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Rice cultivation and mechanization level in: India

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Abstract
The current research work mainly analyses different aspects of rice cropping in India covering it from historical times, emerging issues, present status, mechanization level and constraints. Rice being an important crop for food and economy gets the pressure of fulfilling the needs of a rising population of India and also small scale farmers require support. Literature has emphasized the need of modern technology to cope up with the problems of population growth, declining resources and enhanced agricultural production. It looks into the use of modern mechanization, especially the increasing use of tractors, as India mostly has small land holdings. The article has also critically examined three major rice production methods in the Indian situation and provides a summary of the machinery used for agricultural operations in rice farming. Along with this, the paper has outlined the strengths and weaknesses of mechanical rice transplanters and the Direct Seeding of Rice as an emerging cost-effective alternate in the field of rice cultivation. The study has been focused on rice mechanization practices in India highlighting the crucial aspects of weed, water, and nutrient management that make the modernization efforts successful.

Keywords: Rice cropping, India, rice mechanization, rice cultivation, agricultural mechanization, tractors, small land holdings, rice production methods

Introduction
Rice is one of the most consumed staple crops worldwide, providing a major source of food for almost half of the world's population (Bhatia, 2018; Chakraborty & Garg, 2020). In India, rice plays a dominant role in the agricultural sector, serving as a staple food and contributing significantly to the national economy (Chand & Singh, 2022). Rice production has been an integral component of Indian agriculture for centuries, and maintaining high productivity remains essential for ensuring food security and economic stability.
However, rapid population growth, shrinking natural resources, and the increasing need for agricultural productivity have brought significant changes to rice farming practices. Traditional rice cultivation methods, which rely heavily on manual labor and low levels of mechanization, are gradually becoming unsustainable under current agricultural challenges (Devi & Kumar, 2023).

Mechanization level in Indian agriculture
At present, the country of India can be counted as one of the fastest growing economies on a global platform, and alongside this, mechanization levels in the agricultural sector are also growing. This gradual change in the direction of modernized agricultural practices is, among various things, impacted by the fact that a power source used in activities is a tractor. There is a noticeable increase in tractor usage in India which has set the country on the path of becoming a world leader in the manufacturing and sales of tractors [9, 10]. The average farm power availability in India is estimated approx. around 3.0 kW/ha [11]. clearly illustrate farm power availability in agriculturally active crop producing states of India that are further categorized into three different categories on the basis of power availability; I category stands for state having more power availability than or equal to national average 3.0 kW/ha. Only eight states have achieved the national target of 3.0 kW/ha. II category represents 1.7 to 3.0 kW/ha and for category-III the range is 1.0 to 1.7 kW/ha. Farm power availability at different states varies significantly which is also one of the reasons behind production and productivity variation for agricultural commodities. More detailed estimation at inter district level of individual states further revealed lack of awareness among farmers about the use of modern and advanced machineries in various agricultural operations [12].
Despite major breakthroughs in farm mechanization, its distribution in India remains very uneven. Furthermore, lack of identification and region-specific promotion of suitable equipment for different agro-climatic zones is another major shortcoming [13]. One major aspect of this transition is the link between farm power availability and farm productivity, which highlights the multiple benefits of farm mechanization [14]. Although a significant increase in farm power availability has been registered during the last decade, India is still behind many developed countries, posing a strong case for induced farm mechanization.
Several attempts have been made to find out the reasons for India's lagging behind in farm mechanization for rice cultivation as compared to the major rice producing countries of China, Japan and the USA. In 2021, China's total agricultural machinery power stood at 1.078 billion kilowatts. Overall mechanization in crop cultivation including land preparation, sowing, and harvesting touched 72.03% whereas wheat, rice and corn production reached mechanization at 97.29%, 85.59%, and 90% respectively.
In United States, rice mechanization thoroughly utilizes forefront precision farming technology such as GPS-guided systems, yield monitors, and fully automated machinery that

result in less labor, higher efficiency and production of better quality rice.

Topical and variable rate technology (VRT) have got a lot of attention as potential approaches to phase-specific weed management, but precision weed identification to be the most critical challenge, followed by high costs, integration with existing systems and real-time application mechanisms. As a matter of fact, Japan quickly mechanized rice farming between 1960s and 70s by embracing tractors, binders, seedling transplanters, and rice combines extensively abandoned labor-intensive traditional methods [19].

Currently, mechanization in Japan has reached the extent of automation and robotics leading to fully autonomous farming systems that are capable of executing all operations from tillage to harvesting, especially in large-scale cultivation of rice, wheat, and soybean crops. This comparative analysis shows that India should learn from other countries, implement best practices, and tackle financial as well as structural problems if it wants its agriculture to become more productive and sustainable.

Shows that farm power availability and crop productivity have shown positive trends from 1975 to 2022 [11]. Pearson's correlation coefficients calculated from the data illustrate a robust and positive association between farm power, productivity, and power availability per unit of crop production. The correlation value of 0.97 between farm power (kW/ha) and productivity (t/ha) reveals that as mechanization and energy inputs in agriculture have increased over the years, crop productivity has also significantly improved.

It has been assessed that power availability per unit of crop production progressively increases from 0.46 kW/t to 1.34 kW/t over the past forty-seven years. It must be kept in mind that a rise in farm power availability makes possible a continuous growth in crop productivity which is the major factor that enforcing mechanization at the national level. One of the pressing issues in rice farming in India is that a large number of small land holdings are being the cause with 80% of farms having less than 2 hectares and 62% of farms extending to less than half a hectare.

According to the overall farm mechanization level of the major crops grown in India is 47% which is lower than USA (95%), Europe (95%), Russia (85%), Brazil (75%) and China (60%) [22]. the overall mechanization level of the major crops grown in India. The rice crop obtained the second position in overall mechanization level.

Rice cultivation methods in India

Three principal methods are employed for rice cultivation in India: Dry Direct Sowing of Rice (DDSR), Wet Direct Sowing of Rice (WDSR), and transplanting [26, 27]. The DDSR method is characterized by the direct scattering of rice seeds over the dry fields without raising the seedlings in the nursery. For preparing the land to a state suitable for Direct Dry Seeded Rice (DDSR), tillage operations are carried out using either bullock- or power tiller/tractor-drawn tools. WDSR or wet direct-seeded rice is a technique that uses pre-germinated paddy seeds. These seeds are scattered or sown in rows with the help of a drum seeder. They are placed on seedbeds that have been properly prepared and watered. The area where this policy is implemented is normally dependent on local availability of irrigation. The land preparation for WDSR includes two stages of soil cultivation, namely primary and secondary tillage, with the addition of water to make puddles. Finally sprouting seeds are planted

Transplanted rice involves preparation of the field almost similar to that of WDSR, but the main thing is the transplantation of 3 to 4-week-old seedlings at definite intervals. Seedlings are grown in a nursery bed for the purpose of transplanted rice

For power sources in rice crop production, farmers have mainly used three types namely, tractors, power tillers and animals. Because of the very high cost of maintenance and low efficiency, usage of animals has almost ceased

When power sources are taken into consideration, tractors fitted with the right implements are the major power source of preference

A document showing the equipment which is accessible and being used in rice cultivation practices in India is made available to give a reader a general view.

Field preparation and crop establishment

Quality field preparation is one of the most important actions in the mechanization of rice culture that are necessary to guarantee a level water depth at which the weed growth is restricted as well as pesticide and fertilizer uses are more efficient. Plant material and soil are more efficiently mixed and spread in the target area by ploughing, harrowing, and leveling....

Animal power has been traditionally exploited in rice production with raja, country plough, mould board (MB) plough, disc harrow, spike tooth harrow etc. At the same time tractor is used with MB plough, cultivator, tractor-drawn disc harrows, rotavator, and laser-guided land leveler [31].

Various reports have described the relationship between soil conditions and performance of the sowing and transplanting machinery in mechanized rice cultivation in India context [32]. Transplanting requires a field that is well puddled, leveled and only has a thin layer of standing water (10-20 mm), excessive standing water causing poor machine performance [33]. In a six-row rice transplanter, the water kept at 75 mm for the seedling production (5.20 t/ha) was found to be the best by those experiments. [33]. Proper seedling establishment necessitates the use of a mechanical transplanter with a uniformly puddled field and then left to settle for at least 24 h [31]. This period is extended to 48 h for rotary puddler (single-pass) and peg-type puddler (double-pass) [32].

As far as sedimentation time of puddled soil was concerned, the float sinkage of the transplanter as well as its draft requirement during the operation got indirectly affected. For transplanting, it is desirable to have a sedimentation period of approximately 32 h in order to minimize the proportion of floating seedlings, mechanical damage and missing hills [32].

Interestingly, it has also been shown that mechanical transplantation unpuddled soil may result in higher yields compared to rice transplanting in puddled soil [26].

In terms of rice field leveling, laser land leveling has become an indispensable tool because of a multitude of benefits associated with it. Laser land leveling till now has been a very effective means of imparting uniformity to puddled soil conditions thus at the same time it has also helped in reducing field level conveyance losses as well as improving water and nutrient use efficiency.

In rice production field preparation, usage of technology is quite high for instance, a majority of Indian farmers still rely on tractors with the suitable implements for deep ploughing and puddling. However, seeding, transplantation, harvesting, and threshing still depend largely on manual labor and show very little mechanization (Table 2 and Table 3) [31].

Development of new rice varieties at the same time has led to the introduction of precision sowing and transplanting of rice. Precision seeding is characterized by an accurate deposition of seed which results in higher and more uniform crop densities plant for plant, which contributes to improved resource use efficiency, less weed infestation, and more effective management of pests and diseases. In addition, the Row-crop seeders have been used successfully for cultivating rice in dry lands and along field bunds in which dense seed rate is required [35].

See the following table for details on available seeders for rice direct seeding in dry and wet conditions along with their different metering units.

Mechanical rice transplanting

Rice transplanter usage in India has grown and become popular significantly [31]. These mechanical implements have been instrumental in transforming the agricultural sector of India, especially as a source of labor-intensive component of rice cultivation [38]. Rice transplanting machines enabled Indian farmers to increase their planting efficiency considerably, cut down labor requirement, enhance seedling placement and hence increase yields and overall agricultural productivity. Table 5 depicted the various types of rice transplanters used in India from time to time to present.

Advantages and drawbacks of mechanical rice transplanters

They compared the different type of mechanical transplanter and identified the users' misunderstanding of the mat-type seedling raising process is a main factor of the decline in transplanters' performance. Mat nursery preparation alone requires approximately 40% of the energy input in mechanical transplanting. In manual transplantation, nursery preparation consumes only 11% of the total energy.

Direct seeding of rice

Mechanized direct seeding of rice is one of the most economically efficient rice production methods and, therefore, farmers are showing more interest in it. However, the main factors behind the farmers' change of heart towards mechanized direct seeding of rice are labor shortages and the high costs of agricultural production, which have been increasing in recent years. Besides this, as rice production systems get more advanced technologically, there is a wide range of equipment being provided to farmers, which enable them to reduce both cost and time inputs (Table 6). This table, in fact, collectively illustrates the pros and cons of different rice production methods, with an increasing trend of switching to DSR due to water shortage, labor unavailability, and technological development. The proper handling of weeds, water, and plant nutrients turns out to be one of the major factors for effective DSR adoption, which is a clear indication of the demand for more accurate input usage in the coming rice cultivation.

DSR adoption was considered as one of the alternatives, which could be the solution, and indeed it was, to some extent, in terms of the advantages it brought along: less labor requirement, saving of water and shorter crop duration. On the other side, DSR was confronted with weed problems and quite a lot of concerns about nutrient management. Direct seeding of rice, as one of the rice production methods, is really facing a shortage of acceptance in rain-fed agroecosystems, mostly because of the rather high level of weed infestation, poor crop establishment, and not sufficiently effective water and nutrient management, which are the factors resulting in conventional transplanted rice systems. Research has also pointed out the critical role of weed, water, and nutrient management for the successful implementation of DSR

Nutrient management techniques in rice

Rational application of N, P, K fertilizers to crops (primarily rice) is indispensable for ensuring high and stable crop yields.

Over-nutrition or malnutrition of fertilizer application deviates from recommended dose in most developing countries [49].

An initial ramp up in response to nutrient application is clear at the regional level because accounts show that it has been increasing since the first of the century when the global community started adopting NPK fertilizers.

Application of fertilizers/fertilizers is still largely done in inappropriate times and quantities in many regions, which leads to lower fertilizer use efficiency in rice production [51].

Over-utilization of chemical fertilizers leads to, apart from economic losses, environmental issues such as land degradation, chemical pollution (at the source and across the landscape), greenhouse gas emissions, and yield decline associated with the continuous application of chemical fertilizers.

Excessive N and P fertilizer applications have been shown to lead to significant environmental problems, including increased greenhouse gas emissions, eutrophication of water bodies, and contamination of groundwater, while P fertilizers may be a source of heavy metals and radioactive elements in the soil-water-plant pathway.

On the other hand, application of NPK fertilizers in balanced amounts can soon increase the productivity of rice by 2-3 times [55] and also reduce production costs and promote higher yields if nutrient supplies are optimized [56].

Out of these three, N is most frequently deficient to the extent that it has a very significant economic impact. Crop growth and grain yields are strongly influenced by N fertilizer application. On the other hand, proper nitrogen management depends on spatial information on the distribution of crop nitrogen status and for this purpose, proximal or remote sensing techniques can be used effectively, unlike destructive chemical analyses. Based on the site-specific N management strategy, rice yields were increased by 11% and N recovery efficiency increased by 31-40% on average in Asia [57].

Urea, being the most concentration of nitrogenous fertilizers, is water soluble and generally available to crops. In the soil, it gets converted to ammoniacal forms which prolongs the supply of nitrogen [58].

The application of nitrogen may be accomplished by two methods: broadcasting and deep placement. Urea, which is available in granular form, may be broadcasted on the surface or drilled into the soil. Through manual deep placement procedures, urea briquettes (concentrated N) are placed in the field at a depth of 7-10 cm during the placement of one urea supergranule (USG) per four rice hills as per IFDC guidelines. Though effective, the intense labor time and drudgery are major factors resulting in low adoption of this technology. In the manual deep placement technique, a laborer will put urea briquettes deep down in the field area, one briquette for every four hills, 4-5 cm away from the plants and 3-4 cm deep, in alternate rows. In Indian agricultural systems, it is a common practice to broadcast nitrogen before transplanting resulting in low nitrogen use efficiency as only 30% of applied N is utilized by plants. The deep placement of nitrogenous fertilizer has been demonstrated to improve nitrogen use efficiency in rice [59].

Various researchers have reported mechanical deep placement of urea briquettes significantly raises the yield and nitrogen use efficiency, decreases labor requirements and is more green in the environmental aspect as compared to conventional broadcasting [60].

Few field experiments and trials with different applicators in various places have time and again shown their usefulness in increasing rice yields, cutting down nitrogen losses, and improving nitrogen use efficiency (Alam *et al*., 2005; [61, 66]).

AI and IoT in Modern Agricultural Mechanization

In this digital age, the rapid improvements in digital technologies have fundamentally changed the scope of agricultural mechanization, particularly with the integration of IoT and AI [68].

AI and ML are changing the way farmers monitor crop and soil health, reduce resource usage, and make decisions. Hightech hyperspectral analysis and 3D laser scanning provide highly precise data to farmers helping them make informed decisions. AI recognizes the best seeds, forecasts the weather and decides which nutrients to use to improve soil quality. Intelligent machines plant seeds at perfectly spaced intervals and depths. On the other hand, AI-powered monitoring systems also track crop conditions and suggest nutrient application. These advances help increase production, lower waste of resources, and encourage sustainable farming practices [69].

Among other applications, AI is also being used in the detection of diseases in rice crop. AI and IoT-based smart agriculture systems are capable of providing a fast, real-time response for biotic stresses with deep learning methods, especially convolutional neural networks (CNN) that analyze high spectral images to accurately classify crop diseases. Real-time monitoring allows early detection and effective management which drastically improve the efficiency and accuracy of disease diagnosis [70].

Besides increasing efficiency, this technological change supports sustainability by ensuring higher grain yields, lesser environmental damage and smart data-driven farming. Branch of computer science that believe in making intelligent machines that can learn from experience is referred to as AI (Talaviya *et al*., 2020).

AI and IoT integration raises 'thing-to-thing communication' level, thus leading to further efficiency improvements (Wicaksono *et al*., 2021). The most important AI subfields are deep learning, CNNs, ANNs, SVM, k-NN, and K-clustering (Behmann *et al*., 2015; Tejaswini *et al*., 2022). Machine learning uses data and statistical models to make predictions. It increases accuracy and supports data science and big data through intelligent and high-speed decision-making.

In India, mechanized rice farming can see huge benefits by employing precision agriculture and artificial intelligence (AI). These technologies are capable of optimizing resource use, improving crop health monitoring, and enabling data-driven decisions. They will facilitate productivity increases, input wastage reduction, and improvement of sustainability, leading to more efficient and resilient agricultural systems [71].

Conclusions

This paper has symbolized the long and challenging agricultural path of rice in India with the final result of its increased mechanization level being one effective response to the contemporary problems of Indian agriculture. Rice being an important staple food as well as its contribution to the economy has remained so far very labor intensive. The emergence of tractors as main power sources in connection with the rise of Direct Seeding of Rice (DSR) as a good alternative has completely changed the sector. However, mechanization comes with some difficulties, which include the necessity for extremely precise weed, water and nutrient management.

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