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INFLUENCE OF FARM POWER AVAILABILITY IN SUSTAINABLE AGRICULTURE: A CASE STUDY OF PADDY CULTIVATION IN INDIA

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ABSTRACT

Farm power availability and sustainable agriculture are fundamentally linked, especially in a country like India, where the majority of farmers belong to the small and marginal landholding category. With the ongoing efforts to adopt and adapt to new mechanization technologies, the collaboration between these concepts will become increasingly crucial in shaping the future of Indian agriculture. Therefore, studying the current status, its outputs, and its impacts on sustainability goals is of utmost importance. This study aims to quantify the overall level of farm mechanization, focusing on farm power availability and the sources of farm power currently in use. The objective is to channelize all mechanically and electrically powered machinery to meet present needs without compromising the ability of future generations to meet their own and to reduce dependency on animate power sources, such as human and draught animals, which are the costliest power sources. The study will also assess the contribution of human and draught animal power, as a higher reliance on these sources indicates a lower level of powered mechanization. The evaluation of farm power availability and sources of farm power was conducted using secondary data up to the period of 2021-22. This was analysed through comparative statistical analysis and scatter plots to visualize the relationship between productivity and power density. The study further classified the study area into four clusters: high farm power with high productivity, high farm power with low productivity, low farm power with high productivity, and low farm power with low productivity. The results showed that the area studied was predominantly paddy-cultivated, with 92% of farmers categorized as semi-medium, small, or marginal. The farm power availability was found to be 2.05 kW/ha, with a corresponding productivity of 2.17 t/ha, indicating an almost 1:1 ratio between farm power availability and productivity. The share of inanimate power sources increased from 8.65% in 1996-97 to 79.55% in 2021-22. If this increased powered mechanization channelized properly would lead to sustainable productive agricultural system.

***Key words*:** farm power availability, paddy cultivation, Sustainable agricultural system, small and marginal farmers

Introduction

Farm power availability and sustainable agriculture are intricately connected, particularly in countries like India, where a significant portion of the agricultural workforce comprises small and marginal farmers. In many of Asian countries, a substantial portion of the workforce is employed in the agricultural sector, directly or indirectly. These farmer workforces face many challenges like limited farm power and access to advanced farm machinery. Additionally, agriculture contributes significantly to the country's GDP and is a major source of revenue for both rural households and the national economy as a whole. This limitation of farm power specifically limited powered mechanization not only limits productivity but also escalates production costs, as human and animal power are among the costliest in terms of efficiency and energy output. Numerous studies have extensively documented the advantages of mechanization in agriculture. These benefits encompass heightened productivity and increased farm income (Kahlon, 1984; NCAER, 1980; Vaidyanathan, 2010), a reduction in the physical strain associated with agricultural tasks (Gupta, 2008), the intensification of farming practices (Jodha, 1974), punctual completion of operations (Bhalla & Singh, 2012), and an enhancement in the overall efficiency of farm activities. Nevertheless, the influence of farm mechanization on labour employment, especially in a country like India where there is an abundance of labour, remains a topic of significant debate (Agarwal, 1983; Binswanger, 1978; 1986; 1987; Gifford, 1981; Hazell, 2009). But based on the concept of induced innovation, the rise in wages and scarcity of labour prompt a shift towards utilizing mechanical power and labour-saving technology (Hayami and Ruttan, 1970). There has been a noticeable shift towards the utilization of electrical and mechanical sources of power. In 1960-1961, animate sources accounted for approximately 93 percent of farm power, a figure that has drastically decreased to around 10 percent in 2014-2015. Giles (1974) conducted an extensive analysis of power availability in different countries, demonstrating a positive correlation between potential units of farm power and overall productivity. In 1980, the NCAER highlighted that widespread tractor adoption significantly amplified agricultural output, subsequently invigorating the economy. Moreover, as highlighted in the 2018 Economic Survey, Indian farmers are currently embracing farm mechanization at a swifter pace compared to recent years (Ministry of Finance, GoI, 2018). The sales figures for tractors and power tillers have more than doubled over the past decade. Specifically, annual tractor sales surged from 2.5 lakh in 2004-2005 to 5.8 lakh in 2016-2017 (DoACFW, 2018). Similarly, the annual sales of power tillers saw an increase from less than 18 thousand in 2004-2005 to over 45 thousand in 2016-2017 (DoACFW, 2018). The increase in production intensity, coupled with economic growth and the commercialization of agriculture, has spurred rapid mechanization across numerous Asian countries (Pingali, 2007). The upsurge in agricultural mechanization in India gained significant momentum after 1971, attributed to various factors. These include increased farm productivity, expanded access to credit facilities, the establishment of guaranteed minimum support prices for food grains, rural electrification, growth in agricultural engineering education, strengthened research and development capabilities, and a supportive government stance. This support took the form of excise duty exemptions on tractor and power tiller production, along with more lenient import licenses for tractors. (Singh, 2015). However, this shift must be carefully managed to ensure it aligns with sustainable development goals, ensuring that mechanization does not lead to environmental harm or exacerbate socio-economic inequalities among farmers.

Additionally, the sustainability of these traditional power sources is questionable, given the increasing pressure on agricultural systems to feed a growing population while minimizing environmental degradation. The imperative of sustainable agricultural intensification to meet the surging demands for consumer food, driven by escalating population density, urbanization, and income growth is necessary. While expanding cultivable land or enhancing land productivity are both viable options for crop intensification (Ruttan, 2002), the constraints of urbanization and industrialization underscore the necessity of prioritizing the latter. Singh (2006) revealed that mechanical sources accounted for a substantial 78.5% of farm power. However, when considering the mechanization index based on machinery usage costs, it was found to be 14.5%. Also, a significant 85.5% of operational costs were attributed to human and animal energy. In 2017, Upreti and Singh identified a noteworthy positive contribution of human labour, machinery, fertilizers, insecticides, and plot size to productivity. Therefore, effective management of these inputs has the potential to significantly enhance productivity while ensuring that farming practices remain environmentally sustainable. Even in densely populated Asian nations, the adoption of mechanical technologies to alleviate power constraints has substantially bolstered agricultural productivity while concurrently reducing the unit cost of crop production (Pingali, 2007). Rajkhowa, and Kubik (2021) delved into the relationship between various types of farm machinery and manpower requirements in India, employing household and individual fixed effect estimating techniques. Their findings revealed that each incremental unit of agricultural mechanization escalated the demand for hired labour by 12%. The levels of mechanization for various crops in India were reported as follows: rice 45%, wheat 63%, maize 40%, sorghum 26%, pulses 34%, oilseeds 34%, cotton 26%, and sugarcane 24%. The proliferation of custom hiring centres, hi-tech hubs, and farm machinery banks at the village level has greatly facilitated access to cutting-edge agricultural machinery for various field operations among small and marginal farmers (Mehta *et al.*, 2019). These compelling factors underscore the urgency of prioritizing farm mechanization.

The availability of farm power, particularly mechanical and electrical power, is thus a key determinant of agricultural success and sustainability. Farm power encompasses tractors, power tillers, diesel engines, electric motors, and other equipment that significantly reduce dependence on human and animal labour. This study seeks to examine the current status of farm power availability and its impact on agricultural sustainability. Furthermore, the study employs comparative statistical analysis and scatter plots to visualize the relationship between farm power density and productivity. The correlation between these factors can provide insights into the effectiveness of mechanization efforts across different regions. To enhance understanding, the study also classifies the study area into four distinct clusters: (1) high farm power with high productivity, (2) high farm power with low productivity, (3) low farm power with high productivity, and (4) low farm power with low productivity. This classification allows for a nuanced understanding of how farm power influences agricultural outcomes and where improvements are most needed.

Material and Methods

The empirical foundation of this study is based on secondary data obtained from the 'DBT Schemes for farm implements' the 'Tractor and Mechanization Association' and 'Five Decades of Odisha Agriculture Statistics'. These sources give a wide range of information about number of different farm implements, major power sources like tractors and power tillers available at farmer's field,crop production and productivity, which was then used for analysis.

The comprehensive assessment of mechanisation includes a detailed examination that extends beyond individual parts. It examines the whole availability of farm power as well as the specialised mechanical farm power component, delving into the complicated dynamics of agricultural machinery and power resources. This evaluation procedure takes into account the delicate interplay of numerous aspects, such as the contribution of human labour, the influence of animal power, and the involvement of mechanical devices. The quantification of these parameters is provided methodically in the following manner:

$$F_{Py} = \frac{\left[0.05N_{HLy} + 0.38N_{Ay} + 3.7N_{EMy} + 5.6\left(N_{PTy} + N_{DEy}\right) + 26.1N_{Ty} + 45N_{CHy}\right]}{A_y} \quad (1)$$

Where,

F_{Py} = Total farm power availability in kW/ha.

N_{HLy} = Number of human labours in agriculture in y^{th} year.

N_{Ay} = Number of draught animals in y^{th} year.

N_{EMy} = Number of electric motors in y^{th} year.

N_{PTy} = number of power tiller in y^{th} year.

N_{DEy} = number of diesel engines in y^{th} year.

N_{Ty} = number of tractors in y^{th} year.

N_{CHy} = number of combine harvester in y^{th} year.

A_y = net sown area in ha in y^{th} year.

Statistical analysis

Statistical analysis, including the Tukey HSD test at p = 0.05 and Pearson correlation test, was performed using SPSS version 16. The Tukey HSD (Honestly Significant Difference) test was a post hoc analysis used to determine which specific group means were significantly different after finding a significant result in an ANOVA test. It was a popular method for multiple comparisons because it controlled the family-wise error rate effectively. The significance level of p = 0.05 was standard. The Pearson correlation test was used to assess the linear relationship between two continuous variables.

Study area

Odisha, a major rice-producing state located in the eastern coastal plains of India, serves as the focal area for this study (Fig. 1). Geographically, Odisha is situated between the latitudes of 17.49°N and 22.34°N and the longitudes of 81.27°E and 87.29°E. Of Odisha's total cultivated land, covering 6.18 million hectares, 47% is high land, 28% is medium land, and 25% is low land. Approximately 65% of this cultivated area is irrigated during the *Kharif* season [31 from springer paper]. In terms of operational holdings, marginal farmers (<1 ha) make up 45%, small farmers (1-2 ha) 30%, semi-medium farmers (2-4 ha) 17%, medium farmers (4-10 ha) 6%, and large farmers (>10 ha) 2% [25 from springer paper]. While rice is the dominant crop, cultivating non-paddy crops like pulses and groundnuts also supports financial stability and food security. Enhanced profitability and cost-effectiveness in production can be achieved through strategic capacity building and the dissemination of technical knowledge [32 from springer paper]. The state has seen significant growth in farm mechanization, with agricultural machinery sales surpassing Rs 805 crores in the fiscal year 2022-23, and is targeting Rs 1000 crores

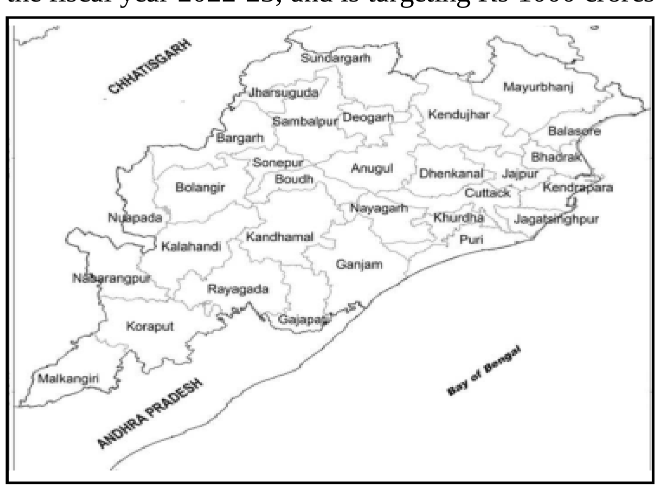

Fig. 1: Location map of study area.

Table 1: Farm power availability from different sources.

Year	Farm power, kW/ha							
	Agricultural workers	Draught animals	Tractors	Power tillers	Combine harvesters	Diesel engines	Electrical power	Total
1996-97	0.021[a]	0.456[a]	0.042[a]	0.001[a]	0.000[a]	0.000[a]	0.003[a]	0.523[a]
2001-02	0.079[b]	0.459[a]	0.070[a]	0.005[a]	0.000[a]	0.0001[a]	0.003[a]	0.616[b]
2006-07	0.082[b]	0.474[a]	0.144[b]	0.013[b]	0.000[a]	0.0004[a]	0.003[a]	0.717[c]
2011-12	0.102[c]	0.316[b]	0.487[c]	0.06[c]	0.003[b]	0.068[b]	0.004[b]	1.036[d]
2016-17	0.096[c]	0.296[b]	0.669[d]	0.12[d]	0.017[c]	0.188[c]	0.007[c]	1.389[e]
2021-22	0.100[d]	0.309[b]	1.048[e]	0.155[e]	0.062[d]	0.307[d]	0.020[d]	2.000[f]

by 2023-24 [33 from springer paper]. These factors highlight Odisha's suitability as a study area, given its substantial role in rice cultivation, prevalence of small-scale farms, and coastal plain location.

Results and Discussion

Farm power availability as an indicator of farm mechanization index

Farm power sources include agricultural labourers, draught animals, tractors, power tillers, diesel engines, and electric motors. In Odisha, the population dynamics of agricultural workers reveal that the state has approximately 10.8 million agricultural workers, with female workers accounting for 44% and agricultural workers comprising around 62% of the total worker population. According to the data presented in Fig. 2, there is a noticeable decline in the number of cultivators, while the number of agricultural labourers has shown an upward trend between the years 1991 and 2011. During the same time frame, there is a notable rise in the quantity of female individuals employed in the agricultural sector (Fig. 2).

Table 1 shows the available farm power and total farm power (kW/ha) in Odisha based on these sources. The proportional share of various power sources for agricultural activities has shifted dramatically during the last three decades. Between 1996-97 and 2021-22, the proportion of agricultural employees in total farm power available in Odisha remained relatively consistent, ranging from 4.04% to 5.01%. The power generated from draught

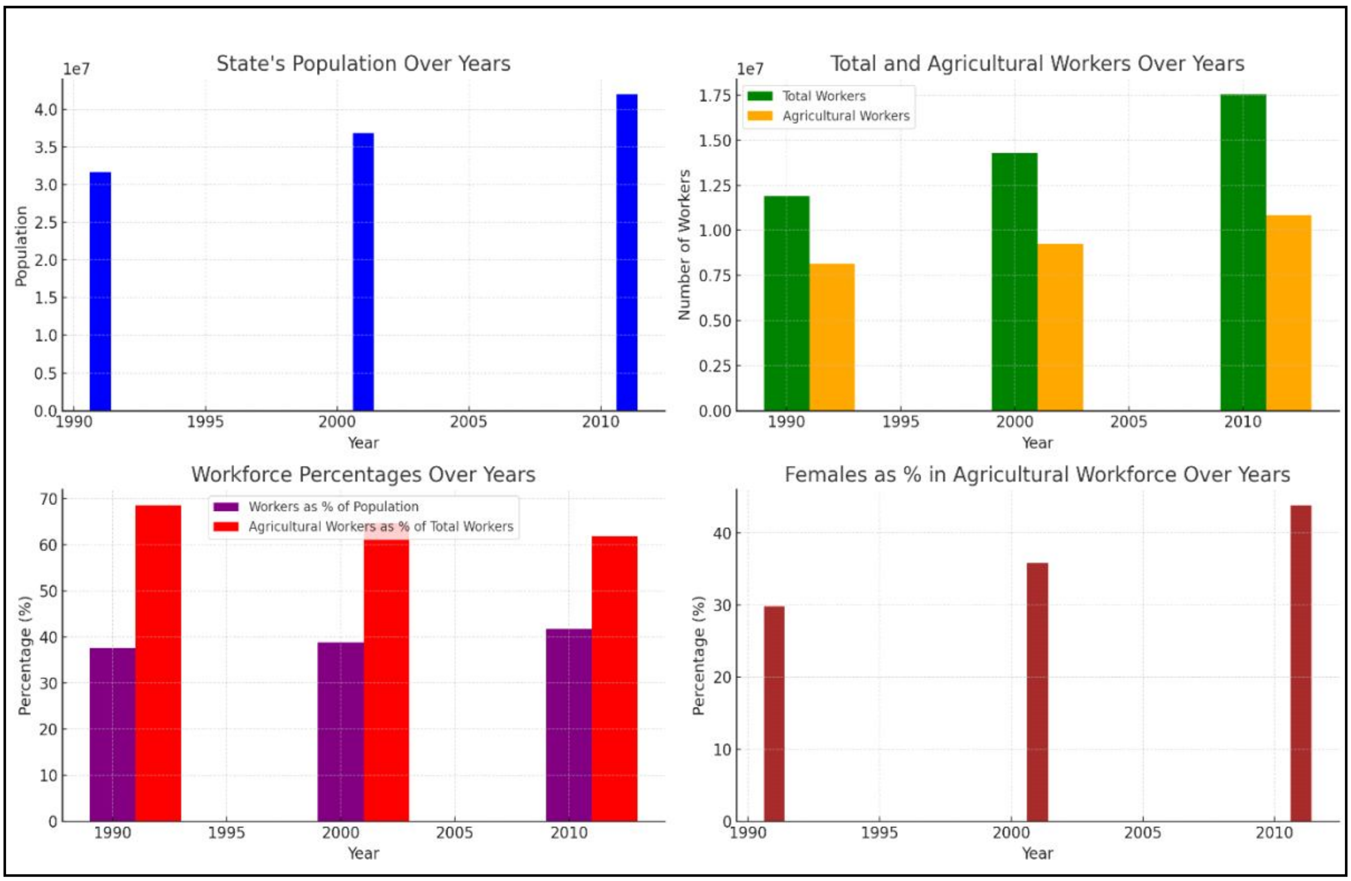

Fig. 2: Representation of agricultural work force in study area (1991-2011).

Table 2: Pearson correlation test with different farm power sources .

	Pearson/Correlation/Coefficients							
	Agricultural workers	**Draught animals**	**Tractors**	**Power tillers**	**Combine harvesters**	**Diesel engines**	**Electrical power**	**Total**
Year	0.819	-0.860	0.957	0.951	0.792	0.908	0.780	0.949
Total Power	0.640	-0.827	0.993	0.982	0.935	0.989	0.926	1.000

animals has decreased from 0.45 kW/ha in 1996-97 to 0.30 kW/ha in 2021-22. However, the percentage share of draught animal power has experienced a substantial reduction from 87.30% in 1996-97 to 15.44% in 2021-22 (Anonymous, 2012). This decline may be attributed to the significant loss of livestock caused by the devastating super cyclone that struck coastal Odisha in October 1999. Over the same time frame, there was an observed increase in the proportion of power derived from tractors, power tillers, diesel engines, and electric motors, with values rising from 0.042 to 1.048 kW/ha, 0.001 to 0.155 kW/ha, 0.000 to 0.307 kW/ha, and 0.003 to 0.020 kW/ha, respectively.

According to the Pearson correlation test (Table 2), with a coefficient of correlation (c.c.) of 0.993 tractor power contributes the most to the total farm power availability, followed by diesel engines (c.c.=0.989), power tillers (c.c.=0.982), combine harvesters (c.c.=0.935), and electrical power (c.c.=0.926). Additionally, it has been noted that agricultural workers tend to make considerable contributions with c.c. 0.640 as the farm power source. Interestingly, barely any of agricultural power is generated by draught animals (c.c.= -0.827). Yet again, throughout the years (1996-2022), the tractor has undergone strong growth (c.c.= 0.957), followed by the power tiller (c.c.= 0.951), diesel engine (c.c.= 0.908), agricultural labourers (c.c.= 0.819), combine harvester (c.c.= 0.792), and electrical prime movers (c.c.= 0.78), while the draught animal has experienced a substantial decline (c.c.= -0.860). Tractors were the most prevalent source of power, contributing 52.41% of the total power available in 2021-2022.

The current population of tractors in Odisha exceeds two lakh units in the year 2021-22 (TMA, 2022). On the other hand, the population of power tillers has experienced a significant surge, rising from 687 units in 1996-97 to 1,49,309 units in 2021-22 (DBT, 2022). Given that Odisha is primarily a rice-growing state with small and scattered land holdings, farmers have shown a greater inclination towards adopting power tillers over the past 15 years. The average annual sale of power tillers in Odisha has surpassed 10,000 units. The percentage share of tractors and power tillers in the total farm power has increased from 7.98% to 52.41% and from 0.12% to 7.73%

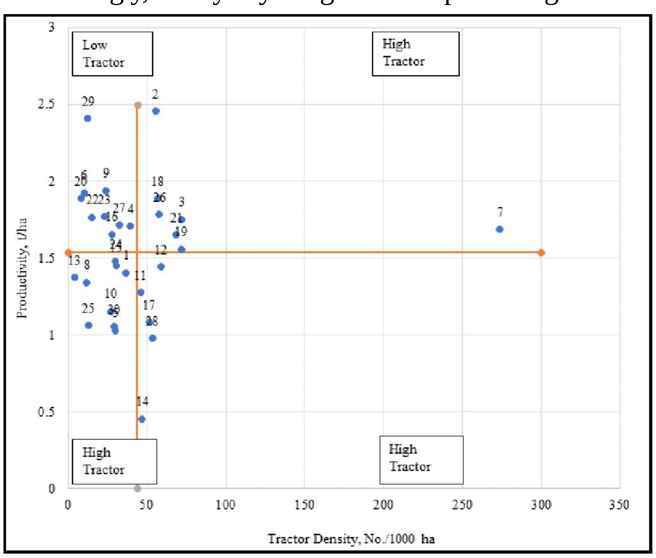

Fig. 3: Cluster Analysis of Tractor Density and Productivity in different districts of study area. [1-Anugul, 2-Balasore, 3-Bargarh, 4-Bhadrak, 5-Bolangir, 6-Boudh, 7-Cuttack, 8-Deogarh, 9-Dhenkanal, 10-Gajapati, 11-Ganjam, 12-Jagatsinghpur, 13-Jajpur, 14-Jharsuguda, 15-Kalahandi, 16-Kandhamal, 17-Kendrapara, 18-Keonjhar, 19-Khordha, 20-Koraput, 21-Malkangiri, 22- Mayurbhanj, 23- Nabarangpur, 24- Nayagarh, 25- Nuapada, 26- Puri, 27- Rayagada, 28-Sambalpur, 29- Subarnapur, 30- Sundargarh].

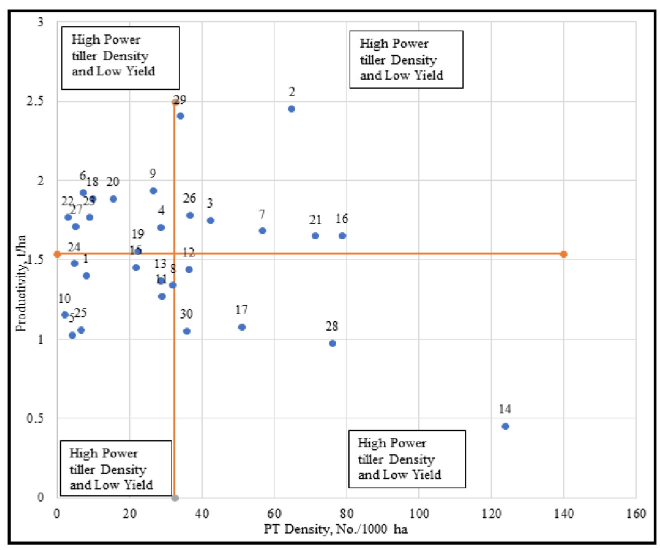

Fig. 4: Cluster Analysis of Power tiller density and productivity in different districts of study area. [1-Anugul, 2-Balasore, 3-Bargarh, 4-Bhadrak, 5-Bolangir, 6-Boudh, 7-Cuttack, 8-Deogarh, 9-Dhenkanal, 10-Gajapati, 11-Ganjam, 12-Jagatsinghpur, 13-Jajpur, 14-Jharsuguda, 15-Kalahandi, 16-Kandhamal, 17-Kendrapara, 18-Keonjhar, 19-Khordha, 20-Koraput, 21-Malkangiri, 22- Mayurbhanj, 23- Nabarangpur, 24- Nayagarh, 25- Nuapada, 26- Puri, 27- Rayagada, 28-Sambalpur, 29- Subarnapur, 30- Sundargarh].

respectively between 1996-97 and 2021-22. The introduction of combine harvesters in Odisha took place in the year 2007-08, and their share in the total farm power availability in the state reached 0.062 kW/ha in 2021-22, with a population of approximately 7407 units. The share of diesel engines in total farm power availability in Odisha has grown from 0.000 kW/ha to 0.307 kW/ha. The percentage share of electrical power in farm power availability has remained relatively low throughout the last 25 years, increasing from 0.55% to 1.00% between 1996-97 and 2021-22. Currently, the estimated total power availability in Odisha stands at about 2.00 kW/ha, exhibiting an increase from 0.523 to 2.000 kW/ha over the past three decades. The targeted value of total farm power availability in 2022 was 1.96, according to SAMS report (Anonymous, 2018). Before the adoption of SMAM, the average farm power availability in the state of Odisha was 1.442 kW/ha (2014), and it grew to 1.647 kW/ha at the end of 2016-17, representing a 14.2% increase in farm power availability in three years (Anonymous, 2018).

Farm power density and productivity

The sale of tractors in Odisha has experienced a Compound Annual Growth Rate (CAGR) of 2.5% over the past 12 years, with the 31-32 kW tractor segment dominating the market. The overall tractor density per thousand hectares of net sown area in Odisha is approximately 40.52 in 2022. However, in India, the CAGR of tractor sale was 10.64 % and the overall tractor density in India was found to be 30.31 per thousand hectares in 2014 (Mehta *et al*., 2014). When examined at the district level, the average tractor density per thousand hectares in Odisha is 44. Cuttack district has the highest tractor density with 274 tractors per thousand hectares, followed by Bargarh (72.166) and Khordha (71.6) districts. Conversely, Jajpur (4), Koraput (8.10), and Boudh (10.12) districts have the lowest tractor density. Fig. 2 illustrates the link between tractor density and productivity in major Odisha districts. The graph divides the districts into four categories based on average tractor density (44 tractors/1000 ha) and average foodgrain productivity (1.535 t/ha). The first category comprises of the districts with high tractor density and high productivity, including Cuttack, Balasore, Puri, Bargarh, Keonjhar, Khordha, and Malkangiri. These districts make maximum use of tractor power to enhance productivity. The second category consists of districts with low tractor density and high yield, such as Subarnapur, Dhenkanal, Rayagada, Nabarangapur, Kandhamal, Koraput, Boudh, Bhadrak, and Mayurbhanj. These districts rely more on human and animal power sources than tractors. The third category encompasses districts with high tractor density but low yield, including Jagatsinghpur, Ganjam, Kendrapada, Sambalpur, and Jharsuguda. Factors contributing to this may include limited awareness of agricultural machinery and tractor usage, decreased soil fertility, and the cultivation of single crops like rice over an extended period. Skill shortages among operators may also limit the utilization of agricultural machinery. The fourth category consists of districts with low tractor density and low yield, such as Nayagarh, Kalahandi, Anugul, Jajpur, Deogarh, Gajpati, Sundargarh, Bolangir, and Nuapada. These districts may face challenges due to resource-poor farmers and limited availability of farm power.

The market for power tillers in India is primarily concentrated in the eastern and southern regions due to the small land holdings of farmers and the intensive cultivation of rice crops. In Odisha, power tillers have gained significant popularity, particularly in irrigated areas where multiple rice crops are grown in a year. Over the last 15 years, the sale of power tillers in Odisha has grown at a compound annual growth rate (CAGR) of 8.6%, with 11,000 units sold in 2021-22. The market for power tillers in India is estimated at 56,000 numbers during 2013-14 (Mehta et al., 2014). In Odisha, the overall power tiller density is around 27.84 per thousand hectares of net sown area. VST Tillers Tractors Ltd., located in Bengaluru, Karnataka, and Kerala Agro Machinery Corporation Ltd. (KAMCO), situated in Athani, Kerala, dominate the power tillers market in Odisha. The average power tiller density per thousand hectares at the district level is 32.425. With 124 power tillers per thousand hectares of net sown area, Jharsuguda district has the highest power tiller density, followed by Kandhamal (79) and Sambalpur (76) districts. Conversely, Gajpati (2.07), Mayurbhanj (3.04), Bolangir (4.11), Nayagarh (4.70) and Rayagada (5.28) districts have the lowest power tiller density in Odisha. Fig. 5 illustrates the relationship between power tiller density and productivity in major districts of Odisha. The graph overlays the average power tiller density (32 power tillers/1000 ha) and average foodgrain productivity (1.535 t/ha), dividing the districts into four categories: high power tiller density and high yield, high power tiller density and low yield, low power tiller density and low yield, and low power tiller density and high yield. The first category comprises districts with high power tiller density and high yield, including Kandhamal, Malkangiri, Balasore, Cuttack, Puri, Bargarh, and Subarnapur. These districts make maximum use of power tillers to enhance productivity. The second category consists of districts with low power tiller density and high yield, such as Dhenkanal, Rayagada, Nabarangpur, Koraput, Boudh, Bhadrak, Keonjhar, Khordha, and Mayurbhanj. These districts rely more on human and animal power sources than power tillers. The third category encompasses districts with high power tiller density but low yield, including Jagatsinghpur, Kendrapada, Sundargarh, Sambalpur, and Jharsuguda. Factors such as soil fertility, agro-climatic conditions, cultivation practices and limited awareness of agricultural machinery usage may contribute to this trend. The fourth category consists of districts with low power tiller density and low yield, including Nayagarh, Kalahandi, Deogarh, Angul, Ganjam, Jajpur, Bolangir, Gajpati, and Nuapada. These districts may face challenges due to resource-poor farmers. The analysis highlights the variations in tractor and power tiller density and productivity across districts in Odisha, reflecting factorssuch as agricultural practices, resource availability, and awareness of mechanization among farmers.

Conclusion

In India, the growth in demand for agricultural machinery-especially tractors and power tillers-has been instrumental in advancing farm power, with a pronounced impact in states like Odisha, where small and scattered land holdings predominate. The rising adoption of mechanized tools, particularly power tillers, has helped meet the operational demands of rice cultivation, reducing dependency on traditional labour-intensive methods. While manual labour remains essential in certain critical tasks such as sowing, weeding, and fertilizer application, the reliance on animal power has significantly declined, with draft animal contributions to total farm power dropping from 87.30% in 1996-97 to 16.19% in 2021-22. This shift highlights the vital role of mechanization in ensuring timely and efficient field operations, essential for sustainable agricultural practices. Over the past three decades, the average farm power availability in India has increased from 0.52 to 2.00 kW/ha, reflecting a transformation towards more energy-efficient farming. This boost in power availability is strongly correlated with productivity gains, following either a linear or exponential trend, as suggested by empirical studies. However, the nuanced interaction between mechanization and sustainability also reveals a complex dynamic. Despite increased power availability, cropping intensity has declined, partly due to social welfare schemes that incentivize small and marginal farmers to seek alternative livelihoods, relying on subsidized food and financial support. This shift away from active cultivation has led to a reduction in cultivators, while the number of agricultural labourers has grown, underscoring a structural change in the agricultural workforce. These trends indicate the need for a balanced approach to mechanization that respects both economic viability and environmental sustainability. As modern technologies and traditional practices coexist, further research and targeted policy initiatives are essential to optimize farm power, enhance productivity, and ensure sustainable agricultural practices that benefit all stakeholders. By strategically integrating mechanization with socio-economic support, India can drive a sustainable, efficient agricultural sector that remains resilient in the face of changing labour dynamics and evolving rural needs.

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