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Trends and patterns of farm mechanization in India

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Abstract
In India, 47% of agricultural operations are mechanized, which is lower compared to developing counterparts like China, with 60%, and Brazil, with 75% farm mechanization. Further, the mechanization levels range between 40-45% in states like Punjab and Haryana while it is negligible in other areas like the north-eastern states of India. In 2023, it was predicted that achieving 75–80 percent mechanization in the country would take approximately 25 years. Advancements in technology are leading to the development of autonomous tractors, drones, robots, and other machinery that can perform a range of farming tasks, from planting and harvesting to soil analysis and crop monitoring. These technologies can help farmers to optimize their resources, reduce labour costs, and increase yields while minimizing environmental impact. One of the most exciting areas of development in future farm mechanization is precision agriculture, which involves using real-time data and analytics to guide decision-making in farming. This can help farmers to optimize their use of resources, such as water and fertilizer, and to tailor their planting and harvesting schedules to maximize yields. Harvesting equipment can include machinery such as grape harvesters, cherry pickers, and citrus harvesters, which are used to pick fruits and vegetables. Similarly, pruning equipment, such as pruning shears and hedge trimmers, are used to shape and maintain the growth of plants, bushes, and trees. Overall, the future of farm mechanization is likely to be driven by a combination of emerging technologies, such as artificial intelligence, the internet of things, and machine learning. By embracing these technologies, farmers can not only improve the efficiency and productivity of their operations but also help to address some of the most pressing challenges facing the global food system.

Keywords: Sustainable farming, mechanization, harvesting equipment, decision making, emerging technologies

Introduction
Mechanization of farming during the 20th century led to sweeping changes in agriculture. Tractors, combine harvesters, planting machinery, ploughs, tillers, weeders and other farm machines help farms produce more. Consequently, the trend since the early part of the 1900s is that fewer people can farm more land. Farm equipment is a major expense for Indian farmers, so it is difficult for small farms to keep up with the latest technological innovations. Machinery has also become more complicated and specialized. A simple tractor used on a small farm for many different tasks cannot be used efficiently on a large-scale farm. On large farms, huge air-conditioned tractors and combines costing well over $100,000 can cover vast areas in a relatively short amount of time. Mechanized irrigation systems have made more land available for farming.

The Agricultural Machinery Market is segmented by Tractors, Ploughing and Cultivating Machinery (Ploughs, Harrows, Cultivators & Tillers, and Others), Planting Machinery (Seed Drills, Planters, Spreaders, and Others), Harvesting Machinery (Combine Harvesters, Forage Harvesters, and Other Harvesters), Haying and Forage Machinery (Mowers, Balers, and Other), Irrigation Machinery (Sprinkler Irrigation, Drip Irrigation, and Others), and Other Agricultural Machinery as shown in Table 1 [1].

Rising mechanization in the country's agriculture sector and the surge in farmers' income are likely to be a primary factor driving the growth. Further, the extensive pressure to improve agricultural land productivity is expected to foster over the forecast period, which will directly promote the tendency of farmers or land operators toward incorporating agricultural machinery in farming.

Table 1: Agricultural machinery market segments

Tillage Machinery	Ploughs
	Harrows
	Cultivators & Tillers
	Others
Planting Machinery	Seed Drills
	Planters
	Spreaders
	Others
Harvesting Machinery	Combine Harvesters
	Forage Harvesters
	Other Harvesters
Haying and Forage Machinery	Mowers
	Balers
	Others
Irrigation Machinery	Sprinkler Irrigation
	Drip Irrigation
	Others

The agricultural machinery market in India was valued at ~INR 991.36 Bn in FY (Financial year) 2022. It is expected to reach ~INR 1,538.99 Bn by FY 2027, expanding at a CAGR of ~7.63% during the FY 2023-FY 2027 period.

Segment insights

India is the world's biggest tractor manufacturer, and accounts for more than one-third of the global tractor production. In FY 2022, the tractor segment held the largest share of the market, accounting for 81.45% of the market revenue.

Tractor penetration is high in northern India's agrarian zone, principally Punjab, Haryana, and Uttar Pradesh. In the south and west, mainly Andhra Pradesh, Tamil Nadu, and Maharashtra, the adoption rate is low. Other segments of the market include rotavators, threshers, and power tillers.

India's foodgrain production for 2021-22 is estimated at 316.06 million tonnes, it is higher by 5.32 million tonnes than year 2020-21.

Domestic tractor sale is highest (45%) in 41-50 hp range followed by 36% in 31-40 hp range. Power availability on Indian farms in 2020-21 = 2.85 kW/ha. Expected to go up to 3.5 kW/ha by 2024-25. Use of Improved implements has potential to increase productivity up to 30%. It can reduce cost of cultivation up to 20%. Estimated that agricultural workers of total work force would drop to 25% by 2050 from 55% in 2011. Thus, there is a need to enhance the level of farm mechanization in the country. The tractor segment is mostly dominated by high-capacity tractors of 30-50 hp.

Among the states, farm power availability in Punjab, Haryana, Western Uttar Pradesh and western part of Rajasthan is higher than the National average of 2.02 kW/ha. In rest of the country, especially in Eastern and North-East Regions, it is significantly lower which necessities promotion of farm mechanization as a special Mission [2].

The farmers in the country have been able to avail themselves of timely subsidies on agricultural machinery purchases. This, in turn, has helped even small-scale farmers invest in the country's agricultural machinery. Additionally, technologically advanced agricultural robotics, like autonomous tractors, ploughing and cultivating machinery, planting machinery, sprayer irrigation machinery, and haying and forage machinery to help United States farmers produce food at low costs to fulfill the growing demand for food, are anticipated to be better prospects for market growth during the coming year. However, high initial procurement costs and high maintenance expenditures will be a barrier to the market.

Furthermore, several industries in the country are taking initiatives to boost the market's growth. For instance, in March 2021, John Deere developed ExactRate, a factory-installed tractor and planter liquid fertilizer solution that precisely monitors and controls the application of liquid fertilizer during planting.

Therefore, an increase in demand for large-capacity farm machinery due to a shortage in farm labour, favourable government subsidies for farm mechanization, and technological innovation to develop innovative agricultural machinery are the factors driving the market growth over the forecast period.

Cultivators & Tillers Holds, Dominates the Market in Ploughing and Cultivating Machinery Segment

The demand for tillers and cultivators is anticipated to increase with the increasing acceptance of machinery over manual work in agricultural fields across the country. There is a rising concept of incorporating autonomous robotics into agriculture to reduce the reliance on manual labour, while increasing efficiency, product yield, and quality. For instance, an automated cultivator was developed by the US Davis Smart Farm, California, as a part of its research initiative. The reduction in the complexity of the technologies used is anticipated to boost the demand for cultivators and tiller machinery in domestic gardening and agricultural applications.

Furthermore, the environmental drawbacks of chemical weed control and its other limitations are reintroducing the mechanical cultivation methods in the country, which is further projected to increase the demand for the tiller and cultivator machinery market in the country during the forecast period. The increase in the number of luxurious villas and homes with winding garden walkways lined with trees, magnolia, chamomile, and begonias will augment the sales of garden tillers and cultivators in the country.

Many house owners in the country, despite the commercial farmers, are investing in gardening projects. The growing focus on organic foods is resulting in a growing number of consumers developing their own organic vegetable gardens in their backyards. As garden spaces increase the home value, there is growing interest in planting different types of shrubs, trees, and herbaceous plants in residential yards.

The investment in environmental horticulture is being increased by municipalities to establish public gardens and ornamental horticulture to rehabilitate degraded sites. A strong emphasis is laid on gardenscapes due to the commercial benefits of having gardens. Thus, the above-mentioned factors are benefiting the demand for cultivators and tillers such as smaller petrol-powered tillers for domestic purposes.

The level of farm mechanization in India stands at about 40-45% with states such as UP, Haryana and Punjab having very high mechanization levels, but north-eastern states having negligible mechanization. This level of farm mechanization is still low as compared to the countries such as the U. S. (95%), Brazil (75%) and China (57%). While the level of mechanization lags behind other developed countries, it has seen an average agriculture growth rate of 3.56% through the last decade [3].

According to Economic Survey, Farm mechanization and crop productivity has a direct correlation as farm mechanization saves time and labour, reduces drudgery, cut down production cost in the long run, reduces postharvest losses and boosts crop output and farm income. Use of improved implements has potential to increase productivity up to 30 per cent and reduce the cost of cultivation up to 20%. At present, Indian farmers are adopting farm mechanization at a faster rate in comparison to recent past. Although, the sale of tractors in India cannot be taken as the only measure of farm mechanization but to a great extent it reflects the level of mechanization. Indian tractor industries have emerged as the largest in the world and account for about one-third of total global tractor production.

Analysis of Farm Power Availability

The different sources of power available on the Indian farm for doing various mobile and stationary operations are mobile power *viz*. human (Men, women, children), Draught animals (Bullocks, buffaloes, camels, horses and ponies, mules and donkeys), tractors, power tillers and self-propelled machines (Combines, dozers, reapers, sprayers etc.); and stationary power i.e. diesel/oil engines (For pump sets, threshers, sprayers and other stationary operations) and electric motors (For pump sets, threshers, sprayers and other stationary operations).

The farm power availability (FPA) of different states which has been evaluated at the end of 2016-17 [4], has been categorized into four groups as given below:

Category-I

The states which have farm power availability more than national average i.e., 2.025 kW/ha (FPA at the end of 2016-17).

Category-II

The states which have farm power availability in between 2.025 and 1.726 kW/ha (FPA at the end of 2013-14).

Category-III

The states which have farm power availability in between 1.726 and 1.000 kW/ha.

Category-IV

The states which have farm power availability less than 1.000 kW/ha.

Table 2: Farm Power Availability (kW/ha)

More than 2.025 (Category I states)	Between 2.025 to 1.726 (Category II states)	Between 1.726 to 1.000 (Category III states)	Less than 1.000 (Category IV states)
Andhra Pradesh	West Bengal	Jharkhand	Assam
Bihar		Himachal Pradesh	Arunachal Pradesh
Gujrat		Jammu & Kashmir	Manipur
H ana		Kerala	Meghalaya
Karnataka		Maharashtra	Mizoram
Punjab		Madhya Pradesh	Nagaland
Tamil Nadu		Chhattisgarh	Sikkim
Telangana		Odisha	
Uttar Pradesh		Rajasthan	
Uttarakhand		Tripura	

The average farm power availability in the State of Andhra Pradesh before the implementation of SMAM was 1.880 kW/ha (2014) and it increased to 2.135 kW/ha by the end of 2016-17, thus registering a 13.6% increase in FPA in three years. The FPA in Andhra Pradesh is 5.4% more than the national average i.e., 2.025 kW/ha at the end of 2016-17. The district-wise farm power availability (2016-17) in the State of Andhra Pradesh is graded as given below in table 3.

Table 3: Farm power availability (2016-17) in different districts of A.P

Name of the District	Farm power availability (kW/ha)
Anantapur	1.422
Chittoor	5.872
East Godavari	2.067
Guntur	1.667
Krishna	2.206
Kurnool	0.952
Prakasam	1.775
SPS Nellore	3.545
Srikakulam	1.219
Visakhapatnam	1.066
Vizianagaram	0.984
Warangal	4.124
West Godavari	2.343
Y.S.R. Kadapa	2.677
Average	2.135

FPA more than 2.03 kW/ha
FPA between 1.00 to 2.03 kW/ha
FPA less than 1.00 kW/ha

Efforts required

The districts whose FPA is less than 1.880 kW/ha need special attention by the State Nodal Officer in respect of organizing demonstrations, training programmes for popularisation of farm machines and priority in providing financial assistance to the individual users and establishing Farm Machinery Banks.

The percent change in farm power availability during 2013-14 and 2016-17, Expenditure (Rs./ha) made under the SMAM during 2014-17 is given in Table 4.

Table 4: Percent change in farm power availability during 2013-14 and 2016-17, Expenditure (Rs./ha) made during 2014-17

States	Net area sown area (ha)	kW/ha 2013-14	kW/ha 16-17	Percent change	Expenditure (Rs./ha)	Productivity (kg/ha) Total food grains
Andhra Pradesh	6861158	1.880	2.135	13.6	138.3	3523
Assam	2744888	0.869	0.993	14.3	29.1	2067
Bihar	4528965	2.470	2.797	13.2	3.4	2320
Jharkhand	1533200	0.998	1.205	20.7	9.8	1738
Gujarat	9362000	2.252	2.565	13.9	29.2	2249
Haryana	3522775	3.868	4.315	11.6	19.9	3713
Himachal Pradesh	563365	0.962	1.135	18.0	119.2	2144
Jammu and Kashmir	858097	0.900	1.115	23.9	16.7	1919
Karnataka	8751764	1.800	2.138	18.8	88.7	2084
Kerala	2040000	0.941	1.095	16.4	23.2	2787
Maharashtra	17385600	0.944	1.185	25.5	42.9	940
Madhya Pradesh	14627100	1.293	1.495	15.6	45.8	2564
Chhattisgarh	4680436	1.020	1.245	22.1	50.8	1481
Odisha	5257533	1.442	1.647	14.2	43.8	1480
Punjab	3834000	3.580	4.398	22.8	12.1	4292
Rajasthan	18034407	1.172	1.373	17.2	14.2	1762
Tamil Nadu	5162839	2.361	2.907	23.1	148.6	3810
Telangana	4961000	2.485	2.886	16.2	5.5	2863
Uttar Pradesh	15724925	2.416	2.836	17.4	51.4	2369
Uttarakhand	741099	2.211	2.640	19.4	71.4	2079
West Bengal	5463660	1.620	1.869	15.4	32.2	2925
Arunachal Pradesh	164000	0.322	0.460	42.9	0	1505
Manipur	136280	0.340	0.500	47.1	87.0	1526
Meghalaya	285659	0.188	0.287	52.7	90.6	2624
Mizoram	94000	0.305	0.477	56.4	529.2	1615
Nagaland	176944	0.415	0.504	21.4	490.9	1666
Sikkim	18122	0.360	0.530	47.2	1257.6	1562
Tripura	255242	1.040	1.320	26.9	213.8	2898
All India	137769058	1.726	2.025	17.3	47.7	2393

The statistical parameters related to farm power availability (kW/ha) as on 31.3.2017 in different States are given below: Sample Variance: 1.01; Range: 3.41; Standard Error: 0.21; Kurtosis: 0.46; Skewness: 1.04

Mechanization Gaps and Future Requirements

About 300 improved agricultural equipment and technologies have been designed and developed for various pre and post-harvest operations operated by human, animal, mechanical and electrical power for timely field operation, facilitating timeliness, removal of farm drudgery, reducing post-harvest losses and addition of value to the agro-produce. Increased productivity does not mean additional income to the growers unless it is matched with appropriate postharvest technologies that minimize post-harvest losses and add value to the produce and by-products.

Farmers and policy makers and developmental agencies now realize that for increasing production and productivity at reduced unit cost of production, free of arduous labour, agricultural mechanization is essential. It is brought in centre stage with globalization of world markets. Introduction of electromechanical power units supplementing and substituting traditional animate sources of farm power is going to continue.

The present farm power availability and requirement of farm power by 2022 and 2030 in different states is given in the Table 5.

Table 5: Present farm power availability and requirement of farm power by 2022 and 2030

States	Farm power availability (kW/ha)		
	16-17	2022*	2030*
Andhra Pradesh	2.14	2.52	3.72
Assam	0.99	1.18	1.97
Bihar	2.80	3.29	4.81
Jharkhand	1.21	1.54	2.65
Gujarat	2.57	3.04	4.52
Haryana	4.32	4.98	7.51
Himachal Pradesh	1.14	1.41	2.29
Jammu and Kashmir	1 12	1.47	2.70
Karnataka	2 14	2.67	4.43
Kerala	1.10	1.33	2.10
Maharashtra	1.19	1.59	3.01
Madhya Pradesh	1 49	1.81	3.79
Chhattisgarh	1.25	1.61	2.86
Odisha	1 65	1.96	2.93
Punjab	4.40	5.45	7.89
Rajasthan	1.37	1.69	2.70
Tamil Nadu	2.91	3.72	6.46
Telangana	2.89	3.51	5.50
Uttar Pradesh	2.84	3.49	6.12
Uttarakhand	2.64	3.32	5.58
West Bengal	1 87	2.25	3.97
Arunachal Pradesh	0.46	0.69	1.57
Manipur	0.50	0.77	1.39
Meghalaya	0.29	0.47	0.75
Mizoram	0.48	0.80	2.19
Nagaland	0.50	0.65	1.13
Sikkim	0.53	0.84	1.61
Tripura	1.32	1.79	3.48
All India Average	2.03	2.50	4.00

***Targeted farm power availability:** The mechanization gap which is prevailing in different states and the future requirements to deal with the gaps are discussed for each state separately.

For achieving desired intensity of cropping average and productivity, farm power requirement of 2.5 kW/ha by 2022 and 4.00 kW/ha by 2030 is considered essential, currently it is 2.03 kW/ha. Shifts in agriculture leading to crop diversification towards horticulture, animal husbandry fishery, forestry and on-farm agro-processing are going to bring in greater degree of mechanization. India dominated by small and marginal land holdings may not have same trend of mechanization as the developed world but it is going to grow close to it. Though, the national average farm power availability in India is 2.03 kW/ha at the end of 2016-17, many states still lag behind the national average.

Initiatives of Government of India to Promote Farm Mechanization

Tewari *et al.* [5] estimated the farm power availability of 3.74 kW/ha by year 2032-33. They further estimated reduction in the percentage of farm workers from total work force to 49.9% in 2021 to 25.7% in 2050 compared to 54.6 per cent in census year 2011.

Agricultural mechanization is crucial in agriculture sector as it contributes towards improving the efficiency and effectivity of the inputs used in the crop production thereby also increasing the productivity of crops. This also reduces drudgery associated with various farm operations.

Taking into consideration the above, to boost the farm mechanization in the country, a special dedicated scheme 'Sub Mission on Agricultural Mechanization (SMAM)' has been introduced by Government of India in 2014-15. The scheme aims at 'reaching the unreached' by making farm machines accessible and affordable for the small and marginal farmers (SMFs) through establishment of Custom Hiring Centers (CHCs), creating Hubs for hi-tech & high value farm equipment and Farm Machinery Banks. Distribution of various subsidized agricultural equipment and machines to individual farmer is also one of the activities under the scheme. Purchasing of farm machines for SMFs is not financially feasible therefore custom hiring institution provide for hiring option of machines to SMFs. Creating awareness among stakeholders through demonstration of machine operations and skill development of farmers and youth and others are also the components of SMAM. The performance testing and certification of machines at designated testing centers located all over the country are ensuring farm machinery qualitatively, effectively and efficiently.

During 2014-15 to 2020-21, a sum of Rs.4556.93 crores of funds have been released under the scheme to the States and other implementing institutions. As of now, more than 13 lakh agricultural machines have been distributed and more than 27.5 thousand Custom Hiring Institutions established. For 2021-22 Rs. 1050 crore budget has been allocated for SMAM which is more than the previous year.

The programs and schemes of GOI on farm mechanization have resulted in progressive increase in the availability of farm power per unit area for performing various agricultural operations. The farm power availability has increased from 2.02 kw/ha in 2016-17 to 2.49 kw/ha in 2018-19. There has been significant increase in adoption of agriculture machines over a period of time which has found expression in the phenomenal expansion of cropped area, cropping intensity and the country's agricultural production.

With government's intention to raise the farm power availability from 1.84kW/ha to increased 4.0 kW/ha, the sector will be seeing engineering inputs which will require development and introduction of high capacity, precision, reliable and energy efficient equipment [6]. The Indian agricultural machinery market is projected to reach US$ 21.1 billion by 2028 from US$ 12.3 billion in 2022; it is expected to grow at a CAGR of 9.5% from 2022 to 2028 [7].

Power Tiller Market in India 2022-2026

The global tiller machines market is valued at 23,508 crores in 2022 and is likely to top a valuation of 33,584 crores by 2032, advancing at a CAGR of 3.6% from 2022 to 2032. As per the analysts, the power tiller market in India is poised to grow by 324.19 crores during 2022-2026, progressing at a CAGR of 7.25% during the forecast period [8].

Agricultural Mechanization (MoA)

- Agricultural mechanization is extremely vital to modernize agriculture and reduce drudgery of farming operations. During the period from 2014-15 to March, 2022 an amount of Rs.5490.82 crore have been allocated for agricultural mechanization.
- Numbers of machines and equipment's provided to farmers on subsidy was 13, 78, 755 till January, 2022 which has increased to 13, 88, 314 in December, 2022.
- 18,824 custom hiring centers, 403 high-tech hubs and 16,791 farm machinery banks are functioning in December, 2022 while 16,007 custom hiring centers, 378 high-tech hubs and 16309 farm machinery banks were available till January, 2022 to make available agricultural machines and equipment's to the farmers on rental basis.
- During the current year 2022-23, so far an amount of Rs. 504.43 Crores have been released for distribution of around 65302 machines on subsidy, establishment of 2804 CHCs, 12 Hi-tech hubs and 1260 Village Level Farm Machinery Banks.
- In order to support the efforts of the Government of Punjab, Haryana, Uttar Pradesh and NCT of Delhi to address air pollution due to crop residue burning, funds amounting to Rs.2440.07 crores have been released to these States during the period from 2018-19 to 2021-22, for crop residue management through mechanization interventions. 38422 Custom Hiring Centres (CHCs) of crop residue management machines have been established and more than 2.07 lakh machines have been supplied to these CHCs and individual farmers of these four States. During the current year, an amount of Rs. 698.10 Crores have been released and the States have targeted to supply 47500 crop residue management machines for in-situ and ex-situ management of crop residue.
- Looking into the unique advantages of Drone technologies in agriculture, a Standard Operating Procedures (SOPs) released the for use of drones in pesticide and nutrient application in public domain on 21.12.2021, which provides concise instructions for effective and safe operations of drones.
- In order to make this technology affordable to the farmers and other stakeholders of this sector, financial assistance @ 100% cost of drone together with the contingent expenditure is extended under Sub-Mission on Agricultural Mechanization (SMAM) for its demonstration on the farmer's fields
- In order the provide agricultural services through drone application, financial assistance @ 40% of the basic cost of drone and its attachments up to a maximum of Rs. 4.00 lakhs, is provided for drone purchase by Custom Hiring Centers (CHCs) under Cooperative Society of Farmers, FPOs and Rural entrepreneurs. The agriculture graduates establishing CHCs are eligible to receive financial assistance @ 50% of the cost of drone up to a maximum of Rs. 5.00 lakhs. Apart from above, the individual farmers are also eligible for financial assistance and the Small and Marginal Farmers, SC/ST Farmers, Women Farmers and the Farmers of the North Eastern States are provided financial assistance @ 50% of the cost of drone up to a maximum of Rs. 5.00 lakhs. The other farmers are provided financial assistance @ 40% of the cost of drone up to a maximum of Rs. 4.00 lakhs
- From within the funds of SMAM, so far an amount of Rs. 124.26 crores have been released towards Kisan drone promotion, which include purchase of 317 Drones for their demonstration in 79070 hectares of land and supply of 239 drones to the farmers on subsidy and also supply of 1519 drones to the CHCs for providing drone services to the farmers on rental basis.

Digital Platform for Farm Mechanization and Technology

The new era of digital transformation in the farming industry and to assess the value proposition of these new technologies that address the expectations of farmers in transforming their business practices. Adoption of agricultural technology has become imperative for farmers, as they are facing tighter farm margins and declining commodity prices. The insights generated from the usage of technology in farming operations assist farmers in mitigating cost challenges and effectively improve production per acre. The inclusion of precision farming by adopting technologies such as Sensors, Drone Imagery, and Big Data analytics will have a positive impact on farming operations. Precision agriculture is slowly and steadily making inroads into developed countries, but is yet to make a mark in emerging economies. Variable rate technologies are one of the more commonly available technologies enabling better input optimisation.

Internet of things and Artificial intelligence have already started capitalizing across all the industries including agriculture. Advancement in these digital technologies has made revolutionary changes in agriculture by providing smart systems that can monitor, control, and visualize various farm operations in real-time and with comparable intelligence of human experts. The potential applications of IoT and AI in the development of smart farm machinery, irrigation systems, weed and pest control, fertilizer application, greenhouse cultivation, storage structures, drones for plant protection, crop health monitoring, etc. are enhancing the crop production and productivity.

Smart farm machinery

Navigation and performance monitoring of tractors

Modern farmers use various farm equipment and machinery to perform various agriculture tasks. Among those, tractors are considered the most essential and irreplaceable farm

power unit. Undoubtedly tractors are an integral part of farm mechanization and constantly helping to raise agriculture productivity day by day. Being a vital part of the agriculture mechanization system, the performance monitoring of the tractor-implement system is very crucial.

The tractor performance monitors measure, record, and help in remotely visualizing the entire operation. The parameters generally taken into consideration are power, fuel consumption, draught and wheel slip. Optimization of these parameters can greatly improve the tractor performance. The draught was measured by strain-gauge mounted on a ring transducer at the front end of the drawbar. The fuel consumption was measured by a positive displacement flow meter and wheel speed by using toothed gears and magnetic pick-ups. A data acquisition system is also handy for monitoring the performance wherein the transducers are mounted for measuring the various operational parameters. The spatial mapping of the tractor-implement performance can be made possible using the Differential Global Position System (DGPS). Global Positioning System (GPS) acts as a major component of this system that provides spatial values. This enables the system to measure, record, and monitor the performance of the tractor implement system relative to the position. Since the performance of a tractor-implement system is influenced by the factors of soil condition and land slope, this mapping system is highly beneficial for calculation of the cost of crop production within the field boundary.

Autonomous tractors and farm machinery

The agriculture sector is continuously challenged by the shortage of skilled labourers and low productivity. The advancement in technology has introduced tractors, cultivators, and ploughs that require minimum human dependency [9]. Farmland is undoubtedly the best place for the use of autonomous machines since they are free from crowds and pedestrians and activities can be carried out with minimum risk. Sensors like radars and lasers are generally used in an autonomous vehicle to identify any obstacles and handle them intelligently.

But the same cannot be applied in the case of tractors as it cannot distinguish between grass and obstacles. So, it cannot be operated like normal autonomous vehicles. One general approach is to use GNSS (Global Navigation and Satellite System) using which the machine can locate its position and move to an area autonomously. But since the system would be unaware of the surroundings, this can lead to a collision. Also, in an orchard like environment, autonomous driving will not be possible with GNSS as the satellite positioning will be less accurate. So recent autonomous systems in agriculture are heavily dependent on stereo-cameras, sensors and deep learning algorithms. RGB camera with multiple infrared cameras is used to capture the depth images via stereo matching. A popular object detection algorithm YOLO [10], which is based on CNN, is used for object detection. This detects the objects in the bounding boxes of pixels [11]. In the industry abroad, tractor manufacturers like John Deere and Case IH have already started offering autonomous tractors to the farmers. Case IH's concept tractor was enabled with cameras and LiDAR (Light Imaging, Detection, and Ranging) which can accurately identify the obstacles.

Faster RCNN [12] and SSDs [13] are other few object detection models that are being utilized for object detection in agriculture applications. Autonomous tractors, rice transplanters, and harvesters have been developed by researchers with nearly the same human efficiency using deep learning-based computer vision methods. The autonomous fruits harvester prototype consisted of mainly an image acquisition module and followed by an image manipulator module that was mounted on a self-propelled carrier [14]. The input was fed into the computer vision-based object detection algorithm to identify the vegetables and fruits for harvesting.

Domestic Tractor Sales Figures Dropped by 6.35% During FY 2022

The current FY'22 (April'21-March'22) Total tractor sales (wholesale) in the FY’22 stood at 8, 42, 266 units with a 6.35% degrowth over 8, 99,411 units sold in FY’21. The domestic tractor sales have fallen a bit, we hope the upcoming season could bring in some positive results. The domestic tractor industry for the FY’22 was represented in Table 6.

Table 6: Domestic tractor industry FY’22 (Apr’21-Mar’22)

Manufacturer	FY'22	FY'21	% Change	MS FY'22	MS FY'21	% Change
M&M Group	337052	343833	-1.97	40.02	38.23	1.79
Tafe Group	151481	165795	-8.63	17.98	18.43	-0.45
Sonalika	101060	117503	-13.99	12.00	13.06	-1.07
Escorts	87168	101849	-14.41	10.35	11.32	-0.97
John Deere	79308	85602	-7.35	9.42	9.52	-0.10
New Holland	32053	35828	-10.54	3.81	3.98	-0.18
Kubota	21104	16809	25.55	2.51	1.87	0.64
Preet	7152	6014	18.92	0.85	0.67	0.18
lndo Farm	6930	4611	50.29	0.82	0.51	0.31
VST	6633	8162	-18.73	0.79	0.91	-0.12
Force	4516	4001	12.87	0.54	0.44	0.09
Captain	3716	4446	-16.42	0.44	0.49	-0.05
ACE	2426	2540	-4.49	0.29	0.28	0.01
SDF	1667	2418	-31.06	0.20	0.27	-0.07
Total	842266	899411	-6.35	100.00	100.00	

(Source: www.tractorjunction.com)

Here could be several reasons for falling domestic tractor sales, including

1. **Economic conditions:** A weak economy or recession can lead to a decrease in demand for agricultural products, which can lead to a decline in sales of tractors.
2. **Weather conditions:** Weather conditions such as drought or floods can impact the agricultural sector and decrease the demand for tractors.
3. **Government policies:** Changes in government policies related to agriculture can impact the demand for tractors, such as changes in subsidies or import/export regulations.
4. **Competition:** Increased competition in the market can lead to a decline in sales for a particular brand or model of tractor.
5. **Technological advancements:** Advancements in technology and automation in agriculture can lead to a decrease in the need for manual labor and tractors, which can lead to a decline in sales.
6. **Shift in agriculture practices:** Changes in agricultural practices such as a shift towards organic farming or crop diversification can impact the demand for tractors.
7. **Supply chain disruptions:** Disruptions in the supply chain due to factors such as the pandemic or natural disasters can impact the availability of tractors, leading to a decline in sales.

Past and present scenario of farm mechanisation and strategies for its promotion: In spite of its top ranking in production of a number of crops including rice, wheat, sugarcane, fruits and vegetables, the stagnancy in productivity and shortage of agricultural labour are two major bottlenecks of Indian agriculture. Several studies suggest a direct correlation between farm mechanisation and crop productivity. Use of improved implements has potential to increase productivity up to 30 percent and reduce the cost of cultivation up to 20 percent. At present, Indian farmers are adapting farm mechanisation at a faster rate in comparison to recent past. Although, the sale of tractors in India cannot be taken as the only measure of farm mechanisation but to a great extent it reflects the level of mechanisation. Indian tractor industries have emerged as largest in the world and account for about 1/3rd of the total global tractor production. According to the World Bank estimates, half of the Indian population would be urban by the year 2050. It is estimated that percentage of agricultural workers of total work force would from 54.6 percent in 2011 to 25.7 percent by 2050. Thus, there is a need to enhance the level of farm mechanisation in the country.

Table 7 presents the share of agriculture in GDP and level of farm mechanisation in different countries by 2018 [15].

Table 7: Share of agricultural GDP and level of mechanisation

Country	Agricultural GDP (%)	Level of mechanisation (%)
USA	1	95
Western Europe	<5	95
Russia	4	80
Brazil	5	75
China	10	48
India	14	40

Different sources of power available on the Indian farms for performing various mobile and stationary operations are mobile power, *viz*., human, draught animals, tractors, power tillers and self-propelled machines, and stationary power, i.e., diesel/petrol/kerosene engines and electric motors. While the population of agricultural workers as percentage of rural population has gone down from about 69 percent in 1951 to about 55 percent in 2014-15 but in absolute terms, due to increase in overall population, the number of agricultural workers available in rural areas increased from 131 million in 1960-61 to 263 million in 2010-11 and corresponding power increased from 6.55 million kW to 13.15 million kW during the same time period. It is estimated that number of agricultural workers will increase to about 336 million and power available from agricultural workers will be 16.84 million kW in 2032-33 (Tables 8 & 9) [14, 16, 17].

Table 8: Farm power sources in India

Year	Population of farm power sources, million					
	Agricultural Workers	Draft animal power	Tractors	Power tillers	Diesel engines	Electric motors
1960-61	131	80.4	0.037	0	0.23	0.20
1970-71	126	82.6	0.168	0.0096	1.70	1.60
1980-81	148	73.4	0.531	0.0162	2.88	3.35
1990-91	185	70.9	1.192	0.0323	4.80	8.07
2000-01	234	60.3	2.546	0.1147	6.226	13.25
2010-11	263	51.3	4.427	0.2943	8.134	17.488
2011-12*	266	50.4	4.843	0.3442	8.212	17.873
2012-13*	269	49.5	5.211	0.3801	8.290	18.245
2013-14*	272	48.6	5.653	0.4240	8.368	18.606
2019-20*	291	43.8	8.370	0.7000	8.860	21.07
2023-24*	304	40.9	11.000	1.0400	9.190	22.89
2032-33*	336	34.8	20.360	2.5300	10.030	27.57
**CAGR,%	1.13	-1.79	8.49	10.34	0.95	2 09

Over the years the annual use of draught animals has been declining. While earlier a pair of animals was being used for about 1200-1800 hours annually, their average annual use has now come down to about 300-500 hours only, that too for tillage, sowing, weeding and rural transport.

The population of draught animals during 1960-61 to 2032-33 is given in Table 8. The declining trend of draught animal power has been more visible in those states where the demand of tractors and power tillers has been high. It is observed that on average a tractor is replacing about 5 pairs

of animals and power tiller about 2 pairs of animals. Draught animal power availability in India decreased from 0.22 kW/ha in 1960-61 to 0.09 kW/ha by 2032-33 (Fig 1).

Table 9: Power available from different power sources

Year	Power available from different power sources, million kW*						Total Power Million kW
	Agricultural Workers	Draft Animal Power	Tractors	Power Tillers	Diesel Engines	Electric Motors	
1960-61	6.55	30.552	0.966	0	1.288	0.74	40.126
1970-71	6.30	31.388	4.385	0.054	9.520	5.92	57.567
1980-81	7.40	27.892	13.859	0.091	16.128	12.395	77.765
1990-91	9.25	26.942	31.111	0.181	26.880	29.859	124.223
2000-01	11.70	22.914	66.451	0.642	34.866	49.025	185.598
2010-1 1	13.15	19.494	115.545	1.648	45.550	64.706	260.093
2011-12**	13.30	19.152	126.402	1.928	45.987	66.130	272.903
2012-13**	13.46	18.81	136.007	2.129	46.424	67.507	284.336
2013-14**	13.60	18.468	147.543	2.374	46.861	68.842	297.689
2019-20**	14.55	16.644	218.457	3.920	49.616	77.959	381.146
2023-24**	15.22	15.542	287.100	5.824	51.464	84.693	459.842
2032-33**	16.84	13.224	531.396	14.168	56.168	102.009	733.803

Due to too much involvement of labour in different farm operations, the cost of production of many crops in our country is quite high as compared to developed countries. Human power availability for agriculture was about 0.046 kW/ha in 1960-61 which is estimated to be about 0.12 kW/ha in 2032-33.

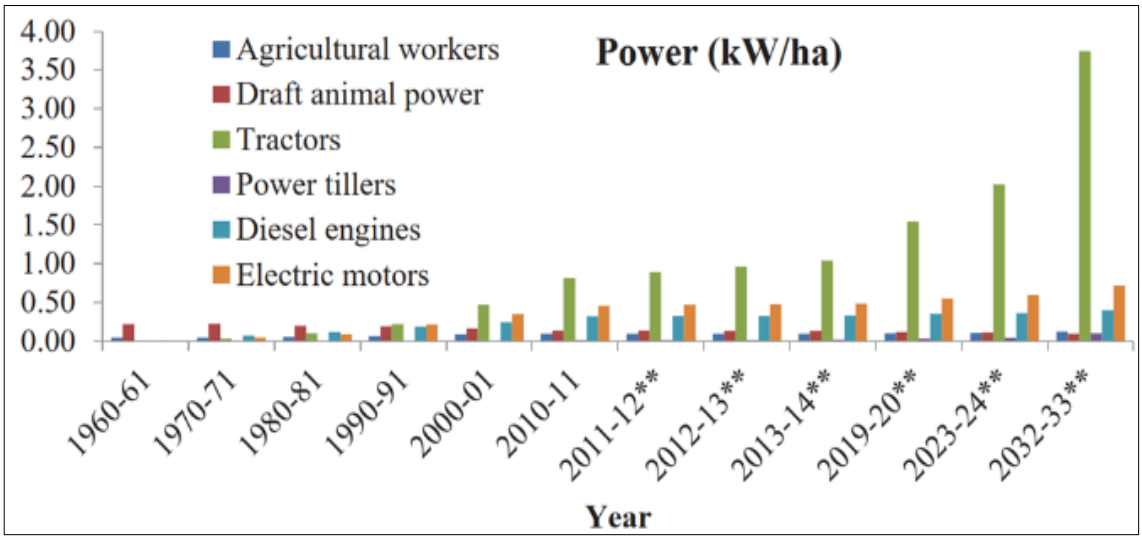

Fig 1: Power availability in India

The share of agricultural workers in total power availability in 1960-61 was about 16.3 percent, which has reduced to 2.3 percent in 2032-33. Compound annual growth rate (CAGR) of different power sources on Indian farms has been given in Table 10 [18].

Table 10: Compound annual growth rate (CAGR) of different power sources

	CAGR (%)					
	Agricultural Workers	Draft Animal Power	Tractors	Power Tillers	Diesel Engines	Electric Motors
1960-61 to 1990-91	1.16	-0.42	12.27	6.25	10.66	13.12
1991-92 to 2013-14	1.54	-1.33	6.65	12.03	2.5	3.29
1960-61 to 2013-14	1.38	-0.82	9.79	9.3	7.04	8.74
2010-11 to 2032-33	1.13	-1.79	8.49	10.34	0.95	2.09

The operation-wise farm mechanisation in the country is about 40 percent for tillage and seedbed preparation, 30 percent for seeding/Planting, 35-45 percent for Plant protection, 60-70 percent for harvesting and threshing for rice and wheat and less than 15 percent for other crops (Table 11). The level of mechanisation varies greatly by region. States in the north (Punjab, Haryana and western Uttar Pradesh) have high level of mechanisation (70-80 percent overall; 80-90 percent for rice and wheat) due to high productive land as well as declining labour force and also full support by state governments. The eastern and southern states have lower level of mechanisation (35-45 percent) due to smaller and more scattered land holdings. In the north-eastern states, the level of farm mechanisation is extremely low mainly due to hilly topography, high transportation cost of farm equipment's, and socio-economic conditions of the farmers.

Table 11: Operation-wise farm mechanisation

Operation	Level of mechanisation (%)
Tillage and seed bed preparation	40
Seeding and Planting	29
Plant protection	35-45
Irrigation	37
Harvesting and threshing (rice and wheat)	60-70

Farm mechanisation has been known to provide a number of economic and social benefits to the farmers. It saves inputs like seeds and fertilizers up to 15-20 percent and labour requirement and operational time by 20-30 percent. On the other hand, it increases cropping intensity by 5-20 percent and crop productivity by 10-15 percent. It helps in encouraging the youth to join farming and attract more people to work.

The agricultural sector in India, for a long time, has depended on cheap and surplus labour. Now, the situation is changing with more opportunities available in factories and services as well as the Government's rural employment creation programs. Labour shortage is being experienced during peak seasons due to enactment of the National Rural Employment Guarantee Act (NREGA) and huge demand from the construction sector in cities. The overall work force in agriculture and allied activities has been declining indicating a rise in secondary and tertiary sectors. Labour is available at a higher cost per hectare and this would increase the demand for mechanisation. It has been observed that the percentage of agricultural workers to total workers in India has been gradually declining from 59.1 percent in 1991 to 54.6 percent in 2011 (Table 12) [19]. It is expected to further decline to 49.9 percent in 2033 and 25.7 percent by 2050 leading to severe farm labour shortage.

Table 12: Population Dynamics of Indian Agricultural Workers (No in Million)

Particulars	1991	2001	2011	2020*	2024*	2033*
Country's population	846.4	1,028.7	1,210.7	1,347.3	1411.5	1570.9
Total number of workers	313.7	402.2	481.7	553.2	587.6	674.9
Workers as percentage of population,%	37.1	39.1	39.8	41.06	41.63	42.96
Number of agricultural workers including cultivators and agricultural labourers	185.3	234.1	263	290.99	304.37	336.76
Agricultural workers as percentage of total number of workers,%	59.1	58.2	54.6	52.6	51.8	49.9
Women workers as percentage of agricultural workers,%	35.1	39.0	37.2	38.2	38.6	39.6

Farm mechanisation in India stands at about 40-45 percent and it is low in comparison to US (95 percent), Brazil (75 percent) and China (57 percent). The farm power availability has grown from 0.28 kW/ha in 1960-61 to 1.83 kW/ha in 2010-11 and expected to be increased to 5.17 kW/ha in 2032-33. Level of mechanisation for major crops in different operations has been given in Table 13.

Table 13: Level of mechanisation for major crops in different operations

Crop	Seed bed preparation	Sowing/Planting/ transplanting	Weed and pest control	Harvesting and threshing
Paddy	85-90	5-10	80-90	70-80
Wheat	90-95	80-90	70-80	80-90
Potato	90-95	80-90	80-90	70-80
Cotton	90-95	50-60	50-60	0
Maize	90-95	80-90	70-80	50-60
Gram	90-95	50-60	60-70	30-40
Sorghum	80-90	30-50	60-70	20-30
Millets	80-90	30-40	60-70	20-30
Oilseeds	80-90	30-40	60-80	20-30
Sunflower	80-90	40-50	80-90	60-70
Fodder crop	80-90	20-40	80-90	10-20
Vegetable crop	70-80	5-10	80-90	< 1
Horticultural crops	60-70	30-40	40-50	< 1

During the past four decades a large number of farm tools, implements and machines have been developed for different farm operations and are being used by the Indian farmers [20] (Table 14). The scenario of farm mechanisation has certainly changed as the Indian agricultural equipment market has experienced a rapid growth with expected strong potential for future growth as well (Table 15). Availability of power operated and animal operated implements with respect to the net cultivated area are shown in Tables 16 and 17 [21]. India's small farms usually do not present an economic condition to permit the extensive use of agricultural machinery. Given the constraint of limited days' usage of machinery, the operational and capital costs may be optimized for the farmers by making the machinery available to the farmers on custom hiring. Thus, even small farmers may be able to get the benefit of agricultural mechanisation.

The medium scale and large-scale industries manufacture diesel engines, electric motors, irrigation pumps, sprayers and dusters, land development machinery, tractors, power tillers, post-harvest and processing machinery and dairy equipment (Table 18).

Table 14: Different farm machines available during past four decades

Farm Machinery	Number of farm machines available ('000)							
	1992-93	2003-04	% Increase over 1992-93	2013-14	% Increase over 2003-04	2031-32*	% Increase over 2013-14	**CAGR, %
Manually Operated Machinery								
Sprayers	1827	2046	12.0	2214	8.2	2611.27	17.9	0.92
Animal Operated Machinery								
Wooden ploughs	43464	44267	1.8	44997	1.6	46440.72	3.2	0.17
Steel ploughs	12649	19622	55.0	25972	32.4	48205.13	85.6	3.49
Seed drills/ Seed-cum-fertilizer drills	472	963	104.0	1474	53.1	3908.61	165.2	5.57
Wet land puddlers	5151	8550	39.7	11640	36.1	23424.81	101.2	3.96
Animal carts	15220	16577	8.9	17663	6.5	20056.07	135	0.71
Tractor/power operated machinery								
Power operated sprayers/dusters	303	561	85.1	796	41.9	1823.82	129.1	4.71
MB Ploughs	408	852	108.8	1328	55.9	3650.89	174.9	5.78
Cultivators	706	949	34.4	1170	23.3	1800.80	53.9	2.43
Disc harrows	531	913	71.9	1260	38.0	2642.02	109.7	4.20
Seed-cum-fertilizer drills	390	1011	159.2	2852	182.1	15708.63	450.8	9.94
Planters	54	75	38.9	92	22.7	145.27	57.9	2.57
Levellers	1057	1827	72.8	2343	28.2	4629.77	97.6	3.86
Threshers/Multi crop threshers	2597	5309	104.4	7775	46.4	19898.79	155.9	5.36
Combines (Tractor-drawn & self-propelled)	8.5	20	135.3	59	195.0	311.06	427.2	9.67

Table 15: Farm equipment's with respect to Indian agricultural market

Items	Numbers	Items	Numbers
Tractors	450000-500000	Power tillers	50000-60000
MB plough	45000-50000	Rotavator	100000-120000
Cultivators	150000-200000	Harrows	120000-150000
Seed ferti drills	60000-75000	Planters	15000-25000
Rice transplanters	2000-3000	Power weeders	35000-40000
Reapers	10000-15000	Threshers	60000-75000
Combine harvesters	3500-4000	Trailers	150000-175000
Sprayers (TD)	10000-15000	Laser land levelers	2500-3500
Potato diggers	25000-30000	Rotary hoes/Power weeders	20000-25000

Table 16: Availability of power operated implements with respect to the net cultivated area

Year	Sprayers & dusters (no/1000 ha)	Harrows (no/1000 ha)	Threshers (no/1000 ha)	Tillers (no/1000 ha)	Ploughs (no/1000 ha)	Planters (no/1000 ha)	Levellers (no/1000 ha)
1972-73	0.249	0.398	1.4631	0.582	0.405	0.064	0.348
1982-83	0.884	1.347	7.3058	2.245	1.019	0.221	2.951
1992-93	2.131	3.734	18.2630	4.965	2.869	0.380	7.433
2002-03	3810	6.218	35.8569	6.565	5.708	0.517	12.472
2012-13	5.459	8.651	53.1709	8.107	9.040	0.636	16.292
2022-23*	7.134	11.125	70.7360	9.689	12.343	0.750	17.261
2023-24*	7.302	11.381	72.5283	9.851	12.663	0.765	17.132
2024-25*	7.472	11.622	74.2776	10.007	12.967	0.772	16.941
2032-33*	8.990	13.850	90.2800	11.390	15.800	0.870	15.720
CAGR,%	2.34	2.21	2.47	1.63	2.50	1.46	-0.93

Table 17: Availability of animal operated implements with respect to the net cultivated area

Year	Wooden ploughs (no/1000 ha)	Steel ploughs (no/1000 ha)	Puddlers (no/1000 ha)	Seed drills & Planters (no/ 1000 ha)	Carts (no/1000 ha)	Cane Crushers (no/1000 ha)
1972-73	0	0	0	0	0	0
1982-83	294.783	50.770	17.954	41.247	98.418	4.939
1992-93	305.654	88.952	36.224	54.191	107.032	5.345
2002-03	312.989	134.469	58.364	69.306	116.579	6.027
2012-13	317.260	178.934	80.021	83.771	124.011	6.716
2022-23*	323.100	224.253	102.059	98.033	131.288	7.438
2023-24*	323.846	228.909	104.320	99.462	132.047	7.514
2024-25*	324.363	233.407	106.508	100.822	132.705	7.585
2032-33*	330.67	273.90	126.06	112.77	138.55	8.230
CAGR,%	0.23	2.02	2.16	1.41	0.54	0.98

Table 18: No. of farm machinery manufacturing units available

Farm machinery	Number of manufacturing units
Agricultural tractors	22
Power Tillers	5
Irrigation Pumps	600
Plant Protection Equipment	300
Combine Harvesters	48
Reapers	60
Threshers	6,000
Seed Drills and Planters	2,500
Diesel Oil Engines	200
Plough, Cultivators, Harrows	5,000
Chaff Cutters	50
Rural Artisans	>1 Mn

The timeliness of operations has assumed greater significant in obtaining optimal yields from different crops, which has been possible by way of mechanisation. It is apparent from Table 19 that the cropping intensity increases with increase in per unit power availability.

Table 19: Timeliness of operations with respect to power availability

Year	Cropping intensity (%)	Food grain productivity (t/ha)	Power available (kW/ha)	Power per unit production (kW/t)	Net sown area per Tractor (ha)
1965-66	114.00	0.636	0.32	0.50	2162
1975-76	120.30	0.944	0.48	0.51	487
1985-86	126.80	1.184	0.73	0.62	174
1995-96	130 80	1 499	1.05	0 70	82
2005-06	136.54	1.715	1.49	0.87	45
2010-11	139.56	1.930	1.85	0.96	34
2011-12	138.77	2.079	1.93	0.93	31
2012-13	138.92	2.129	2.02	0.95	29
2013-14	139.29	2.200	2.11	0.96	27.24
2019-20*	141.40	2.650	2.74	1.03	18.7
2023-24*	142.82	3.000	3.26	1.09	14.55
2032-33*	146.06	3.960	4.81	1.21	8.27
**CAGR,%	0.25	3.14	4.44	1.41	-6.08

Tractor Technologies that are likely to become mainstream by 2025

1. Autonomous Tractors

Autonomous or self-driving tractors are already being developed by CNH Industrial, Deere, AGCO, and many other companies. These unmanned tractors will resolve the issue of having trained and experienced drivers to navigate through the fields without causing crop damage and will also facilitate longer work hours.

At present, human supervision is still required for automated tractors, but fully automated ones that can be programmed to complete all the tasks are a possibility in the near future.

2. Smaller, Automated Tractors

Smaller and lighter versions of automated tractors will be employed on farms and will accomplish the same or higher amount of work. Their benefits include less amount of storage space required, reduction in labour costs, reduction in soil compaction, better crop yields, and increased farm revenue.

3. Tractors with Objection Detection Capabilities

Tractors with inbuilt radar sensors, multiple camera systems, and LiDAR systems that can detect moving objects under different light and weather conditions will strengthen and improve unmanned farm work.

4. Tractors with Smart CAB

Currently, many tractors already come with air-conditioned cabins, but we can look forward to more luxurious models with climate-controlled interiors, camera displays, touchscreen operations, and lights that are operated by eye-motion detecting sensors.

These smart CAB tractors may have both fully automated and driver-operated options, and they will make farm tasks easier on very hot days, allow for better precision agriculture, allow for longer working hours, and, thus, help push up the farm revenue.

5. 101 HP and Above Tractors

In coming years, farmers are likely to invest in medium-powered and high-powered tractors in order to achieve better agricultural work results in a lesser amount of time. These tractors will have lower fuel consumption and will be more efficient in soil cultivation and maintenance.

6. Tractors using Internet of Things (IoT)

Connecting tractors to the internet will allow farmers to control the machines from their personal computer or mobile device. Such connectivity is already available with the tractors produced by John Deere and many other manufacturers, but improved versions may mean that the farmer won't even need to step into the field in the near future.

7. Tractors with Global Navigation Satellite Systems (GNSS) Technology
Tractors with GNSS technology will make it easier to navigate and cultivate extensive tracks of farmlands.

8. Tractors with Robotics
Robots already perform many important farm tasks. Further developments in agricultural robotics will lead to autonomous tractors with better manoeuvrability and a better ability to gauge and navigate different terrain types [22].

9. Data Collecting Tractors
Tractors fitted with sensors will collect and instantly make available data on various agricultural aspects such as the moisture content in the soil, the amounts of fertilizers and pesticides that have been used or need to be used in the fields, weather conditions that can affect the crops, the trends in crop prices, the current status of the commodities market, the tractor's fuel consumption, and much more.

10. Tractors with Connectivity
Syncing tractors with other agricultural machines such as harvesters and combines will increase farm productivity and lead to higher agricultural profits. The farmer will only need to input the tasks that need to be done and the automated and connected machines will refer to one another and get the work finished in less time than would be required by human labour.

Following strategies may be considered for promoting farm mechanisation in the country [15]:

1. Reduce or eliminate subsidies and use these funds to reduce interest rates on loans and taxes for purchase of equipment and machinery for agricultural operations and food processing.
2. Promote on-farm storage, processing and marketing facilities in catchment areas.
3. Number of custom hiring centres, especially in areas of small and marginal land holdings should be increased substantially.
4. Quality of farm machines must be assured at as it brings more confidence among farmers for adoption of farm mechanisation.
5. Strengthen support services for research and development; testing and standardization; as well as for human resource development in support of agricultural mechanisation.
6. Manufacturing facilities should be developed especially in areas with low level of farm mechanisation by providing incentives to manufacturers establishing such facilities in these areas.
7. Since percentage of women workers in agriculture is increasing day by day development of gender friendly equipment should be taken up.
8. In order to provide economical mechanisation solutions to the farmers, cooperative farming should be promoted in areas of small sizes of holdings.
9. More research and development efforts should be diverted towards development of machines for mechanisation of horticulture and hill agriculture.
10. In order to reduce the input cost the use efficiency of various farm inputs needs to be improved through high-tech interventions such as site-specific nutrient management, mechatronics and opto-electronics.
11. Skill development in the area of operation, repair and maintenance of farm machines should be taken up.

Conclusion
Farm mechanization is expected to continue to evolve and advance rapidly in the coming years, with significant technological breakthroughs and innovations that will transform the way we grow food. The use of autonomous machinery, such as self-driving tractors and drones, is likely to become more widespread in farming. These machines can operate around the clock, increasing efficiency and reducing labour costs. Precision agriculture technologies will continue to advance, with more sophisticated sensors, drones, and analytics tools that can help farmers optimize their use of resources and maximize yields. The use of robotics in farming is expected to increase, with robots performing a wide range of tasks from planting and harvesting to pruning and weeding. Farm mechanization is likely to be increasingly focused on sustainable practices that reduce waste, conserve resources, and minimize environmental impact. As more data is collected from farm machinery and sensors, farmers will be able to make more data-driven decisions that improve efficiency, productivity, and profitability.

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