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Conservation Agriculture Machinery: Research Advances and Contributions towards 'Make in India'

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ABSTRACT

Conservation agriculture (CA) system is increasingly adopted to meet the goals of sustainable crop production intensification in feeding growing global population whilst conserving natural resources. Mechanization is a key input for CA. Satisfactory progress has been made in developing and evaluation of a number of CA machines such as laser land leveller, no till drill, Turbo Happy Seeder, multi-crop planters, and relay seeders - all suited to major cropping systems in India. There is however, a need for further refinement in the machinery for CA to increase efficiency to adapt to diverse soil and climatic conditions, particularly for smallholders and rainfed cropping systems. Smallholders of the country often face problems in making the necessary investments. As a long-term solution for smallholders farmers of the country, who often fails to make necessary investments, supply-chain needs for locally manufactured machinery with service back-up support should be built up to continue availability at affordable price. It is important to equip and train CA custom service providers. With the right equipment in meeting the needs of the local farmers, and the right technical and business management training, such custom service providers can make a livelihood by supplying high quality CA and other mechanization services at the door step of smallholders on affordable rent. Training / testing of CA equipment design, development of multi-tasking equipment and latest manufacturing techniques will certainly help the growth of agricultural machinery industry to achieve the mission "Make In India"

Key words: CA mechanization, custom service providers, multi-crop planters, smallholders, training needs, Turbo happy seeder

Introduction

Combine harvesting of rice and wheat leaves large amounts of loose and anchored crop residues in the fields. While about 75% of wheat straw is collected using the straw combine for use as fodder, rice straw is considered to be a poor feed due to its high silica content, and it has no other economic use. The loose rice residues in the fields hamper tillage and seeding operations for the subsequent wheat crop. Therefore, open-field burning of rice residue is a common practice in northwest India to clear fields for timely sowing of wheat. Substantial losses of plant nutrients (especially N and S) and organic C occur in the process, with important implications for soil quality and human health (Singh *et al.*, 2010). In-field retention of crop residues is important for replenishing soil nutrient stocks and organic matter, thus conservation agriculture (CA) contributes to sustainable RW production systems (Yadvinder-Singh *et al.*, 2005, 2014). In-situ incorporation of

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rice residues is however, energy- and time-intensive and delays wheat sowing, affecting yields adversely (Singh *et al*., 2010). Cost-effective management of crop residues is thus becoming a major challenge although proves an opportunity for increasing the sustainability of the intensive rice-wheat (RW) system.

Relay seeding of crops in wheat-based systems offers an excellent opportunity to improve crop productivity and farmers' income in India. In cotton-wheat system, yields of wheat are markedly lower after cotton due to delay in sowing compared to that after rice and maize. New machinery is therefore needed for timely seeding of wheat into the standing cotton crop. Similarly, integration of short-duration mungbean in wheat-based cropping systems can provide protein for poorly nourished population, and enhance farmer's income beside improving soil health. However, sowing of mungbean after the harvest of wheat gets delayed leading to crop failure due to overlapping of maturity period with the onset of monsoons. Again, relay seeding of mungbean in standing wheat crop helps in advance sowing so that the crop matures before the monsoon season.

Maize-wheat and rice-maize systems are receiving greater attention than before for diversifying RW system. Although progress has been made in developing and promoting machinery for direct seeding of wheat into combine harvested rice fields, CA machinery is still lacking for a range of other crops and cropping sequences. Majority of land holdings in India are between 1-2 ha, and therefore, CA machinery is needed for both large and smallholder farms. Small size of land holdings, poor economic condition of farmers, low seasonal use of machinery, irregular size, shape of fields, competition among machine and labour and mind set of farmers towards zero till sowing of crops can be listed as major constraints in adoption of CA machinery in India.

Machinery for Conservation Agriculture

CA based management practices must be evolved for both large and smallholder farmers to realize its potential. CA is not just a simple change in ones production practice, it involves simultaneous change in a number of cultivation practices including agricultural machinery. Developing CA machinery suited to local conditions and diverse cropping systems has been a crucial factor in the diffusion of CA technology in South Asia. Development of appropriate machineries for all types of field operations (seeding, fertilizer management, water management, residue management, irrigation, herbicide and pesticide applications) is needed for successful implementation of CA.

CA Machinery for Four-wheel Tractors (4WTs)

Laser land leveller

Irrigation is the most crucial input in agricultural production system in India, as nearly 40% of irrigated cropland accounts for 60–80% of total food production (Yadvinder-Singh *et al.*, 2014). Uneven fields and unlined irrigation channels cause loss of a huge amount of irrigation water. Results from a number of studies have indicated that laser land levelling (LLL) saved irrigation water by 20-25% by increasing application efficiency. It improved crop and water productivity of rice, wheat and sugarcane by 15-25%, and provided economic benefits to the farmers (Sidhu *et al*., 2007a; Jat *et al*., 2015; Kaur *et al*., 2012).

LLL is a laser-guided (light amplification by stimulated emis-sion of radiation) precision levelling technique used for achieving very fine levelling with the desired grade on the field within ±2 cm of its average micro-elevation (Fig. 1). It uses a laser transmitter unit that constantly emits 360° rotating beam parallel to the required field plane. This is received by a laser receiver (receiving unit) fitted on a mast on the scraper unit. The signal received is converted into cut-and-fill level adjustment and the corresponding changes in scraper level are carried out automatically by a two-way hydraulic control valve. Laser levelling maintains the grade by automatically performing the cutting and filling

Fig. 1. Field Demonstration of laser land leveller to trainees from West Africa at BISA, Ludhiana

operation. A grid survey is performed using grade rod to identify highs and lows in the field and mean grade is calculated.

The LLL has been successfully adopted on 1.75 M ha area in Punjab state alone and more than 7850 locally manufactured or assembled laser units are in operation. The cost of buying laser leveller is quite high and its limited use prevent the individual farmers to own the equipment. Thus, use of LLL is economically feasible and accessible through custom hiring services, even to low-income small farmers. However, farm size matters for achieving opera-tional efficiency of the LLL to manifest its full potential.

No-till (NT) seeder for anchored stubble conditions

The prevailing NT machinery in India is 4WT-drawn seed drill to place the wheat seed directly into untilled soil with a single pass. The drill was introduced in India in 1989 by CIMMYT and the first prototype of NT seed drill for Indian conditions was developed in 1991. The NT drill has inverted T-type furrow openers in place of shovel type furrow openers for tearing of anchored stubbles. This coulter and seeding system place the seed into a narrow slit made by the inverted-T as it is drawn through the soil by the 4WT. The coulters can be rigid or spring loaded depending on the design and cost of the machine.

NT seeder generally consists of a 6-row seed-cum-fertilizer drill with 1.2 m width. The seed drill has the most commonly used fluted roller mechanism. It can be operated by a 35 hp or above tractor. Its effective output is 0.35 to 0.40 ha h-1. The NT seeding of wheat is beneficial in terms of economics, irrigation water saving and improved timeliness of wheat sowing in comparison with conventional tillage (Malik *et al.*, 2004; Singh *et al.*, 2008; Erenstein and Laxmi, 2008; Lohan *et al.*, 2018). Earlier planting is the main reason for the additional yields of wheat obtained under NT system. However, wheat sowing with NT drill can be adopted only after removal or burning of loose rice residue from the fields because loose residue often interferes with the placement of seeds. Therefore, farmers frequently burn the loose residues in fields which is not an eco-friendly practice.

No-till drill for seeding into crop residues

There are problems with direct drilling of wheat or any other crop into loose rice residue using the standard NT seed drill due to: (i) straw accumulation in the seed drill furrow openers, (ii) poor traction of the seed metering drive wheel due to the presence of loose straw, and (iii) the need for frequent lifting of the implement under heavy residue conditions, resulting in uneven seed depth and thus crop establishment. Therefore, NT seeding into crop residues requires drills capable of cutting through loose straw, penetrate into soil and place seeds at proper depth. Generally, single- or double disc opener, and triple disc opener i.e. double disc opener equipped with either powered or unpowered rotary disc coulter are needed for managing crop residues in RW systems. Depending on the seeder, the components of these units are designed to cut residue only, or both residue and soil without causing significant disturbance to the seedbed. Cutting units, whether PTO powered or ground-driven, are normally fitted ahead of all other soil engaging components (to allow for free movement of furrow openers placed behind them), hence, minimizing blockage caused by accumulation of residues.

The development of Turbo Happy Seeder (THS) for seeding into rice residues commenced in 2002 at PAU Ludhiana with collaboration of ACIAR, and the first version of Happy Seeder was developed and recommended in 2007 (Sidhu *et al.*, 2007b; Singh *et al.*, 2009). Through series of further modifications, improved version of latest Happy Seeder (known as THS) was developed and evaluated for direct seeding of wheat into heavy loads of rice residue by PAU, Ludhiana in 2012 (Sidhu *et al.*, 2015). The THS consists of a rotor for managing the paddy residues and a zero till drill for sowing of wheat. The J-type flails are mounted on the straw management high speed (1000–1300 rpm) rotor which cuts (hits/shear) the standing stubbles/ loose straw coming in front of the sowing tine and clean each tine twice in one rotation of rotor for proper placement of seed and fertilizer in soil. The rotor blades/flails guide/push the residues as surface much between the seeded rows. The THS leaves the seeded rows exposed and clearly visible, enabling accurate lining up of adjacent sowing passes. This PTO driven machine can be operated with 45 hp tractor and can cover 0.3-0.4 ha hr^{-1} (Fig. 2).

Sowing of wheat into rice residue with the THS has many benefits, both economic and environmental. By avoiding the need to burn the

Fig. 2. Turbo Happy Seeder sowing wheat into rice residue

rice residue, significant air pollution can be reduced, soil nutrients are recycled and soil organic matter is increased (NAAS, 2017). THS performed well in farmers' fields across Punjab, with an average yield increase of 3.2% in wheat over the farmer practice. Previous studies on farmers' fields and on-station (Sidhu *et al.*, 2007b; Gathala *et al.*, 2011) showed similar or higher yields of HS seeded wheat compared to conventional practice. The increases in wheat yield for THS could be related to increased soil water availability due to reduced soil evaporation and better soil thermal regime with surface residue retention (Sidhu *et al.*, 2007b; Singh *et al.*, 2011). The lower canopy temperature in the THS sown wheat plots in mid-March led to increase in grain yield of 10-20% in abnormal years compared to farmers' fields (Gupta *et al.*, 2010). Sowing of wheat using the THS can save as much as 83% of the energy use compared to CT, and also reduce emissions of CO_2 through reduced fuel consumption. Economic analysis by Singh *et al.* (2008) showed that the HS technology is more profitable (Rs. 6757 ha^{-1}) than conventional cultivation when similar wheat yields were considered under the two practices. The net financial benefits almost doubled over conventional practice with a grain yield increase of 5% using the HS. In the majority of the experiments, early sowing of wheat using THS did not require pre-sowing irrigation due to presence of sufficient residual soil moisture in the rice fields. Thus, 75–100 mm of irrigation water can possibly be saved from the adoption of

HS technology. Residue mulch reduced soil moisture loss through evaporation by about 40 mm, and thereby can save one irrigation in wheat when irrigation scheduling was based on soil moisture potential. THS is now being extensively used in the IGP for direct seeding of wheat into paddy fields. The introduction of energy efficient blades and triple action straw management rotor in THS further reduced the operational power requirement by 20-25% and improved the field capacity by 15% (Manpreet Singh PAU, Ludhiana; Personal Communication). There were around 9737 and 4983 THS and Super SMS attachments operational in the NW India in 2018-19 wheat season. In Punjab, area under wheat sown using THS was 4,74,000 ha in 2019, which was 16% of the total area under RW in the state. The long-term use of THS with rice residue retention for four years or above improved soil organic carbon content and RW system productivity has increased by 560 kg ha^{-1}. THS can be used to sow wheat in rice residue, and dry seeded rice (DSR), moong bean and maize in wheat residue.

Straw management system (SMS) for attachment to combine harvester

The ‘combine’ harvests the rice and wheat crops in a width equal to its cutter bar width, and, throws straw from straw walkers in the centre of harvested area. The width of straw walkers is usually 1/3rd of the cutter bar width of combine which forms the lines of loose residues in the field parallel to combine operation. This uneven residue load hinders the operation of straw management machines. Uniform spread of loose straw is a precondition for the smooth operations of all second-generation drills and this operation takes around 8-13 man-h ha^{-1} for spreading of loose straw.

Super SMS was developed and evaluated jointly by PAU, Ludhiana and CIMMYT-BISA in 2016. It chops and spreads uniformly the loose straw coming out of harvester straw walkers. It can be mounted at the rear of the self-propelled combine harvester having 4.27 m cutter bar and engine power of 110 hp. The straw coming out of the straw walkers of the combine harvester is fed to the unit from one side and is discharged from the outlet of the housing. The chopped material is blown off tangentially and deflected using a deflector for uniform spreading the residues in the entire width of combine harvester (Fig. 3). Governments of Punjab and Haryana have made it mandatory for SMS attachment to the self-propelled combine harvesters. The weighted mean size was < 20 cm for the Super SMS attachment compared to > 30 cm for the traditional combine harvester without Super SMS attachment, respectively. The Super SMS attachment is precursor for all in-situ paddy residue management machines and it increases the field capacity of THS by 0.6 ha/day. Additional cost of straw spreading with Super SMS combine harvester over manual spreading is around Rs. 500 ha^{-1}. However, it resulted in the overall system saving of Rs. 300 ha^{-1} when considering increase in field capacity of THS.

Fig. 3. Combine harvester with Super SMS attachment while harvesting rice

THS for seeding mungbean and maize fodder

In general, about 75% of wheat straw is collected after combine harvesting using straw combines in the region and remaining 25% of wheat straw is burnt by the farmers. Turbo Happy Seeder (after a small adjustment in seeding mechanism) can also be used for direct seeding of summer mungbean or maize for fodder immediately after the wheat harvest, thus providing additional income to the farmers (Fig. 4). Therefore, CA interventions not only increase

Fig. 4. THS sowing mungbean in wheat straw (left) mungbean crop establishment in wheat straw field (right)

the income of farmer but also provide a window to add a legume crop in the RW cropping system.

NT planter for direct seeding of rice

A shift in rice production system from puddled transplanted rice (PTR) to dry seeding of rice (DSR) is a resource conservation technology (Gupta *et al.*, 2006). DSR avoids puddling and does not need continuous submergence and thus reduces the irrigation requirement for rice cultivation. The adoption of DSR cultivation in India, especially in NW is increasing at a fast rate due to the scarcity of labour for conventional PTR. This technology significantly reduces cost of rice production (Jat *et al.*, 2009). In the absence of suitable DSR seeding equipment, farmers were using a very high seeding rate for manual seeding or using inappropriate seed drills. This practice led to poor yields of DSR because greater competition for sunlight and poor translocation of photosynthates to reproductive parts. Thus, there was a dire need to develop a planter for DSR and other crops. A DSR planter with inclined plates developed in India has now been developed in NW India and is being promoted for adoption by the farmers. The seed metering and delivery system of the planter consists of seed box, inclined rotary metering plates, seed cups, seed metering strip, seed delivery pipe and seed boot. These rotating plates have grooves which guide the seed and drop it into the cups. The seed metering strip attached to the seed box in such a manner that the seed box is tilted when there is an adjustment on the system. It is a strip of iron on which equally spaced holes are provided. The holes connect the strip to the seed box with the help of nut. By changing the holes, the seed rate can be adjusted. The DSR planter maintains optimum plant to plant and row to row (20 cm) distance without any mechanical seed injury using a seed rate of 15-20 kg ha^{-1} at seeding depth 2-3 cm. The planter has a working width of 1.8 m and field capacity is 0.4 ha/h. There are different seed metering inclined plates for different crops (Fig. 5). The plates vary from each other in size of groove, number of grooves and shape of the grooves. The size, number and shape of the grooves are designed to suit the specific crops. To change the plates, the nut in the centre of the plate is opened and then after changing the plate it is tightened again. The inclined plate metering box can also be attached to the existing ZT drill/ THS as an alternative to buy a separate machine. The present cost of the machine is about Rs. 75000. The DSR planter is also gaining popularity in the eastern IGP.

An additional inclined plate box can also be attached to the existing NT drill or THS as an alternative to buy a separate machine (Fig. 6). This machine can be operated with any 35 hp tractor.

PAU, Ludhiana has also developed a Luck seed drill for DSR with spraying attachment. The drill consisted of an inclined plate seed metering mechanism with notched cells and having 9 furrow openers, a tank, hydraulic pump, and nozzles mounted on boom. The drill plants the

(a) (b) (c)

Fig. 5. Types of inclined plates used in multi-crop planter, a) wheat, b) maize and c) rice

Fig. 6. Happy Seeder with inclined plate attachment for sowing rice, maize and other crops

rice seeds and simultaneous sprays the weedicide. Thus, there is a saving of labor and timely spraying helps in better control of weeds.

4WT Front Mounted Knife Roller for Managing Maize Residue

Maize-wheat and rice-maize are the two other important cropping system followed in NW India. Maize is considered a promising option for diversifying agriculture in upland areas of India. Traditionally, seed bed preparation for maize involves several tillage operations. However, maize can be grown without any preparatory tillage on both permanent raised beds and flat beds with zero till/THS having inclined plate planter mechanism.

For managing maize stover, a knife roller developed locally by BISA Ludhiana can be attached in front of the tractor and the seeding machine (THS) on the rear of tractor can be used for the direct drilling of wheat into maize residue in a single pass of the tractor. Knife roller consists of straight knives mounted on the entire periphery of the rollers (Fig.7). The knife roller rotates with passive power from soil surface. The knives cut the maize or any other residue by shearing the residues between the soil surface and knife edge. Knife roller is a tractor front mounted and on the rear of tractor the seeding machine can be used so that the direct drilling of next crop (wheat) can be done in single pass of the tractor. The knife roller can be operated with 45 hp tractor and field capacity of this machine is 0.8 ha h^{-1}. It is commercially available in NW India from several manufacturing companies.

4WT Tractor Driven Relay Seeder for Cotton-Wheat System

CW rotation covering an area of about 3.5 mha is one of the potential candidates for major gains in future wheat production in India. Wheat planting after cotton is often delayed due to late

Fig. 7. Knife roller with Turbo Happy Seeder for sowing wheat into maize residues

pickings in cotton and the time involved in 5-6 tillage operations for seed bed preparation for the following wheat. The average productivity of wheat after cotton is lower (about 3.2 t ha^{-1}) compared to that after rice in RW system (about 4.7 t ha^{-1}) (Buttar *et al.*, 2013). Delay in wheat sowing in the CW system can be avoided by relay seeding in standing cotton (Buttar *et al.*, 2013). The traditional 4WTs with ground clearance of around 45 to 50 cm cannot move in the standing cotton field as the plants are about 100 to 130 cm tall. To address this issue, a high clearance platform attachment for a 4-wheel tractor was developed by PAU Ludhiana in collaboration with BISA Punjab, India and Rajar Agricultural works, Mullanpur, Ludhiana (Punjab). This platform increased the ground clearance of the tractor to 115 cm to make the tractor move easily above the standing cotton (Fig. 8). The track width of mounted tractor was increased by 1.5 times the standard one (from 135 cm to 202.5 cm), which enables high clearance tractor to move in both 67.5 and 101 cm row geometries of cotton and increase the stability of the tractor. Any traditional tractor (ground clearance ~45 cm) can be converted to high clearance tractor by mounting on high clearance platform in 4 to 6 hours.

Relay seeder (suitable for 67.5 and 101 cm cotton row spacing) fitted with three types of furrow openers (zero-till inverted T-type), ZT double disc (ZTDD) and strip rotor were

Fig. 8. Normal tractor and mounted on high clearance platform (left) and 15-row relay seeder with ZTDD openers relay seeding wheat into standing cotton (right) (Source: Manpreet-Singh *et al.*, 2016)

evaluated, and ZTDD furrow openers proved superior for relay seeding of wheat in standing cotton crop in a single operation (Fig. 8). Early sowing of relay wheat by 31 days compared to CTW increased grain yield by 19% (Manpreet-Singh *et al.*, 2016). Net returns from CW system were Rs 20,837–27, 625 ha^{-1} more (an increase of 27- 37%) under relay seeding of wheat using high clearance tractor due to lower tillage costs and higher yields of seed cotton compared with the conventional CW system.

Relay seeding of mungbean in wheat

The high clearance 4-wheel tractor driven relay seeder was also evaluated for relay seeding of MB in to the standing wheat in the month of March (Fig. 9). Wheat was planted in paired row system and MB was planted in the wider space in paired rows. Early relay sowing of MB by 20-25 days ensured MB yield of about 1.0 t ha^{-1} escaping challenge from early onset of monsoon rains obstructing the harvest of the crop.

Machinery for permanent raised bed planting system

Raised bed planting, a form of controlled traffic, is a promising resource conservation technology, which was introduced for wheat in India the mid-1990s. Permanent raised beds (PRBs) with stubble retention (a form of CA) add the opportunity for NT seeding of crops with associated benefits of CA. The PRB planting system also provides opportunities to reduce the adverse impact of excess water on crop production, particularly in MW system and other water logging sensitive crops. The PRB system also offers many other benefits, including 25-30% irrigation water saving, opportunity for mechanical weed control as well as reductions in lodging and seeding rate. Bed size depends on soil type and cropping system (e.g. row spacing) followed and may vary from 50-120 cm. The most common size of each bed (mid of on bed to mid of adjoining bed) is 67.5 cm; 37.5 wide from top with 30 cm wide furrows. In CA, the PRB are maintained with minor shaping during seeding. Bed planters have been developed for farmers who grow crops on PRBs which simply reshape the beds before planting the next crop and retain all or part of the crop residues on the surface. The PRB planter consists of double disc furrow openers along with bed shaper (Fig. 9). The double disc furrow openers make a narrow slit for seed and fertilizer placement and managing maize residue thereby causing little damage to the permanent beds compared to other types of openers. The double disc planter sows one maize row at centre of bed with seed to seed spacing of 20 cm and two rows of wheat at 30 cm row spacing in the presence of residues. The NT planter with double disc openers to cut the maize or any other residue coming in front of seed row. The passive anti-blocking double disc planter is powered by 4WTs. NT planters having inclined plate seed metering systems facilitates in placement of seed and fertilizers at proper depth in one operation. The press wheels are also

Fig. 9. Inclined plate planter with double disc furrow openers sowing wheat MW system on PRBs (left) and earthing up/weeding in PRBs in wheat (right). (*Source:* BISA, Ludhiana)

Fig. 10. Band placement of fertilizer nitrogen in wheat using double disck planter nitrogen (*Source:* R.K. Jat, BISA, Pusa, Bihar, India)

attached behind the double disc openers to close the seed row for better soil seed contact to enhance the germination. The multi-crop double disc planter has also been developed which can be used for planting of different geometry crops. The NT bed planters can also be used for weeding in standing crop. The PRB planting helps in getting good crop stand, and higher productivity and resource use efficiency in MW system (Parihar *et al.*, 2016).

Surface application (broadcast) of fertilizer under CA leads to more loss of nutrients resulting into poor nutrient use efficiency and environmental pollution. Therefore, proper placement of fertilizer is very crucial to ensure that plant roots can absorb required nutrient during the growing period and thereby increase the nutrient use efficiency (Sandhu *et al.*, 2019b). The NT planters can also be used for placement of fertilizer at appropriate depth in the standing crop of wheat, direct seeded rice, and maize using 4WT with narrow tyres (Fig. 10). The double disc openers can place the nutrient at 5-10 cm depth near root zone in standing crop under CA or permanent raised bed system. Drilling of fertilizers improved wheat grain yield (by 670 kg/ha), profitability (by Rs. 7700/ha).

Mechanization of smallholders CA systems

In various forms, CA is now being practised over 180 million ha globally (Kassam *et al.*, 2019) but mostly in large mechanized farms and rainfed and supplementary irrigation areas. Smallholders in many Asian countries are limited by farm power shortages. Conventional 4WTs operated CA machines may not feasible for many smallholders owing to their high capital costs, unsuitability for fragmented holdings as well as farm topography and slope. Rapid adoption and scaling out of the use of the 2WTs for primary tillage has occurred in many Asian countries (Haque *et al.*, 2017). As a result, there are now large numbers of 2WTs operating in Asia. However, there are only a few 2WT-based planters suitable for CA systems.

Low powered tractor operated THS

Currently, efforts have focused on expanding CA among smallholder farmers in South Asia. Example of innovation in CA planters for smallholder farmers in eastern IGP of India and Bangladesh are the development of smaller versions of THS that require low powered 4WTs and 2WTs as human and animal labour becomes less available (Fig. 11). The low hp 4WT operated THS has 5 seeding rows for direct seeding of wheat into rice residue for the smallholder farms. The smaller version of THS can be mounted on the 2WTs by removing the tiller attachment. Though, 2WTs have higher degree of operational complexity and maintenance requirements (and associated costs), but were supported with a higher level of training support provided by the manufacturers. The THS machine fitted to the rear of a 2WT can plant up to four rows with ZT.

Two-wheel tractor driven Laser leveller

The normal laser leveller requires 50 hp tractor for smooth operation in the field. Moreover, small holding size and irregular shapes of the field are hindrance to economic use of 4WT driven laser leveller, in eastern parts of the IGP. Efforts were made to design and develop laser leveller applicable for small-size holdings that can

Fig. 11. Turbo Happy Seeder coupled to a 2WT (left) and low powered 4WT (18 hp) (Right) (H.S. Sidhu, BISA Ludhiana).

be can be mounted onto 2WTs. Keeping this in view, a prototype of 2WT operated laser leveller was developed by Borlaug Institute for South Asia (BISA), Ladhowal, Punjab for the small farmers in Asia (Fig. 12).

Fig. 12. 2WT driven laser-assisted precision land leveller for small-holder farmers

NT planters for 2WTs

The development of NT planters for 2WTs provide a platform for implementing CA principles that will decrease costs of crop production (less fuel consumption and decreased labour requirements) and improve the crop productivity in the eastern IGP. There are few planters available for CA planting of crops using the 2WT (Bell *et al.*, 2019). The lightweight Versatile multi-crop planter (VMP) has been designed and developed as a NT seeder for smallholder farms which can be operated by a 12–16 hp 2WT (Fig. 13). Evaluation of the 2WT driven VMP showed promising results for the establishment of a range of crops in rainfed cropping systems in Bangladesh (Bell *et al.*, 2019). The effective field capacity of VMP ranges from 0.11 to 0.20 ha h^{-1}. The ex-factory price is INR. 70,000. Rice and wheat can be directly sown in strips by the VMP while maintaining crop residues and minimum soil disturbance as required for CA.

Fig. 13. Versatile multi-crop planter (VMP) attached to a two-wheel tractor (Bell *et al.*, 2019)

The 2WT operated bed planters are used for making raised beds for sowing, maize, wheat, rice and other crops on PRBs. For single axle 2WTs one or two row precision NT planter attachments are available, similar to the ones used on 4WTs, however with a limited residue handling capacity.

Two-wheel tractor self -propelled relay planter

A self-propelled relay seeder for 2WTs was developed by the Cereal Systems Initiative for South Asia (CSISA) and CIMMYT team in collaboration with PAU Ludhiana and Amar Agro Industries, Ludhiana, Punjab (Fig. 14). Relay seeding of wheat increased cotton yield by 11-14% by creating opportunity for one additional picking, which was made possible with the extended growing period for about 30 days. Wheat yield was increased by 25% under relay seeding compared to conventional sowing (Buttar *et al.*, 2013).

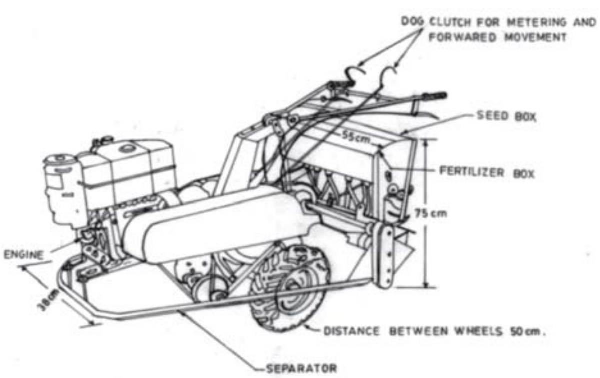

Fig. 14. Two -wheel tractor driven 3-row relay seeder for seeding wheat into standing cotton

The wheat yield gains with self-propelled walk behind type relay seeder were 12–41% compared with conventional till wheat after cotton. Being manually driven, it has a low field capacity (<0.6 ha day^{-1}).

Suggestions for Large Scale Adoption of CA Machinery in India

Currently 4WT driven CA seeders are available for commercial use in India. However, their uptake is slow and concentrated to some specific regions and production systems. A wider adoption of CA machinery across multiple regions and production systems will depend upon the availability of location-specific machinery, their spares and after sale services locally through a strong network of institutions including both state and central government organizations as well as active participation of industry/manufacturer of agricultural machinery and the farming community. With a view to procure socially inclusive outcomes, deployment of a capital-intensive CA mechanization technology, such as happy seeder, can be done through private-sector service providers. In order to develop high-performance CA machinery, the following are the key recommendations;

1. There is a need to develop a well-defined CA machinery requirement for different production systems and agro-ecologies for better targeting as one size doesn't fit all. This will provide a clear information to industry and policy planners for investment decisions
2. Policy support is crucial for the rapid development of the scale appropriate seeders/ planters, including provision of adequate research funding for the development of new machinery for the implementation of CA.
3. Although a variety of CA seeders have been developed and fabricated, further improvements/modifications are needed to suit to range of crops and soils in different geographical regions.
4. Efforts should be made towards developing and promoting multi-crop and multi-utility CA machinery for reducing burden on both public and private investments and effective use of investments
5. Effective policies need to be developed for the engagement of service providers, extension, machinery manufacturers and farmers in the implementation of CA in India.
6. For marginal farmers, limited resources and farm size, purchase of large machinery (built locally or imported) is a constraint. Therefore, the CA seeders need to be light-weighted, simple, affordable and suited to low horse power tractors.

7. For heavy clayey soils, CA seeders should use tines instead of discs, to facilitate planting and simplicity in design and operation.
8. In hilly areas, agricultural production is hampered by natural obstacles (rough/sloppy surfaces), therefore all no-till seeders should be modular having depth-control mechanism and contour-following capability with individual soil covering devices and pressing wheels.
9. Anti-blocking or self-cleaning tine mechanisms play an important role in the no-till seeder, especially in high residue conditions to ensure good performance and their adoption.
10. Research institutions, enterprises and farmers should have closer cooperation in designing suitable CA planters for different cropping areas.
11. Smallholder farmers are often not in a position to invest in expensive farm machinery. Financial support to these farmers should be provided to assist them in the purchase of CA equipment which will directly stimulate the local supply chain.
12. Private sector should be encouraged to conduct demonstration plots, machinery fairs and the formation and consolidation of CA farmer mutual support groups.
13. There is a need to equip and train entrepreneurial CA service providers. Service providers not only need good CA equipment but will also often need training in the technical aspects of its right use, calibration and maintenance, as well as training on the managerial skills of identifying and running a successful service provision model.
14. Avoid cross or counterproductive messaging and policies eg promoting no till drills and rotavators or roto-seeders at the same time. Similarly promoting ex situ and in situ crop residue management to the farmers.
15. Given the manufacturing capability of Indian Industry, quality standards and relatively competitive costs, India has a significant potential not only serve as CA machinery hub for Indian farmers but has significant potential for export specially for several Asian and African countries and contribute to 'Make in India' mission.

Conclusions

Although a number of CA machines have been developed in India for different crops and cropping systems, there is still a need for the low-cost and precision CA machinery for the different agronomic operations (e.g., fertilizer placement, weed and pest management, etc.) suited to different soils and cropping systems both in irrigated and rainfed systems to facilitate and accelerate the adoption of CA. The development new machine designs and the refinement of the existing CA machinery, and their adaptation to regional differences in soil, climate and crop production system is a continued process. Local manufacturing and service back stopping of CA equipment is a desirable goal as it not only helps to stimulate the local economy, but also provides the opportunity to adapt technologies to local conditions such as soils, climate, power source availability and production systems.

The CA opens new opportunities for wider use of CA machinery driven by single-axle 2WTs as a power source for small-scale farmers, such as multi-crop no-till seeders. Training of CA equipment design, multi-utility equipment development and latest manufacturing techniques will certainly help the growth of agricultural machinery industry to achieve the mission "Make In India". For accelerating the pace of adoption of CA and diversification in the region, development and evaluation of multi-crop, multi-utility sensor-controlled machines for CA and human resource development need immediate action as *"Un-sustainability cannot be an option in the modern agriculture"*.

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