Rice mechanization in India: Key to enhance productivity and profitability

PK Guru, N Borkar, M Debnath, D Chatterjee, Sivashankari M, S Saha and BB Panda

SUMMARY

Rice mechanization contributes to sustainable increase in productivity and cropping intensity. Without a review of patterns and progress in farm power availability farmers would struggle to emerge from subsistence production. Present scenario of rice mechanization including availability of farm machinery/implements for different field operations starting from field preparation, sowing/transplanting, intercultural operations, harvesting, threshing and post harvesting operations is compiled. Future research areas are identified to enhance the mechanization level by performing field operations timely, precisely, and efficiently. Precise and need based application of inputs results in reducing cost of rice cultivation with optimal use of energy and drudgery reduction in farm operations.

1. INTRODUCTION

Indian agriculture has made significant progress in the last five decades. However, past some years stagnating net sown area, reduction in per capita land availability, climate change and land degradation are posing serious challenges to it. India's population is increasing in a rapid rate which is likely to reach to 1.30 and 1.38 billion by 2020 and 2030, respectively (Goyal and Singh 2002). Rapid increase in population leading an immense pressure on Indian agriculture to produce more food in order to get food and nutritional security. On the contrary, the average land holding size is in a decreasing trend in India. The average estimated size of land holding in India would be mere 0.68 ha in 2020, and would be further reduced to a low of 0.32 ha in 2030. With all these challenges, India has the herculean task of ensuring food security for the most populous country by 2050. Hence, farming should effectively address local, national and international challenges of food, water and energy insecurity; issues related to climate change; and degradation of natural resources. Farm mechanization can play a key role in addressing these challenges for large as well as small-holder farmers.

Farm machinery and equipment provide a package of technology to (i) increase land productivity by improved timeliness of operations, reduced crop losses and improved quality of agro-produce; (ii) increase efficiency of inputs used through their efficient measurement and placement; (iii) increase labour productivity by using labour saving and drudgery reducing devices, and (iv) reduce cost of cultivation. Machinery is also important to harness available moisture at the time of tillage and sowing, hence dryland areas also experienced growth in farm machinery. Farm machines like rotavator, ferti-seed-drill, raised bed planter and laser leveler boost water use efficiency of little water/moisture that is available; thereby enhancing productivity in dryland areas. There is a strong linear relationship between power available and agricultural productivity. Improved agricultural tools and equipment are estimated to contribute to the food and agricultural production in India by savings in seeds (15-20%), fertilizers (15-20%), time (20-30%), and labour (20-30%); and also by increase in cropping intensity (5-20%), and productivity (10-15%). International and national experiences have established the benefits of engineering inputs in terms of enhanced productivity by about 15% and reduction in cost of production by 20%, apart from increase in cropping intensity (20%), timeliness in farm operations and drudgery reduction.

Presently, India is the largest manufacturer of tractors in the world accounting for about one third of the global production. India also has a big network of agricultural machinery manufacturers. However, there is wide variation among the states at the level agricultural mechanization. The highest concentration of tractors is in northern India. After liberalization and with development of research prototypes of machines manufacturing got a big boost particularly in Haryana, Punjab, Rajasthan, Madhya Pradesh and Uttar Pradesh. Combine manufacturing is concentrated mainly in Punjab. About 700-800 combines are sold annually. Combine harvesting of wheat, paddy and soybean is well accepted by farmers in this area. The estimated levels of mechanization of various farm operations in India are: 40% for tillage, 30% for seeding/planting, 37% for irrigation and 48% for threshing of wheat, 5% for threshing of rest of the crops and 35% for plant protection (CIAE, Bhopal). There is close nexus between farm power availability and increased productivity. The productivity of rice in Punjab, Haryana and Western UP was more than other states namely Assam, Bihar, Jharkhand, eastern UP, Chhattisgarh, Odisha, and West Bengal as these states had farm power availability less than 1.50 kW per ha. The farm power availability in Indian agriculture and productivity increased from 0.25 to 1.84 kW ha^{-1} and 0.52 to 1.92 t ha^{-1}, respectively over the years from 1951 to 2012. The predicted values of farm power availability and productivity in India for the year 2020 is going to be increased to 2.2 kW ha^{-1} and 2.3 t ha^{-1}, respectively (Mehta et al. 2014). In farm mechanization level India is lacking behind other developing countries. Farm power availability in India is very low as compare to the level of mechanization of United State (95%), Western Europe (95%), Russia (80%), Brazil (75%) and China (57%) (Renpu 2014). One possible reason for India's low productivity in rice is the small size of individual farm holdings. The 2001 census found that 80% of farm holdings were less than 2 hectares in size, with 62% averaging less than half a hectare. Just 1% of the holdings was classified as large (over 10 hectares) and averaged 17.1 hectares. The overall average size of all holdings was only 1.33 hectares. A more recent government report noted that small farms have gotten even smaller, and that 85% of farmers lack access to farm inputs and credit. This is not surprising as the rural population has grown but the available farm acreage has not.

Farm mechanization is low in the rice-based farming systems in eastern India. However, it is picking up and many of the small and big farm-machineries are now a common sight in eastern India. Even combine is also being used to harvest rice crop in some parts of eastern India. Over these years there was rapid shift in farm power uses from animal power to mechanical power. Mechanical power helps in timely farm operations with less labour and cost, but reduction in animal uses on farms increases the problem of crop biomass burning. In rice based cropping system managing rice straw is a big challenge. Complete machinery package is needed to be introduced to enhance the production and also it helps in minimize the input energy and cost involved in rice based cropping system. The use of machinery for field preparation operation for rice cultivation is high and most of the farmers of India are using tractor with matching implements for deep ploughing and puddling operation. But the further operation viz. sowing, transplanting, harvesting and threshing is done manually and having very low level of mechanization. In India, the availability of draught animals power has come down from 0.133 kW ha^{-1} in 1971-72 to 0.094 kW ha^{-1} in 2012-13, whereas, the share of tractors, power tillers, diesel engines and electric motors has increased from 0.020 to 0.844, 0.001 to 0.015, 0.053 to 0.300 and0.041 to 0.494 kW ha^{-1}, respectively during the same period. The rice transplanters market in India has grown from about 550 in 2008-09 to 1,500-1,600 units in 2013-14. The industry is expected to grow by more than 50 % in 2014-15 with Chhattisgarh, Odisha, Bihar and southern states showing positive sign of adoption of technology (Mehta et al. 2014). The objectives of the chapters are i) to study present status of farm machinery used in rice cultivation in India; and ii) to identify future research area to enhance rice mechanization in India.

2. PRESENT STATUS OF RICE MACHINERY IN INDIA

2.1. Tillage

On animal powered farms primary tillage is done by using Desi hal (Country plough), and MB plough. Animal drawn plough is still used for tillage in Himachal Pradesh, Assam, Bihar, UP, Odisha, West Bengal and Andhra Pradesh. Mostly these ploughs are manufactured by local craftsman and their design differs from place to place. Animal drawn disc harrow, spike harrow, spring type harrow, blade harrow, zig-zag harrow, three and five tyne cultivators, clod crusher, chisel ploughs, sub-soilers, scraper, bund former and wooden leveler are commercially available. On tractor powered farms mould board plough (MB) and cultivators are two most commonly used implements. Mould board plough is used for primary tillage operation and cultivator is used for primary as well as secondary tillage operations (Fig. 1). Tractor drawn disc harrows are popular for dry secondary tillage operation. Now rotavator is gaining popularity due to its capability for multiple

Fig. 1. Field preparation using tractor drawn MB plough (a) and cultivator (b).

operations in one time. Saving of 60-70 per cent in operational time and 55-65 per cent in fuel consumption with single rotavator compared to the conventional method of seed bed preparation with separate ploughing and harrowing operations have been observed, besides conservation of moisture due to destruction of capillaries.

2.2. Puddling

Puddling operation is performed to reduce deep percolation of water, to suppress weeds by decomposing them and to facilitate transplanting of paddy seedlings by making the soil softer (Fig. 2). In animal powered farms for puddling operation bullock drawn cono-puddlers, disc harrow-cum puddler, in power tiller or tractor powered farms power tiller mounted cono-puddler, power tiller rotavator and tractor drawn paddy disc harrow, cage wheel with cultivator and rotavator, are machinery used for puddling which are commercially available.

Fig. 2. Puddling using tractor rotavator (a) and animal drawn disc harrow (b).

2.3. Land leveling

In India rice farmer's uses traditional land leveling and laser land leveling for final field preparation. Traditional land leveling includes animal drawn leveler or tractor or even bulldozers in the case of highly undulated land. The accuracy of these implements is low, which results in uneven distribution of irrigation water. Laser land leveling is an alternative to achieve higher level of accuracy in land leveling. This gives uniform land for seed sowing or transplanting with uniform distribution of irrigation water (Fig. 3).

Fig. 3. Tractor drawn laser land leveller

2.4. Seeding, planting and transplanting

Rice is grown either by direct seeding i.e. broadcasting, drilling in dry soil, sowing in wet soil or by transplanting. As per power availability (manual, animal, power tiller, and tractor) on farms there are plenty of sowing implements developed and most of them are for dry direct sowing of rice including one, two and three row manual seed drill, three row animal drawn seed drill, self propelled hill seeder, power tiller and tractor drawn seed drill (Fig. 4) for upland conditions for plain terrain whereas manual, bullock drawn and power tiller drawn seed drills are suitable for hilly terrain. For wet direct sowing of rice manual operated drum seeders are popular. The manual drum of 4-rows and 6-rows seeder being light in weight can be operated easily by female farm women in low land area. Manual drum seeders of 4, 6 and 8-rows are available commercially. For transplanting of rice manual operated transplanter and power operated transplanters are commercially available (Fig. 4).

Fig. 4. Tractor drawn seed cum fertilizer drill (a) and self propelled eight row transplanter (b) in operation.

2.5. *Weeding*

The weeds are more competitive with crops during the initial stages of their growth (2-6 weeks after planting). Controlling weeds during this time is very essential for realizing maximum crop yield. Manual uprooting of the weeds with hand in squatting and bending postures is the common practice for wetland rice. For weeding in rice hand hoe, finger weeder, conoweeder animal drawn weeder, power tiller operated weeder, power tiller operated and self-propelled weeders are commercially available and used by the farmers (Fig. 5).

Fig. 5. Weeding in rice with two row wet land weeder (a) and single row dry land weeder (b).

2.6. *Fertilizer application*

Mostly manual broadcasting of fertilizer is performed by farmers. However, for deep placement of fertilizers for higher efficiency of applied nutrient (mostly N), deep placement applicator are used (Fig. 6).


Fig. 6. Deep placement of urea briquettes.

2.7. *Plant protection*

Timely application of herbicides, pesticides and fungicides (collectively called Crop Protection Products) at peak periods play a vital role in ensuring better yields from a crop. The magnitude of this problem is further amplified due to shortage of labour during this time. Different types of duster and sprayers have been developed for operation by hand, a small engine, power tiller and also by using the tractor power source. For application of pesticides, the farmers most commonly use hand compression sprayer, knapsack sprayers and power sprayers. Low volume and ultra low volume (ULV) sprayers, which require comparatively smaller quantity of water, are also in use.

2.8. Harvesting

For rice harvesting many technologies have been developed such as reaper, combine harvester etc. but in eastern India still manual harvesting using sickle is predominant method of paddy harvesting. It takes about 170-200 man hours to harvest one hectare of paddy. Improved sickles, walk behind self-propelled vertical conveyor reaper (Fig. 7), power tiller operated vertical conveyor windrower, animal drawn reaper, tractor rear mounted reaper windrower, tractor operated straw combine, reaper binder and combine harvester are available commercially. These harvesting equipments are being used by famers for harvesting of paddy for plain field on custom hiring basis.

2.9. Threshing

Threshing is one of the most mechanized operations in rice cultivation. On animal powered farms threshing by bullock treading is practiced on large scale in the country but it is also time consuming and involves drudgery. Pedal operated thresher is used for threshing of rice by the farmers of West Bengal, Odisha, Assam, Andaman, Bihar and Jharkhand states. The output capacity, threshing efficiency and labour requirement were 44 kg/h, 98.8% and 5 man-h/q, respectively. Power operated axial flow thresher (Fig. 7) works on axial flow principle. It consists of spike tooth cylinder, straw thrower, concave, sieve shaker and aspirator blowers. It is suitable for threshing rice. It can be operated with power tiller, tractor, engine and electric motor. Axial flow thresher operated by single 1.5 kW motor/power tiller engine was developed for hilly region. The capacities of power tiller and tractor operated axial flow threshers are 3 to 5 q h^{-1} and 10 to 12 q h^{-1}, respectively. Pedal operated, animal drawn, power tiller operated, tractor drawn and electric motor operated threshers are commercially available and have become very popular for threshing operation in plain region.

Fig. 7. Threshing by power operated drummy thresher (a) and harvesting by reaper (b).

2.10. Straw management machinery

Ministry of New and Renewable Energy (MNRE 2009), Govt. of India estimated that about 500 MT of crop residue is generated every year. The surplus residues i.e., the residues generated, in excess of the less amount of residues used for various purposes, are typically burned in the field or used to meet household energy needs by farmers. Burning of crop residues leads to 1) release of soot particles and smoke causing human health problems; 2) emission of greenhouse gases (GHGs) such as carbon dioxide, methane and nitrous oxide causing global warming; 3) loss of plant nutrients such as N, P, K and S; 4) adverse impacts on soil properties and 5) wastage of valuable C and energy rich residues. There are several options which can be practiced such as composting, generation of energy, production of biofuel and recycling in soil to manage the residues in a productive manner. Generally, many farmers are keeping rice straw in form of heap for feeding to animals. In north-western (NW), India combine harvesting of rice and wheat is now a common practice, leaving large amount of crop residues in the fields. Rice straw incorporation is practiced by less than 1% farmers as it is energy and time-intensive. It is a common practice that crop residue is burnt directly in the field, causing environment pollution. It is an important challenge to manage the huge quantity of crop residue and its proper utilization. Conservation agriculture (CA) practices in North India offers a good promise in using these residues for improving soil health, increasing productivity, reducing pollution and enhancing sustainability and resilience of agriculture. The technologies (RCTs) involving no- or minimum-tillage, direct seeding, bed planting and crop diversification with innovations in residue management are possible alternatives to the conventional energy and input intensive agriculture. But most of the technologies are for rice- wheat cropping system. In eastern India in irrigated lands rice-rice cropping system is dominant. Here farmers got paddy straw two times in a year and no energy efficient technology is used by the farmers. Paddy straw management machinery available in India is straw chopper cum spreader, happy seeder (Fig. 8), straw management system for combine harvester and baler.

Fig. 8. Happy seeder (a) and spatial till drill (b) in operation.

2.11. Water management in rice

To produce 1 kg of rice around 3000-5000 liters of water are often used which is more than any other crop like wheat and maize (Satyanarayana et al. 2007). Generally surface irrigation method, viz., check basin method is used for irrigating paddy crop. Unfortunately, the efficiency of surface irrigation in India varies from 30-40% where as in country like Australia the efficiency in surface irrigation ranges as high as between 60-85% (Burton 2016). Fresh water for irrigation is becoming increasingly scarce due to population growth, increasing urban and industrial development (Bouman 2007; Belder et al. 2005). Any measure contributing saving in irrigation water in rice will yield in large saving of water. Source of irrigation water may be either surface water or ground water. Over the past three decades ground water has become the main source of growth in irrigated areas which at present accounts for over 60 per cent of the irrigated area in the country (Gandhi et al. 2009). Generally, internal combustion engine (IC) like diesel engines are used for pumping irrigation water in India. It is a costly affair also the NOX gases released during use of IC engine for irrigating crop has environmental pollution effect.

2.12. Post harvest management

Paddy after harvesting undergoes a series of processing operations to convert to an edible form. The edible portion of paddy is the rice. The various unit operations involved in the processing of paddy to rice include cleaning, drying, storage, parboiling (optional) milling and polishing. Care should be taken at each one of these unit operations to minimize the loss and maximize the head rice yield recovery. Use of modern rice mill with the improved unit operations and equipments gives higher return with improved quality. Spoilage in paddy occurs due to improper handling and storage practices. Moisture content of paddy plays a major role in maintaining the quality of the product. Recommended moisture content for harvesting is 20-25% and safe moisture content for storage of paddy for 2 to 3 weeks, 8 to 12 months and more than a year are 14-18%, 13% or less and 9% or less respectively. So, drying also plays a major role in controlling the moisture level, thereby in deciding the quality of the rice. Presently farmers are using open sun drying for drying of threshed paddy and after drying storage in soil bins or concrete silos.

Rice milling is the oldest and the largest agro processing industry of the country. Paddy grain is milled either in raw condition or after par-boiling, mostly by single hullers of which over 82,000 are registered in the country. Apart from it there are also a large number of unregistered single hulling units in the country. A good number (60%) of these are also linked with par-boiling units and sun-drying yards. Most of the tiny hullers of about 250-300 kg h^{-1} capacities are employed for custom milling of paddy. Apart from it double hulling unit's number over 2,600 units, under run disc shellers cum cone polishers numbering 5,000 units and rubber roll shellers cum friction polishers numbering over 10,000 units are also present in the country. Further, over the years there has been a steady growth of improved rice mills in the country. Most of these have capacities ranging from 2 t h^{-1} to 10 t h^{-1}.

3. ICAR-NRRI DEVELOPED MACHINERY/IMPLEMENTS FOR RICE CULTIVATION

For rice cultivation improved farm implements/machines were developed by ICAR-NRRI Cuttack and popularized among farmers. These machines include bullock drawn implements, manual drawn implements, power tiller operated machines, self-propelled machines, weeding implements, transplanting implements, and post-harvest machines (Fig. 9 and 10). Most of the machines are low cost and suitable for marginal and small farmers. ICAR-NRRI developed farm implements/ machines for rice were commercialized through MOU with private manufacturers. Farm implements/machines were supplied to different states of the country. In last 10 years total 14 no. of farm implements/machines were commercialized and around 4000 number of units were sold.

Table 1. ICAR-NRRI developed machinery for rice mechanization.

Tillage implements	
Bullock Drawn two gang notch type disc harrow	Field Capacity- 0.35 ha h^{-1} This implement can be used in light as well as heavy soils by increasing and decreasing the weight by filling sand inside the empty drum. Price- Rs. 20,000/-
Bullock drawn drum type disc harrow	Field Capacity- 0.4 ha h^{-1} Used for light as well as heavy soils by increasing and decreasing the weight by filling sand inside the empty drum. Price- Rs. 20,000/-
Sowing implements	
One row manual seed drill	Field capacity- 0.01 ha h^{-1} Saves 45 % time over manual seeding Gives uniform row to row spacing Price- Rs. 1500/-
Two row manual seed drill	Field capacity- 0.019 to 0.022 ha h^{-1} Adjustable seed delivery rateuniform row to row space for weeding operation Price- Rs. 3000/-
Three row manual seed drill	Field capacity- 0.03-0.04 ha h^{-1} Saving in seeds and labours in sowing of crops Easy weeding and inter-culture operation Price- Rs. 4000/-
Three row manual puddle seeder	Field Capacity- 0.15 ha h^{-1} Adjustable seed rate, saving of seed and time of seeding Price- Rs. 3500/-
Four row manual drum seeder	Field capacity- 0.030-0.034 ha h^{-1} Reduced seed rate by 60-65 % as compared to broadcast seeding. Price- Rs. 4500/-
Six row manual drum seeder	Field capacity- 0.04 ha h^{-1} Reduced seed rate by 55-60 % as compared to broadcast seeding. Labour requirement in weeding in drum seeder plots was reduced by more than 70% due to use of mechanical weeders. Price- Rs. 6500/-
Eight row manual drum seeder (hyperboloid shape)	Field capacity- 0.093 to 0.097 ha h^{-1} Sowing of this method reduced seed rate by 50-55 % as compared to broadcast seeding. Price- Rs. 8500/-
Power tiller operated Multicrop seed drill	Field Capacity- 0.15 ha h^{-1} One hactare area can be easily covered in single day by an operator About 70-80 % labour saving over manual operated sowing implements Price- Rs. 20,000/-

Contd....

Power tiller operated seed drill for rice and groundnut	Field capacity- 0.15 ha h^{-1} Different seed rates i.e. 30 to 100 kg/ha for rice and 40 to 135 kg/ha for groundnut could be achieved. Price- Rs. 22,000/-
Self-propelled eight row hill seeder	Field capacity- 0.25 ha h^{-1} Reduced drudgery involved in sowing in puddled field condition Uniform seeds per hill (3-4)Labour saving by 60% over manual drum seeder application Price- Rs. 60,000/-
Transplanter	
Two row transplanter	Field capacity- 0.02 ha h^{-1} Saving in labour by 40-45 % as compared to manual transplanting Gender friendly technology females can easily operate it Price- Rs. 6500/-
Four row transplanter	Field capacity- 0.03 ha h^{-1} Saving in labour by 55-60 % as compared to manual transplanting Price- Rs. 8500/-
Deep placement urea briquette applicators	
Two row urea briquette applicator	Field capacity- 0.07 ha h^{-1} Labour requirement- 15 man-h/ha Price- Rs. 3500/-
Three row urea briquette applicator	Field capacity- 0.08 ha h^{-1} Labour requirement- 12 man-h/ha Price- Rs. 4500/-
Injector type urea briquette applicator	Field capacity- 0.03 ha h^{-1} Labour requirement- 40 man-h ha^{-1} Price- Rs. 2000/-
Weeding implements	
Wheel finger weeder	Field capacity- 0.022 ha h^{-1} Saving in labour by 40-50% as compare to manual weeding Price- Rs. 700/-
Finger weeder	Field capacity- 0.012 ha h^{-1} Saving in labour by 27-30% as compare to manual weeding Price- Rs. 320/-
Star-Cono-Weeder	Field capacity- 0.013-0.017 ha h^{-1} Saving in labour by 30-32% as compare to manual weeding Price- Rs. 1900/-
Single row power weeder	Field capacity- 0.025 ha h^{-1} Saving in labour by 50-55% as compare to manual weeding Reduced drudgery during weeding operation Price- Rs. 22,000/-

Contd....

Post Harvest and Processing machinery	
Power rice winnower cum cleaner	Capacity clean grain – 500 kg h^{-1} Cleaning efficincy- 98 % Cost of operation Rs. 6 per quintal as compare to manual cleaning Rs. 16 per quintal Price- Rs. 20,000/-
Mini paddy parboiling unit	Capacity-75 kg $batch^{-1}$ Time required- 6 h per batch Cost of operation Rs. 30 per quintal as compare to manual Rs. 40 per quintal Price- Rs. 6500/-
Manual rice winnower	Capacity- 90 kg h^{-1} Cost of operation- Rs. 10/quintal Price- Rs. 6000/-
Chaff and husk stove	It consumes 1.5-2.0 kg husk in one batch burns for 45 min $^{-1}$ hr Price- Rs. 800/-
Power operated paddy thresher	Capacity- 3-4 q h^{-1} Threshing efficiency- 98.5% 60% saving in labour requirement and 54% saving in cost of threshing as compared to those of pedal type paddy thresher

Fig. 9. NRRI developed three row seed drill (a), six row drum seeder (b) and power operated single row dry land weeder (c) in operation.

Fig. 10. Manual operated three row (a) and two row urea briquette applicators (b)

4. FUTURE THRUST AREA

4.1. Mechanical rice transplanting

Transplanted paddy cultivation is considered to be better from crop management and productivity point of view. Farmers of India used traditional methods of rice transplanting involved more human work rather than use of advanced technologies. Mechanical transplanter is most prominent option to avoid drudgery and time involved during transplanting operation. For Indian conditions the present need is to mechanize the small holding transplanting operation by introduction of low cost mechanical transplanter. The transplanters are used for only limited period of 15-30 days in a year. Therefore, farmers do not want to invest large amount on costly machines. To reduce the cost and to overcome the problems associated with operation of manual transplanter there is need to develop a small self-propelled type transplanter. The transplanting mechanism and forward speed should be power driven and controlled by the operator, so operator only needs to guide the transplanter. The existing popular transplanters are needed to be modified for simultaneous application of urea in root zone of rice and to reduce the nitrogen losses from field. Development of mechanical transplanters for large mat type seedlings is needed so that it can be more popular on custom hiring basis and easily available for small and marginal farmers. Nursery seeder may be developed for sowing of paddy seeds in nursery trays. This gives the uniform seedling population in trays and also the soil media selected becomes easy for cutting by transplanter fingers and gives optimum seedlings per hill. Transplanter capable for working under adverse field conditions viz. standing water on fields, less prepared field, plant residue on surface, are needed to be developed. Root-wash type seedlings transplanters need to be developed, so that the need of mat type nursery can be eliminated. Precision transplanters can be developed for large farmers to save time and to reduce the input cost.

4.2. Nitrogen management in rice cultivation

Urea, widely used nitrogenous fertilizer, is available in various forms like prilled urea, pelleted urea, briquetted urea etc. Among these various forms prilled urea are used in most of the cases. Owing to the problem of its larger surface area, only 30–45% of the broadcasted prilled urea can be utilized by the plants and rest are lost in the various sinks into the environment (Dong et al. 2012). To avoid this loss, the urea is deep placed in reduced zone in rice field or slow release forms are used (e.g. supergranules, urea mudballs, briquettes, coated urea). Some advantages of deep placement using urea briquette applicator are: (a) higher yield and nitrogen use efficiency (b) reduces loss of nitrogen (c) reduce greenhouse gas emission (d) less labour cost (e) precise placement. Compared to the manual placement, use of machine for deep placement of urea briquette is more precise and the most promising technology. Precise urea briquette applicator can improve the placement and reduce manual errors in placement depth.

4.3. Precision rice machinery

Developments in electronics, sensors, and information technology are now permitting considerable up gradation of farm machinery in terms of minimizing the wastage of inputs, reducing drudgery, improving the quality of farm produce and making agriculture more environment-friendly. The input applicators such as seeders/planters, fertilizer applicators, agro-chemical applicators and irrigation systems need to take into account the spatial variability in the field while dispensing the precise quantity of inputs. The present technologies of sensors, remote sensing, electronics, and mathematical modelling permit their integration with machinery design to permit the precision input applicators' development. Development of pneumatic planter for precise seed rate, precision fertilizer applicator based on site specific requirement, precision mechanical transplanter, and variable rate chemical applicators need to be developed for rice crop.

4.4. Paddy straw management machinery

To avoid burning of paddy residue, improved machinery need to be developed and commercialized. A series of implements were developed in North India but still these implements were not being used by the farmers. On-farm management of paddy straw machines can save time, maintain soil health and remove the need of multiple operations to be done to incorporate the paddy straw. Straw chopper, happy seeder, combine with straw management system, half feed combine etc. are technology available in the Indian market. These machines need to be tested and popularize in different areas of the country.

4.5. Energy efficient machinery

Energy requirements in agriculture sector depend on the size of cultivated land, level of mechanization, cropping pattern, and climatic conditions. Climate change and environmental sustainability are the key issues, must be dealt with while producing more food grains under use of various energy resources. These issues can be checked through efficient utilization and conservation of energy at the most. Maximum benefits in agricultural production can be drawn through optimal and proper utilization of energy inputs involved in various farm operations available with farmers. As per the size of land holding and method of crop cultivation, selection of energy efficient technology is due important.

In present conditions, farm machinery available and used is mostly operated by non-renewable sources of energy (Fossil fuels). Limited fossil resources emphasizes the need for new sustainable energy supply options through use renewable energies. Solar farming is slowly getting popularity and stationary agricultural tools such as watering systems, dryers, green house etc. are available in market. There is a need to give more emphasize on standardization and popularization of these technologies. There is need to develop solar energy based farm machines/implements to replace the fossil fuel based engines. Use of solar energy and modern micro irrigation techniques in rice crop cultivation will help in increasing crop water productivity and yield besides reducing cost of cultivation.

In rice cultivation use of machinery for field preparation is high and most of the farmers of India are using tractor and power tiller with matching implements for deep ploughing and puddling operations. But, for other operations viz. sowing, transplanting, harvesting and threshing human labour or animals are used which leads to higher use of energy input in rice production. Optimal use of energy sources available in farm can reduce the input energy without affecting output. Based on the energy footprints of rice cultivation improved package of practices through inclusion of improved implements are recommended for cultivation of rice by different methods viz. DDSR, transplanting and WDSR (Table 2).

Table 2. Improved cultivation practices for direct sown rice cultivation for optimal energy use.

Farm type	Dry direct sowing	Transplanting	Wet direct sowing
Animal Farm/ small farm (less than 2 ha)	Bullock ploughing (MB Plough) x 1 + bullock disc harrow x 2; sowing by bullock drawn seed drill; weeding: chemical + mechanical + manual; FYM application by bullock cart; chemical spray by hand compression sprayer; harvesting by improved sickle; threshing by manual pedal thresher; transportation by bullock trolley	Bullock ploughing (MB Plough) x 1 + bullock disc puddler x 3; mat type nursery preparation; transplanting by manual transplanter; weeding: chemical + mechanical + manual; FYM application by bullock cart; chemical spray by hand compression sprayer; harvesting by improved sickle; threshing by manual pedal thresher; transportation by bullock trolley	Bullock ploughing (MB Plough) x 1 + bullock disc puddler x 3; sowing by Manual drawn six row cylindrical drum seeder; weeding chemical + mechanical + manual; FYM application by bullock cart; chemical spray by hand compression sprayer; harvesting by improved sickle; threshing by manual pedal thresher; transportation by bullock trolley
Mechanized farm (more than 2 ha)	Power tiller/ tractor - cultivator (2) + disc harrow (2); sowing with PT seed cum fertilizer drill/tractor drawn seed cum fertilizer drill; weeding with power weeder + manual weeding; manual fertilizer application; chemical spray by power sprayer; harvesting by reaper and threshing by power operated drummy thresher/ harvesting by combine harvester; transportation by tractor trolley	Power tiller/tractor - cultivator (2) + Disc harrow (2); mat type nursery preparation; transplanting by power transplanter; weeding with power weeder + manual weeding; manual fertilizer application; chemical spray by power sprayer; harvesting by reaper and threshing by power operated drummy thresher/ harvesting by combine harvester; transportation by tractor trolley	Power tiller/ tractor- cultivator (2) + disc harrow (2); sowing with eight row cup type power seeder; weeding with power weeder + manual weeding; manual fertilizer application; chemical spray by power sprayer; harvesting by reaper and threshing by power operated drummy thresher/ harvesting by combine harvester; transportation by tractor trolley

4.6. Post harvest processing and value addition

Single pass rice mills with metal polisher need to be improved with rubber roll sheller for better performance. Rice parboiling and drying system need to be improved for better energy efficiency. Rice husk and straw can be properly utilized for energy generation. Community level improved methods for drying, cleaning, milling, and packaging can help in increase of farmer's income. Value added products of rice (Rice flour, puffed rice, rice flakes) have excellent commercial demands, to popularize these values added products low cost and user friendly technology needs to be developed.

5. WAY FORWARD

- Development of decision support system and expert system for precise input application and crop management for different agro-ecology regions of India
- Promoting establishment of more custom hiring centers with large machinery tractor, combines, thresher etc is essential to enhance the mechanization level for future of the industry.
- Testing facility of farm implements/machines need to be established in region specific to maintain the quality and ensure safety.
- Community level improved methods of drying, cleaning, milling, and storage of rice need to be promoted.

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