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Last Mile Delivery of Conservation Agriculture in India: Business Models, Capacity Needs and Government Programmes

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ABSTRACT

The rice-wheat system in the north-western India produces huge amount of crop residue, which is being burnt by the farmers leading to environmental pollution. It presents huge opportunity for adoption of conservation agriculture in the region. Zero and minimum tillage seeders, like Happy Seeder, have been developed for sowing wheat, which helps resolve many associated issues viz. residue management, cost of cultivation, irrigation water and herbicide usage. But, conservation practices do not appeal to the farmers, owing to lack of immediate visible response. Therefore, they require multi-disciplinary and multi-stakeholder participatory approach based tools and techniques for last mile delivery, which involve capacity development, exposure visits, policy support and legislations, effective monitoring and tracking systems etc. The key constraint of the mind-set of farmers towards tillage should be targeted through awareness and capacity building programmes in popularizing conservation practices. Moreover, developing business models of machinery banks for effective and efficient adoption among farmers was emphasized by promoting entrepreneurship development of rural youth. A systematic pathway was developed for promoting conservation agriculture through frequent farmer-scientist-industry meets, involving rural youth, providing timely advisory services, establishing active bi-directional link between research and farmers and policy advocacy. This capacity building process comprised five inter-related stages ranging from dialogues amongst the stakeholders, capacity needs assessment, formulation of strategy to its final delivery and monitoring & evaluation at every stage. Likewise, with the Government support, different machines like Happy Seeder, Super Straw Management System, multi-crop seeders, mulchers/choppers, zero till drills, rotary slashes etc. were provided to the farmers at reasonable cost. Further, to promote conservation agriculture, efforts should be made to provide scale appropriate machinery, development of model technology hubs and scalable and sustainable business models, realizing multiplier effect of farmer-to-farmer extension, building partnerships, skilling manpower and harnessing information and communication technologies to the fullest.

Key words: Happy seeder, rice-wheat system, zero tillage, weed management, machinery

Introduction

Conservation agriculture (CA) is described by FAO as a concept for resource saving agricultural crop production which is based on enhancing the natural and biological processes above and below the ground (http://www.fao.org.ag/ca). Scientific evidences indicate that adopting CA helps in arresting soil degradation and restoring soil health, conserving and efficient use of water

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and nutrients, building resilience against climate risks, reducing costs of cultivation and increasing farmers' income. In India, zero tillage (ZT), a form of CA was introduced around 25 years back to address the second-generation problems of the Green Revolution in rice-wheat system (RWS) with notable success in adoption of ZT in wheat (Bhan and Behera, 2014). Traditionally in South India the second crop of legumes like greengram and black gram were grown as relay crop after rice without tillage. Later ZT maize was introduced in rice fallows in Andhra Pradesh, although CA has not been adopted in rainfed semi-arid regions. However, India has a potential to adopt CA in 40 million ha (GoI, 2019) in next one decade (15 Mha in irrigated, 20 Mha in rainfed and 5 Mha in rice-fallow ecologies).

The yield decline in ZT was observed in initial years and hence to boost CA at grass root level, farmers must be compensated for their environmental services on par with carbon trading in many advanced countries. The lessons learnt elsewhere (like USA, Brazil, Argentina, Australia, Canada, Kazakhstan, etc.), covering almost 180 Mha area, reveals that adopting CA for sustainable intensification could be the real pathway for restoring our degraded soil health both in dryland and irrigated regions with low soil organic C.

Although RWS is the most prevailing production system in North-Western (NW) India covering almost 4.7 million ha and recognized as heartlands of Green Revolution Maize can also be grown here in rotation with wheat. Rice-maize had been primarily introduced in Andhra Pradesh, Tamil Nadu, Karnataka and partly in Bihar and West Bengal, and could be introduced in other states also. The RWS produces huge quantities of crop residues and a large share of the surplus rice straw, estimated as 23 Mt. However, it is being burnt by the farmers in the months of October and November due to a short window for preparing the land for subsequent wheat crop (NAAS, 2017) and lack of its alternative economic use. Burning crop residue causes pollution in the atmosphere, apart from nutritional loss and soil health deterioration, (Keil *et al*., 2021). Rice-rice and rice-pulses are predominant cropping systems in south India, where rice residues are not left on the soil surface as these have alternative uses like fodder. In the rainfed areas, availability of residues for recycling is a major constraint since it has competing uses like fodder, and also due to uncontrolled grazing, low biomass production, single crop season (in alfisols), termite infestation, faster decomposition due to high temperature, and blown away of residues by winds. All of these impose challenge for adoption of CA at ground level in rainfed dryland ecosystems in India. It is imperative that farmers need to educate about the benefits of CA, which can be realised when all the three principles of CA are practiced. Crop diversification in rice-wheat, rice-pulses systems can be propagated through intercropping with legumes, relay cropping, introducing pulse crops like mung bean or cowpea as a pre-monsoon cover crop or post monsoon principal crop, Similarly, residues in rainfed regions can be improved by manipulation of harvest heights of the rainfed crops like 30 cm in pigeon pea and horse gram and 60 cm in cereal crops. Growing of legumes as pre monsoon crops or post monsoon crops and as live mulch can increase the residues.

Development of Innovative Machines for CA

Conventional tillage (CT) practices in wheat typically involve multiple passes of the tractor to accomplish ploughing, harrowing, planking and seeding operations (Erenstein and Laxmi, 2008). In contrast, ZT practice uses zero-till drill to sow the crop directly into unploughed fields in a single pass. During last couple of decades, ZT/minimum tillage seeders have been found economical for wheat, and provided timely sowing in comparison with CT in the RWS (Aryal *et al*., 2016; Jat *et al*., 2020; Keil *et al*., 2017). The early sowing of wheat helps in reduction of *phalaris minor* infestation and induce yield gains. However, there are problems with direct drilling of wheat into combine-harvested rice fields using the standard ZT seed drill due to accumulation of straw in the furrow openers, poor traction of the seed-metering drive wheel in presence of loose straw, resulting in uneven seed depth and poor crop establishment (Sidhu *et al*., 2015).

A recent version of Happy Seeder (HS) has been recognized as one of the key technological innovations, which were developed and validated over many years under diverse farmer circumstances (Sidhu *et al*., 2015). The HS is capable of direct drilling of wheat after the rice harvest with residual soil moisture, thereby saving pre-sowing irrigation equivalent to 1 million litres of water ha^{-1}. The use of HS reduces labour requirements for crop establishment by as much as 80%, fuel use by more than 50%, irrigation needs by 25%, and herbicide use by as much as 50% (Saunders *et al*., 2012; Keil *et al*., 2021; Singh *et al*., 2018). It further improves crop productivity, particularly under climatic stress conditions (Aryal *et al*., 2016; Saunders *et al*., 2012; Sidhu *et al*., 2015). The machine works best in combination with a simple straw-spreading mechanism, called the 'Super Straw Management System' (Super SMS) that can be attached to the combine harvester, making a uniform spreading of residue across the harvesting width. The development of the Super SMS enhances the efficiency of the HS and improves crop establishment and yields (Lohan *et al*., 2018; NAAS, 2017). However, the HS does not work satisfactorily in rainfed regions since the topography is undulating and crop residues are low in these areas. Moreover, seed covering mechanism may not be required in irrigated system due to presence of high residues, while in rainfed regions, amount of residue is lower and therefore, unable to cover the seeds. In addition to this, depth of placement of seeds also varies. Furrow opener works well in rainfed CA systems. Fuel efficient implements were developed at ICAR-Central Research Institute for Dryland Agriculture (ICAR-CRIDA) to sow the crops in rainfed regions under the CA system. The ICAR-CRIDA precision planter (zero till planter with herbicide and fertilizer applicator), like in the conventional planters has seed, fertilizer boxes, seed metering device, seed and fertilizer delivery tubes and seed depth control wheels in addition to herbicide tank. But the wide furrow openers are replaced with inverted T type openers to place seeds and fertilizers at appropriate depth in narrow furrows, which helps in placement of seeds at appropriate depth and seed coverage. A better seed soil contact and seed coverage helps in germination. Integration of *in-situ* moisture conservation through permanent furrow or permanent bed and furrow has proved to be an efficient technology for success of CA. Raised bed planter and CRIDA paired row planter aims for integration of soil moisture with three principles of CA. These planters can be used to reshape the bed and furrow every year and sow the crop without disturbing the beds and furrows.

Scaling out CA Innovations-Participatory Approach

The irony of CA based technologies is that they do not show immediate visible response to convince farmers, unlike the quick impact of using improved seed/fertilizer/irrigation. Therefore, dissemination of CA based innovations requires different approach, capacity and tools for the last mile delivery. Participatory approach is the most vital tool for delivery of CA-based innovations (providing need-based machines/ inputs etc.) on real time basis and reaching quickly to the farmers. Therefore, there is an urgent need to align the real need of farmers and provide professional solutions on CA. Following are some of the ways and means to promote CA by making robust programs by involving NARS:

- Facilitate large scale farmer's participatory demonstrations of proven CA practices through national initiative on CA.
- Capacity development and exposure visit to create awareness about conservation technology.
- Provide a common platform for convergence of the investments on sustainable soil and crop management practices, soil and water conservation for faster adoption of CA by the farmers in both irrigated and rainfed farming systems,
- Provide sound science based strategic support to the government for incentivizing farmers for eco-systems services,
- Serve as a capacity development & knowledge network through bringing together

the consortium of research and development public and private institutions for last mile delivery,

- Effective monitoring and periodic tracking of CA adoption, and
- Timely sowing of the crops by recycling of crop residues and preventing of residue burning.
- Proper and strict legislation incentives and punishment for discouraging residue burning.

Constraints for Adoption of CA

CA is a knowledge-intensive technology needing multi-disciplinary, multi-stakeholder participatory approach to harness its full potential and increase farmer income while conserving natural resources. Although best yield advantage can be obtained through adoption of all three components of CA, but often these are used in isolation. In rice-based cropping systems in Indo Gangetic Plains, ZT is practiced only in *rabi* crops. Direct seeded rice has several constraints Most importantly, the mindset of farmers towards tillage (Hobbs and Govaerts, 2010) is the key constraint, since farmers practise conventional tillage (CT) practices for many decades. Even researchers, extensionists, technicians and machine operators believe that successful cultivation is only possible with soil tillage. In rainfed regions also everyone believes that weed management is possible only through tillage. Therefore, for promoting CA, change in mind set and attitudes of the farmers and other stakeholders to adopt ZT is necessary (Derpsch, 2001). This can be achieved by organising field demonstrations and different educational programs. Further, easy access of low-cost CA machinery (e.g., ZT seeders) is needed, which is another major constraint for mechanized farmers, unless it is possible to modify their existing seed drills/ planters. The major constraints encountered for scaling out of CA technologies are shown in Fig. 1.

A transition from CT to CA may result in a mix of positive and negative effects that vary with

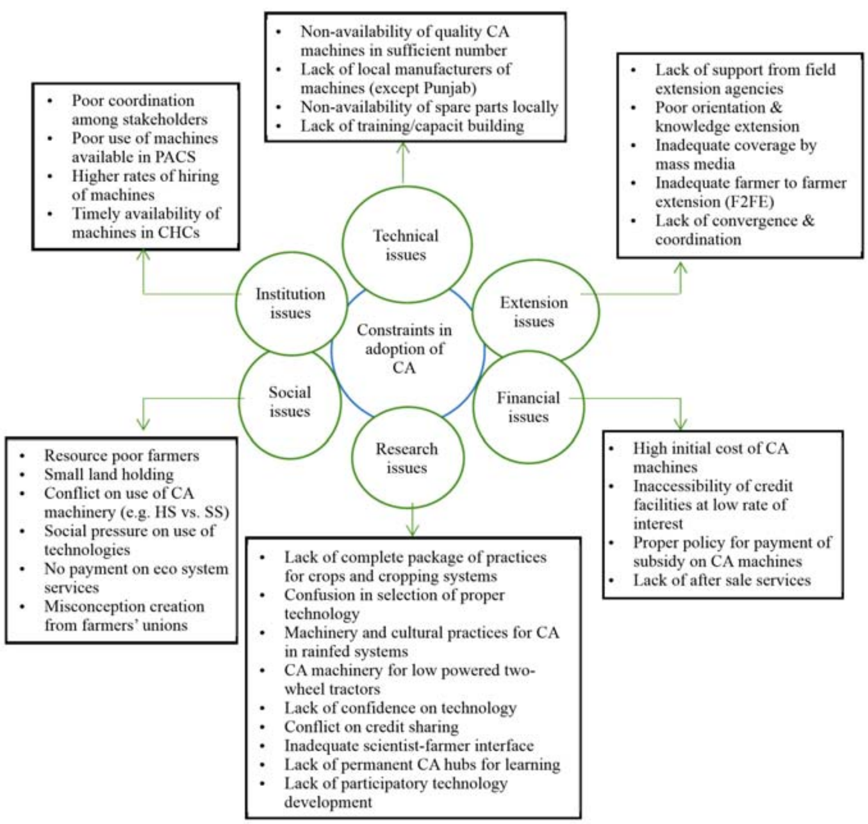

Fig. 1. Major constraints in adoption of CA Practices

the specific context. The combination of positive and negative effects in any given area will affect the yield, production cost and labor requirement in a crop or cropping system. If the principles of CA are taught broadly and farmers innovate and adapt, then it is more likely that they will be able to maximize the benefits and minimize the negative effects of CA using the resources judiciously.

Weed management is a major concern in CA system in both irrigated and rainfed regions. If all the three principles are adopted, weed infestation can be reduced to a great extent. However in rainfed agriculture, this will still be an issue as the efficacy of the herbicide depends on the soil moisture content. Affordability of herbicide by the farmers is another major concern. Integrated weed management without disturbing the soil may be adopted and farmers may be educated on the use of herbicides. The farmers need to be educated on the use of herbicide and adopt integrated weed management practices.

Business Models for Fast Spread of the CA Technology

The implementation of CA with all the three principles is important. Machinery use for promotion of CA is an essential component for its horizontal spread. Majority of the farmers, especially in the rainfed regions, are small and marginal and cannot afford to purchase machines. Also, underutilization of the costly machines has been noticed because of lack of custom hiring opportunities. Hence implements may be supplied at subsidy rates and soft loans may be provided for the procurement of the implements. Primary Agricultural Credit Societies (PACS), other state agencies and entrepreneurs may be encouraged to establish farm machine banks (MBs) and provide tractors and other CA implements on custom hiring. For upscaling innovative CA machinery like HS, different options are described below.

i) *Individual ownership of machine:* This model is primarily suitable for large and medium farmers (generally having > 4 ha land) who have their own tractors. These farmers are resourceful and can purchase machines for their own use, however, they can also provide machines to other fellow farmers on rent.

ii) *Individual ownership for self-use and custom hiring:* Medium farmers can purchase machines for their own fields, and carry out local custom hiring as well. Such farmers have the prospect to supplement their incomes by custom hiring beside own use. This model has the capacity of bringing higher operational efficiency of machines due to strong linkage between owner and fellow farmers within the village or in neighbouring villages. This model is also suitable to small farmers who take land on lease and can utilize the machines in very efficient way by cultivating their leased land and also on custom hiring of fellow farmers.

iii) *Custom hiring centres through Cooperative Societies:* The PCAS are very effective institutions due to strong and functional linkage with farmer members. Many PACS have their tractors and MBs, and provide these machines on hiring basis at competitive rates (with or without tractor and driver). Establishing Custom Hiring Centres (CHCs) of CA based machines can be very useful in horizontal spread of these machines.

iv) *Custom Hiring Centres (CHCs) or Machine Banks by private entrepreneurs:* Establishment of CHCs or MBs is an innovative solution for promoting machines for CA and has tremendous potential for increasing the income of farmers and bringing employment in rural areas. These banks/ centres can serve a bigger purpose by ensuring availability and accessibility to machines. Alongside, it provides larger opportunities to the owners to move into off-farm remunerative venture as service provider to the farming community. This model has the capacity of delivery of machinery services through entrepreneurship development.

v) *Availability of CA machines at farmers' door steps:* Easy access to CA machines is the need of the time. With the support of central government, more than 1.25 lakh CA related machines have been provided to farmers, owners of MBs, CHCs for use in fields for residue management. To harness the synergy and easy availability of machines at every corner of north-western India, there is a need to build a platform where all details of CA-machines and their availabilities are ensured. Department of Agricultural Cooperation & Farmer Welfare (DAC&FW), Ministry of Agriculture & Farmers' Welfare (MoA&FW), Govt. of India has developed Multi-language Mobile App platform 'FARMS- Farm Machinery Solutions' (https://agrimachinery.nic.in/Index/farmsapp) to facilitate local farmers of different states across the country with custom hiring services of MBs, CHCs and Hi-tech Hubs established under various government schemes without any computer support system. This app will help the individual farmers, willing to provide their agricultural machinery & equipment's on rental basis to increase their farm income besides making the optimum utilization of the available agricultural machineries available in MBs/CHCs/Hi-tech Machinery Hubs. This app will also provide a platform for sell and purchase of old agriculture machinery to farmers, and will facilitate easy and hassle-free access to machines and encourage CA machines available at farmers' door steps. Till date, 5.5 lakh farmers/users have registered; more than 70,000 numbers of CHCs/BMs/service providers have boarded their information on this platform besides more than 1.6 lakh implements offered their services for hiring. In coming times, such efforts will strengthen easy access of machines across states and regions thus paying path of *uberization* of CA machines.

vi) *Model of MBs for attracting rural youth for entrepreneurship development:* Looking into the need of capacity development of farmers on the use of CA machinery, each KVK in Punjab, Haryana and UP has developed MBs for dual purpose of imparting hands-on training to farmers and machine operators, and providing machines for use in their fields (Singh *et al.*, 2020). Each Machine Bank is having 25-30 machines for CA like HS, zero till drills, choppers, mulchers, MB ploughs etc. During 2018-21, KVKs of Punjab organised more than 365 hands-on five days training programmes in which more than 9500 rural youth, farmers and tractor owners participated. The trainees were specifically informed about the combo technology of Super Straw Management System (Super-SMS) and HS and its multiple advantages. Farmers were given literature on effective usage of machines in the field, certain specific tips, dos and don'ts etc. Separate Question-Answer (Q&A) sessions were conducted to clarify doubts in terms of using machines. Similarly, live method demonstrations on operating machines and sowing wheat while managing paddy straw have been effectively organised. Result demonstrations on HS-sown wheat, Zero-Till drill sown wheat, etc. were also organised at strategic locations of the farmers' fields to exhibit actual field conditions while managing crop residues *in-situ*. Demonstrations in farmers' fields on *in-situ* residue management technologies were conducted on 21,500 ha areas with participation of >32,000 farmers (Singh *et al.*, 2020). Efforts have been made to put all information of these machines available in MBs at KVKs on a single platform. Consequently, ICAR-ATARI, Ludhiana has developed mobile app platform 'KVK Machinery Bank App' which is available at Google Play Store (https://play.google.com/store/apps/details?id=in.gov.icar.atariz1). Farmers can use this app to get access to machines available in KVKs.

Last Mile Delivery–designing Pathways for Promotion of CA

In India, 70% of 100 million small and marginal farmers don't have access to critical agricultural extension services. In spite of the government investment in strengthening the public extension system, only 9% of the population uses the public-sector extension for information (NSSO, 2014). One of the most significant short coming of public agricultural extension *is its inability to reach small and marginal farmers due to absence of strong and effective last-mile connect at the village level.* Promoting CA in a mission mode is required to disseminate proper knowledge and skills through trained extension specialists, including youth, service providers and farmers, make available farm machinery on custom hire basis and the quality seeds of crops that adapt well and enable sustainable intensification. Thus, eliminating constraints on the last-mile delivery of customized services to farmers will require full attention of all stakeholders involved in the agri-food chain. This mission should target last-mile delivery at the grass root level by designing robust strategy in a participatory way:

- Creating mass awareness among farmers about benefits of CA through frequent farmer-scientist-industry meets,
- Strengthening capacity building programs on CA involving rural youth,
- Providing access to machines/inputs, technologies at low cost,
- Providing advisory services that optimize the use of technologies including credit,
- Providing an active bi-directional link between research and farmers, and
- Policy advocacy about the importance and long-term benefits of CA.

Improving last-mile delivery – Out of box approach

New approaches to supplement public extension and deliver the right information in the right format and at the right time are essential. Since CA is knowledge and capital-intensive, the researcher, extension agencies should lead efforts, in partnership with all relevant stakeholders, to improve farmers' access to CA based best management practices (CA-BMPs). Encouraging the adoption of CA-BMPs through effective delivery systems is the best option to maximize the benefits and minimize the negative impacts associated with CA. Following are some of the effective factors for promoting CA-BMPs that meet the expectations of the different stakeholders to gain public confidence:

- Engagement with farmers requires dialogue rather than one-way communication. The interactive mode is best mechanism to understand the perception of farmers.
- Location-specific technology/recommendations are essential based on socio-economic conditions of farmers. Customization is vital if farmers are to find the information relevant.
- Peer farmer behaviour remains a major driver for change in the absence of demonstrated improvement in performance through extension systems.
- Farmers' understanding of the cost-benefit ratio of every technology is critical.
- The availability and accessibility of the right agricultural inputs, including credit, is a crucial driver.
- Increasing the number of advisers and their proficiency is also essential. In this connection, private sector staff should be trained to complement public extension.
- Due consideration should be given to innovative approaches to the creation of user-friendly and real-time knowledge sharing platforms. Use of information and communications technologies, such as the internet and mobile telephony, had positive results in some developing countries and should be scaled up.

Training and Capacity Development Need for CA

Capacity development (CD) has emerged as one of the most important interventions for sustainable development in agriculture. According to Horton *et al.* (2003), capacity is the ability of an individual and an organization to perform effectively, efficiently and in a sustainable manner whereas CD is an ongoing process to increase the abilities of individuals, groups, organizations and societies to perform core functions, solve problems, define and achieve objectives and understand and deal with their development needs in a sustainable manner. Similarly, UNDP (2008) stated that CD as the process through which individuals, organizations and societies obtain, strengthen and maintain the capabilities to set and achieve their own development objectives over time. The CD is a knowledge-creating process, in which training and institutional strengthening are linked to local or tacit knowledge and aspects of ownership and is an iterative process of design-application-learning-adjustment.

Promotion of CA practices, famers need to use specially designed machines (for example HS) for *in-situ* crop residue management. The use of residue management machinery demands CD of farmers with respect to the operation of machines, their calibration, maintenance and remedies if any problem surfaces. The do's and don'ts of operating machinery is must to know for its long-term usage and effective management of crop residues. The lack of skills may also prevent farmers from purchasing or using machines as they may find the technology complex and tricky. Therefore, CD of farmers and machine operators was considered fundamental not only to ensure the timely operations and efficiency in machine usage but also in terms of developing confidence among farmers. Before organizing CD programmes for the farmers and machine operators, it is essential to develop the capacity of trainers (training of trainers) on *in-situ* residue management machinery. The systematic approach to CD consists of logically structuring and sequencing the disparate types of activities. This is achieved by CD process, which consists of five inter-related step/stages ranging from dialogues amongst stakeholders, capacity needs assessment, formulation of strategy to its final delivery and monitoring & evaluation at every stage (Fig. 2).

Before capacity needs assessment (CNA), it is necessary to involve all stakeholders in CD process. Stakeholders can be any group of people within or outside an organization who conduct, participate in, fund, or manage a programme, or who may otherwise affect or be affected by decisions about the programme or the evaluation (Horton *et al.*, 2003).

A need is considered as a gap between 'what is' and 'what should be', and is an essential element required for change (Hakimian and Teshome, 1993; Stephen and Triraganon, 2009). 'What is' represents present situation whereas 'what should be' is the desirable situation and the difference between these two situations is the gap. A training need exists when a gap between the work performance of an individual or organisation and a desired level of competency is perceived. Similarly, CD is considered important where there is a gap in terms of incumbents' knowledge, skills, and attitudes for a particular situation at one point in time. This gap is called a problem, which usually occurs when a difference exists between desired performance and actual performance.

CNA is an integral part of the CD at an early stage in the process. Thus, CNA is an analysis of desired against existing capacities which generates baseline data upon which all planning decisions are made. It helps in avoiding common mistakes such as spending unnecessary time on teaching difficult, yet relatively unimportant materials; or

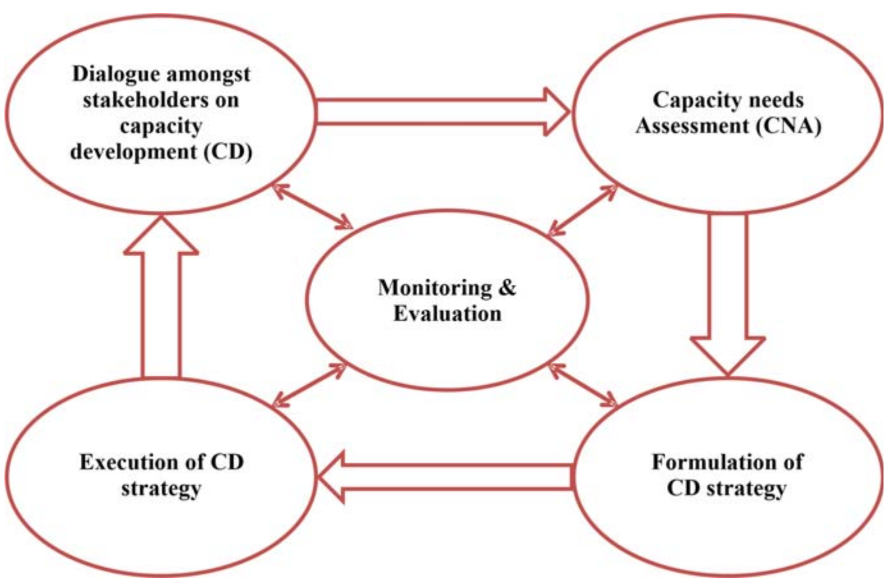

Fig. 2. Capacity development process for conservation agriculture

forgetting to include highly essential, but easy to teach materials; teaching what trainees already know, etc. Overall, it improves the effectiveness of CD programmes.

Capacity development programmes on in-situ crop residue management

The ICAR through its 60 KVKs has implemented central sector schemes on the promotion of agricultural mechanization for *in-situ* management of crop residue in the states of Punjab, Haryana, Uttar Pradesh and NCT of Delhi. In 2018, ICAR-ATARI, Ludhiana in collaboration with Department of Farm Machinery and Power Engineering, PAU, Ludhiana organised three CD programmes on "*in-situ* paddy residue management through machinery" for 120 scientists of KVKs of the above states/region. These programmes targeted at providing technical know-how of machines, their usage, etc. along with the details of the scheme and expectations from KVKs. Live demonstrations on machine operations, hands-on training sessions and visits to machine fabricators, CHCs etc. were also conducted for the participants. The participants were encouraged to develop a common understanding about the schemes and clear their questions/doubts related to the technologies. They were asked to provide feedback to the research system for timely upgrades in the technology packages. Based on CNA, 120 scientists of 65 KVKs were trained who organised 955 CD programmes on *in-situ* crop residue management using machinery during last three years (2018-19 to 2020-21) benefitting approximately 30,000 farmers, machine operators, owners of CHCs etc. These programmes helped reduce the gaps in knowledge, skills and attitudes of trainees about *in-situ* crop residue management in general and operation of machines, their calibration, maintenance in particular. Extension literature on residue management technologies in local languages including manual on HS were also provided to the trainees during CD programmes.

Government Efforts for Upscaling CA Practices

Looking into the scenario of residue burning in NW India and in pursuance to the Orders of National Green Tribunal (NGT), DAC&FW, MoA&FW, GoI released funds from within the sanctioned budget for 'Sub-Mission on Agricultural Mechanization' (SMAM) to promote CA practices in the form of *in-situ* residue management in NW India. Later on, it was noticed that interventions through SMAM are inadequate and need to be augmented through a separate scheme.

To address the problem of crop residue burning by promoting CA practices, MoA&FW, GoI initiated the central sector scheme on "Promotion of agricultural mechanization for *in-situ* management of crop residue in the states of Punjab, Haryana, Uttar Pradesh and NCT of Delhi" amounting Rs. 1152 Crores for two years (2018-19 and 2019-20) (MoA, 2018). It was later extended for the third year (https://agrimachinery.nic.in/Files/Guidelines/CRM.pdf). The scheme was fully financed by the Central Government. Under this scheme, financial assistance @ 50% of the cost of machinery was provided to the farmers for purchase of machineries for crop residue management, and financial assistance @ 80% of the project cost was provided to the Cooperative Societies of Farmers, Farmers Producers Organization (FPOs), Self-Help Groups (SHGs), Registered Farmers Societies and Panchayats for establishment of CHCs and establishment of farm MBs of crop residue management machinery. The major outcomes of these governmental efforts are mentioned below:

i) *Availability of CA machines for residue management:* With the rolling out of the Central Sector scheme to promote mechanization for *in-situ* crop residue management, farmers were made aware to procure machines on subsidy. The financial assistance in the form of subsidy to individual farmers and group of farmers resulted in procurement of large number of machines by the farmers and other agencies in Punjab and Haryana. During three years (2018-21), a total of 1,15,427 machines were provided to the farmers for *in-situ* management of crop residues in Punjab and Haryana (Fig. 3). The machines procured under this scheme included HS, Super SMS, super seeders, mulchers/choppers, zero till drills, rotary slashes etc. in Haryana and Punjab.

ii) *Establishment of Machine Banks/Custom Hiring Centres:* The scheme encouraged to establish MBs /CHCs for providing machines to fellow farmers on rent so that business model can be established for easy availability of machineries for crop residue management by small farmers. Consequently, a total of 24,392 CHCs were established with 69,075 machines in Punjab and Haryana in last three years (Fig. 4).

iii) *Impact on rice residue burning:* Rice residue burning was monitored by a multiple number of satellites with thermal sensors during paddy harvest and sowing of wheat (1st October to 30th November) over several years in the state of Punjab. The area under rice straw burnt was estimated by using moderate resolution multidate satellite images. The images were classified using hierarchical decision rule-based algorithm and ground truth was validated by Consortium for Research on Agro-ecosystem Monitoring and Modeling from Space (CREAMS) Laboratory at Division of Agricultural Physics, ICAR-IARI, New Delhi. The total number of burning events detected in the states of Punjab, Haryana and Uttar Pradesh during 2016, 2017, 2018 and 2019

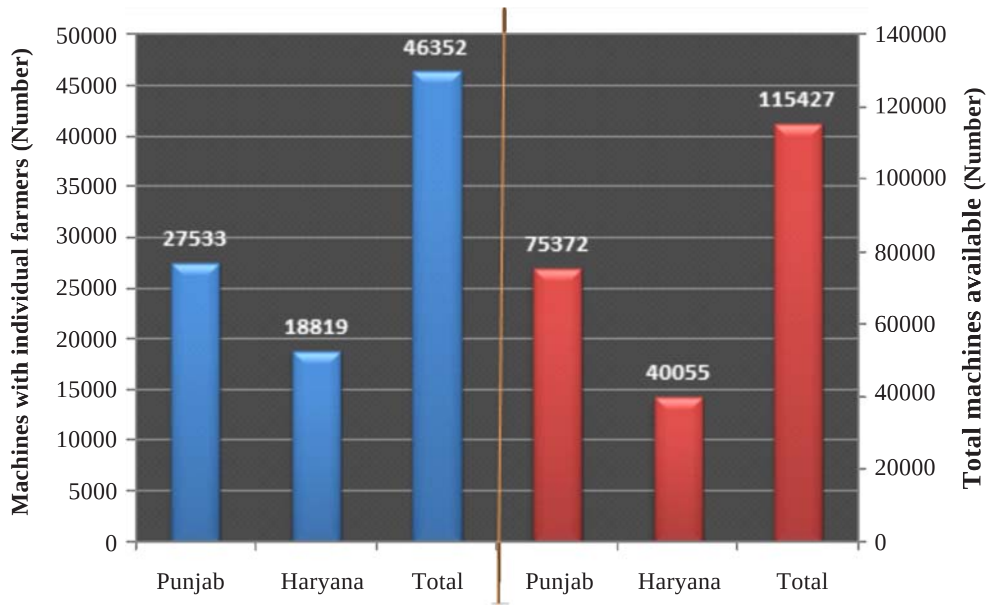

Fig. 3. Machines with individual farmers against the total machines available in Punjab & Haryana

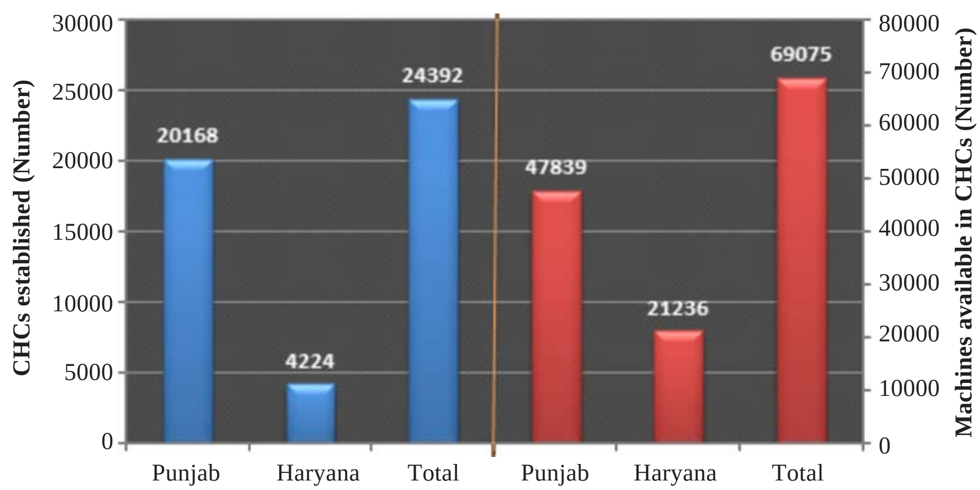

Fig. 4. Number of custom hiring centres (CHCs) established against the number of machines available in CHCs

were 12,7874, 88,948, 74,932 and 61,332, respectively (Fig. 5). Approximately 18%, 31% and 52% reductions in number of burning events were observed in 2019 compared to that in 2018, 2017 and 2016, respectively.

iv) *Impact on horizontal spread of direct seeded wheat using Happy Seeder:* The *in-situ* crop residue management practices has multiple benefits such as nutrient cycling, reduction in tillage cost, conservation of soil moisture, resilience to climate change and improvement in soil health. The efforts to popularize HS technology were started in 2014-15 and a large number of demonstrations were laid out at strategic locations in different districts of Punjab and Haryana by the KVKs. The area under wheat sown with HS started picking up from 2016 onwards in Punjab (Fig. 6). For example, the area under HS-sown wheat was only 15,000 ha in 2016 which increased to 35,000 ha in 2017.

The thrust by the Government of India to stop residue burning in NW India resulted into an unprecedented increase in the area of wheat sown by HSs. In 2018, with the availability of large number of machines on subsidy, the area under wheat sown with HS touched new record of 5.5 lakh ha, which accounted for 17% of area under wheat in Punjab (Punjab Remote Sensing Centre,

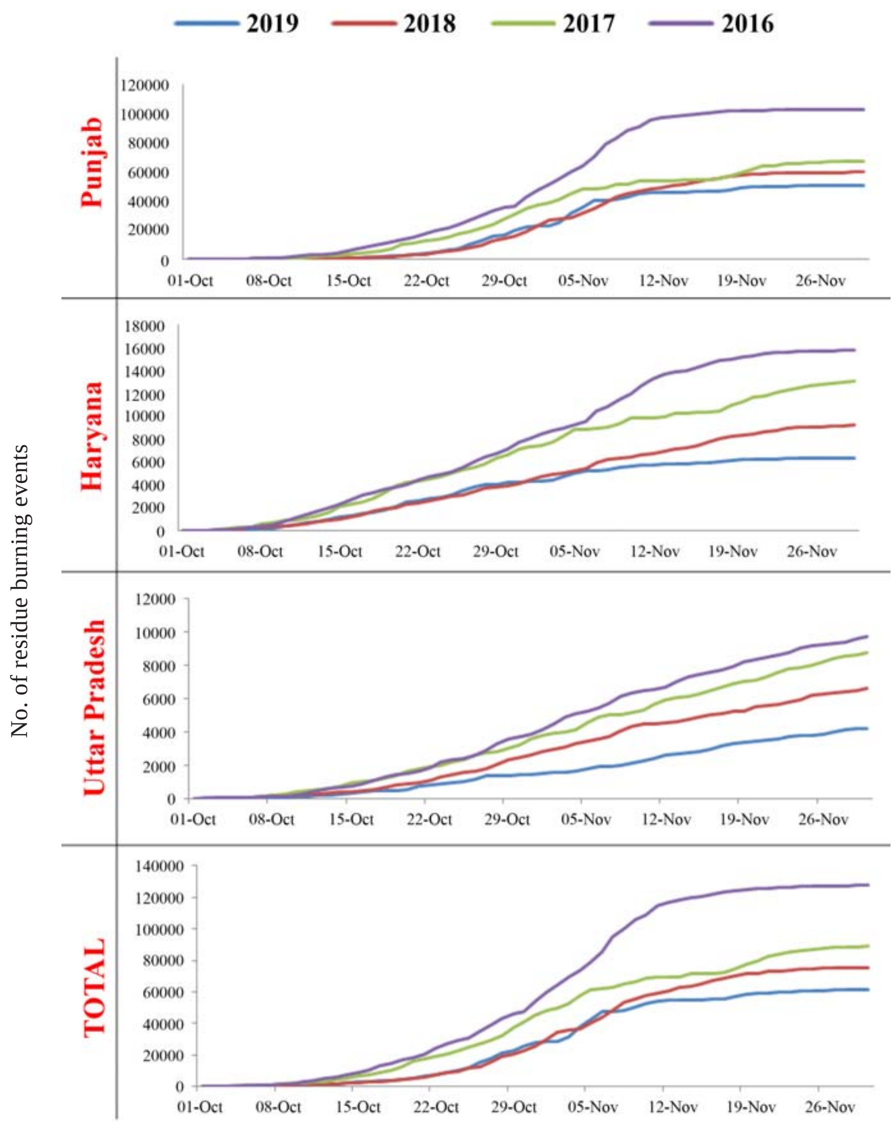

Fig. 5. Crop residue burning events over the years in Punjab, Haryana and UP

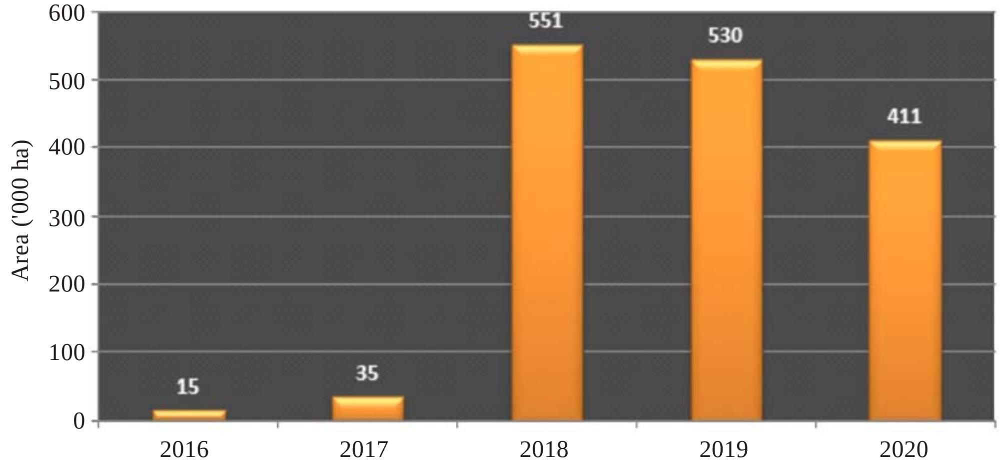

Fig. 6. Area ('000ha) under wheat sown with Happy Seeder in Punjab during 2016 to 2010

Ludhiana). In 2019, the area under HS-sown wheat was slightly reduced (3%) to 5.30 lakh ha compared to 2018. However, the area under HS-sown wheat reduced further to 4.11 lakh ha (25%) mainly due to introduction of new machine 'Super Seeder' recommended by the state government which attracted farmers and more than 10,000 machines were procured on subsidy during 2020-21.

The direct seeding of wheat with HS/zero-till drill into rice residue provides substantial saving of energy (diesel) and helps in timely sowing of wheat. Results from earlier studies based on 4100 demonstrations laid out on 1640 ha clearly showed saving of cost of cultivation to the tune of Rs. 4500 ha^{-1} (Singh *et al.*, 2018). If we extrapolate on an area of 0.8 million ha, the saving into cost of cultivation is Rs. 360 crore $year^{-1}$ in the states of Punjab and Haryana in 2018.

Similarly, the economic value of loss of nutrients due to burning of paddy straw is estimated as Rs. 3300 ha^{-1}; thus, the total value of nutrient loss due to burning of paddy straw is Rs.264 crore $year^{-1}$. In addition, sowing wheat immediately after rice harvest with HS will result in saving of pre-sowing irrigation water (7 cm or 700 m^3 ha^{-1}) with a total water saving of is 560 Million Cubic Meter (MCM) of water annually. In addition to this, it also helps in overall improvement in soil and air quality along with other eco-services due to non-burning of paddy residue.

Way Foreward for Large Scale Diffusion of CA

CA adopted over 180 million ha across the world has emerged as a strong substitute to tillage-based conventional agriculture. CA addresses several major challenges confronting agriculture in India including climate change, water scarcity, soil health deterioration, low farm profitability, environmental pollution and its adverse impacts on ecosystem and human health. In most part of India especially in rainfed and drylands, the low yields of food crops and oilseeds can be increased significantly through bridging the yield gaps by widespread adoption of CA-based sustainable intensification practices, yet conserving and protecting natural resources and reducing climatic risks.

With continuous reduction in farm size, small and marginal farmers owning <2 ha, individual ownership of agricultural machinery in general and happy seeders in particular, will be uneconomical. The challenge to policymakers will be to provide machinery at affordable rates or establish farm MBs and create high-tech productive equipment hub for custom hiring. Some important suggestions for large scale adoption of CA are described below:

i) *Providing commercial availability of scale appropriate machinery:* This is one of the critical factors for success and large-scale adoption of CA. Although significant efforts have been made in developing and promoting machinery for seeding wheat in no-till systems, successful adoption will call for accelerated effort in developing, standardizing and promoting quality machinery aimed at a range of crop and cropping sequences in different agroecologies. Providing machines and training to farmers will build confidence and capacity to use these machines for promoting CA. Hence, CA mechanization priorities need to be defined and strengthened in the regions having week manufacturing capacity and distribution channels. Special emphasis should be made on establishing CA mechanization hubs in rainfed ecologies and in Eastern IGP of India.

ii) *Development to CA Hub in different states and regions:* Direct benefit of CA like improvement in soil health and containment of climate change is not visible immediately as is the case with response of HYVs and fertilizers. In order to influence famers' mindset, there is need to develop CA hubs in different states and regions addressing different cropping systems. All the SAUs as well as ICAR research institutions and KVK farms should conduct large-scale demonstrations of CA-based systems for training of young researchers. The practical crop production program at undergraduate level should be mandated for CA-based production system. Similarly, scientists of research institutes/SAUs need to work closely with farmers through the medium of adaptive trials lasting for at least for 5 years. These pilots need to be in large numbers for spreading the message across large areas.

iii) *Scalable and sustainable business models of CA machinery:* Sustainable business models should be developed for promoting adoption of CA on large scale through motivating and attracting youth in agriculture and empowering women for creating effective CHCs as well as manufacturing hubs. Enhanced capacity development of all stakeholders involving farmers service providers-scientists-to policy makers should be an integral part of such models.

iv) *Harnessing multiplier effect of farmer-to-farmer extension (F2FE):* Many studies have shown that farmers prefer to learn from fellow farmer primarily because of ease of access, social closeness and the trust developed between both. When lead farmers play a key role in sharing the knowledge, they stand a chance of doing better than technicians because they are more familiar with the audience and environment. Indeed, F2FE can reach a large number of farmers at low cost through multiplier effects.

v) *Building partnership:* Partnership at various level (local, national and regional) is important for promotion of CA on vast tracts of irrigated and rainfed ecologies in the country. To make various programs people oriented, making alliance and broadening partnership with farmers, private sector, farmer organizations, women and youth, will be the key for future success. Improving access to technology and knowledge is an important way to share ideas and faster innovation. Hence, it is extremely important to build strong partnerships with all the stakeholders for accelerating growth in CA.

vi) *Skilled and scientific manpower:* Managing CA systems calls for enhanced capacity of scientists to address problems from a systems perspective and to be able to work in close partnerships with farmers and other stakeholders. Strengthened knowledge and information sharing mechanisms are needed. Similarly, there is urgent need of creation of knowledge and publication of literature in local languages about the potential of CA to agriculture leaders, extension agents and farmers.

vii) *Knowledge empowerment through ICTs:* Real time access to knowledge and information to value chain actors is critical for keeping pace with new challenges and harnessing opportunities for CA.

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