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Enhancing safety in agricultural mechanization: A critical review of farm machinery hazards and policy interventions in India

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Abstract

The accelerating pace of agricultural mechanization in India has significantly transformed farming operations, enhancing productivity and efficiency. However, this transition has also led to a surge in farm machinery-related accidents, raising serious concerns about the safety and well-being of the agricultural workforce. This comprehensive review critically examines the prevalence, patterns, and causes of such accidents across different regions of India. It presents an in-depth analysis of the contributing factors-including mechanical flaws in farm equipment, insufficient operator training, lack of awareness, and unsafe working environments. The paper explores the socio-demographic profiles of those most affected, identifying small and marginal farmers, women, and youth as particularly vulnerable to machinery-related injuries and fatalities. The consequences of these accidents are far-reaching, extending beyond physical harm to include substantial economic losses, psychological distress, and long-term impacts on rural livelihoods and household income stability. In evaluating India's existing safety frameworks and agricultural policies, the study highlights significant gaps in enforcement, awareness dissemination, and inclusivity in policy implementation. It also critiques the limited accessibility of safety features in low-cost machinery frequently used by smallholder farmers. To address these challenges, the paper draws upon international examples of successful safety interventions and regulatory frameworks from countries with advanced mechanized farming systems. By synthesizing national and global insights, the paper offers a set of actionable recommendations aimed at strengthening farm machinery safety in India. These include the development of context-specific safety guidelines, enhanced training programs, integration of safety standards into farm equipment design, and the creation of inclusive policies that prioritize the protection of all categories of agricultural workers. Ultimately, the review calls for a paradigm shift in India's mechanization agenda one that balances technological advancement with human safety and social equity.

Keywords: India, agricultural mechanization, farm machinery safety, accident risk factors, rural labor protection, safety policy, socioeconomic impact, inclusive mechanization policies

Introduction

Agriculture remains the backbone of India's economy, employing over half of the country's population and playing a pivotal role in ensuring food security and rural livelihoods. With the progressive adoption of mechanized farming techniques, the agricultural sector has experienced significant gains in productivity and operational efficiency. Tractors, power tillers, harvesters, and other machinery have become essential components in modern Indian agriculture, facilitating various tasks such as tillage, sowing, harvesting, and post-harvest processing (Babu & Hallam, 1989; Bell *et al*., 1998) [4, 11]. While mechanization has catalyzed growth in agricultural output, it has also introduced new challenges most notably the rising incidence of farm machinery-related accidents and occupational hazards.

The increasing prevalence of mechanized tools has amplified safety risks for farmers and laborers, who often operate these machines under strenuous field conditions with minimal protective measures. As a result, the frequency of injuries and fatalities associated with farm equipment is becoming an alarming issue that requires immediate policy attention and scientific investigation. Aurora and Morehouse (1972) [3] highlighted the complexity of technological choices in Indian agriculture, especially for smallholders, further underscoring the gap between innovation and ground-level safety adoption. Moreover, India's growing reliance on mechanized equipment without proportional improvements in safety awareness and regulatory enforcement has exacerbated the vulnerability of agricultural workers, especially women and marginal farmers, who form a substantial part of the workforce.

As per recent estimates, India had around 242 million agricultural workers by 2020, with women comprising nearly half of this number. This demographic pattern not only highlights the inclusive nature of India's agricultural workforce but also signals the critical need for targeted interventions to safeguard their health and wellbeing. Studies have shown that addressing safety concerns can directly lead to improved productivity, reduced accident rates, and fewer chronic health issues among workers (Arellano & Bover, 1995; Bationo *et al*., 2011) [2, 18].

The historical evolution of mechanization in India provides important context for these challenges. Although the country's total agricultural land area has increased by only

5% since 1960, grain yields have surged by nearly 300%, supported by land-saving innovations like irrigation and fertilizers. Equally important is the rise in tractor use estimated to cover just 10% of land preparation in 1980, which increased to about 20% by 1990. These trends mark a significant transition that has placed India ahead of many African nations in the extent of tractor adoption, offering critical lessons for similar economies.

Despite these advances, the sector still lacks a robust safety infrastructure. Existing safety standards are often outdated or poorly enforced, and training programs remain inaccessible to a majority of small and marginal farmers. Therefore, this paper aims to conduct a comprehensive review of farm machinery safety in Indian agriculture. It examines the trends, risk factors, and demographic vulnerabilities associated with machinery accidents, assesses current safety regulations and practices, and presents internationally proven strategies for mitigation. The goal is to identify evidence-based pathways to promote a safer, more sustainable mechanization landscape that ensures the dignity and security of India's agricultural workforce.

Research and Development in agricultural mechanization

In India, the trajectory of research and development (R&D) in agricultural mechanization has been significantly influenced by the private sector, mirroring global trends. By the late 1970s, several major Indian manufacturers had established in-house R&D divisions, often through joint ventures with international firms to develop tractors and related equipment (Morehouse, 1980) [7]. This momentum carried forward into the 1980s, with capital investment in R&D infrastructure reaching approximately $5 million and recurrent annual expenditures nearing $2 million (Mohan, 1986) [8], equivalent to around $10 million and $4 million today, respectively.

Between the mid-1980s and the mid-1990s, R&D expenditure in the Indian agricultural machinery industry nearly doubled (Pray & Nagarajan, 2014) [9]. By 2008/2009, the sector invested about $40 million (in 2005 prices) in R&D, with Indian firms accounting for half of this amount and the remainder contributed by multinational corporations (Pray & Nagarajan, 2014) [9]. Despite this progress, the industry's R&D spending remained modest around 1% of total sales when compared to the global average of approximately 2.7% (Pray & Nagarajan, 2014) [9].

While the private sector has played a dominant role, the public sector has also made significant contributions. Government institutions have supported the development of indigenous equipment designs, engineering education, and outreach programs to disseminate mechanization knowledge (Singh, Verma, & Tandon, 1984) [10]. Additionally, public agencies facilitated technology transfer and innovation during the early phases of mechanization, particularly through initiatives linked to the import and study of foreign machinery (Bell, Dawe, & Douthwaite, 1998; Chauhan *et al*., 2012) [11, 13].

Policies toward inclusive growth of agricultural mechanization

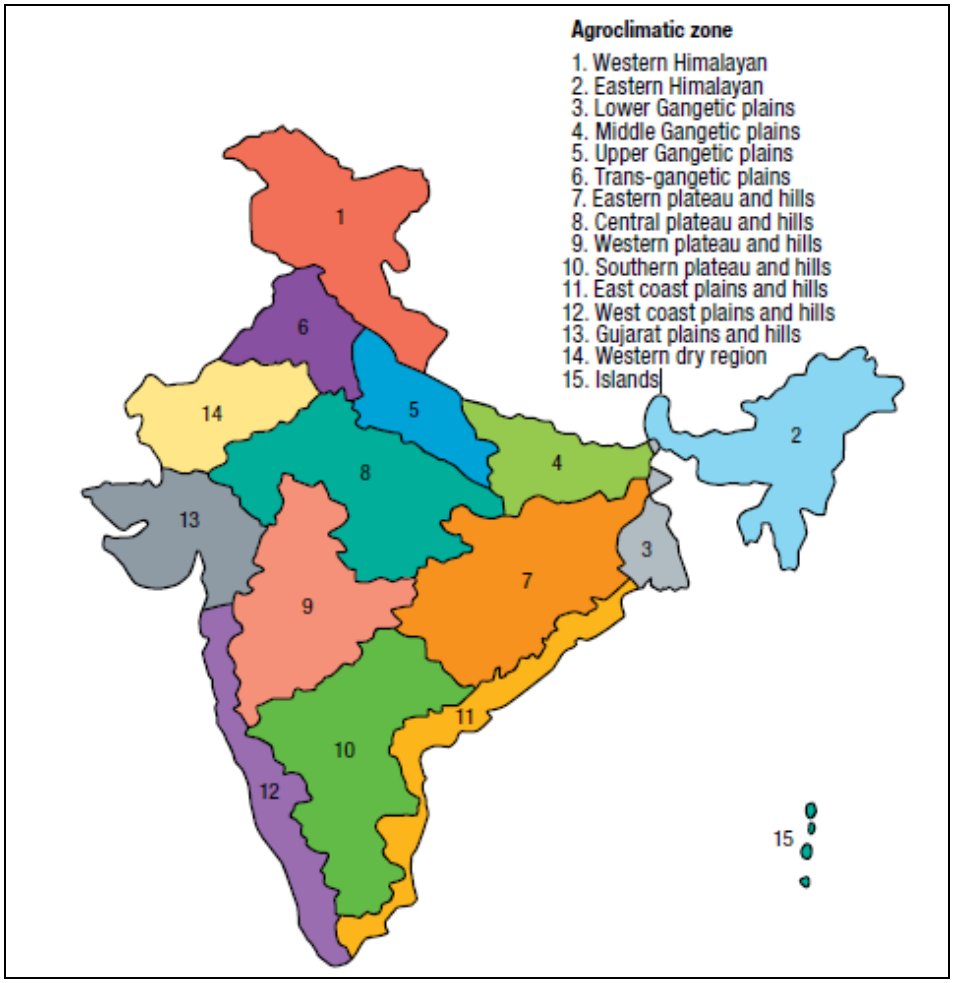
India's journey toward mechanized agriculture has been marked by notable disparities across regions. While states in the northwest have experienced rapid mechanization, the eastern and northeastern regions have continued to lag behind (CSAM, 2014) [14]. To address this imbalance, the Government of India launched the *Sub-Mission on Agricultural Mechanization* (SMAM) during the 12th Five-Year Plan (2012-2017) with a financial allocation of ₹35 billion (approximately $550 million) (India, MOAFW, 2015) [15]. This initiative aimed to promote inclusive mechanization through subsidies for equipment purchases and support for the establishment of custom hiring centers.

The uneven spread of mechanization has posed substantial policy challenges. However, as mechanization levels increase nationally, targeted interventions in under-mechanized regions become more viable and impactful (Deininger & Byerlee, 2012) [16].

The evolution of India's agricultural machinery manufacturing sector, particularly in the production of tractors, illustrates how the enabling environment fostered by the government rather than any single policy has contributed to industrial growth. Key government roles included improving rural infrastructure such as electricity and roads (Fan, Hazell, & Thorat, 2000) [17], offering training and R&D support, and instituting a regulatory framework conducive to industrial expansion (Binswanger & Donovan, 1987; Bationo *et al*., 2011) [18].

India's robust domestic demand also facilitated the growth of its mechanization industry. In the 1960s and 1970s, protective policies limited the import of tractors, encouraging local manufacturers to innovate and adapt. By the early 1970s, India's annual tractor demand had reached 10,000 units, and by 1992, over 15 domestic manufacturers were producing tractors (Ito, 1986; Bell, Dawe, & Douthwaite, 1998) [12, 11]. India's historical strength in engine and component manufacturing, dating back to the 1930s, laid a solid foundation for this growth (Mukherjee, 1978; Patel & Gandhi, 1996) [21, 22].

Following economic liberalization in the 1990s, foreign direct investment increased, and global brands entered the Indian market. Although tractor manufacturers typically do not produce attachments, the rise of over 10,000 small-scale implement manufacturers across the country has cultivated a vibrant support industry. This decentralized yet interlinked ecosystem continues to play a critical role in advancing India's mechanized agriculture landscape (Figure 1).



Source: India, MOEIT (2018)

Fig 1: Map showing major agro climatic zones of India

Comparative analysis of agricultural fatalities

Agricultural work remains one of the most hazardous occupations globally, with a consistently high rate of fatalities and injuries. According to Unal *et al*. (2008) [30], Turkey experiences an agricultural fatality rate of 16 per 100,000 workers annually. In contrast, Myers *et al*. (2008) [29] reported a higher rate of 25.4 per 100,000 workers in the United States. These elevated rates are particularly noteworthy in highly mechanized economies, where agricultural power availability is significantly greater estimated at approximately 13.0 kW per hectare. In comparison, India lags behind with only 1.5 kW per hectare. To meet the ambitious goal of doubling food grain production by 2020, India must increase its power availability to at least 3.5 kW per hectare (GOI, 2002). Failing to address this gap may not only hinder productivity gains but could also escalate the incidence of agricultural accidents and fatalities (Table 1).

Table 1: Category wise and severity wise brief summary of the agricultural accident data collected by ESA centres (Kumar A *et al*, 2023) [28]

Sl. No.	Source	Fatal	Non-fatal	Total	% of Total Accidents
1	Farm machinery	39	659	698	30.5%
2	Hand tools	1	782	783	34.2%
3	Other sources (snake bites, animal bites, and fall in well/pond, lightning, heat stroke etc.)	84	725	809	35.3%
Total		124	2166	2290	100%

Analysis of machinery-related agricultural accidents in India

A survey of 698 farm machinery accidents conducted across agricultural regions in India revealed that 5.6% were fatal while 94.4% were non-fatal in nature (CIAE, 2007) [24]. The analysis identified tractors and tractor-operated implements as the leading cause of accidents, accounting for 31% of total incidents. These were followed by animal-drawn implements (22%), threshers (14%), electric motors and pump sets (12%), chaff cutters (9%), power tillers (6%), sprayers (4%), and other miscellaneous machinery (2%) (Gite & Kot, 2003) [25].

In terms of fatalities, the majority were attributed to tractors and their implements (44%), followed by electric motors/pump sets (31%), sprayers (13%), power tillers (10%), and threshers (2%). The fatality rate due to machinery-related incidents was calculated at 5.7 per 100,000 workers per year, whereas the rate for non-fatal

injuries stood at 95.7 per 100,000 workers (Kumar *et al*., 2023) [28]. These findings underscore the urgent need for safety-focused interventions, particularly targeting tractors, electric motors, pump sets, and spraying equipment.

Drivers of Unsafe Agricultural Practices

The increasing availability and adoption of agricultural machinery, often used without adequate training or safety mechanisms, significantly contribute to the growing number of accidents. Farmers frequently operate such equipment under extreme environmental conditions such as high temperatures, rainfall, or darkness driven by the necessity to boost productivity (Banthia, 2004) [23]. Moreover, a substantial portion of India's agricultural workforce operates in the unorganized sector, where safety protocols are either lacking or inadequately enforced. In such contexts, safety takes a backseat to employment obligations, with workers compelled to use machinery or perform tasks without proper safeguards (Gite *et al*., 2006) [26].

Strategic Recommendations for Enhancing Agricultural Safety

In light of the findings, a comprehensive strategy combining engineering, education, and enforcement is essential for reducing agricultural accidents. The following engineering interventions are recommended.

Tractor Safety Improvements

- Mandatory implementation of Rollover Protective Structures (ROPS) to mitigate overturn fatalities.
- Installation of turning indicators, rear lights, and Slow-Moving Vehicle (SMV) emblems on all tractors and trailers.
- Ergonomic design improvements for operator workstations and simplified hitching systems.

Machinery Modifications

- Fitting rotating parts and power transmission systems with proper guards.
- Safe feeding systems for chaff cutters and cane crushers.
- Built-in fuel meters for tractors to monitor fuel efficiency.

Electrical and Spraying equipment safety

- Ensuring proper installation and grounding of electric motors and pump sets to prevent electrocution.
- Use of Personal Protective Equipment (PPE) such as aprons, goggles, and masks during pesticide spraying.

Government's role in agricultural accident minimization programs

In India, agriculture is a state subject, with the primary responsibility for implementation of safety and welfare programs resting on the respective state governments. While the Central Government offers policy direction and financial assistance, execution occurs at the state level. The Directorate of Labour Safety operates at both central and state levels; however, its mandate predominantly covers the organized industrial sector, thereby excluding the vast majority of agricultural laborers who are part of the unorganized workforce (Gite *et al*., 2006) [26]. This administrative gap leads to a stark disparity in budg*et al*location: while over Rs. 3,000 million is annually allocated for the welfare of 41 million workers in the organized sector, less than Rs. 100 million is earmarked for the safety and health of over 241 million agricultural workers (CIAE, 2007) [24].

Recognizing this disparity, the All India Coordinated Research Project on Ergonomics and Safety in Agriculture (AICRP on ESA) has proactively engaged with both central and state authorities to initiate dialogue and propose systemic reforms. Early interactions have shown promise in mobilizing support for improved safety protocols and compensation mechanisms in agriculture (Kumar *et al*., 2023) [28].

Dangerous Machines (Regulation) Act, 1983

The Dangerous Machines (Regulation) Act, enacted in 1983, was a significant legislative step aimed at regulating the manufacture, trade, and use of agricultural machinery particularly threshers to ensure the safety and welfare of machine operators. The Act mandates compensation for laborers who suffer death or bodily injury while operating such equipment (Gite *et al*., 2006) [26]. However, more than two decades since its enactment, adoption remains limited and sporadic among states. For example, Madhya Pradesh adopted the Act in 1989, but resistance from machinery manufacturers, who labelled it a "cruel act," hindered its broader implementation.

To address these challenges, AICRP on ESA initiated a coordinated information-gathering effort by corresponding with Secretaries and Directors of Agriculture across various states. Based on the responses, a revised proposal was formulated to address the shortcomings of the original Act and facilitate smoother adoption. This proposal has been submitted to the Department of Agriculture and Cooperation, Government of India, for further consideration and action.

Compensation provisions for farm machinery accident victims

Ensuring occupational safety in agriculture necessitates not only the implementation of preventive measures but also robust compensation frameworks for victims of machinery-related accidents. To this end, AICRP on ESA conducted collaborative assessments with several state governments to identify existing compensation schemes. Five states Punjab, Haryana, Rajasthan, Gujarat, and Uttar Pradesh were identified as having instituted financial assistance programs for accident victims and their families.

Leveraging these insights, a model insurance proposal was developed wherein the State Agricultural Marketing Boards would partner with insurance providers to establish a compensation scheme. The annual premiums for this insurance would be financed through the revenue generated by the Agricultural Marketing Boards. This proposal has been disseminated across all states and forwarded to the Department of Agriculture and Cooperation for nationwide implementation.

Encouragingly, these initiatives have catalyzed the formulation of new social security schemes in various states, aimed at safeguarding the livelihoods and dignity of agricultural workers. Such measures mark an important step

towards addressing the systemic neglect of farm safety in India's unorganized agricultural sector (Mohan & Patel, 1992; Mukherjee & Ping, 2008; Lakhtakia, 2000) [34, 35, 32].

Conclusions

This paper offers several key policy lessons drawn from India's agricultural mechanization experience. Initially, although India eventually developed its domestic tractor and agricultural machinery manufacturing industries, the country adopted less restrictive tractor importation policies in its early stages. By importing a wide range of foreign tractors with varying designs, brands, and functionalities, India fostered innovation and knowledge transfer among local engineers and fabricators. This diversity of machinery contributed to learning and adaptations at the local level, ultimately leading to the establishment of a robust and dynamic manufacturing sector. While taxes and tariffs were later introduced to generate government revenue, these measures were implemented only after sufficient demand and imports had developed and local manufacturing capacity had grown.

The Indian government has also made significant contributions in providing public goods. These include facilitating private-sector research and development (R&D) by developing new machine designs, training engineers, and offering extension programs. Moreover, substantial public investments have been made over time in infrastructure, such as roads and irrigation, as well as in complementary technologies like improved crop varieties. While India's economic, institutional, and political conditions differ from those of many African nations, the Indian experience demonstrates the effectiveness of a government strategy that focuses on public goods provision and market facilitation, with minimal market distortions. These principles are likely to be vital for African countries as they consider reforms to support agricultural mechanization.

This paper also examines the current landscape of agricultural accidents in India, with a particular focus on farm machinery-related accidents. Based on the data collected, the paper proposes recommendations for addressing and reducing these accidents. By giving adequate attention to these safety issues within the agricultural sector, the well-being of farmers and workers can be significantly improved, while also reducing the financial losses incurred due to such accidents, thereby benefiting the nation as a whole.

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