Original Research Article

MECHANIZATION CHALLENGES IN SELECTED DISTINCT AGRICULTURAL SYSTEMS IN INDIA

Abstract

Mechanization has significantly advanced various sectors, particularly agriculture, by enhancing productivity, efficiency, and sustainability. But still mechanization finds challenges in several agricultural systems. This study explores the challenges of mechanization in some distinct agricultural systems in India. Through survey of previous literature from India, various agricultural systems were identified. Following, brainstorming on such agricultural systems, based on ranking, distinct agricultural systems with significant mechanization challenges were selected and insights were made. Results states the practices such as the water logged paddy farming system, protected cultivation, pandhal system, hill farming, mixed and intercropping systems, organic farming, and shifting cultivation were identified as distinct agricultural systems holding unique hurdles towards mechanization. Each system was discussed with the insights derived on brainstorming. Practicable strategies to overcome the discussed hurdles on the distinct systems were identified and presented in short. In overall, the study explores the various research gaps and challenges upon mechanization of some agricultural systems in India for which further investigations and actions needed.

Keywords: *Complex agricultural systems; Mechanization confronts; Sustainable production; Traditional practices*

Introduction

Mechanization has transformed industries as well as agriculture, becoming a cornerstone of modern development. In agriculture, mechanization has drastically increased productivity (Hamilton*et al.,* 2022), efficiency (Vortia*et al.,* 2021), and sustainability (Devkota*et al.,* 2020). By integrating advanced machinery and technologies, farmers can now perform tasks that once took days or weeks in mere hours. Tractors, combine harvesters, and plows have revolutionized soil preparation, planting, and harvesting, reducing the labour needed and minimizing human error. This increased efficiency not only boosts crop yields but also lowers production costs (Peng *et al.,* 2022), contributing to food security and economic stability.

Beyond farming, mechanization drives advancement in manufacturing, construction, and transportation. Automation and robotics in manufacturing streamline production processes, boost precision, and decrease costs. Transportation innovations, such as automated vehicles (Ghobadpour *et al.*, 2022) and advanced logistics systems, optimize the movement of farm goods and inputs, fostering easy mobility and good connectivity (Tamene & Megento, 2017). Modern machinery designed to be more energy-efficient and eco-friendly, assisting reductionsin carbon footprints. For instance, precision agriculture tools minimize the use of water and fertilizers, leading to less environmental degradation.

India's current mechanization level depicts that farm power availability has crossed 2.6 kW/ha (Gulati & Juneja, 2020). Complete mechanization on paddy, sugarcane, cotton, maize etc., were concentrated. Certain areas still present challenges (Madhukar *et al.*, 2021) for its design (Rathinavel *et al.*, 2022) and implementation. Complex environments (Sarkar, 2020) and intricate tasks can limit the effectiveness of machinery and automation. Additionally, regions with limited infrastructure (Rathinavel *et al.*, 2023) or access to technology face hurdles in adopting advanced machinery, which can exacerbate disparities between developed and developing areas. Addressing these difficulties requires innovative solutions (Devkota *et al.*, 2020) and ongoing research to develop adaptable, versatile technologies that can overcome the unique challenges of these areas in India. Hence this study this study was undertaken to discuss the unique/complex environments exhibiting challenges on mechanization through collection of literature survey, brainstorming and drawing the insights.

Methodology

The study was conducted with three different phases as follows: literature survey, brainstorming for classification and drawing insights. Various literature on mechanization keywords was surveyed through Google Scholar, Research Gate and Springer. More than 100 research/review/popular/magazine articles in English language within India were utilized on identification of diverse agricultural systems in India. Different agricultural systems were identified across India from the literature survey. Wetland system, orchard system, dryland system, floating paddy system, rotational system, intercropping or mixed cropping system, hill agriculture, protected cultivation system, shifting cultivation system, silviculture system, forestry system were identified for mechanization aspects and brainstorming performed during the year 2024. With a panel of 15 experts in the field farm mechanization from different parts of the India with diverse nature (different zones, cadres, expertise). Systems were identified with following difficulty criteria – Crop speciality, crop morphology, climatic conditions, geographic difficulty, cultivation practices, nature of inputs, suitability with regular/existing machinery. 10 point scoring scale was used (Valizadeh & Hayati, 2021). Each criterion was ranked with 10 grade points: 10 having most difficulty and 0 with least, and intermediary values accordingly. Top score skewed systems were identified and insights were drawn on the found systems for mechanization difficulties.

Result and Discussion

The various agricultural systems were prevalent in India including rainfed agriculture, irrigated agriculture, dryland agriculture, mixed cropping, agroforestry, pandhal system, hill farming, organic farming, pastoralism, urban agriculture, wetland agriculture, water-logged paddy farming, protected cultivation system were found. In these, complex agricultural systems shortlisted are water-logged paddy system, protected cultivation system, pandhal system, hill farming system, mixed and intercropping systems, shifting cultivation system, organic farming system. Each selected system was discussed as follows.

Water-logged paddy system

According to Indian Council of Agricultural Research (ICAR), in India, about 3.0 million ha paddy field is affected by water logging, especially in the coastal region.But some parts of country is exclusively cultivating the paddy under water logged conditions naturally. The water-logged paddy system (Lim*et al.*, 2022) was predominantly practiced in Kerala including Pokkali (Rathinavel *et al.*, 2022), Kole (Chandran *et al.*, 2021), Kaipad (Purandhar*et al.*,2022) lands which have unique saline water logging nature. Characterization and classification of natural and altered hydromorphic saline soils (Kaipad soils) of North Kerala and West Bengal, is characterized by the cultivation of rice in waterlogged, marshy beds. This traditional method, known for its adaptation to flood-prone regions and/or salinity, involves cultivating rice on a natural water stagnated condition or manually created fields with water using back waters controlled through sluice gates. Mechanization in this system faces notable challenges due to the unique environmental conditions. The waterlogged, marshy, unstable nature of these fields makes it difficult for conventional agricultural machinery to operate effectively (Rathinavel, 2021). Tractors and harvesters, designed for stable, dry land, struggle with the floating, which cannot enter the fields. Bunds formed for stagnating the water within the field are also a major constraint for movement of machinery in between the fields. Consequently, while mechanization has revolutionized many agricultural practices, its application in water-logged paddy systems requires tailored solutions to address these specific challenges.

Fig.1 Waterlogged paddy cultivation in Kerala

Protected cultivation system

Protected cultivation in India is mere grown to 2.0 lakh ha (Singh, 2023). Protected cultivation systems, such as greenhouses and shade houses, offer a controlled environment for growing crops, shielding them from adverse weather and pests (Phani *et al.*, 2021). However, mechanizing these systems presents several challenges.

The confined and complex layout of protected structures restricts the movement and operation of larger machinery. The delicate nature of the crops grown in these systems necessitates precision and care. Customizing equipment to fit the specific dimensions and requirements of different protected cultivation setups, differing from field machinery can be both costly and technically demanding. Due to the weather parameter inside the protected cultivation house may restrict the use of weather (temperature, moisture etc.,) sensitive components in machinery. Overcoming such hurdles, protected cultivation machinery needs versatility over crop rotations within the same protected cultivation house.

Fig.2 Poly House Capsicum Field

Pandhal system

The Pandhal system, traditionally used in regions like Kerala for growing vegetables (Bharathi *et al.*, 2020) such as bitter gourds (Bhanuprakash *et al.*, 2021), bottle guards (Tadkal *et al.*, 2019) involves cultivating crops on raised, slatted platforms supported by a framework of bamboo or wood. The shape may be square, rectangular or triangle shaped. This method provides several benefits, including improved drainage, reduced pest damage, and easier harvesting.

Mechanizing this system poses significant challenges through its intricate structure of Pandhal setups makes it difficult for large farm machinery (size of machinery is directly proportional to field capacity) to navigate. The variability in platform design and size across the country will complicate the development of standardized mechanized solutions. Operation of machinery within short height range pandhal systems poses a difficulty of operator to have a straight posture which makes ergonomical discomfort. Since, they are temporary nature, removal and placement of poles itself needs a mechanized solution.

Fig.3 Pandhal System for bitter guard

Hill farming

Potential of hill agriculture has remained under-exploited due to various reasons (Bharadwaj*et al.*, 2024). Hill agriculture, characterized by farming on steep, uneven terrains, presents significant challenges for mechanization (Vatsa, & Singh, 2021). The rugged landscape and variable slopes make it difficult for conventional machinery to operate efficiently and safely. Tractors and other large equipment may struggle with stability (Yan *et al.*, 2024) and traction on inclines, leading to potential soil erosion and damage. The complex layout of terraced fields, often designed to prevent erosion and maximize water retention, further complicates mechanized farming, as these systems require cautious maneuvering and specific operation. Additionally, the limited size and accessibility of hill farms can restrict the use of larger machines, necessitating specialized, smaller-scale equipment that can handle the unique operations of the hilly environment. As a result, mechanization in hill agriculture often involves higher costs and complex solutions tailored to the specific challenges of the terrain.

Fig.4 Hill farming practices

Mixed and intercropping systems

Mixed or relay or intercropping systems, where multiple crops are grown together in the same field, pose significant challenges for basic farm operations (Olaoye, 2012). These systems often involve diverse plant species with varying growth patterns, heights, and harvest times, making it difficult for machinery to efficiently handle multiple tasks simultaneously. The irregular spacing, differing growth stages of the crops, lodgings, cross overs, soil disturbances due to machinery movement were supposed to be challenging factors for mechanization. The presence of multiple crops can lead to irregular wear and tear on blades. These complexities make it challenging to design and implement mechanized solutions that are both effective and adaptable to the varied needs of mixed and intercropping systems.

Fig.5 Intercropping in Coconut

Organic Farming

In India, according to certification from National Programme for Organic Production and Participatory Guarantee System, India had 5.91 million ha of land covered with organic farming (as of July 2022). In organic farming, mechanization faces several challenges due to the fundamental principles and practices that distinguish it from conventional agriculture. Organic farming emphasizes minimal use of synthetic chemicals and artificial inputs, focusing instead on organic inputs such as composts, manures like panchakavya (Bajaj *et al.*, 2022), litters, biofertilizers (Suchithra *et al.*, 2022), meal (Gowthaman *et al.*, 2021), pest control methods (Costa *et al.*, 2023) etc., and sustainable practices. Existing chemical based machinery and equipments like sprayer were not readily adaptable for organic practices. This requires modifications on nozzles of sprayer, broadcasting mechanism of fertilizers/manures, fertigation systems etc.

Organic approach often involves diverse crop rotations (Das *et al.*, 2020), varied planting systems (Montgomery *et al.*, 2021) may not sync with the seasonal machinery plans existing in the locality. Organic farming emphasizes state of soil maintenance, might misalign with existing machinery represents a significant challenge.

Shifting cultivation

Shifting cultivation (Sharma *et al.*, 2023), like Jhum, prevalent in north eastern India (Das *et al.*, 2021) poses unique challenges for mechanization due to its inherent practice of rotating fields and using cleared forest land, which complicates the consistent application of machinery. The traditional method involves manual clearing and cultivation of land, followed by a period of fallow to restore soil fertility. Also, Bharadwaj*et al.* (2024) stated that shifting cultivation causes deforestation and further climate change.

Unstable farming locality makes the machinery management complex. Shifting can be in diverse terrain and soil nature, makes optimizing machine design. Adoption levels of shifting cultivation holders is also notable.

Practicable strategies

Development of machinery for distinct agricultural systems is necessitated by the labour shortage, ecological balance, sustainable food production including diversified crops, conservation of traditional cultivars and heritages, timeliness and increased food production. Some of the key strategies discussed to for mechanizing the above discussed distinct agricultural systems were discussed as follows.

- Development of mechanization packages for distinct agricultural systems through farmer – engineer – government based combination approach
- Utilization of advanced technologies such as robotics, automation, 5G network, drones, artificial intelligence to combat some above discussed challenges.
- Involvement of Non Governmental Organizations (NGOs), Corporate Social Responsibility (CSR), grants and subsidies to be prioritized towards the distinct agricultural systems.
- Identification if similar systems worldwide to explore the mechanization practices and collaborative measures with them
- Policy decisions on distinct crops and ecology to favour mechanization.

Conclusion

Based on the survey of previous literature, various agricultural systems were listed out and distinct systems were identified via brainstorming session. With the selected distinct agricultural systems, the insights on mechanization were found and discussed. From this study, confronts on mechanization were exposed and emphasized for framing policy towards special mechanization package development programmes on these distinct agricultural systems exclusively under state level farm mechanization. Bridging such mechanization gap in distinct agricultural practices is crucial for enhancing food security

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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References

1. Bajaj, K. K., Chavhan, V., Raut, N. A., & Gurav, S. (2022). Panchgavya: A precious gift to humankind. Journal of Ayurveda and integrative medicine, 13(2), 100525.
2. Bhanuprakash, C., Sankari, A., Ushanandhini Devi, H., & Arthanari, M. (2021). Performance Analysis of Bitter Gourd (Momordica charantiaL.) under Different Training Systems. Madras Agricultural Journal, 108.
3. Bharadwaj, K., Boruah, P., Bathari, M., Maibangsa, M., &Terangpi, H. (2024). Sustainable Management of Land, Water and Crop in Hills of North East India. International Journal of Environment and Climate Change, 14(2), 847-855.
4. Bharathi, C. S., Mohan, B., & Akila, N. (2020). Women Empowerment through Additional Crop Cultivation–A Climate Resilient Practice of Namakkal District. Journal of Krishi Vigyan, 8(2), 313-318.
5. Chandran, A. V., Jose, S. K., & Gopalan, S. V. (2021). Dragonflies and damselflies (Insecta: Odonata) of the Kole Wetlands, central Kerala, India. Journal of threatened Taxa, 13(3), 17963-17971.
6. Costa, C. A., Guiné, R. P., Costa, D. V., Correia, H. E., & Nave, A. (2023). Pest control in organic farming. In Advances in Resting-state Functional MRI (pp. 111-179). Woodhead Publishing.
7. Das, S., Chatterjee, A., & Pal, T. K. (2020). Organic farming in India: a vision towards a healthy nation. Food Quality and Safety, 4(2), 69-76.
8. Das, P., Mudi, S., Behera, M. D., Barik, S. K., Mishra, D. R., & Roy, P. S. (2021). Automated mapping for long-term analysis of shifting cultivation in Northeast India. Remote Sensing, 13(6), 1066.
9. Devkota, R., Pant, L. P., Gartaula, H. N., Patel, K., Gauchan, D., Hambly-Odame, H., ... & Raizada, M. N. (2020). Responsible agricultural mechanization innovation for the sustainable development of Nepal's hillside farming system. Sustainability, 12(1), 374.

10. ESCAP, U. (2019). Enhancing rural transport connectivity to regional and international transport networks in Asia and the Pacific.

11. Ghobadpour, A., Monsalve, G., Cardenas, A., & Mousazadeh, H. (2022). Off-road electric vehicles and autonomous robots in agricultural sector: trends, challenges, and opportunities. Vehicles, 4(3), 843-864.

12. Gowthaman, S., Yamamoto, M., Nakashima, K., Ivanov, V., & Kawasaki, S. (2021). Calcium phosphate biocement using bone meal and acid urease: An eco-friendly approach for soil improvement. Journal of Cleaner Production, 319, 128782.

13. Gulati, A., & Juneja, R. (2020). Farm mechanization in Indian agriculture with focus on tractors. ZEF-Discussion Papers on Development Policy, (297).

14. Hamilton, S. F., Richards, T. J., Shafran, A. P., &Vasilaky, K. N. (2022). Farm labor productivity and the impact of mechanization. American Journal of Agricultural Economics, 104(4), 1435-1459.

15. Lim, S. H. (2022). Floating Rice Fields, The Quest for Solutions to Combat Drought, Floods and Rising Sea Levels. In WCFS2020: Proceedings of the Second World Conference on Floating Solutions, Rotterdam (pp. 219-239). Springer Singapore.

16. Madhukar, B., Reddy, P. B. H., Lakshmi, T., & Ramu, Y. R. (2021). Constraints in adoption of farm mechanization and suggestions to overcome the constraints. The Pharma Innovation.

17. Montgomery, D. R., &Biklé, A. (2021). Soil health and nutrient density: beyond organic vs. conventional farming. Frontiers in Sustainable Food Systems, 5, 699147.

18. Olaoye, J. O. (2012). Challenges of weeding operation in intercropping and mixed cropping systems in Nigeria. Agrociencia Uruguay, 16(3), 144-151.

19. Peng, J., Zhao, Z., & Liu, D. (2022). Impact of agricultural mechanization on agricultural production, income, and mechanism: evidence from Hubei province, China. Frontiers in Environmental Science, 10, 838686.

20. Phani, V., Khan, M. R., & Dutta, T. K. (2021). Plant-parasitic nematodes as a potential threat to protected agriculture: Current status and management options. Crop Protection, 144, 105573.

21. Purandhar, E., Sreelatha, A. K., Anil Kumar, K. S., & Nideesh, P. (2022). Characterization and classification of natural and altered hydromorphic saline soils (Kaipad soils) of North Kerala, India, The Pharma Innovation Journal, 11(8): 592-595

22. Rathinavel, S., (2021). Design analysis of suitable cutter header assembly for pokkali paddy harvester, Doctoral dissertation, Department of Farm Machinery and Power Engineering, Kerala Agricultural University, Kerala, India.
23. Rathinavel, S., Bhaskar, S., Mathew, M., & Jayan, P. R. (2022). Investigation on Mechanized Harvesting Requirements of Pokkali Paddy for Optimizing Harvester Design, Eco. Env. & Cons. 28 (3) :; pp. (1571-1575)
24. Rathinavel, S., Kavitha, R., Gitanjali, J., & Saiprasanth, R. (2023, October). Role of 5G Technology in Enhancing Agricultural Mechanization. In IOP Conference Series: Earth and Environmental Science (Vol. 1258, No. 1, p. 012010).
25. Sarkar, A. (2020). Agricultural mechanization in India: A study on the ownership and investment in farm machinery by cultivator households across agro-ecological regions. Millennial Asia, 11(2), 160-186.
26. Sharma, A., Manpoong, C., Pandey, H., Gupta, C. K., Baja, Y., Singh, M. S., &Mounglang, C. C. (2023). A comprehensive update on traditional agricultural knowledge of farmers in India. In Wild food plants for zero hunger and resilient agriculture, Singapore: Springer Nature Singapore. 331-386
27. Singh, B. 2023. Exploring potential of protected cultivation in India - a review, Current Horticulture 12(2): 3–11
28. Suchithra, M. R., Muniswami, D. M., Sri, M. S., Usha, R., Rasheeq, A. A., Preethi, B. A., &Dineshkumar, R. (2022). Effectiveness of green microalgae as biostimulants and biofertilizer through foliar spray and soil drench method for tomato cultivation. South African Journal of Botany, 146, 740-750.
29. Tadkal, R., Beaulah, A., Krishnamoorthy, V., & Thangaraj, K. (2019). Evaluation of ash gourd (Benincasa hispida)(Thunb.)(Cogn.) genotypes for growth and yield under pandal system of cultivation. International Journal of Chemical Studies, 7(3), 2933-2937.
30. Tamene, S., & Megento, T. L. (2017). The effect of rural road transport infrastructure on smallholder farmers' agricultural productivity in Horro Guduru Wollega Zone, Western Ethiopia. Auc Geographica, 52(1), 89-99.
31. Valizadeh, N., & Hayati, D. (2021). Development and validation of an index to measure agricultural sustainability, Journal of Cleaner Production, 280, 123797.
32. Vatsa, D. K., & Singh, S. P. (2021). Advancements in Mechanizational Input for Sustainable Development of North Hill Farming Ecosystem, RASSA Journal of Science for Society, 3(3), 156-165.

33. Vortia, P., Nasrin, M., Bipasha, S. K., & Islam, M. M. (2021). Extent of farm mechanization and technical efficiency of rice production in some selected areas of Bangladesh, GeoJournal, 86, 729-742.
34. Yang, F., Liu, Q., Yuxuan, J. I., Chu, H., Duan, L., Lin, Z., ... & Liu, Z. (2024). Development and validation of sloped ground pressure prediction model for a tracked tractor in hilly and mountainous environments, Soil and Tillage Research, 241, 106135.