Review

Farm mechanization in rice production: a review

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ABSTRACT

Indian agriculture is dominated by small farm holders. With an average holding size of just 1.08 hectares (in 2015-16) and 86 per cent of holdings being of less than 2 hectares in size, Indian agriculture transformed the country from functioning 'ship-to-mouth' during the mid-1960s to being a net exporter of agri-produce today. This would not have been possible without the onset of the Green Revolution post-1965 which resulted in increased food grain production and productivity. Among various inputs such as seeds, irrigation and fertilizers, the productivity of farms also depends greatly on the availability and judicious use of farm power by the farmers. Between the mid-20th century and 2013-14, India witnessed a tremendous shift away from traditional agriculture processes to mechanized processes. Today 88 per cent of the total farm power comes from tractors, diesel engine pump sets, electric pump sets and power tillers. Additionally India has emerged as the largest manufacturer of tractors in the world followed by the USA and China. But how has farm mechanization especially the use of tractors evolved in India over time? What were the key drivers of the demand for tractors? And how efficiently are the tractors being used in terms of usage by number of hours/year? Given the high cost of tractors, it is also interesting to see how far they have penetrated the small and marginal holdings viz the issues of inclusiveness and financial viability and sustainability. These are some of the key questions that are addressed in this study.

Keywords: Farm mechanization; rice; systemic rice intensification; equipment

INTRODUCTION

Indian agriculture is predominantly characterized as smallholder agriculture with the average farm holding size showing a continuous decrease from 2.28 hectares in 1970-71 to 1.08 hectares in 2015-16 (Anon 2020). Overall 86 per cent of total holdings cover less than 2 hectares each ie they are categorized as small and marginal accounting for about 47 per cent of all agricultural land in 2015-16, the latest year for which official data is available (Anon 2020). With such small holding size, large sized, high cost farm machinery, like tractors, does not seem to be an appropriate choice. At the same time India has emerged as the largest producer of tractors in the world followed by the USA and China producing about 9,00,000 tractors and exporting more than 92,000 tractors during the financial year 2019 (April 2018-March 2019) (http://www.tmaindia.in/tractor-industry.php). Not only this, India has also experienced a significant shift away from human and draught animal power in farming towards mechanical and motorized power. According to available statistics, in 1951 about 97.4 per cent of farm power was coming from human and draught animals but in 2013-14 their contribution had reduced to about 12 per cent while that of mechanical and electrical sources had increased from 2.6 per cent in 1951 to about 88 per cent in 2013-14 (Singh et al 2014). Most importantly tractors now contribute about 48 per cent of the total farm power. What led to this dramatic change towards mechanical power specifically tractors in Indian agriculture, is a story of transformation in Indian agriculture that may provide lessons for many smallholder economies of south and southeast Asia as well as sub-Saharan Africa. In order to understand this transformation it is necessary to revisit the Green Revolution of the mid 1960s. The introduction of high yielding varieties of wheat and rice was accompanied with a rising need for irrigation (http://farmech.gov.in/06035-01-15052006.pdf). Farmers who were open to these new grain varieties soon realized that the traditional water lifts, which were driven by draught animals or operated manually, could not meet the water demand of the high yielding varieties. Lift irrigation was therefore quickly mechanized through the use of electric motor- or diesel engine-powered pumps. This was followed by the extensive use of tractors for primary tillage and transport as well as of tractor-powered or self-propelled harvesting equipment to save time and labour in the race to grow at least two crops (kharif and rabi) in time. In 1961-62, India produced only 880 tractors with the support of foreign collaborations and imported another 2,997 units (Randhawa 1986, Singh 2015). But as the Green Revolution spread food grain production and productivity increased in the country raising agricultural income. This in turn created demand for farm machinery both for groundwater irrigation through pump sets (electric and diesel) and tractors for several field operations. This led to one of the major transformations in Indian agriculture replacing human and draught power with new motorized farm machinery for better performance and higher productivity. This study explores how India achieved its current levels of farm mechanization with primary focus on tractors. Simple ordinary least square (OLS) regression analysis has been used to test the hypothesis regarding the significance of various driving factors such as farmers' income, long term agricultural credit, real price of tractors, relative price of tractors with respect to cost of agriculture labour and structural changes on the demand for tractors. Further the emerging trend and government policy shift towards the institution of 'uberization of tractors' that promises a leap forward for more efficient utilization of tractors on farmers' fields at lower costs was evaluated. It was also being looked at how this was giving smallholder farmers access to modern farm machinery and whether this business model was scalable and financially sustainable.

Yield parameters (number of tillers/plant, panicle length, grains/panicle, grain yield and straw yield) were increased with the advancement of yield stage. Number of passes and depth resulted significant effect; higher number of passes caused higher yield parameters. One pass with power tiller of both depths (7.5 and 15 cm) gave the lowest yield attributes and the 4 passes with power tiller at 15 cm depth gave the higher yield attributes at all the stages (Rahman et al 2004).

Yield parameters (panicles, filled grains, 1000-grain weight and fertility) were significantly influenced by different crop establishment methods. The highest number of panicles was produced in DWSR by drum seeder which was followed by farmers' and seedling throwing method (Sarker et al 2007). Yield components (effective tillers, panicle weight 1000-grain weight and grain yield) were significantly influenced by different crop establishment methods. The highest yield components were observed in drum seeding (wet bed, un-puddle) which was followed by direct seeding method (Gill et al 2014).

Senthilkumar (2015) reported that SRI system of planting influenced the plant height, number of tillers, LAI and dry matter production. SRI machine planting recorded significantly higher growth characters which was on par with SRI square planting. The maximum plant height (101 and 100 cm), number of tillers (28 and 26), LAI (5.25 and 4.74), dry matter production (8,015 and 7,780 kg/ha) were recorded under SRI machine planting. There was a progressive increase in plant height, number of tillers, LAI and DMP under SRI system of planting as compared to random transplanting and other establishment methods.

SRI system of planting significantly influenced the yield characters and yield. SRI machine planting recorded significantly better yield characters and was on par with SRI square planting. Among the different rice production methods, the maximum yield characters viz number of panicles per square meter (238 and 224), number of grains per panicle (218 and 204) and panicle length (26 and 27 cm) were recorded under SRI machine planting during kharif and rabi seasons respectively (Senthilkumar 2015).

The yield attributes viz productive tillers per hill, panicle length and number of grains per panicle were higher in mechanized transplanting than manual transplanting during three consecutive years though statistically there was no significant difference between manual and mechanized transplanting (Sreenivasulu and Reddy 2014).

Nayak et al (2014) reported that among different weed management practices averaged over rice plant population treatments, at 20 days after sowing significantly lower (59.9/m) weed population was recorded with pre-emergence application of pendimethalin followed by post-emergence application of bispyribac-sodium (or) pre-emergence application of anilofos followed by post-emergence application of 2,4-D sodium salt. This effect was seen only up to 20 DAS. During the advanced stages of crop growth hand weeding twice and weeding twice with conoweeder showed excellent effect on reducing weed population and all these treatments significantly reduced the weed population in comparison to weedy check.

In SRI, rotary weeder was the best weeder having field capacity 0.18 ha/day/labour. There was 50 per cent saving in time and minimum cost of operation was Rs 500/ha. Mechanization increased little input cost but it significantly increased the productivity of paddy in systems of rice intensification (SRI) (Deshmukh and Tiwari 2011).

Among the crop establishment methods, SRI had the lowest dry weight of total weed and drum seeding plots had the highest dry weight of weeds both at 40 and 60 DAS/DAT. The treatment PSE + conoweeder significantly reduced the total weed dry weight followed by PSE and Almix alone. Absolute WCE was only in weed-free check, above 95 per cent in PSE + conoweeder, PSE and Almix and below 75 per cent in conoweeder. Besides that Almix had the certain level of phytotoxicity in DS and SRI treated plots at the early stage of crop growth (Mandal et al 2013).

Sahoo et al (2015) reported that nutrient management practices exerted significant influence on N, P and K uptake by grain, straw and total N uptake in pooled data. The nutrient supplement through 50 per cent RD + 50 per cent FYM recorded the highest uptake of total N, P and K (107.1, 21.0 and 113.1 kg/ha) respectively which was significantly higher than 100 per cent FYM but statistically at par with RDF. When the weeds were controlled by conoweeder there was statistically higher N, P and K uptake by grain, straw and total N uptake than the Mandva weeder. The crop transplanted with different age of seedlings had significant influence on nutrient uptake. The total N, P and K uptake by grain, straw and total N uptake was recorded with 12 days old seedlings which was statistically higher than the crop transplanted with 8, 16 and 20 days old seedlings.

The germination of paddy seed harvested by different combine harvesters did not show significant difference in comparison to control samples except samples harvested by Agrotech combine harvester. The Agrotech combine harvester was relatively old therefore seed damage was relatively higher than other combine harvester. The harvesting by combine harvester had no significant effect on reducing germination percentage of paddy seed (Chandrajith et al 2016). The minimum and maximum performance was respectively 100 and 100 per cent (Ismail et al 1984) for threshing efficiency. These results are in conformity with the earlier finding (Garg 1999, Jadhav and Deshpande 1990, Jadhav and Turbatmath 1997) 95.57 and 96.79 per cent for cleaning efficiency, 2.63 and 16.45 per cent for seed damage and 0.88 and 4.23 per cent for seed loss. The drum speed of 1,200 rpm recorded the highest significant cleaning efficiency of 96.79 per cent whilst the least significant value was recorded 95.57 per cent at 600 rpm (Biaou Olaye et al 2016).

SWOT analysis on farm mechanization

Strengths: Twenty thousand manufactures in small scale industry, vast network of academic and R&D institutions, trained manpower for R&D in agricultural engineering, AICRPs & cooperating centres.

Weaknesses: Unreliable after sales service of agriculture equipments, poor ToT for agricultural engineering technologies, poor liaison with industries for R&D and commercialization, non-effective feedback system, non-systematic marketing of agriculture equipment.

Opportunities: Entrepreneurship through custom hiring, reduction in post-harvest loss, establishment of value chain for commercial supply, increasing irrigated area through micro-irrigation, reducing yield gaps and increasing productivity.

Threats: Low profitability in agricultural enterprises, migration of farmers from agriculture, fragmentation and continuous reduction of operational holding, slow pace of R&D and commercialization, inadequate infrastructure for after sales support, rnewable energy technology still subsidy dependent.

Strategies for mechanization

The strategies for mechanization are promoting custom hiring centres at block level, promoting high cost machinery through subsidy, promoting tax free imports, encouraging rural innovation, conduct of machinery Melas, conducting more FLDs through KVKs and promoting prototype manufacturing workshop (PMWS).

Economics of farm mechanization

It is of utmost importance to examine whether the use of machines has been economical or not. On the basis of a study covering 203 farmers having 218 tractors in different districts of Punjab (Singh and Jindal 1993) it was brought out that the total use of the tractor which on an average came out 397 hours per annum is much less than the possible extent of 1,000 hours. The cost per hour turned out to be very high due to high fixed cost which can be reduced by increasing the hours of working of the tractor. If it finds work for 600 or more hours per annum, the cost per hour can be lowered significantly. The overall average cost/hour which was Rs 103.04 by its existing quantum of work ie 397 hours declines to Rs 91.77, 86.26 and 82.97 by working per 600, 800 and 1,000 h per annum. The machine becomes economical only if it is gainfully employed for rather than accounting for its productive use. Custom servicing increases annual use of farm machinery. A committee set up by the Planning Commission in 1975 observed that harvester combines were generally demanded by big cultivators and it displaced a large number of agricultural labour in the harvesting season when the opportunities of employment in agriculture were higher for them. The committee justified the use of harvester combine only if their contribution to production arising out of saving in grain from vagaries of weather and shattering and from multiple cropping and change in cropping pattern was substantial. Laxminarayana et al (1981) concluded that there was no social gain due to the use of harvester combines in terms of increase in cropping intensity or farm productivity. On the other hand there is net social loss in terms of considerable labour displacement that would seriously jeopardize the employment opportunities of the casual labour force and more particularly migratory labour coming from labour surplus areas.

Singh (1986) on the basis of a sample of 35 combine harvesters study reported that the average area covered by a combine harvester of small size was 192.1 acres of wheat and 173.6 acres of paddy. With an average rate of Rs 210 per acre, annual gross return of Rs 76,203 was estimated while the annual fixed and operating costs were worked out to Rs 48,538 thus showing a net profit of Rs 27,664 during 1984-85. Anon (1983) recognized time saved, freedom from overburdened work, improvement in social status, increase in overall production, timeliness of operations, reduction in cost, increase in the number of cropping and adoptions of inter-cropping as gains. Increased debt, cost of fuel and repair, unemployment, disparity in income were considered as losses due to farm mechanization.

Mechanization rate vs population engaged in agriculture (Fig 1)

Comparing India vis-a-vis its global competitors in the agri-space, the level of mechanization in India as of 2010-11 is about 40 per cent while the share of the population engaged in agriculture is ~55 per cent. The corresponding figures for developed countries like the US are 95 and 2.4 per cent. For a developing country like Brazil the corresponding figures are 75 and 14.8

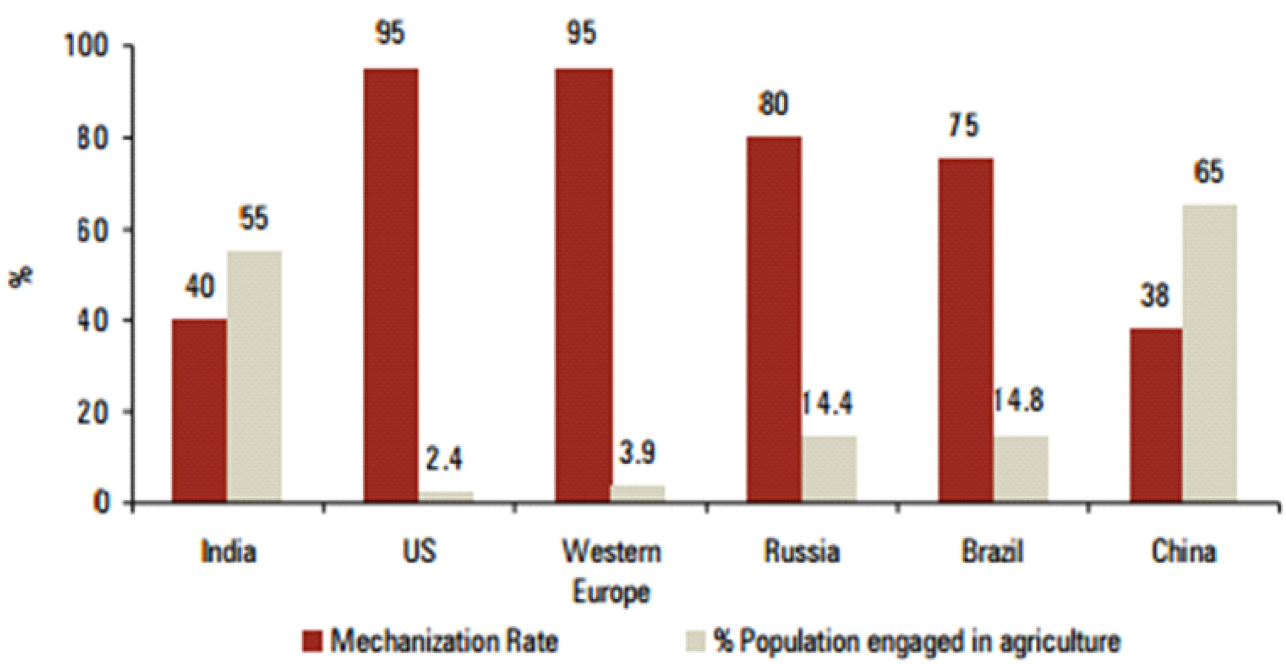

Fig 1. Mechanization rate vs population engaged in agriculture

per cent depicting the high intensity of manual labour in India vis-a-vis its global competitors (Srinivas et al 2017).

Labour saving in paddy due to mechanization

Rice is a labour intensive crop. About 850 to 900 man hours of labour are required for cultivating one hectare. Table 1 gives the operation-wise labour requirement in rice cultivation. Transplanting, weeding and harvesting operations consume most of the labour requirement in rice cultivation and hence thrust should be given for mechanizing these operations in order to reduce the labour requirement in rice cultivation. High labour demand during peak periods adversely affects timeliness of operation thereby reducing the crop yield.

Table 1. Labour reqired for different operations in paddy cultivation

Operation	Per cent age of total labour requirement
Puddling	11
Transplanting	38
Weeding	19
Harvesting	20
Threshing	12

The steady drift of agricultural labour to industrial sector is adding more to the woes of the rice farmers. Because of drudgery and notion that the farm operations are below the dignity, labour availability in general has decreased considerably to farm operations. To offset these problems, stress on mechanization is the need of the hour.

Farm power in India

Tracking the level of farm mechanization in India through the globally accepted index of agriculture mechanization ie power availability per unit area, it has been observed that mechanization levels have improved in India over a period of time. The speed however has been as low one (Fig 2).

Sources of farm power in India (Table 2)

In India, farm power ie mechanical power used in farms is available through various sources that includes agricultural workers, tractors, tillers and diesel engines among others.

Improved farm implements and machinery for rice cultivation

Land preparation equipment: Puddling is the most important operation in the preparation of soil bed for transplanting rice. The soil physical properties like soil structure, viscosity, bulk density etc change due to puddling. Puddling creates an impervious layer and this assists in reducing the deep percolation losses. Prerequisite for puddling is preparatory dry tillage. The indigenous plough is the most prevalent implement used as a puddler in spite of its poor efficiency. An indigenous plough can cover only about 0.15 ha/day. There are several animal drawn and power operated puddlers developed in India.

Among the power-operated puddlers, power tillers and tractors are popular. APAU puddler is a bullock drawn implement. With the movement of the bullocks, the shaft rotates the blades which in turn churn the soil. It is suitable for all types of soils. It is advisable to puddle the soil twice or thrice. The implement set up has provision for seat for the operator. Conopuddler utilizes a new concept of conical shape rotors for puddling in soft paddy soil. It operates in the soil in a horizontal back and forth movement. It can be operated in all types of soils since it is a light weight and modular implement.

Power tiller is a 12 hp self-propelled machine specifically useful for rice fields and orchards as it can take short turns. It comes with a package of implements like rotavator for puddling and cultivator for land preparation. It can be used for operations like pumping, threshing and for farm transport. It takes about 5 h to puddle one hectare. Its cost is approximately Rs 1 to 1.5 lakh.

Tractors are available in two power ranges. Small power range tractor with 18 hp is meant for rice cultivation. It is a light weight tractor with four wheel drive with rotavator used for puddling. It has a small turning radius. Trafficability problem can be avoided with this tractor due to its light weight. It can puddle one hectare in 2.5-3 h.

Seeding and planting equipment: Different kinds of equipments are available.

Direct sowing row seeder: A row seeder (also known as drum seeder) sows the pre-germinated paddy seeds

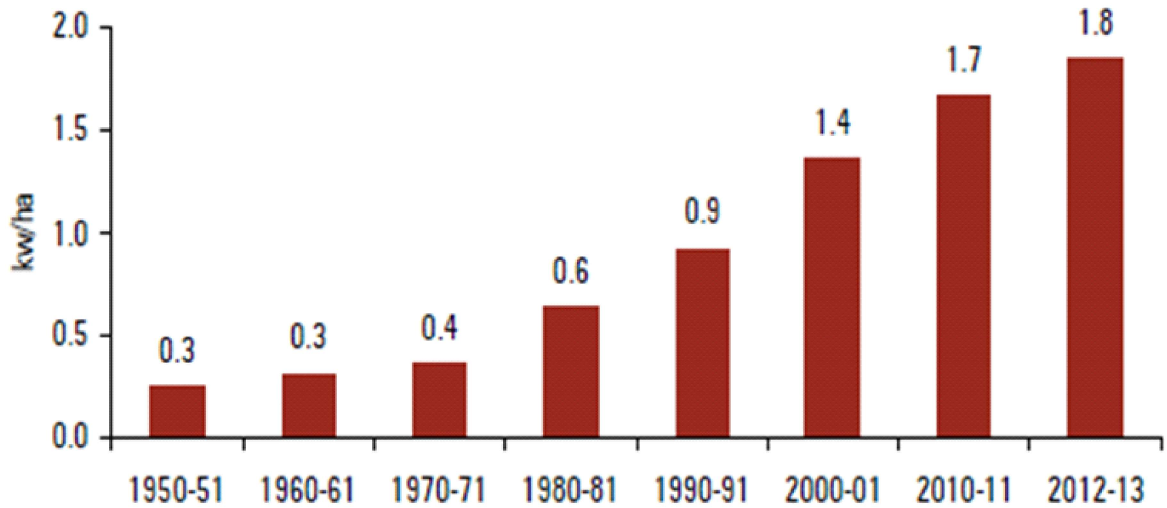

Fig 2. Change in mechanization levels in India

Table 2. Sources of farm power in India

Year	Source						
	Agricultural workers	Draught animals	Tractors	Power tillers	Diesel engine	Electric motor	Total power (kw/ha)
1971-72	0.045	0.133	0.02	0.001	0.053	0.041	0.293
1975-76	0.048	0.135	0.04	0.001	0.078	0.056	0.358
1981-82	0.051	0.128	0.09	0.002	0.112	0.084	0.467
1985-86	0.057	0.129	0.14	0.002	0.139	0.111	0.578
1991-92	0.065	0.126	0.23	0.003	0.177	0.159	0.760
1995-96	0.071	0.124	0.32	0.004	0.203	0.196	0.918
2001-02	0.079	0.122	0.48	0.006	0.238	0.250	1.175
2005-06	0.087	0.12	0.70	0.009	0.273	0.311	1.500
2011-12	0.100	0.119	0.804	0.014	0.295	0.366	1.698
2012-13	0.093	0.094	0.844	0.015	0.3	0.494	1.841

in the rows at a spacing of 20 cm in puddle soil. There is saving in the cost of cultivation to the tune of 35 per cent by using this device.

***DRR 8 row drum seeder*:** The advantages of the machine are lightness of the machine, ease of operation with one operator, ease of fabrication at any local workshop and low cost.

***Direct sowing row seeder with wider spacing (25 cm x 25 cm) SRI - drumseeder*:** A row seeder with a spacing of 25 cm row to row sows the pre-germinated paddy seeds in the rows at a spacing of 25 cm in puddle soil. The other principles of SRI can be well adopted with this seeder to enhance the productivity. The drum seeder is under testing at DRR to save seed and enhance profitability.

***8-row paddy transplanter (Chinese design)*:** It is a self-propelled machine driven by 3-4 hp diesel engine. The machine transplants at a row spacing of 23 cm with a provision to vary the plant to plant distance of 10-12 cm and vary the depth of planting and number of plants per hill. It requires mat type nursery. DRR has standardized the size of the mats to be used with this transplanter and developed a suitable frame to prepare the mats which save labour in nursery preparing and cutting of mats and ensures uniformity of seedling density over mats.

The machine can cover about 0.8 ha in a day with a net saving in labour of about 40 per cent. The machine is more suitable for light-textured soils. Further at present the mechanical transplanters can plant 2 seedlings per hill at a spacing of 24 cm (row to row) and 12-24 cm (plant to plant) for adoption of other SRI principles. This will be a very good development in promoting SRI in large scale.

Weeding equipment

Weeds are serious menace to crops as they reduce the yields and farmers income as they affect crop growth and development in many ways. Problems associated with weeds can be enumerated as reduction in yield and quality and increase in pest and disease problems.

Conoweeder: Weeding requires 120 man hours per hectare. Most work on weeding emphasizes on the timeliness of operations. Timeliness is the key factor for successful and effective weeding. System of rice intensification is paddy cultivation using less seed, less water and less fertilizer. This system encourages farmer participation and innovation to make it more appropriate to local conditions and more owned by the users.

In SRI, first weeding is done after 10-12 days of transplantation. Subsequent weedings are done every 10 days until the crop permits operation. Weeding at 10 days interval is necessary. The field is irrigated one day before weeding and at least half inch water is retained for easy operation. Weeder is moved front and back between every two rows both vertically and horizontally. Mechanical weeding alone increases the plant height and enhances the grain yield as compared to manual weeding. Use of appropriate weeding equipments coupled with suitable weedicides gives the best results against weeds. Conoweeder can be used as a package implement for row seeder and extensively used in the SRI type of cultivation.

Harvesting equipment

Delayed harvesting due to non-availability of labour leads to yield losses on account of shattering. Main equipment used for harvesting is sickle. In the improved sickles the cutting edge is serrated instead of being plain. The serrated edged-blades facilitate self-sharpening and better quality of the cut. The handles are made light with a better grip to improve the operators comfort. Some of the commercially available sickles are MAIDC, Vaibhav and Naveen. These sickles harvest 17 per cent more area in a given time in comparison to traditional sickles.

Vertical conveyor reaper: Vertical conveyor reaper (VCR) harvests and windrows the crop to one side. This augurs well with the farmers' practice where the paddy is left in the field for some time for proper drying. One of the commercial models available in the market is operated with 3 hp petrol-start, kerosene-run engine. It can harvest about half an acre in one hour. The fuel consumption is only 2 liters kerosene/acre. The shattering losses are also minimized. The machine is fully commercialized.

Combine harvester: This is self-propelled (105 bhp at 2,200 rpm) machine which cuts, conveys, threshes, cleans and bags the produce from the field. It can harvest even a lodged crop. Wheel and chain combines are available. The chain combine is having more maneuverability by having lesser turning radius. It has working width of about 4.2 m. It can harvest 0.8-1.2 ha/h of paddy. The straw disposal and utilization seem to be problematic with the use of combines.

Threshing equipment

Traditionally threshing is done by treading with bullocks or trampling by tractors. It takes more time and loss of yield through unthreshed paddy is more. This has been replaced by power-operated threshers of 5 to 15 hp with either diesel or electrical power-driven source.

Pedal operated thresher: It consists of wire-loop type threshing cylinder operated by foot pedal. It is suitable for threshing rice. It saves 20 per cent labour and 40 per cent operating time compared to conventional method of hand beating on a wooden platform.

CONCLUSION

For enhancing the expected level of output from farming it is important to take up farm mechanization. By overcoming the constrains incurred there is scope for increasing farm mechanization in India. There should be effective linkage between R&D system and manufacturing and need to have effective feedback system.

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