custom Hiring Centres (CHCs). Under the Sub-Mission on Agricultural Mechanization, the government aims to create 7,000 new CHCs by 2026, targeting regions dominated by small and marginal farmers. This initiative helps to increase the adoption of modern machinery, leading to higher productivity and reduced labour costs. Particularly beneficiary states are Punjab, Haryana, and Gujarat.

Research and Development

Institutions like the Indian Council of Agricultural Research (ICAR) conduct extensive research to develop and improve Indian adopted agricultural technologies. ICAR's efforts include designing affordable, scale-appropriate machinery for smallholders and promoting innovations such as solar-powered irrigation pumps, precision farming tools, and conservation agriculture equipment. For instance:

- ICAR-Central Institute of Agricultural Engineering (CIAE) has developed low-cost machinery for paddy transplantation and harvesting.
- Over 500 Krishi Vigyan Kendra (KVKs) across India disseminate these technologies at the grassroots level.

Training Programs

Government agencies organise training courses to teach farmers about modern mechanization techniques and best practices. Key initiatives include:

- Training of Rural Youth for Self-Employment (TRYSEM): Focuses on skill development for operating and maintaining agricultural machinery.
- Rashtriya Krishi Vikas Yojana (RKVY): Provides funding for mechanization-related training programs.
- Krishi Vigyan Kendra (KVKs): Conduct hands-on training for farmers and rural youth on using advanced machinery and adopting sustainable practices.

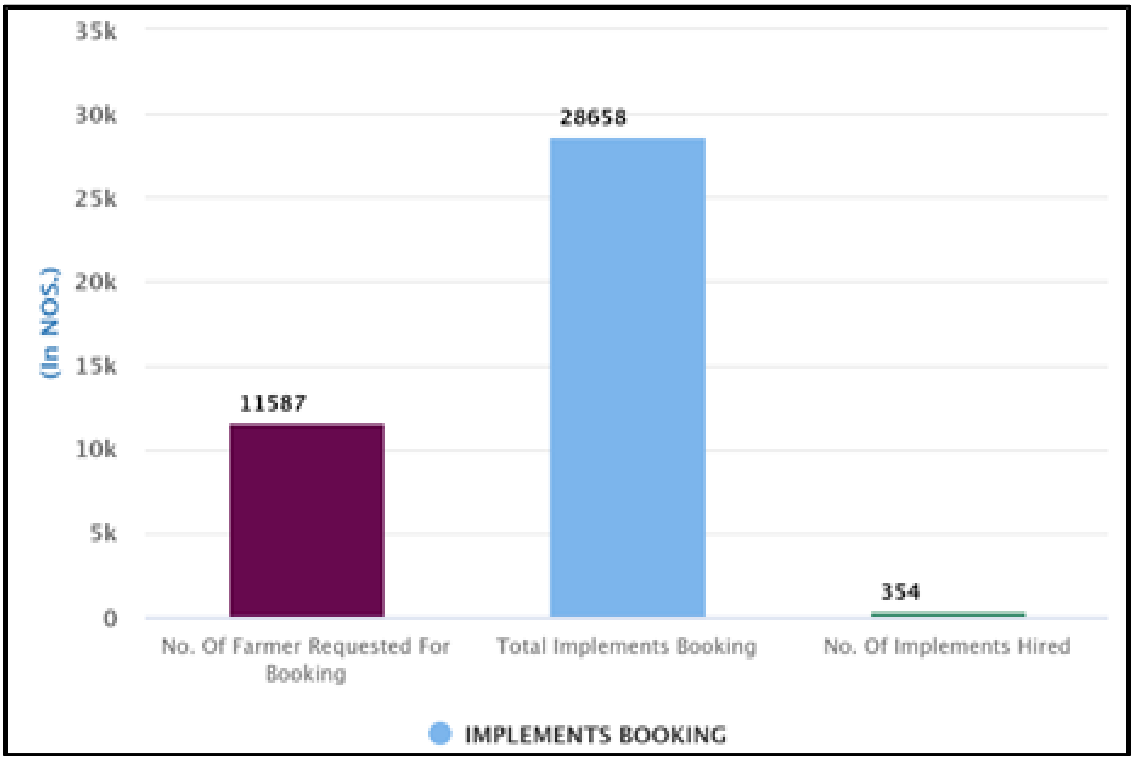


Figure 5: Agriculture Machinery and Implement booking on FARMS portal

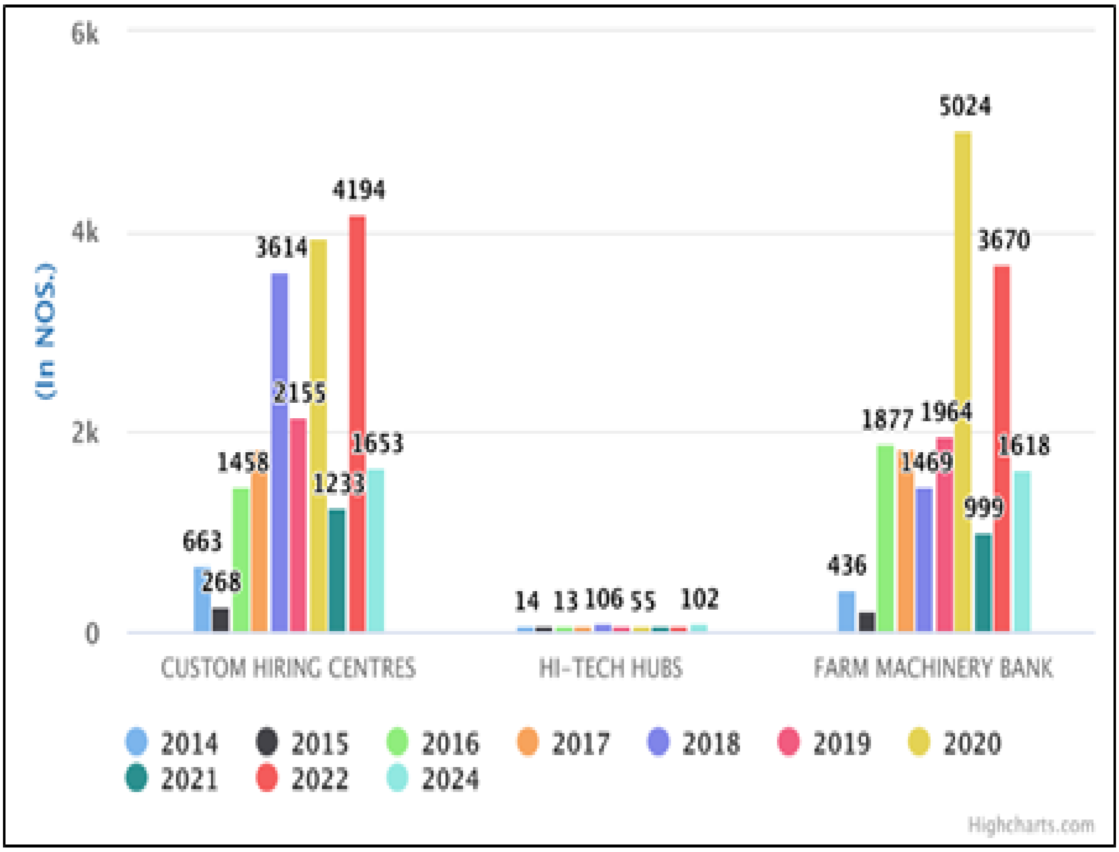


Figure 6: Fig. Mechanisms established under SMAM scheme from 2014-25

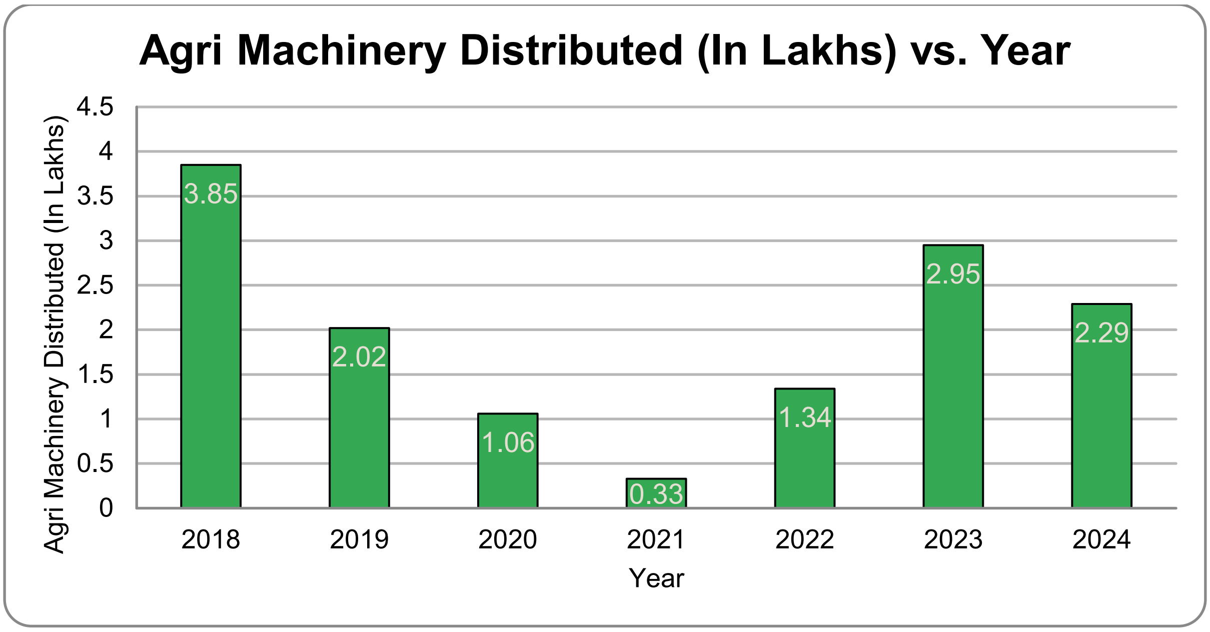


Figure 7: Agriculture Machinery Distributed with CHC mechanism for year 2018 to 2024

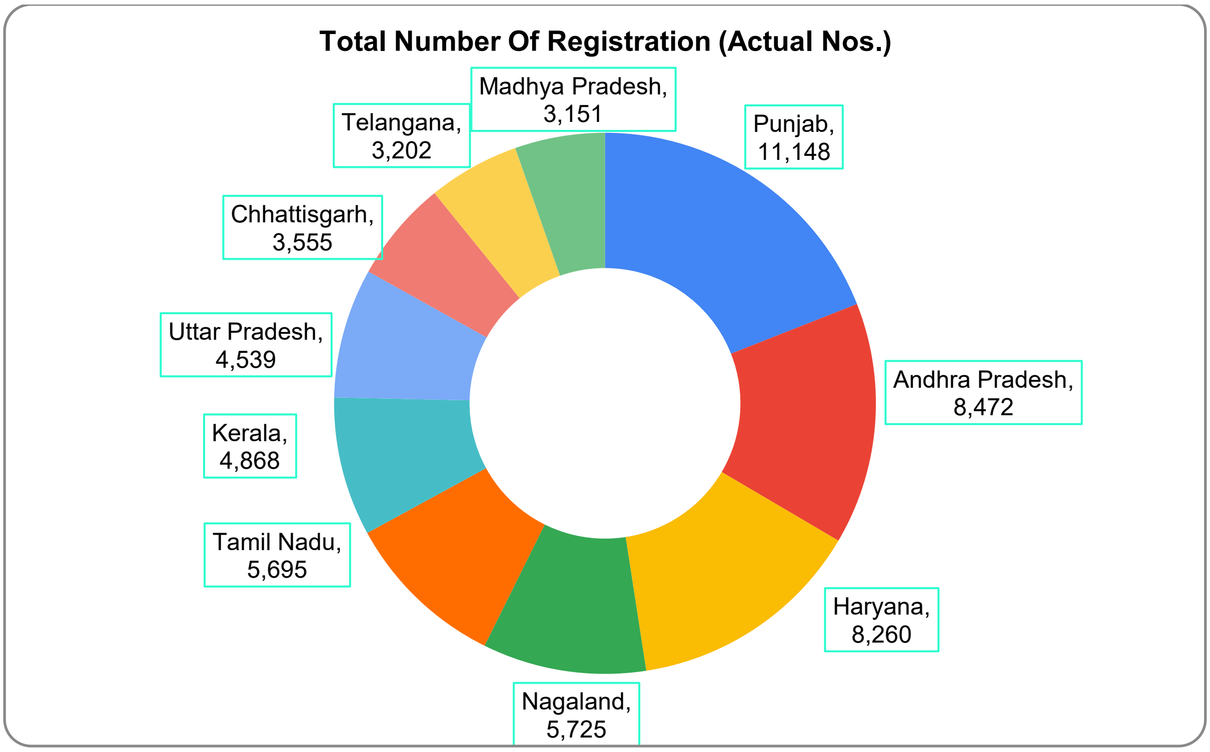


Figure 8: State Wise CHC registered (September 2025)

To refine this section of your report, I have restructured the dense text into a **high-impact case study** format. This layout uses a "Challenge-Solution-Impact" framework, which is the industry standard for professional reports.

11. Case Study: FARMS – Farm Machinery Solutions App

(Digital Public Infrastructure for Scale-Appropriate Mechanization)

A. The Challenge: The "Smallholder Gap"

In India, small and marginal farmers face a "mechanization paradox": they need machinery to overcome labor scarcity and rising costs, but fragmented land holdings (average < 2 ha) make individual ownership financially unviable.

- **Information Asymmetry:** Dependence on informal, unorganized rental networks.
- **High Capital Costs:** Machinery remains unaffordable for the bottom of the pyramid.[1]
- **Service Inconsistency:** Lack of transparency in rental rates and equipment availability.

B. The Solution: FARMS Digital Marketplace

Developed by the Department of Agriculture & Farmers Welfare (DoA&FW) under the SMAM scheme, the FARMS app acts as a Digital Aggregator, connecting demand with supply.

Feature	Description
Aggregator Model	Links farmers with Custom Hiring Centres (CHCs), FPOs, and private owners.
GIS Integration	Real-time tracking and location-based machine listings.
Multilingual Support	Accessible interface designed for rural users with varying literacy levels.
Tech Backbone	Maintained by NIC, ensuring secure, national-level scalability.

C. Strategic Impact (By 2023)

The platform has transitioned from a government tool to a thriving **Digital Public Infrastructure (DPI)**:

- **Scale:** Over **1 Million farmers** reached and **40,000+ machinery units** registered.
- **Efficiency:** Reduced rental costs through market competition and improved machine utilization rates.
- **Entrepreneurship:** Transformed CHCs and FMBs into viable, data-driven service enterprises.
- **Traceability:** Enabled government monitoring of machinery performance and regional mechanization gaps.

D. Critical Constraints & Future Roadmap

Despite its success, the platform faces structural hurdles that define its next evolution:

- **Connectivity & Literacy:** Smartphone penetration and GPS reliability in remote/tribal areas remain a barrier.
- **Ecosystem Fragmentation:** Limited integration with private-sector agritech apps.
- **Quality Assurance:** Absence of a standardized "Uber-like" rating system for machine condition and service reliability.

The FARMS App is a pioneering model of Government-as-a-Platform. By leveraging digital governance to democratize access to high-cost assets, it provides a replicable roadmap for inclusive, sustainable agricultural intensification across the Global South.

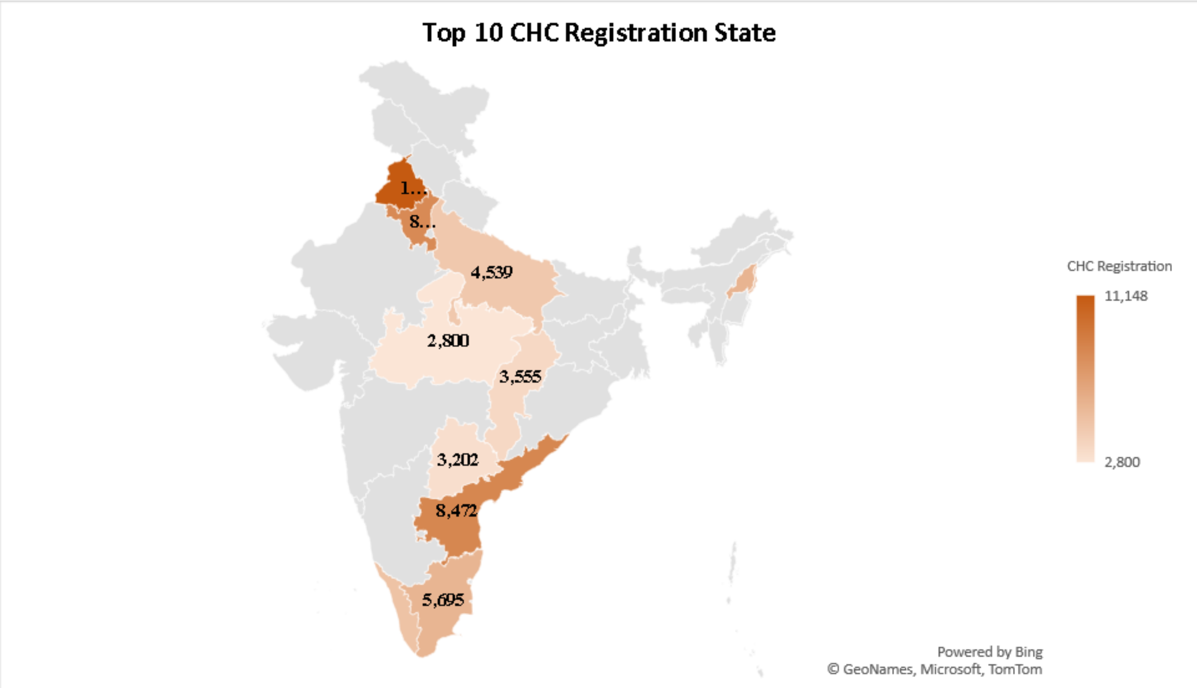


Figure 9: Total CHC Registration by State (Top 10) in India from 2019-25. (Data Source: FARMS Platform)

12. Objective and Design Features

The FARMS app operates as a machinery-on-demand platform, enabling farmers, Custom Hiring Centres (CHCs), and private machinery owners to register, locate, and hire equipment efficiently.

Table 9: Feature of FARM app: -

Feature	Description
Implementing Agency	Department of Agriculture & Farmers Welfare (DoA&FW), Govt. of India
Launch Year	2018
Integration	Linked with the SMAM database and CHC online portal
Functionality	Provides information on availability, location, and cost of machinery and implements for hire
User Categories	(i) Farmers (demand side), (ii) Custom Hiring Centres and individual machine owners (supply side), and (iii) Government agencies (monitoring and reporting)
Coverage	Operational in all major agricultural states; >40,000 registered machinery units and >1 million farmers accessed as of 2023
Accessibility	Multilingual mobile application (Android) with integrated GIS tagging and feedback system

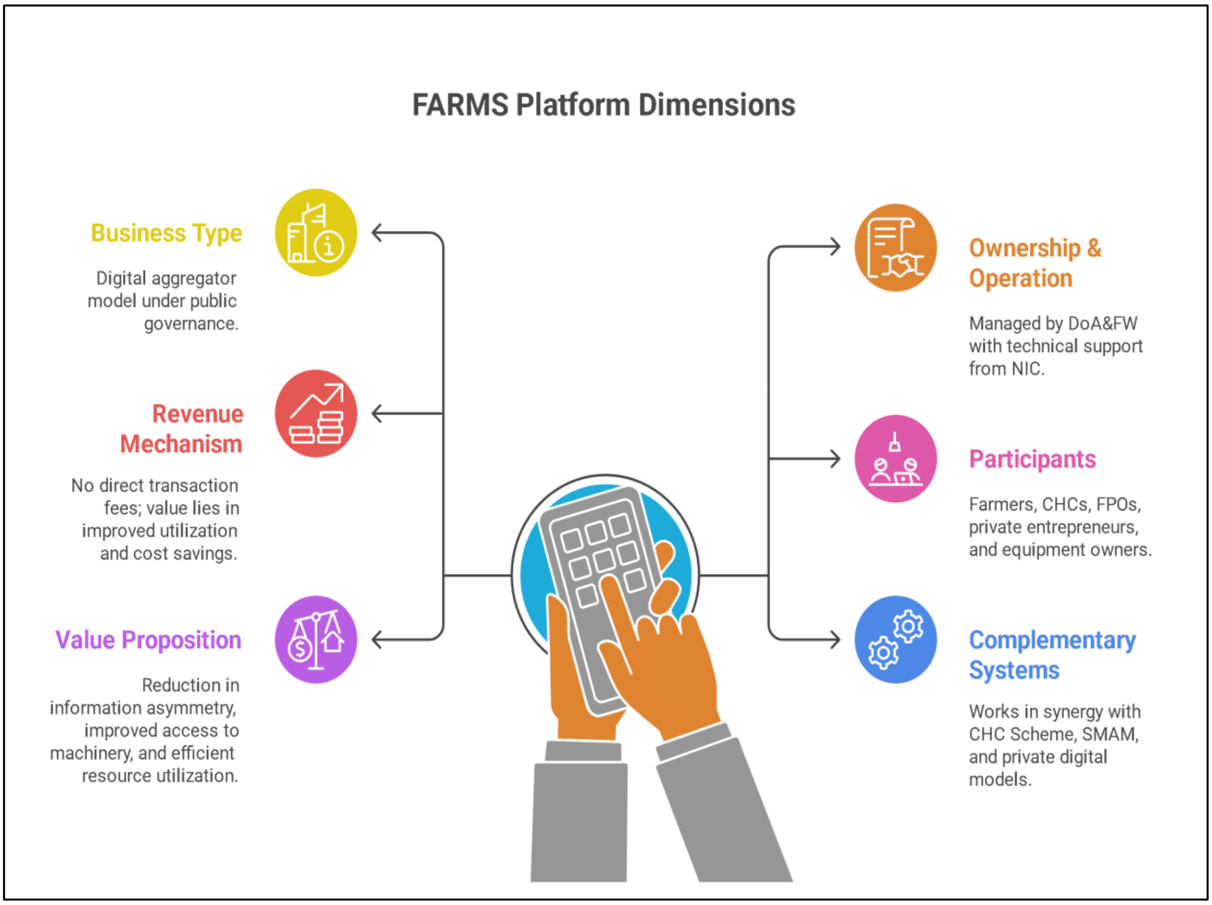
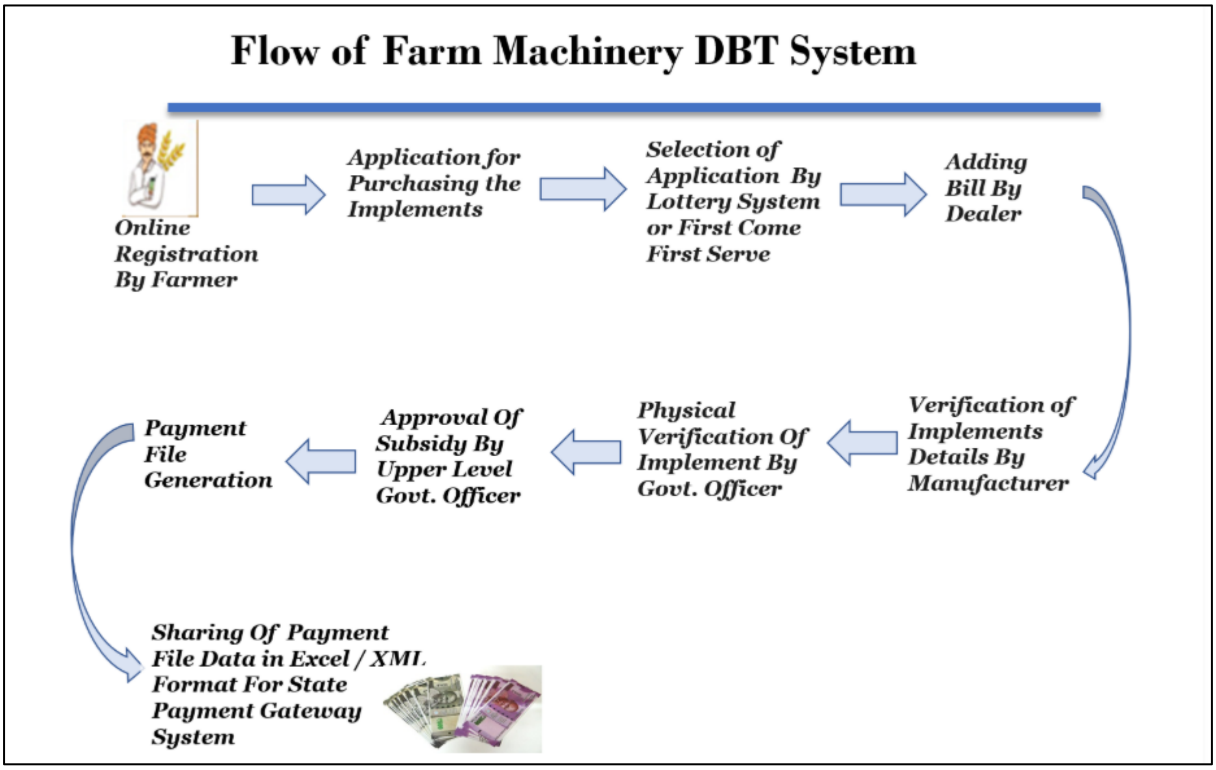


Figure 10: Dimensions of FARMS Platform

13. Flow of Farm Machinery DBT System



14. Private ownership business model for mechanization

The India private sector redefined agricultural mechanization by introducing market discipline, digital logistics, and capital efficiency. The focus has moved from selling machines to "Mechanization-as-a-Service, where farmers access machinery on-demand without the burden of ownership. This transformation is being driven by Agri-tech start-ups, global Original Equipment Manufacturers and collaborative platforms that harnessing technology to make mechanization accessible, affordable, and effective.

Key players such as Mahindra & Mahindra, TAFE have diversified beyond manufacturing. They now offer integrated solutions, including funding through captive Non-Banking Financial Companies, technology enabled service platforms, and pay-per-use models. At the same time, Agri-tech companies are revolutionising access to mechanization through innovative, technology-driven delivery mechanisms.

15. Case Study: Mahindra Trringo – Mechanization on demand

Mechanisation of demand Launched by the Mahindra Group in October 2016, Trringo is the first organised Indian platform for renting agricultural equipment to small and marginal farmers who cannot afford to buy tractors and machines outright. By January 2018 - just 15 months after its launch - Trringo had already provided more than 100,000 hours of mechanized work in more than a thousand villages in five states: Maharashtra, Gujarat, Karnataka, Madhya Pradesh, Rajasthan and Uttar Pradesh.

Trringo, operating through a network of 100+ franchise centres, allows farmers to access tractors and machines by telephone (1800 266 8), on its website or by mobile application, under the simple slogan: Ab Tractor Call Karo. The pay-as-you-go model eliminates upfront capital costs and increases productivity and reduces labour costs. In addition to empowering farmers, Trringo has created a rural livelihood for local entrepreneurs by training them to run the hubs and by employing qualified tractor drivers. Its digital first approach has been recognised with awards such as the IDC Digital Transformation Award and the SABRE South Asia Awards (2017). Today, Trringo is a pioneering example of farm-as-a-service farming in India, proving that mechanisation does not have to be proprietary to be effective.

16. JFarm (TAFE) Model

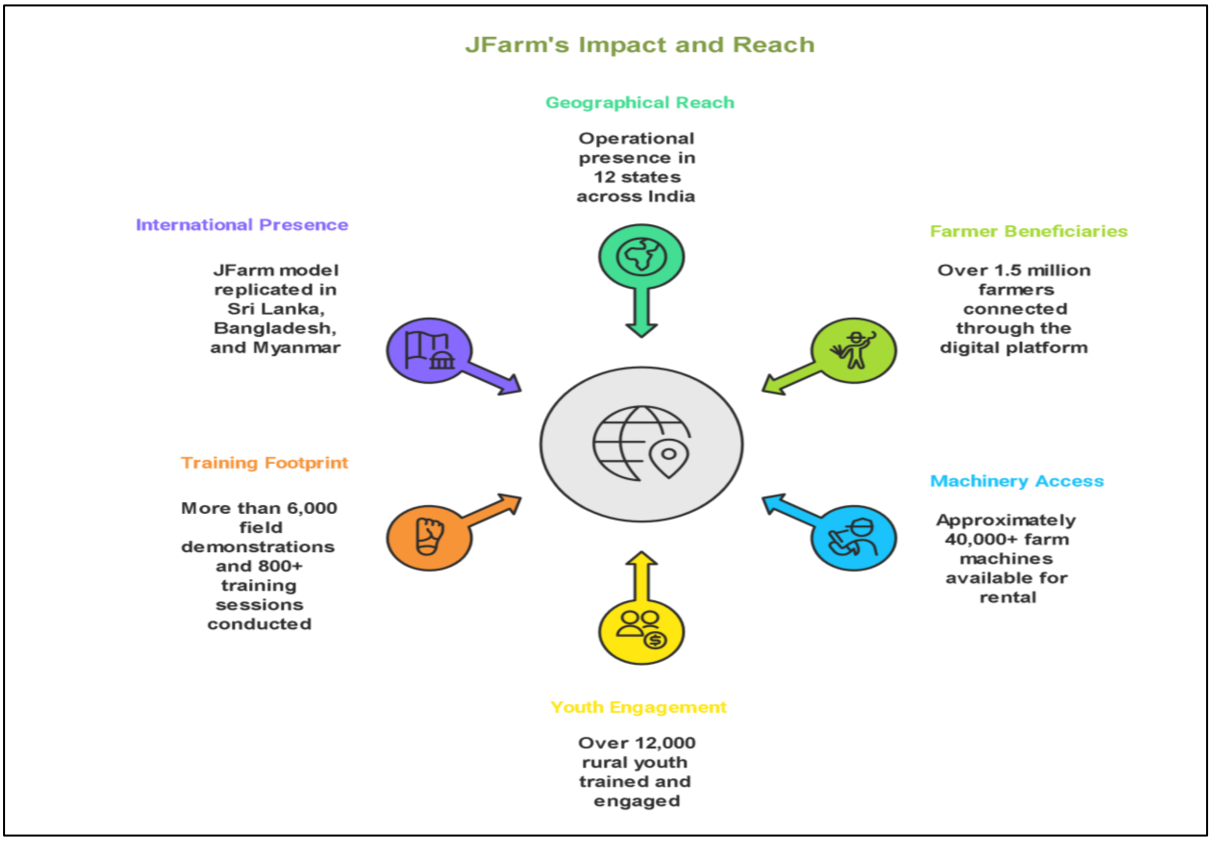
Overview

The JFarm model, conceptualized by TAFE (Tractors and Farm Equipment Limited), represents one of India's most prominent public–private agritech ecosystems integrating mechanization access, skill development, and localized innovation. Established originally in Chennai, Tamil Nadu, JFarm has expanded across multiple Indian states and into international markets, functioning as a hub for farm mechanization demonstrations, training, and custom-hiring services targeted at smallholder farmers.

Operational Framework

Component	Description
Core Concept	A field-based, experiential learning platform where farmers, dealers, and youth entrepreneurs can engage with machinery demonstrations and hands-on training.
Lead Institution	TAFE Ltd. – one of India's largest tractor manufacturers (Massey Ferguson and Eicher brands).
Operational Nodes	JFarm–Tamil Nadu (HQ, Chennai), JFarm–Rajasthan (Tonk), and collaborative extensions in Punjab, Bihar, Odisha, and Jharkhand.
Collaborative Partners	State Departments of Agriculture, Krishi Vigyan Kendra (KVKs), and Farmer Producer Organizations (FPOs).
Service Components	1. Machinery demonstration & evaluation 2. Rental & Custom Hiring through JFarm Services (digital platform) 3. Youth training and Agri-entrepreneur incubation 4. Advisory and farm productivity solutions
Technology Platforms	JFarm Services App (launched in 2018) connecting farmers directly with tractor and implement owners for pay-per-use rentals; integrated with the FARMS portal under the Ministry of Agriculture.

JFarm: Impact and Reach



17. JFarm: Economic and Social Outcomes

Enhanced Access to Mechanization:

Through its shared machinery and rental model, JFarm has reduced operational drudgery and improved timeliness in land preparation and harvesting, especially among small and marginal farmers.

Employment and Entrepreneurship:

The JFarm ecosystem has created decentralized employment for rural youth as equipment operators, rental agents, and mechanics — fostering local mechanization-based microenterprises.

Increased Efficiency and Income:

Studies from TAFE internal assessments and state agriculture departments indicate an average cost reduction of 15–20% in field operations and yield improvements of 8–12%, primarily due to timely field operations.

Inclusive Reach

JFarm has facilitated access for women farmers and FPOs by enabling short-term machinery rentals, addressing both capital and skill barriers associated with mechanization.

Digital Integration for Last-Mile Access:

The JFarm Services App complements the Government's FARMS portal, bridging farmers and machine owners through real-time demand–supply matching, transparent pricing, and improved machine utilization efficiency.

18. Schemes, Policies and Impact on Agriculture

In India, the government has implemented several agricultural mechanizations through various schemes such as Rashtriya Krishi Vikas Yojana (RKVY), National Food Security Mission (NFSM), National Mission on Oilseeds and Oil Palm (NMOOP), Mission for Integrated Development of Horticulture (MIDH), and lately Sub-Mission on Agricultural Mechanization (SMAM). In addition, government has also implemented the National Mission on Agricultural Extension and Technology (NMAET) to strengthen the extension machinery and utilize it for synergizing the interventions made in various schemes as follows:

Table 10: List of schemes and its benefits

S. No	Name of the Scheme	Origin Year	Objective	Coverage	Benefit
1	Rashtriya Krishi Vikas Yojana (RKVY)	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
2	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
3	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
4	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.
5	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
6	Sub Mission on Agricultural Mechanization (SMAM)	2014-15	To increase mechanization among small and marginal	All states	Financial assistance for machinery, Custom Hiring Centres, Farm

			farmers and in low farm power availability regions		Machinery Banks, training, testing & demonstration
7	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
8	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
9	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

19. Sub Mission on Agricultural Mechanization (SMAM)

Custom Hiring Centres of Agricultural Machineries' operated by Cooperative Societies, Self Help Groups and private/rural entrepreneur are the best alternative in enabling easy availability of farm machineries to the farmers and bringing about improvement of farm productivity for the benefits of Small & Marginal farmers. Department of Agriculture & Farmers Welfare has integrated the components of agricultural mechanization under various schemes and programmes aiming at catalysing an accelerated but inclusive growth of agricultural mechanization in India. The following specific interventions with a special emphasis on 'reaching the unreached' will bring small and marginal farmers' at the core. With this aim the Ministry of Agriculture and Farmers Welfare, Department of Agriculture and Farmers Welfare, Mechanization and Technology Division has implemented a dedicated scheme "Sub Mission on Agricultural Mechanization" with following components;

1. Promotion and Strengthening of Agricultural Mechanization through Training, Testing and Demonstration:
2. Demonstration, Training and Distribution of Post-Harvest Technology and Management (PHTM):
3. Financial Assistance for Procurement of Agriculture Machinery and Equipment:
4. Establish Farm Machinery Banks for Custom Hiring
5. Establish Hi-Tech, High Productive Equipment Hub for Custom Hiring

6. Promotion of Farm Mechanization in Selected VillageS
7. Financial Assistance for Promotion of Mechanized Operations/hectare Carried out Through Custom Hiring Centres
8. Promotion of Farm Machinery and Equipment in North-Eastern Region:
9. Promotion of Drone Technology

The interventions of the crop residue management will be implemented as a component of Rashtriya Krishi Vikas Yojana (RKVY) With this aim the Ministry of Agriculture and Farmers Welfare, Department of Agriculture and Farmers Welfare, Mechanization and Technology Division has formulated a dedicated scheme "crop residue management" with following components:

Financial assistance to farmers for procurement of crop residue management machines on individual ownership basis: The rate of financial will 50% of the cost of machinery.
Establishment of Custom Hiring Centres of Crop Residue Management Machines: Financial assistance 80% of the project cost for the projects of Custom Hiring Centres (CHCs) costing up to Rs. 15 lakhs will be available to Rural Entrepreneurs (Rural youth and farmer as an entrepreneur), Cooperative Societies of Farmers, Self Help Groups (SHGs), Registered Farmers Societies, Farmer Producer Organizations (FPOs) and Panchayats. The maximum permissible assistance per machine under the CHC project will be the amount arrived by multiplying the maximum permissible assistance for each machine. The maximum permissible assistance for each project should not exceed Rs. 12.00 lakhs per project.

Establishment of crop residue/paddy straw supply chain: The project proposal based financial assistance will be provided only on the capital cost of machinery and equipment like Higher HP Tractor, Cutters, Tedder, Medium to Large Balers, Rakers, Loaders, Grabbers and Telehandlers. The capital subsidy will be released into the bank Escrow account of beneficiary through Direct Benefit Transfer (DBT).

Information, Education and Communication (IEC) for awareness on crop residue management: The machines to be demonstrated shall be identified by the implementing agencies. The implementing agencies will be provided full cost of machines to be procured and a contingency expenditure Rs. 6000/- per hectare will also be provided for taking up demonstrations on the farmers' fields.

20. Key achievements of SMAM include

A. **Increased access to mechanization:**
   a. Since 2014, more than 25,000 CHCs and FMBs have been established across India, benefiting more than 10 million small and marginal farmers.

b. The program has promoted the use of machinery such as happy seeders, zero-till drills, and combine harvesters, which are essential for sustainable agriculture practices.

B. **Regional impact:**

a. In Punjab and Haryana, SMAM played a key role in addressing stubble burning through the support of machinery and straw management systems.

b. In Eastern India (Bihar, Odisha, and West Bengal), the programme has introduced scale-appropriate machinery for paddy transplantation and harvesting, reducing labour dependency during peak seasons.

C. **Digital Integration:**

a. States like Odisha and Tamil Nadu have integrated digital platforms with SMAM, enabling farmers to book machinery online through apps for Tractors and Tractor Junction.

b. GPS tagging of machinery ensures transparency and accountability in usage.

D. **Socioeconomic benefits:**

a. Farmers using CHCs report a 20-30% reduction in input costs and a 15-20% increase in yields due to timely operations.

b. The initiative has also created rural entrepreneurship opportunities, for rural youth becoming service providers.

21. Challenges and Future Outlook

While the SMAM has made significant progress, there are some challenges remain:

- Under-utilization of CHCs: many centres facing low demand due to in enough awareness among farmers.
- Maintenance Issues: lack of trained operators and poor maintenance systems often result in equipment being out of service.
- Regional differences: Adoption rates vary significantly between progressive states like Punjab and backward regions such as Eastern India.

To address these challenges, the government plans to:

- Enhance awareness campaigns to promote use of CHC.
- Strengthen training programs for machinery operation and maintenance.
- Expand digital platforms to ensure wider accessibility and transparency.
- Building on the successes of SMAM and addressing its limitations, India is poised to achieve inclusive and sustainable agricultural mechanization, empowering millions of small and marginal farmers.

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

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.

Mechanization is widely recognized for improving agricultural labour productivity. Studies indicate that mechanized farms experience significant reductions in labour hours per hectare while increasing yields (Mellor, 2017). A 2018 survey found that countries with high mechanization adoption see up to a 40% increase in agricultural output per worker compared to traditional labour-intensive methods

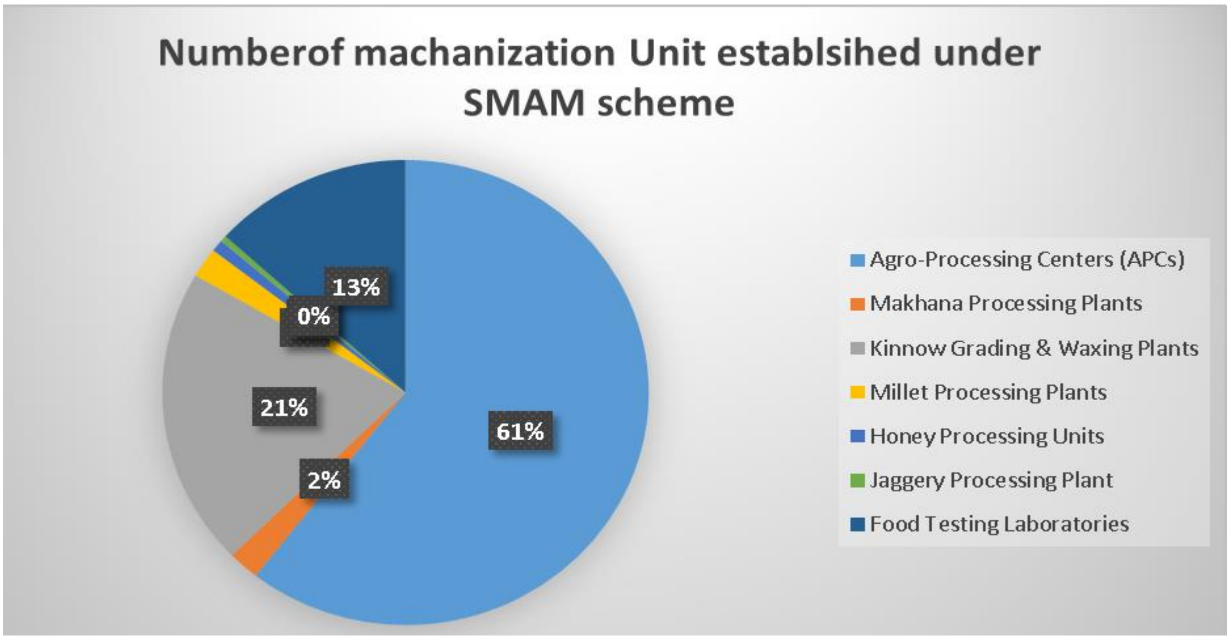


Figure 11: Number of mechanization unit established under SMAM Scheme

In India, Takeshima (2020) reported a 25% reduction in labour hours per hectare while increasing crop yields by 20% due to mechanized farming practices. Countries such as China and India have successfully implemented subsidized tractor and harvester programs, leading to a 70% mechanization rate in cereal production (Huang et al., 2018)

- Wheat productivity among beneficiaries improved from 39.11 q/ha to 40.95 q/ha after availing CHC services. Furthermore,
- CHC beneficiaries experienced a 9.4% reduction in cultivation costs (₹40,564/ha) compared to non-beneficiaries (₹44,793/ha).
- CHC ownership also contributed significantly to household income. The perception index value of 0.88 among beneficiaries indicated a favourable outlook towards CHCs. Owners reported an increase in annual income from ₹5,62,500 to ₹8,39,625 post-ownership, with CHCs contributing 20.24% to their total income.

Efficient machinery helps in increasing productivity by about 30% (Table 11) besides, enabling the farmers to raise a second crop making the agriculture attractive. Raising more crops with high productivity is a path for meeting the future food requirement of population. Development and introduction of high capacity, precision, reliable and energy efficient equipment is the need for judicious use inputs. For crop production human, animal and mechanical energy is extensively used. In small and marginal farms, except for tillage, other operations such as sowing/ transplanting, weeding, cotton picking harvesting and threshing (paddy) are normally manually performed. Table 11. Economic Advantage of Mechanization in per cent $ Increase in productivity up to 12-34 $ Seed-cum-fertilizer drill facilitates Saving in seeds 20 Saving in fertilizer 15-20 $ Enhancement in cropping intensity 5 - 22 $ Increase in gross income 29-49 of the farmers.

Table 11: Economic advantage of mechanization in percent

Economic Advantage of Mechanization	Percentage (%)
Increase in productivity up to	12 - 34
Enhancement in cropping intensity	5 - 22
Increase in gross income of the farmers	29 - 49
Seed-cum-fertilizer drill facilitates:	
• **Saving in seeds**	20
• **Saving in fertilizer**	15 - 20

Source: *India Agristat*

22. SAM: Opportunities, Challenges and Constraints

Opportunities for Scale-Appropriate Farm Mechanization (SAM)

The transition to Scale-Appropriate Mechanization (SAM) provides multifaceted opportunities that address both economic and sustainability goals for smallholder farmers.

Employment and Entrepreneurship Opportunities

Local employment and entrepreneurship opportunities will be created through the development of custom hiring centres (CHCs) and service-based business models. This encourages entrepreneurship in machinery rental, repair, and fabrication tailored specifically to local crop systems and varied terrain, supporting the creation of skilled agricultural jobs. Providing scale-appropriate machines reduces the initial investment and encourages the development of local service ecosystems.

Promoting Regional Manufacturing and Innovation

The demand for SAM opens significant opportunities for the local manufacturing of small, affordable and crop-specific machinery. This strengthens crucial linkages between research institutions, private enterprises, and farmer cooperatives for co-design and innovation, fostering a self-sustaining regional industry. Linking CHCs with local manufacturers and innovators fosters the development of region-specific and crop-specific machinery. Such adaptive innovation strengthens local manufacturing capacities and ensures that machines meet the practical needs of farmers.

Enhanced access to Machinery

CHCs can serve as hubs providing small and medium-sized machinery suited to diverse farm sizes and cropping systems. By offering scale-appropriate equipment—such as mini-tillers, reapers, planters, and threshers—CHCs enable equitable access to mechanization across varying landholding patterns.

Cost-effective Mechanization

The pay-per-use model of CHCs allows farmers to utilize machinery without bearing the full capital cost. This promotes inclusive mechanization, reduces drudgery, and improves productivity, especially in regions with fragmented landholdings.

Improving Resource-Use Efficiency

Smaller, fuel-efficient, and precision-based SAM technologies available through CHCs can minimize energy use, reduce soil compaction, and support climate-smart agriculture practices. SAM technology supports the precise application of inputs, such as seeds, fertilizers, and water, thereby drastically reducing overall production costs. Furthermore, it actively promotes conservation agriculture practices, including minimum tillage, controlled residue management, and mulching, leading to healthier soil systems.

Enhancing Crop Diversification

SAM is a key enabler of crop diversification by providing customized tools and machinery suitable for various crop rotations and intercropping systems. Mechanized operations for high-value crops like pulses, oilseeds, and vegetables encourage farmers to move beyond cereals, consequently leading to improved income and better nutrition security across rural households.

Reducing Drudgery and Promoting Gender Inclusion

The adoption of lightweight designed tools and implements effectively reduces physical strain, making mechanization more accessible for smallholders and, critically, for women in agriculture. This increases women's participation in farm operations and improves their role in household decision-making.

Supporting Climate-Resilient and Sustainable Systems

By integrating sustainable crop-soil management practices, SAM facilitates the conservation of soil moisture and organic matter, thereby enhancing farming systems' resilience to drought and erratic rainfall. The focus on appropriate-scale technology also encourages the adoption of low-emission technologies and machinery powered by renewable energy sources.

Enabling Digital and Smart Agriculture Integration

Small-scale mechanization is inherently compatible with the integration of digital tools and Smart Agriculture practices, such as GPS-enabled seeders, soil sensors, and farm management applications. This capability facilitates data-driven management, improved monitoring, and increased efficiency, even within the complex context of smallholder farms.

23. Challenges and Constraints to SAM Adoption

Despite the significant opportunities, the scaling of SAM faces persistent structural, financial, and institutional barriers in India.

High Investment Costs and Limited Access to Affordable Machinery

The high initial costs, even for small-scale or low-horsepower machines, remain prohibitive for most resource-poor farmers who also face limited access to affordable credit, leasing options, or tailored financial instruments. Compounding this challenge is the limited availability of suitable equipment, as many machines are adapted from large-scale systems and are not optimized for diverse local crops, soils, topographies, or dryland farming needs.

Weak Custom Hiring and Service Infrastructure

The service delivery system remains a weak point due to the limited presence of well-functioning Custom Hiring Centres (CHCs) in remote rural areas. Issues such as poor maintenance, a chronic lack of spare parts, and inadequate business management skills among operators all contribute to reduced service reliability and constrain access for smallholders.

Inadequate Technical Knowledge and Skills

There is a significant lack of skilled operators and technicians, as many farmers and local service personnel lack adequate training in the operation, maintenance, and safety protocols for modern machinery. The absence of vocational programs and local repair workshops leads to poor machine utilization, frequent breakdowns, and increased dependency on distant service centres.

Limited Research, Design, and Supply Chain Support

Weak linkages between R&D institutions, local manufacturers, and end-users lead to technology designs that are often mismatched with farmers' real needs, resulting in slow innovation and limited optimization for smallholder conditions. Furthermore, poor supply chain and after-sales service—including irregular supply of spare parts and inadequate local dealerships—increase machine downtime and long-term maintenance costs.

Financial, Institutional, and Infrastructural Constraints

Investment is constrained by financial and institutional barriers, including the fact that mechanization subsidies and credit schemes often inadvertently favour larger farmers over smallholder enterprises. Underlying this are infrastructural and logistical barriers, as poor rural roads, inadequate storage, and irregular power supply (especially for solar or electric equipment) hinder the smooth operation and transport of machinery.

Fragmented and Small Landholdings

The fundamental constraint is the dominance of small, scattered, and irregularly shaped fields, which severely limits the efficiency and economic viability of individual machinery ownership. The necessity of frequent movement between scattered plots increases operational time and fuel costs, thereby reducing profitability and discouraging private investment from achieving economies of scale.

Gender and Social Inclusion Gaps

Despite policy intent, gender and social constraints persist, with most machinery designs failing to consider women's ergonomic needs or access limitations. Social norms and traditional ownership patterns often restrict women's ability to operate or manage farm equipment businesses, limiting the full potential of gender-friendly mechanization.

Energy and Infrastructure Limitations

Irregular power supply and limited access to renewable energy options (like solar) constrain mechanization in remote areas. Poor transport and road connectivity hinder the movement of machinery and service delivery.

Advantages of SAM

Some of the important advantages for scale-appropriate mechanization are as follows: Farm mechanization helps in the timely completion of various farm operations and proper utilization of soil moisture for multiple cropping, leading to increased system productivity. Mechanized farming encourages farmers for crop diversification (to expand to new crops) since there is higher capital investment with the machinery and more time in hand. Custom hiring as a new livelihood option for unemployed youths will provide opportunities for production, repair and maintenance of machines, implements, and spare parts through skill up-gradation in various vocations, leading to a more self-reliant society.

The Way Ahead

Scale-appropriate mechanization offers a practical pathway to increase agricultural productivity, reduce labour bottlenecks, and enhance resilience-especially for smallholder-dominated farming systems. Unlike conventional models that rely on large machinery, this approach promotes tools and technologies tailored to local contexts, farm sizes, and cropping systems. Moving forward, progress depends on coordinated action in technology development, service provision, financing, supply chains, and policy support.

The next phase of mechanization should prioritize locally adapted, efficient, and sustainable technologies, including small-scale multipurpose equipment and renewable-energy-powered solutions. Because many smallholders cannot afford machinery outright, Mechanization-as-a-Service through hiring centres, cooperatives, and digital booking platforms-will be central to expanding access. Strengthening rural businesses and providing operator training will help sustain these services.

Improved financing mechanisms such as leasing, asset-backed loans, and pay-as-you-use models can lower barriers for both farmers and service providers. Building robust supply chains for spare parts, repair services, and local manufacturing is equally critical to keep machines operational and affordable.

Future mechanization must also be inclusive, providing ergonomically appropriate tools for women and entrepreneurship opportunities for youth. Integrating mechanization with climate-smart practices, such as conservation agriculture and low-emission equipment, will help ensure environmental sustainability.

Finally, supportive policies-including national mechanization strategies, quality standards, targeted incentives, and improved rural infrastructure-are essential to unlock widespread adoption. Strengthened research, extension, and monitoring will guide continuous improvement.

Overall, advancing scale-appropriate mechanization requires a holistic approach that combines innovation, market-driven service systems, inclusive finance, and enabling policy frameworks. This will ensure that mechanization becomes a driver of equitable and sustainable agricultural transformation.

24. Call to Action

Capacity Development and Knowledge Systems for Scale-Appropriate Mechanization in India

The successful adoption of Scale-Appropriate Mechanization (SAM) among smallholder farmers in India relies heavily on access to suitable equipment, the ability to operate and maintain it, and a broader understanding of improved agronomic practices such as residue retention and reduced tillage. Mechanization for smallholders is knowledge-intensive, and the transition from traditional practices requires targeted skill development for all actors engaged in the value chain.

Strengthening awareness of viable mechanization business models—custom hiring centres, service providers, cooperative ownership, and local manufacturing—can help farmers understand operational choices, cost implications, and the economic and environmental benefits of shifting away from residue burning and labour-intensive operations. Showcasing clear business cases also aids policymakers in assessing the broader public value of mechanization investments.

Capacity development remains a key bottleneck in scaling SAM. Many farmers, operators, and service providers lack the technical skills needed to handle modern small-scale machinery. Institutional and community-level weaknesses further limit the spread of innovations. Training programs must therefore target manufacturers, mechanics, operators, extension workers, farmer groups, rural youth, and local entrepreneurs to ensure a functional ecosystem for SAM.

Extension approaches such as the Lead Farmer Model, farmer-to-farmer learning, and village mechanization champions can help address human resource shortages at the local level. Demonstrations, exposure visits, and on-farm trials provide practical orientation and build confidence among early adopters.

Long-term mainstreaming of SAM requires the integration of mechanization and conservation-aligned agronomy into curricula at agricultural universities, polytechnics, and vocational training centres. These institutions can play a strategic role by offering dedicated courses and hands-on modules, aligned with field-level research and feedback mechanisms. Strengthened collaboration between research institutions, state departments, KVKs, private manufacturers, and civil society partners can enhance the reach and relevance of the training programs.

Targeted information campaigns, digital advisory tools, and structured capacity-building initiatives co-designed by multiple stakeholders can rapidly accelerate awareness among farmers and service providers. Engagement of policymakers and district-level decision makers through workshops, exposure visits, and policy dialogues is essential to embed SAM in state programs and resource allocation frameworks.

Overall, sustained investment in human capital—through structured training, responsive extension, and institutional capacity building—is central to scaling scale-appropriate mechanization for India's smallholder farming systems.

Table 12: Implication, Policy, and Recommendation for Mechanization in Indian Agriculture

Theme	Key Finding	Implication	Policy Direction
Mechanization Level	Highly uneven across states and farm sizes (e.g., Punjab (80-85%), Eastern/NE states (30-40%).	Regional strategies are crucial; a one-size-fits-all approach fails.	Strengthen localized Custom Hiring Centres (CHCs); incentivize small/marginal farmer-friendly machinery.
Skill Gap	35–50% shortfall in technical manpower (operators, maintenance, supervisors) in CHCs and repair units.	Urgent need for upskilling to ensure machinery utilization and reduce downtime.	Launch a National Mechanization Skill Mission focused on certified training for CHC operators, technicians, and local manufacturers.
Financial Access (Subsidy)	Subsidy schemes (like SMAM) are often complex and slow, favouring large farmers or established manufacturers.	Small/marginal farmers and start-ups face exclusion and high upfront costs.	Streamline subsidy disbursement (e.g., direct benefit transfer); introduce differential subsidies favouring small farmer implements.
R&D and Innovation	Lack of region/crop-specific machinery (e.g., for rice	Low adoption rates and high labour requirement persist	Mandate R&D collaboration between ICAR/SAUs and private

	transplanters in Eastern India or hill agriculture).	in specific crop cycles and geographies.	manufacturers; create Zonal Testing Centres for local validation.
Custom Hiring Centre (CHC) Model	Utilization rates are low (often <40%) due to market failure, poor maintenance, and lack of coordination.	Unsustainable business model for many CHCs; government investment is sub-optimally utilized.	Develop a digital platform for CHC booking/tracking; promote Farmer Producer Organization (FPO)-owned CHCs for better coordination and trust.
After-sales Support	Inadequate service and spares network (especially in remote/Eastern states) leading to significant machinery downtime.	Machinery becomes a liability rather than an asset, reducing farmer confidence in mechanization.	Promote a "Mechanization Service Hub" model in block/cluster levels; incentivize local youth to set up certified repair workshops.

Source: IIM Report on Mechanization in Agriculture, May 2023 and Multiple Sources

Table 12: State-Wise Farm Mechanization Findings and Recommendations

State Category / Theme	Key Finding (State-Specific)	Implication	Specific Recommendation
High Mechanization	Over-mechanization observed, particularly with high-HP tractors (45-50 HP) leading to farm profit squeeze and stubble burning issues.	Capital is locked in under-utilized, large machines; environmental issues persist (air pollution, soil health).	Promote low-HP and specialized implements (e.g., Happy Seeder, Super Seeder) through targeted subsidies and stringent regulatory compliance on stubble burning.
High Mechanization	High dependency on migrant labour for manual operations (e.g., rice transplantation, vegetable harvesting).	Labour scarcity during peak season remains a critical constraint despite high mechanization.	Focus R&D and subsidy on transplanting/harvesting equipment suitable for local cropping patterns, replacing manual labour.

Low Mechanization (e.g., Bihar, Assam)	Farm power availability is extremely low (e.g., 1-2 kW/ha in parts of Bihar/Assam) due to small landholdings and lack of capital.	Timeliness of operations (sowing, harvesting) is compromised, directly impacting yields and cropping intensity.	Massive roll-out of Small-Farm Friendly Machinery (power tillers, low-cost micro-implements, manual tools). Incentivize rental services from FPOs/SHGs, not just private CHCs.
Low Mechanization (e.g., Bihar, Assam)	Low machine ownership; high reliance on informal rentals, but the formal CHC model (Sub-Mission on Agricultural Mechanization/SMAM) has low penetration.	Benefits of government subsidies do not reach most small and marginal farmers.	Simplify the subsidy process (e.g., token-based or DBT); promote community-owned Farm Machinery Banks (FMBs) tailored to small-scale demand.
Regional Disparity (e.g., Uttar Pradesh)	Stark contrast in mechanization levels between the Western region (high, like Punjab) and the Eastern region (low, fragmented holdings, subsistence farming).	Policy solutions applied uniformly across the state are ineffective; Eastern UP needs targeted support.	Prioritize Eastern UP for scheme allocation; develop and promote wet-land-specific machinery (e.g., low-HP, lightweight rotavators, small transplanters).
General Skill Gap (Across States)	High demand for mechanics and operators, but lack of certified training institutes and standardized curriculum.	High machinery breakdown rates and poor utilization due to operation/maintenance errors.	Establish State-Level Directorates of Agricultural Engineering (recommended by the committee) and create certified training programs (like ITIs/Polytechnics) for farm machinery repair and operation.

Source: Author’s conceptualization

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26. ANNEXURE

Annexure I: Population trends of diverse types of cattle in India (20th Livestock Census)

Year	Indigenous Cattle (million)	Crossbred Cattle (million)	Total Cattle (million)
1982	183	8.8	192
1992	188	15.2	204
2003	164	22.6	187
2007	166	33	199
2012	151.2	39.7	190.9
2019	142.1	50.4	192.5

Annexure II: Farm power availability from various sources in India

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
Year	Power, kW/ha						Total power, kW/ha
	Agric. workers	Draught animals	Tractors	Power tillers	Diesel engines	Electric motors	
1971-72	0.045	0.212	0.02	0.001	0.053	0.041	0.372
1975-76	0.048	0.209	0.04	0.001	0.078	0.056	0.432
1981-82	0.051	0.206	0.09	0.002	0.112	0.084	0.545
1985-86	0.057	0.204	0.14	0.002	0.139	0.111	0.653
1991-92	0.065	0.193	0.23	0.003	0.177	0.159	0.827
1995-96	0.071	0.182	0.32	0.004	0.203	0.196	0.976
2001-02	0.079	0.172	0.48	0.006	0.238	0.25	1.225
2005-06	0.087	0.155	0.7	0.009	0.273	0.311	1.535
2011-12	0.1	0.134	0.804	0.012	0.295	0.366	1.711
2015-16	0.076	0.111	1.265	0.018	0.33	0.541	2.341
2021-22	0.082*	0.075	1.932	0.020*	0.368*	0.568*	3.045

Source: Mehta et al., 2024. *= Estimated

Annexure III: **CHC/Service Provider on FARMS platform**

S.N.	State Name	Farmer	Entrepreneur	Societies
1	PUNJAB	911	45	10192
2	ANDHRA PRADESH	4605	28	3839
3	HARYANA	3487	28	4746
4	TELANGANA	6101	22	456

5	TAMIL NADU	4045	1112	1141
6	NAGALAND	5651	17	57
7	KERALA	4100	97	671
8	UTTAR PRADESH	3557	92	890
9	CHHATTISGARH	3391	12	154
10	MADHYA PRADESH	588	2675	67
11	GUJARAT	2328	24	124
12	RAJASTHAN	1379	59	305
13	MAHARASHTRA	1294	65	251
14	UTTARAKHAND	340	14	861
15	ASSAM	796	9	290
16	ODISHA	891	116	21
17	KARNATAKA	173	508	258
18	BIHAR	622	40	171
19	JHARKHAND	357	5	425
20	WEST BENGAL	314	43	68
21	SIKKIM	357	1	44
22	MEGHALAYA	379	0	2
23	TRIPURA	39	2	152
24	HIMACHAL PRADESH	125	2	2
25	GOA	58	3	24
26	MIZORAM	3	0	59
27	MANIPUR	11	3	33
28	DELHI	6	9	12
29	JAMMU AND KASHMIR	7	2	9
30	ARUNACHAL PRADESH	5	3	1
31	CHANDIGARH	3	1	1
32	ANDAMAN AND NICOBAR ISLANDS	4	0	1
33	DAMAN AND DIU	0	0	1
Total		**45927**	**5037**	**2532**

About

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a pioneering, international non-profit scientific research for development organization, specializing in improving dryland farming and agri-food systems. The Institute was established as an international organization in 1972, by a Memorandum of Agreement between the Consultative Group on International Agricultural Research and the Government of India. ICRISAT works with global partners to develop innovative science-backed solutions to overcoming hunger, malnutrition, poverty, and environmental degradation on behalf of the 2.1 billion people who reside in the drylands of Asia, sub-Saharan Africa, and beyond.

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