Climate Change and Indian Agriculture: Challenges and Adaptation Strategies

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Climate-Smart Technology Based Farm Mechanization for Enhanced Input Use Efficiency

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Abstract

Farm mechanization is a basic need in extensive agriculture production system. It plays a key role in timeliness of farm operations, quality of work and enhanced agricultural production. The agricultural production is observing erratic yield variations and unpredicted negative impacts in the wake of climate changes globally. In view of present challenges throughout the production system, the future growth has to come from the acceleration in the rate of farm mechanization. The farm mechanization level in India is 40 % with average 2.24 kW/ha farm power availability. On the other hand, Punjab has reached 4.4 kW/ha whereas in the hills of Uttarakhand, it is 1.05 kW/ha. The present mechanization is distinctly different throughout the country and still low to cope up with climatic variations in the agricultural sector as well as to enhance input use efficiency of natural resources. In addition to this, the crop residue is largely responsible for the degradation of climate during the peak season of wheat sowing due to the burning of crop residue. This chapter encapsules overall mechanization practices and the potential of some of the frontier farm machinery used in the various farm operations right from seedbed preparation to threshing and processing through enhanced input use efficiency for attaining climate-smart agriculture. Also, it discusses the possible strategies to increase climate-smart farm mechanization in the area of agricultural production system in every possible way.

Keywords: Climate-Smart Agriculture, Climate Resilient Agriculture, Farm Mechanization, Farm Machinery, Input Use Efficiency

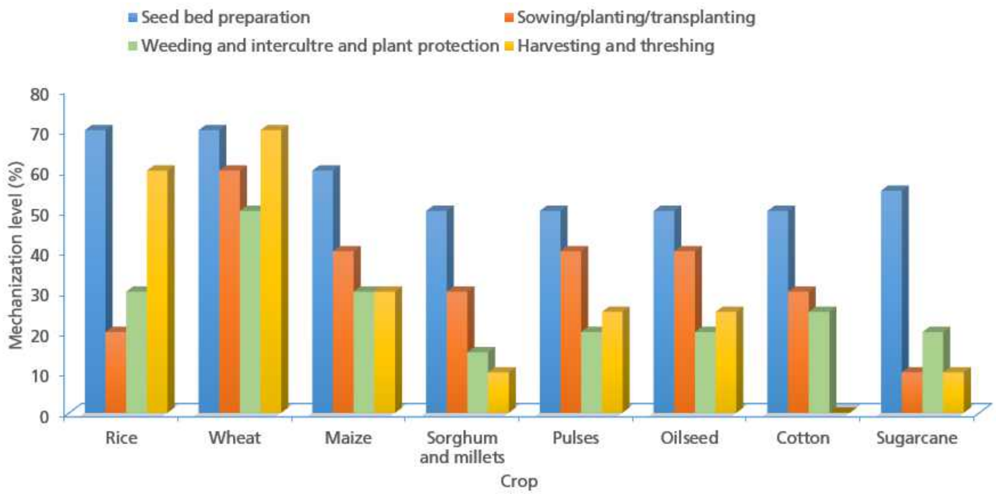
I. Introduction

I.1 An Overview of Mechanization for Sustainable Climate: Hand-in-Hand Approach

Agriculture is prone to natural and climatic risks that can have deleterious effects on the agricultural production system. Variability in climate poses a hazard to the agriculture production system and livelihoods of farmers (Wood *et al*., 2014). Agricultural production systems are confronting competition from other areas for limited natural resources. The improper management practices of these resources and their quality is also being affected by change in climatic and weather conditions. In order to cope with this situation, agriculture must be transformed through improved sustainable performance and resilience to the impacts of climate change in such a way that it does not compromise food security for all. These challenges have been intricately related and expected to be addressed simultaneously through climate-smart agriculture. Farm mechanization can be an effective answer to address these challenges which have a bearing on climatic conditions. Moreover, climate-smart technology based farm mechanization is a strategy for sustainable development of agricultural production systems and food value chains to ensure food security under climate change through judicious use of agricultural machinery. Climate-smart technology based mechanization in agriculture would help in building an agricultural system resilient to climate change as well as increased incomes through higher agricultural productivity. Also, there may be an increase in carbon sequestration with conservation agriculture or climate-smart agriculture, whichever is possible. Mechanization is not a new thing but adapting it for climate-smart agriculture is new, and innovative to lead to more productive and sustainable agriculture. This pathway would help to enhance the capability of farm machinery to adapt and mitigate climate change. Climate-smart agriculture is associated with actions in the field, involves the assessment and application of smart technologies and agronomical practices. Also, incorporation of supportive government policy, research framework and construction of investment strategies.

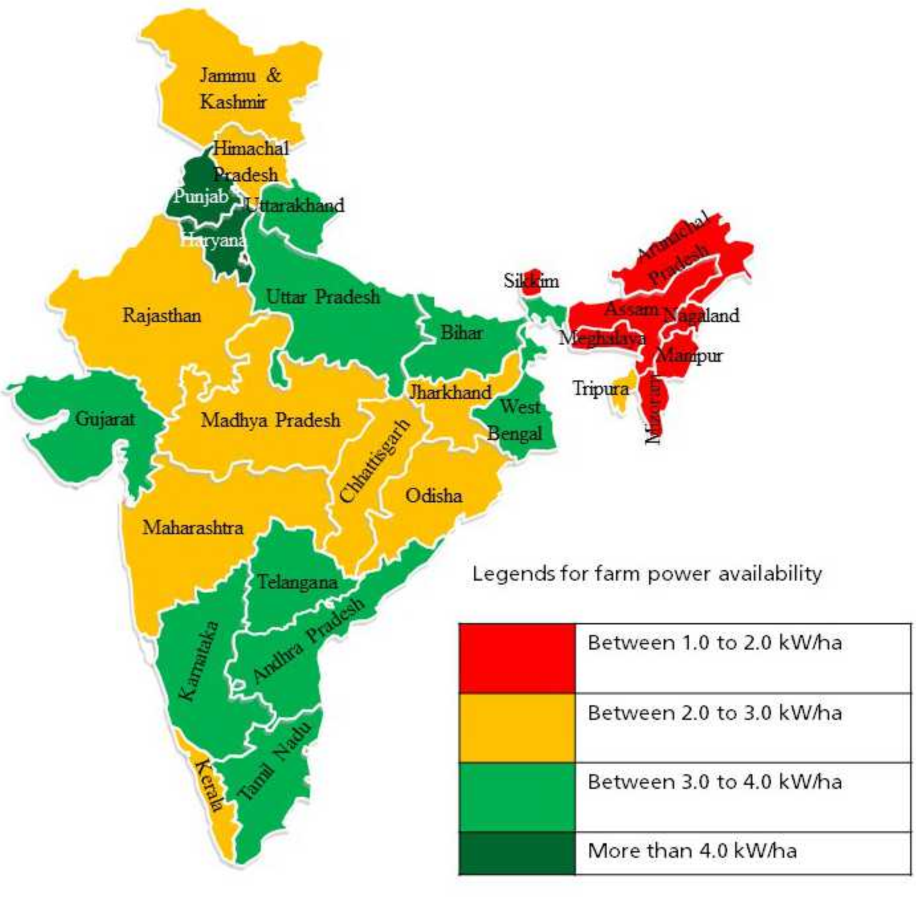
I.2 Mechanization Status, Demands and Opportunities

Farm mechanization is crucial to boost input use efficiency along with increased production and productivity. While looking into the global scenario; United States of America, Western Europe, Russia, Brazil and China have attained the mechanization level approximately 95, 95, 80, 75 and 59.5 %, respectively (Grant Thornton, 2017; Fang, 2017). On the other hand, India reached up to only 40 % mechanization level (Mehta *et al*., 2019). Mechanization level for major crops in India is shown in Fig. 1. Within India; Punjab, Haryana and Uttar Pradesh are the leading states in terms of farm power availability whereas North-eastern states are lacking behind (Fig. 2). The tractor penetration has been increasing whereas other farm implements are lagging behind.



Source: Mehta et al., 2019

Fig. 1: Mechanization Level for Major Crops in India



Source: DACFW, 2018

Fig. 2: Farm Power Availability in India

Farm mechanization is facing the constraint of fragmentation of farm size. In India, average farm size is less than 1.08 ha in which small and marginal farm land holdings (< 2.0 ha) contribute to 86.21 % of total operational land holdings and cover 47.35 % (DACFW, 2019). In spite of smaller land holding agricultural systems are highly vulnerable to climate change. Also, it may be subjected to lower farm mechanization in the farm operations to become food secure. The confronting challenge is fragmentation of land hat has contributed to small farm holdings. Decrease in availability of farm labourers which is expected to reduce about 26 % by 2050 is another problem. Custom hiring centers, co-operative societies and farmer producers organisations are the opportunities to the perk up present Indian agriculture. Providing financial support to the local manufacturers through Make-in-India initiative to develop farm machines or equipment as per local requirements which are expected to be imported from the developed countries. Small-scale mechanization and custom-hiring centers are fast evolving as feasible solutions for small landholding farmers.

The number of farm technologies have been developed but its frontline demonstration and the reach to the end user is still lesser in states of India which lies in between 2-3 kW/ha. Encouraging the use of available climate-smart technologies through climate-smart solutions could impact Indian agriculture in a focused manner. The management of ecosystems can lead to sustainable productivity with increased farm profitability through food security and environment protection while at the same time preserving and enhancing natural resources. Potential range of climate-smart agricultural techniques offered to farmers is large and as such the number of technologies accepted is highly subject to the farmer characteristics, farm situations and other economic conditions, affordability, government intervention, availability of market and information access. Farmers would adopt several technologies concurrently in cases where technologies are complementary. For example, water conservation can be accomplished through different technologies such as happy seeder, including those that reduce soil erosion (minimum conservation/ tillage and mulching), while a farmer undertaking livestock rearing may utilize the manure from that enterprise for soil health improvement. Climate-smart based mechanization is an agricultural development paradigm extensively promoted in developed countries to transform agriculture under a changing climate environment. There is ample scope for increasing farm productivity in India through technical, managerial and policy interventions to bridge the yield gap. Various studies (Government of India, 1996) revealed that the adoption of suitable mechanizing technologies could lead to

- Increased farm production and productivity by 10-15%
- Higher cropping intensity by 5-20%

- Savings in seeds up to 15-20%
- Saving in fertilizer and chemicals up to 15-20%, and
- Reduction in time and labour up to 20-30%.

I.3 Government's Initiatives for Farm Mechanization

Climate-smart agriculture is a present need in the scenario of enhanced agriculture inputs use as well as need for higher input use efficiency. In order to promote the usage of farm mechanization, the Government of India has initiated a scheme named as sub-mission on agricultural mechanization (SMAM) by increasing the farm power availability up to 2.5 kW/ha. SMAM is a Central Sector Schemes under several components for conducting training, testing, promotion, demonstration and strengthening of agricultural mechanization and management as well in which the Government of India contributes 100 %. contributes In Centrally Sponsored Schemes from the Government of India and states is 60 and 40 % except Northeastern states and Himalayan regions states where it is kept as 90 and 10 %, respectively. In the case of Union Territories, it is 100% centre share (SMAM, 2020). Also, a major issue of residue burning emerged and gained attention to make climate-smart strategies through promoting agricultural mechanization for in-situ management of crop residue with an investment of Rs 591.62 crore (DACFW, 2019). Government of India has provided financial assistance for establishing custom hiring centres for in-situ crop residue management by underwriting 80% of the project cost (PIB, 2020).

II. Climate-Smart Technology-Based Farm Mechanization

Climate-smart mechanization incorporates extensive range of farm machinery in various farm operations starting from seedbed preparation, sowing/transplanting, intercultural operations, irrigation, nutrient management, plant protection, harvesting and threshing or even in post-harvesting of crop *i.e.* straw management. The present climate-smart farm technologies in operation are discussed in this chapter

II.1 Mechanization in Seedbed Preparation

Seedbed arrangement is the primary stage for ideal crop development which has a major impact on yield potential. Seedbed preparation involves first operation *i.e.* tillage. Tillage is the mechanical manipulation of soil for weed control, seedbed preparation and a good porous root environment. It reduces soil organic matter, incorporates air into soil, leads to an increase in biological activity in case of mouldboard and chisel plough (Yiqi and Zhou, 2010).

Conservation tillage (CT) system conserves natural resources such as soil, water and energy resources through reduction of intensity of tillage and retention or mulching of crop residue (Uprety *et al.*, 2012). CT involves limited disturbance of soil for planting, growing and harvesting of crops. It maintains at least 30 % of the soil surface with crop residue while planting (Dinnes, 2004).

Conservation tillage methods include zero-till, strip-till, ridge-till and mulch-till. One million litres of water per hectare (100 mm) can be saved compared with conventional practices due to the mulch on the soil surface which reduces evapotranspiration (Rehman, 2007). Application of conservation tillage like no-tillage leads to sequestration of soil organic carbon (SOC) higher than the conventional tillage (Lenka and Lenka, 2014). Singh *et al.,* (2019) reported that the use of zero tillage in rice-wheat cropping system had reduced one million litres of irrigation water and diesel about 98 litres apart from these, reducing 0.25 mg of carbon dioxide emission. CT always does not increase SOC storage, an increased SOC at the top soil can be compensated by decrease at deeper soil (VandenBygaart, 2011). No-tillage has been an alternative to conventional seedbed preparation because it leads to an increase in carbon at top soil (Lenka and Lenka, 2014). Excess tillage stimulates organic matter decomposition, which leads to emission of CO_2 to the atmosphere (Uprety *et al.*, 2012).

Rotary tiller aids in mixing manure or fertilizer and removing and mixing weeds with soil. It reduces time and cost by around 30-35 % and 20-25 %, respectively (ICAR, 2007). Combined tillage is defined as simultaneously operating two or more different tillage implements to manipulate the soil, reduce the number and time of field operations. It reduces the soil compaction, labour and fuel cost as it reduces the number of trips. Combination tillage has a higher performance index of tillage than the conventional tillage. Furthermore, it reduces cost and time from 44 to 55 % and 50 to 55 %, respectively for seedbed preparation (Prem *et al.*, 2016). The laser levelling is a laser guided precision levelling technique

Table 1: Climate-Smart Technologies for Sowing/Transplanting

Nomenclature	Indented Function	Saving	Source
Zero till seed-cum-ferti drill	Sowing wheat directly in paddy harvested fields without seedbed preparation	Saving in time 50-60% and 40-50% in sowing cost as compared to the conventional practice of seedbed preparation and sowing with seed-cum-fertilizer drill.	ICAR, 2020a
Turbo happy seeder	Seeding wheat in rice residues	Reduction in power requirement and fuel consumption by 15.8 and 14.9 %, respectively.	Sidhu *et al.*, 2015
Tractor mounted raised bed planter	Sowing wheat at raised bed	Water saving 20-30 % and seeds 20 % as compared to conventional methods.	ICAR, 2020a
Strip-till seed-cum-fertilizer drill	Minimum soil manipulation and wheat crop sowing	Saving diesel to the extent of 42 l/ha and time 65-70% in comparison with the conventional tillage planting.	
Furrow irrigated raised bed (FIRB) planter	Making of furrow and planting wheat without field preparation	Saving in cost of operation 20-30 %, seeds 25 %, fertilizer 25% and irrigation water 20-30%	ICAR, 2020b

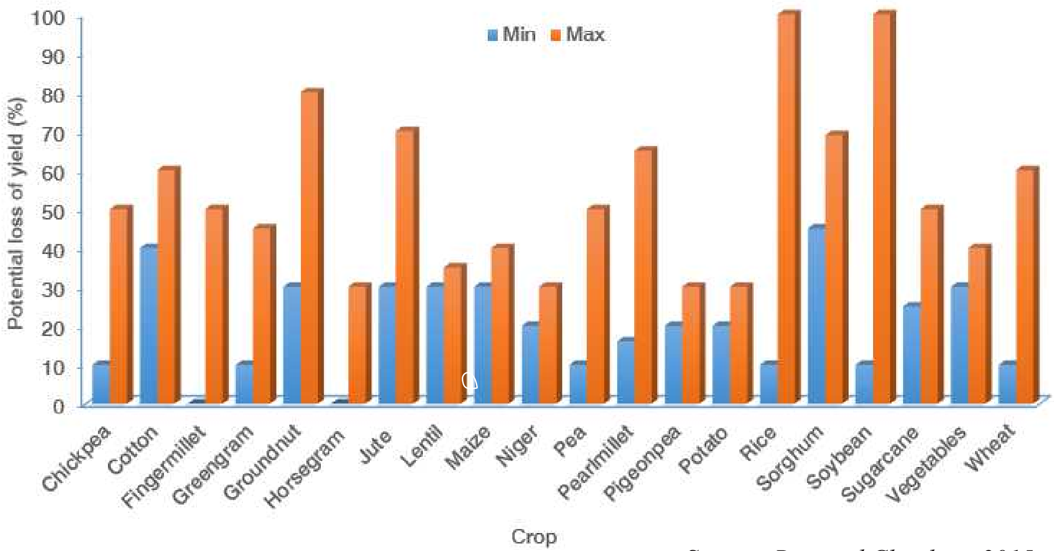
Broad bed and furrow (BBF) planter	Preparation of broad bed and planting crop	Saving in time 25-30 %, in irrigation and water saving up to 25-30% as compared to the conventional method	Vikaspedia,2020
Drum seeder	Seeding of rice	Saving irrigation water up to 40%.	
Self-propelled rice transplanter	Transplanting paddy seedlings in puddled soils	Saves about 65% labour and 40% cost of operation as compared to manual paddy transplanting	ICAR, 2020a
Animal drawn jyoti multicrop planter	Plant multicrop seeds	Saving in time over local seed drill was 3.72 hours/ha	
Animal drawn CRIDA drill plough	Different type of crop sowing	Reduction in energy requirement by about 54.5 % compared traditional practice	
Tractor drawn ananta groundnut planter	Sowing of groundnut in scarce rainfall zone (AP)	Reduction in cost of cultivation by Rs. 1150/ha compared to the traditional seed drill	Reddy *et al.*, 2015
Semi-automatic vegetable transplanter	transplanting vegetables	Saving labour in tomato, brinjal and chilli as 84.86, 85.58 and 88.41%, respectively over manual method.	Bhambota *et al.*, 2018.
Tractor operated small seed planter	Planting small seeds like onion	Saving in cost of operation 50 % and labour requirement 81 % as compared to traditional method of onion sowing.	ICAR, 2020a
Tractor operated garlic planter	Planting of garlic	Saving 82% in labour requirement and 57% in cost of operation as compared to manual planting.	
Tractor drawn turmeric rhizome planter	Turmeric rhizome ridger planting	Savings of 51%, 88% and 50% in cost of operation, labour and rhizome quantity, respectively as compared to the traditional method	
Cotton ridge planter	Cotton planting	Saving in cost of operation 42.72 % conventional method.	Raghavendra *et al.*, 2013
Tractor operated BT cotton planter	BT cotton planting	Savings in cost of operation, labour and time were 75.37, 88.23 and 90.27%, respectively as compared to hand dibbling method.	ICAR, 2020a
Sugarcane cutter planter	Cutting, planting and fertilizer application in a single operation	Reduction in labour requirement by 78 % and time of operation by 50 %.	ICAR, 2020b
Ridge fertilizer drill cum seed planter for soybean crop	Placing fertilizer below the soybean seed on the ridge of deep vertisols	Productivity level of soybean crop improved approximately by 30 % and saved 40% of basal dose of fertilizer	ICAR, 2017

used for achieving very fine levelling with the desired grade on the agricultural field. It also enhances environmental quality and crop yields and reduces greenhouse emission.

Controlled wheeling system has a wide range of benefits including extra output and reduces the variable input costs. It reduces the compaction yield by improving the structure of soil by around 15 %. Moreover, it operates with35 % less fuel requirement. The power requirement can be reduced by 30 % due to improved structure leading to less draught requirement (McCrum *et al.*, 2009). So, minimizing the amount of tillage enhances the carbon sequestration in the soil. Reducing the number of passes of equipment in the field reduces the cost of fossil fuel and associated carbon emission to the atmosphere which implies enhanced use efficiency of all inputs by decreasing losses.

II.2 Mechanization in Sowing/Transplanting

The sowing or transplanting is the critical phase in the agricultural production system. It must be done in the intended period to achieve the desired crop yield. Number of crops have to be sown at a time in various fields. The sowing or transplanting of a particular crop within the time frame with the manual method is not possible due to the labour crisis and human limitations. This can delay the operation if done manually and lead to climatic variation. The mechani-zation can bring in timely operation, precision, cost-effectiveness, resources and input efficiency, resource conservation like soil and water. Some climate-smart technologies for sowing/ transplanting are presented in Table 1.



Source: Rao and Chauhan, 2015

Fig. 3: Potential Loss of Yield Due to Weeds in Various Major Crops in India

II.3 Mechanization in Weeding and Intercultural Operations

Weeding is one of the critical management practices for the production of agricultural crops. Weeds compete with crops for water, nutrients and sunlight and, if uncontrolled, can adversely effect on crop yields and quality (Slaughter *et al.*, 2008). There are lot of factors influencing the magnitude of yield and loss of quality, including the productivity of the crops and weeds present, the density of the crops and weed plants, time the weeds appear relative to the crop, the span of the weeds and the relative propinity of crops to the weeds (Weiner, 1982; Pike *et al.*, 1990). Several studies have noted the yield loss associated with weed competitiveness. In a survey, weed scientists in India estimated potential yield losses from 10 to 100 % as shown in Fig. 3 (Rao and Chauhan, 2015).

For centuries, different mechanical weeding tools *viz.*, hand hoes, push-pull type weeders, wetland weeders, animal drawn weeding tools, power operated weeding tools and tractor drawn row crop cultivators were used in the crop rows to reduce weeds. In the present scenario, the availability of enough labour and equipment for weeding operations does not synchronize with the ideal season. Hence, majority of the farmers are not able to complete the weeding operations in time. Therefore, conventional weed control methods give low performance resulting in delayed weeding at high cost. To tackle the above problems, various researchers from the developed and developing countries have focused on mechanization in weeding operation over the last decade. Intelligent weeders are now being built that provide more sophisticated ways of controlling weeds and to leave the crop plants unharmed. The inclusion of innovative technologies like sensing and robotic weed control systems, machine vision and RTK GPS guidance systems, in conjunction with new cropping systems, might lead to a breakthrough in mechanical weed control in row crops (Van der Weide *et al.*, 2008). This tends to significant reduction in drudgery and weeding time.

In spite of many challenges in implementing mechanical weed management, there is tremendous scope for developing robotic weed control system. More research is needed on inter and intra row weeding for various field crops. The use of mechanical weeders for weed management is a profitable deal corresponding to the high cost of weed control and environmental hazards associated with the overuse of herbicides. More attention should be given to employing mechanical weeding as an alternate weed management strategy. Future weed management can benefit from greater use of mechanical and autonomous weeding principles to change weed management practices, agricultural environment and global climate.

Weed monitoring can be achieved either by mechanical or chemical use. Herbicides are intended to control weeds, but are also toxic to desirable plants and animals, including humans. Herbicides are generally less toxic than insecticides, but some of them are potentially toxic to living organisms and their transformed products in the environment. The global environmental contamination problem caused by overuse of herbicides and the rising cost of chemicals call for alternative crop protection methods. The cost of some herbicides is also very high since the basic ingredients are imported from developed countries to manufacture herbicides. A possible way to reduce chemicals is to employ precise techniques for different types of agricultural operations so that chemicals can be used where they have an optimum impact at a minimum quantity. It is even possible to abandon the use of chemicals in some operations and implement other methods i.e. mechanical weed control (Astrand and Baerveldt, 2002). Thus, eliminating the need for chemical weed control will result in considerable savings in both ecological and economic terms. But the situation has been changing rapidly during the previous decade due to urbanization. Higher wages in construction sector and industries led to the labour crisis in the agriculture sector. Farming community started opting for technologies which require less manpower. Herbicide use during this time frame has increased and is still on the rise.

The intercultural operation in horticultural crops seems difficult due to its crop canopy and reach of regular implement. Weeding beneath the plant canopy and around the plant girth becomes easy using an offset rotavator. This allows us to do intercultivation operations in an efficient way which leads to saving in time as well as drudgery. In India, offset rotavators are being introduced which have good field performance but higher operational cost (Namdev *et al.*, 2017; Namdev *et al.,* 2019)

Tractor operated weeder and earthing up is an equipment used for weeding and earthing up in row crops. The equipment consists of three shanks made of spring steel with a sweep on each shank. The row to row spacing is adjustable according to the crop. Rotary power weeder is a self-propelled engine operated power weeder for intercultural operation in horticulture and wider row crops. The weeding efficiency of the machine varies from 80-94 % depending upon the type of crop with field capacity of 0.6 to 1.0 ha/day. The performance of the machine for weeding is found satisfactory on cotton, sugarcane, sunflower and gram. Tractor operated rotary weeder is suitable for weeding in wider row crops. There is approximately 74 % saving in labour and 56 % saving on the cost of operation.

II.4 Mechanization in Irrigation

Water plays a vital role in agricultural development under rainfed condition. Persistent population increase and the expected impacts of climate change, including precipitation changes and melting of glaciers, make the water problem very serious. It is especially important for a large country like India, which is in the tropical belt and is experiencing extreme climate and rainfall variations across the country. In India, about 65 % of agriculture is rain dependent (Singh and Kumar, 2009). There are substantial differences in rainfall, the westernmost part receives less than

100 mm per year and the easternmost part receives 100 times more. A significant amount of water is wasted in irrigated agriculture as evaporation and/or leakage during storage and transportation of the water to the fields where the crops are grown.

Micro and mechanized farming systems help to reduce water wastage. Small farmers emphasize the implementation of these systems, intending to raise crop yields by using minimum water. Besides, local governments around the world encourage farmers to adopt such products, encouraging market growth and encouraging various market participants to produce micro-irrigation products that are effective and low-cost. On the farm level, irrigation systems typically used can be generally categorized as sprinkler systems, surface systems and drip systems. In sprinkler systems (e.g., solid sets, centre pivots and travelling irrigators), water is delivered in form of sprays using overhead sprinklers. Also, there is an indication towards better water management practices with subsurface drip irrigation. It has also been observed that the application rate of micro irrigation is much higher than the surface methods with an efficiency ranging from 85-90 %.

Soil moisture plays a crucial role when it comes to irrigation. Moisture in the soil is difficult to measure, and cannot be easily controlled at its target levels. That is why the best solution for this problem would be an automated irrigation system. The soil moisture sensor will refer to the soil moisture level and the system automatically activates when the moisture level is less than the sufficient level for the plants to grow healthily. The device will stop automatically for such a specific time when the soil moisture level is reached as we set the time in the morning and evening. The brain for this system is microcontroller. Also, it has reliable parts and relatively low costs (Rasyid *et al.*, 2015). Using micro irrigation system has shown results that crop WUE (water usage efficiency) was observed to improve compared to conventional irrigation. Real-time irrigation scheduling based on soil moisture is a modern technique (water savings of 15-20 %), where the irrigation scheduling method decides the feedback needed for the control algorithms. It has been observed over decades that the ponding of water by surface irrigation for paddy crop leads to an anaerobic reaction which gives rise to an increase in release of methane which is a dominant causative factor in adverse climate change. So moving towards the micro-irrigation leads to an increase in WUE and also helps in growing more crop per drop.

The unevenness in field leads to non-uniformity in seed germination, poor crop stand increases weed intensity, uneven crop maturity ultimately affecting yield and grain quality as well. Laser land leveller saves nearly 20-25 % of irrigation water that could have been lost due to unevenness of the fields. With this technology, effective land levelling is intended to have optimum water and nutrient use efficiency, better crop establishment and reduction in time for applying irrigation. Also, there is increase in productivity and yield as well as increase in cultivated area by about 3 %. Tensiometer gives the moisture or crop water demand which can predict irrigation requirement in the crop production system. It was used in the paddy crop which helps in 20 % irrigation water saving. An irrigation system can also be automated using real-time clock, moisture sensor, temperature sensor and humidity sensor along with irrigation supply system and system controller. Also, an automated drip irrigation system improves yield by applying right amount of irrigation at right time for cucumber crop (Prakash *et al.*, 2017). Use of water can be reduced by sowing the crops such as rice, wheat, maize, groundnut, cotton sugarcane etc.

Dryland farming plays a significant role in the growth of Indian agriculture. Thus, tractor driven former phule check basin is beneficial for dryland farming in Maharashtra for in-situ rain water harvesting. It creates 6×2 m size check basins and facilitates 30 to 40 % timeliness and saving up to 50-60 %. This rain water conservation enhances the production of Rabi crops in the region (Turbatmath and Deshmukh, 2016). The farmers struggle to achieve timeliness in various unit operations of groundnut to take advantage of the favorable conditions in drylands of Andhra Pradesh. Bollavathi *et al.* (2018) developed an aqua planter to solve this problem. Aqua sowing is concurrent seed sowing and the supply of an equal quantity of water, quite enough for the seeds to

Fig. 4: Measurement and Management of N (i) LCC, (ii) Spad Meter and N-Management Device (iii) Spectroradiometer and (iv) CCI Meter

germinate regardless of whether it rains or not for the first few days. This is a modern technology designed for the advantages of dryland farmers and specifically for seed sowing during late monsoon contingency season. Pusa aqua-ferti seed drill is used for applying aqueous fertilizer alongside the seed, which tends to improve germination and initial crop production, particularly under rain-fed conditions. It increases germination and wheat crop yield by 53 and 35 %, respectively and has field capacity 0.25 ha/h (IARI, 2020).

II.5 Mechanization in Nutrient Management

In crop production management, real time, non-destructive and high-throughput acquisition of crop growth information is an important requirement. Conventional detection methods are subjected to the destructive sampling of plants. While in indoor physical and chemical analysis are laborious, time consuming and have poor timeliness, the leaf colour chart (LCC) is a simple technology to detect nitrogen (N) deficiency in the crop. It is compatible with paddy, wheat and maize crops. The colour of each field's youngest fully expanded leaf (second from top) of 10 randomly picked disease-free plants/hills is matched with the LCC colour strip (Kumar *et al.,* 2018). With the tractor mounted N-sensor, spectrometers are able to scan about 32 % of the total wheat area. Algorithms were developed for tillering and booting stages which are useful for the estimation of N-application rate for wheat crop. Algorithm and sensor value predicts N-application rate similar for plots with different levels of N applied (Singh *et al.*, 2015). Measurement and management of N is shown in Fig. 4.

The portable chlorophyll content meter (CCM) was evaluated by Rathore and Jasrai (2013) and found that CCM is an effective tool for estimating relative chlorophyll content in selected plant species. Optical sensors provide a rapid and non-destructive in-season diagnosis of cotton N status and cotton biomass. Green seeker on the go variable rate urea application system operated by mounting on the back of the operator can be used for top dressing. It was capable of measuring the nitrogen in the range of 8.5-30 kg/ha N with the help of a fluted roller when operated with 2.0 km/h speed. A GPS based VRT fertilizer applicator for granular fertilizer application consisting of a microcontroller and actuator with seed cum fertilizer drill can be used in a precision map based system. This reduces the variability of granular fertilizer up to 15 % and saves 13-15 % fertilizer as compared to the conventional method (CIAE, 2016). These technologies give input in a precise manner through saving input i.e. enhanced input use efficiency.

N management through airborne and satellite imagery is one of the efficient ways in fertilization. Multispectral, hyperspectral, and thermal aerial imaging acquired from unmanned aerial vehicle (UAV) flights is a useful tool for detecting crop requirements for N. There are different categories of remote sensing imaging systems, which are used in fertilization applications. Among them, RGB/CIR cameras, which combine infrared (CIR), red, green, and blue light imagery (visible or RGB) allow to estimate of green biomass and N status from NDVI. Multispectral cameras, which is in the VIS NIR regions can obtain a limited number of spectral bands at once, are commonly used for assessing green biomass, fertility status, pigment degradation and photosynthetic performance. Infrared cameras or thermal imaging cameras have significant use to determine the distress of nutrients in crops.

Nowadays, various companies provide farmers aerial remote sensing services through multispectral and hyperspectral or thermal aerial imagery, which is used for the diagnostics of crop nutrient deficiency in different crops (wheat, rice, cotton, horticulture and other crops). Various models of nitrogen applications are produced using images from the aerial network, allowing for better control of farm N management. These, N algorithm models, developed through the information gathered by N-sensor, can help farmers to determine the correct dose of N supply required by crops and position, thus increasing crop production and reducing the environmental contamination due to excessive N fertilization.

Multispectral and hyperspectral satellite imagery also has a major role to play in controlling crop growth. Satellite imagery data (sometimes with free access) are often used on a broad spatial and temporal scale in fertilization control and soil analysis. Compared with handheld or vehicle-mounted sensors, the benefit of using satellite data for N field management is that the data collected covers large areas and can be used on a variety of scales, from catchments and landscapes to fields (Söderström *et al*., 2017). New low-cost or publicly accessible satellite systems such as Sentinel-2 with high temporal resolution and external wavebands aimed at measuring crop resources opening up exciting possibilities for better N production and quality of nutrient use for more efficient food chains. Another significant effect of remote sensing technologies and ground sensing systems in handling nitrogen is environmental protection. Excessive and long periods of fertilization with nitrogen accumulate contaminants in the soil causes damage to the environment. In the case of nutrient runoff, overfertilization can be a source of unnecessary extra costs and an environmental hazard (Guérif *et al*., 2007). Water quality degradation is also one of the most serious global environmental problems resulting from the unnecessary fertilization of crops with nitrogen. Groundwater or surface water is mostly polluted by nitrates when overfertilization occurs in crops. According to Riley *et al.*, (2001), the movement of N from fertile fields to surface waters has been related to freshwater eutrophication and estuaries. Elevated fertilization rates result in N losses with negative consequences not only on concentrations of atmospheric greenhouse gas (GHG) but also on the quality of the water. The surplus nitrogen fertilizer may be leached down into soil, combined with surface waters, or released into the atmosphere as gases, creating a high rate of emissions to the ecosystem. Furthermore, balancing N formulation and crop criteria mitigate the deleterious environmental effects of improper fertilization, either through water nitrate contamination or gaseous emissions.

All of these adverse environmental consequences, combined with inadequate nitrogen fertilizer, therefore need new technological solutions to enhance resource management. Using remote sensing data to monitor the dosage and timing of nitrogen fertilizer will protect the environment and allow better crop management for more sustainable farming. Besides, the fertilizer application incorporation of green manuring is an environment-friendly technique. Although, green manuring is an effective and cost effective technology which enhances soil health and assists to reduce cost of chemical fertilizers it also safeguards productivity. A tractor operated biomass incorporator ultimately offers sustainability through the green manuring and reduced climate degradation with smart mechanization (Verma, 2019).

Fig. 5: Drone Spraying for the Field Crop

II.6 Mechanization in Plant Protection

The complexity of interactions and variability in climate are the two important deciding factors of risks in agriculture. Due to the occurrence of extreme weather events and fluctuations of weather elements there is a shift in pest's species diversity and their population. This in turn leads to enhanced use of pesticides in the form of higher quantities, concentrations, frequencies and different combinations or forms of applicable products in crop growing season. Technological interventions also have immense influence on pesticides application. Site specific management of pests through sensor based identification and monitoring of the infested locations in field, level of infection on crops and GPS mounted field sprayers shows the advancement in agricultural technologies in plant protection. Precision farming with target based applications promotes more efficient usage of pesticides/decreased the needed amount of pesticide application volume for effective control of pests, when compared to the conventional practice of application of pesticides (Dworak *et al.*, 2013).

An auto rotate type gun sprayer is used for effective and efficient spraying on crops (375-1000 l/ha spray material) especially for the control of sucking pests like whitefly attack on the cotton crop. It has wider swath of about 30 m in a run and covers 3-4 ha/h. Presently, spraying different crops becomes difficult as the machine or person has to walk through the fully matured crop. There are some high clearance vehicles used for spraying in different crops. PAU Multipurpose high clearance sprayer has boom and drop up type

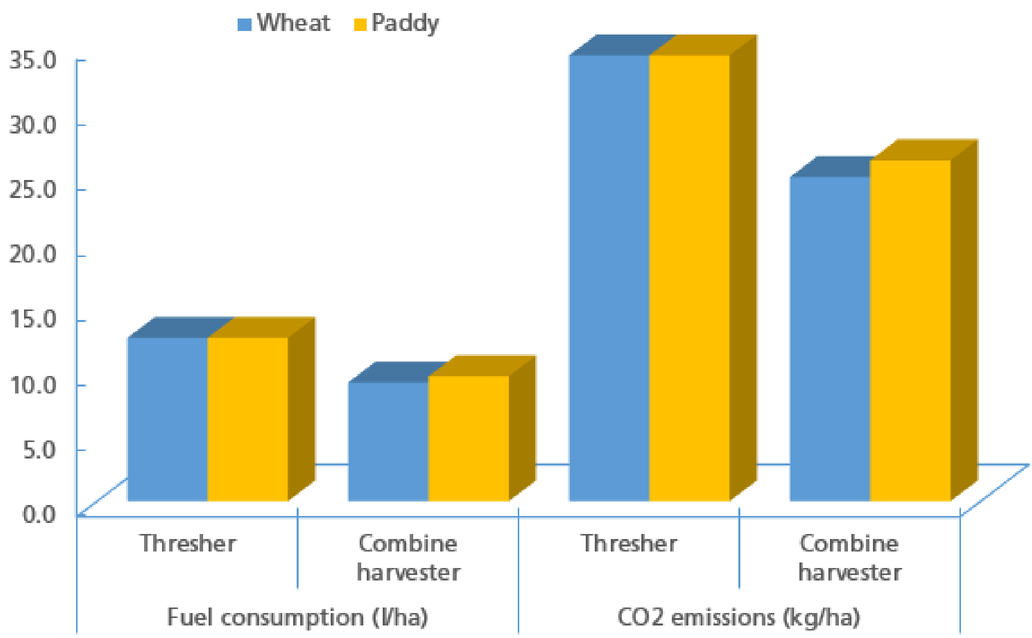


Fig. 6: Fuel Consumption and CO_2 Emissions from Thresher and Combine Harvesters

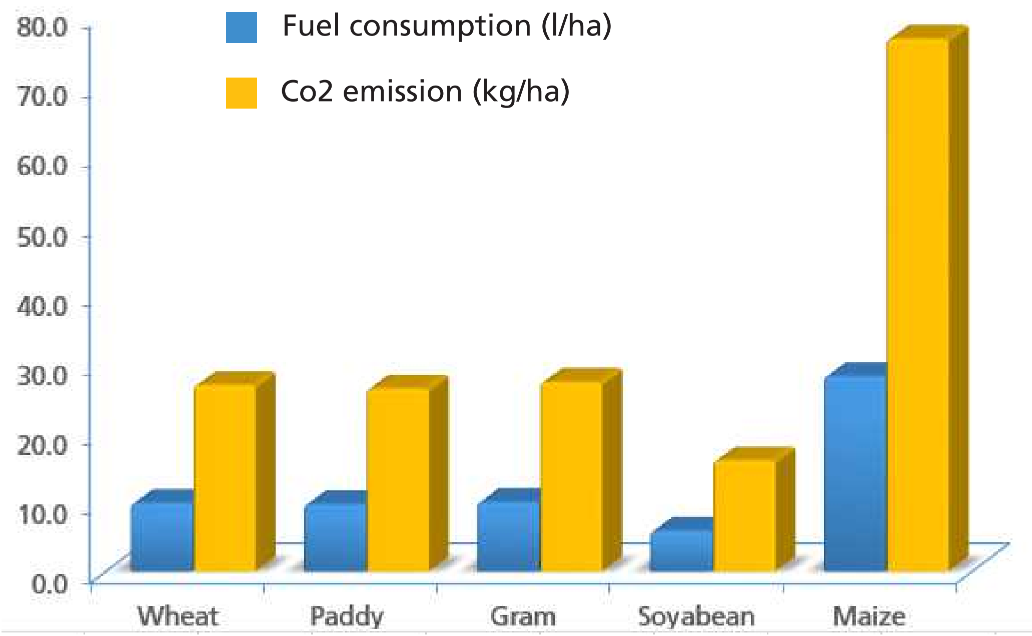


Fig. 7: Emission Footprints during Combine Harvesting (for Kartar 4000)

Fig. 8: Burning of Paddy Crop Residue and Emission of GHGs

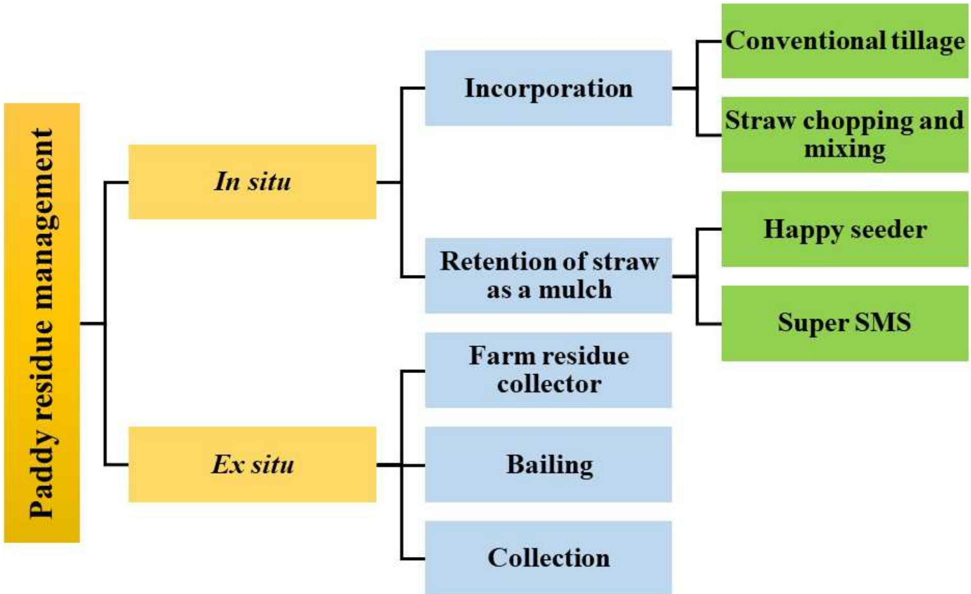


Fig. 9: Paddy Residue Management Techniques

mechanism along with auto rotating gun mechanism used for effective spraying at all growth stages of the crop. The actual field capacity of the high clearance sprayer was found as 1.78 ha/h. It saves cost, labour and time by 66, 95 and 95%, respectively as compared to knapsack sprayer (Singh *et al.*, 2018).

Electrostatic spraying of pesticides or fertilizers improves not only the efficacy but also the spatial distribution of deposited droplets over the plant canopy, particularly beneath the leaf where pests usually hide and reside. Electrostatic sprayer mobile back pack type air assisted electrostatic sprayer with an on-board compressor and spray gun was developed for charging the spray particles in the nozzle. Air and liquid enter separately at the outmost of nozzle. Spray deposition on the upper side and underside of leaves by electrostatic sprayer is 80 and 85% more than knapsack sprayer respectively. Average drift loss of electrostatic sprayer is approximately 50% lesser as compared to knapsack sprayer. Overall bio-efficacy in terms of percentage of insects killed by electrostatic sprayers i.e. 68% is comparatively higher than hand operated knapsack sprayer i.e. 50% (Singh *et al.*, 2018). The development of spraying attachments for drones and its application for the plant protection in the for different crops is in progress (Kumar, 2018; Parmar, 2019). Automatic section control technology is precision agriculture technology called as auto-swath technology. It reduces over-application of crop inputs by automatically turning off boom sections as they pass over previously treated areas, waterways or non crop areas.

UAV or drones are small aerial platforms weighing less than 20 kg, excluding boarding of the human body. This technology is gradually occupying the agriculture sector. In PAU, an agricultural spraying system developed on drone for better spray deposition on the targeted surface of the crop (Fig. 5). Spray deposition observations regarding bioefficacy was done in cotton, rice and moong crop. Drone flying height 0.5 m and 2.0 m/s forward speed above the plant canopy offers the best results corresponding to spray deposition (Parmar, 2019). This technology allows farmers to ensure efficiency of crop inputs such as water or chemical fertilizers which can lead to enhanced productivity with better product quality. On the other hand, drone-based pesticide application in Indian small landholding can affect nearby natural resources like farm pond, open well and animal shelters due to the spray drift. Generally, Indian farms are situated near village hamlets, if precautions are not taken, the drone application pesticide may be hazardous. Spray drift will carry the fine hazardous chemicals outside the field of application for which drift control technology is needed.

II.7 Mechanization in Harvesting and Threshing

In India, harvesting and threshing operation is mechanized to the extent of 60-70% for rice and wheat and mechanization is less than 30 % for other crops (Mehta *et al.*, 2019). Paddy and wheat are majorly grown crops. So the carbon footprint generated during harvesting of these crops is relatively large among all other agricultural crops which need to be quantified. Combines are

Fig.10: Happy Seeder with Press Wheel Operating in the Combine Harvested Field

tractor driven or self-propelled type. Self-propelled combines are of wheel type or track type. Track type self-propelled combines are used in southern India where harvesting is done in sticky and wet type soil.

Total annual sale of combine harvesters and threshers are 5,000 and 90,000-1,00,000, respectively (The Indian Express, 2016). Threshers are used when the terrain is hilly or marginal farmers are unable to pay for combine expenses. Wheat, paddy and multi-crop threshers are available in the market for efficient threshing of crops with least grain damage. Multi-crop thresher is used for threshing of wheat, sorghum, barley, soybean, millets, oats, grams (chick-peas) and pulses. Some of the recent design modifications that occurred in harvesting and threshing machinery to make them more ergonomic to human use and giving finer straw output for quick mixing in the soil have resulted in a slight increase in the carbon emissions from the harvesting and threshing machinery. Combine harvesting consumes less diesel than manual/reaper harvesting of crops followed by threshing in threshers.

Thresher (Dasmesh MultiCrop 22×36) is compared with the combine harvester (Kartar, 4000) to estimate the amount of fuel consumed for wheat and paddy (DAC, 2013; Dashmesh, 2020). Thresher capacity is 0.4 ha/h with fuel consumption of 12.5 l/ha. Combine capacity for wheat and paddy is 1.10 and 0.92 ha/h with fuel consumption of 9.09 and 9.56 l/ha, respectively. Based on this data the carbon emission was calculated and shown in Fig. 6. It is clear that thresher has more emission than combine harvester.

In average fuel consumption self-propelled combine harvester (Kartar, 4000) for different crops and emission factor (for diesel is 2.73 kg CO_2/litre) were taken and emission was calculated (UNDP, 2010; DAC, 2013). It is clear that maize crop has higher emission than other crops as shown in Fig. 7. Apart from petroleum fuel, renewable fuel (biofuel) produced from agricultural waste can be utilized in agricultural engines without sacrificing useful agricultural land with lower emission (Modi *et al.*, 2017; Modi *et al.*, 2018; Modi *et al.*, 2019a). Renewable fuel has better utilization ability than diesel which can help in climate resilience (Modi *et al.*, 2019b).

III. Climate-Smart Technologies for Straw Management

The crop residue management is an emerging issue in Indian agriculture especially in northern India. It is not only degrading the environment for human beings but also reducing the soil health and destroying microorganisms as well. This has become a huge problem in the paddy-wheat cropping system. India produces about 500 million tonnes of crop residue annually. Majorly Northwestern states of India produce 4.5 million tonnes of paddy straw. This straw is not preferred as an animal fodder due to higher percentage of silica in it. Burning of paddy crop residue and emission of GHGs is shown in Fig. 8.

The management of crop residue in

the field is known as in-situ whereas taking out of the field is *ex-situ*. Presently, farmers choose to burn the crop residue such as paddy straw in the field. This is due to a lesser window period during sowing of wheat and harvesting of paddy crop. Affordability and availability of climate-smart farm machinery to handle the paddy residues in-situ is in urgent need. An ex-situ residue management is economically not feasible due to the collection and transportation of huge volume of paddy residue. Paddy residue management techniques are shown in Fig. 9.

III.1 *In situ*

Incorporation: Incorporation of the crop residue offers several benefits to the environment in terms of soil health attributes such as carbon, pH, organic, infiltration rate and water holding capacity and hydraulic conductivity (Gupta *et al.*, 2004; Sahai *et al.*, 2011). The decomposition of paddy residue in soil leads to an increase of 6-9 kg N/ha during wheat crop. Wheat yield increased in the fourth year after subsequent incorporation of paddy straw in the soil as compared to ex-situ or burning of straw (Gupta *et al.*, 2007). Also, there is an increase in soil organic carbon when paddy straw is incorporated (Mandal *et al.*, 2004). This means that the incorporation has benefits inclined towards climate-smart agriculture extensively. There are some climate-smart technologies available for incorporating the crop residue. Farm implements such as stubble shaver, MB plough, disc harrow, cultivator and palnker are generally used for crop residue incorporation. The paddy straw chopper cum spreader, PAU straw cutter cum spreader, stubble shaver and rotavator are used for the mixing the paddy crop residue. Subsequently, wheat crop can be sown by no-till drill and strip till drill after 15-20 days (operation of rotavator in the flooded condition) depending upon the soil type. These are environment friendly technology as farmers do not need to burn the paddy straw left in the field which also improves the soil health.

Mulching: Mulching of crop residue conserves moisture, moderates thermal regimes, suppresses weeds and improves soil health. Mulching is beneficial both in irrigated and rainfed environment (PAU, 2010). There are some technologies to perform direct sowing of wheat in a combine harvested field. The happy seeder with press wheel combines the stubble mulching and seed drilling functions into the one machine. The strip of stubble in front of the sowing tynes is cut, picked up and placed on the side of the drilled seed as mulch. The sowing tynes therefore engages bare soil. Happy seeder sows wheat directly in paddy residue in combine harvested field hence, prevents residue burning thus reduces air pollution. Mulched crops residue improves the soil hearth and added organic matter to the soil. This machine can also be used for sowing subsequent moong crop in wheat residue. Happy seeder with press wheel operating in the combine harvested field is shown in Fig. 10. Happy Seeder in a single operation cuts the straw in front of furrow openers and throws it over the sown crop which acts as a mulch to improve the soil health. However, an equal distribution of paddy straw is a prerequisite of working for happy seeder. Thus, super straw managing system (SSMS) for combine harvester comes into the picture. It chops paddy straw coming from straw walkers and sieves of the combine harvester with even distribution of straw in field. Kumar (2019) has developed a tractor operated paddy straw bale shredder for mulching of paddy straw on the vegetable crops. Average effective field capacity and average fuel consumption during machine operation was 0.25 ha/h and 4.61 l/h, respectively. This depicts reuse of the paddy straw in the filed to combat the climatic variations in moisture while conserving it.

III.2 *Ex situ*

Straw baler is a machine which collects the paddy straw and compresses it in the shape of rectangular or round bales. Before the operation of baler, standing stubbles are first harvested with the help of stubble shaver. It can form rectangular bales of varying length from 40-110 cm. These bales can be used for power generation, making card board, packing material, composting, biogas production, mulching etc. Thus baler provides a solution for straw management to make the climate-smart. The reaper is the machine used to collect the straw from the field. This is mostly used in the wheat crop due to its economic value as used for animal feed as compared to paddy straw. A wheat straw combine is the most popular machine used to recover wheat straw after combining operation. Straw collected by straw combine is chopped into small size and collected in the trolley having a net to remove the dust. Also, some grains are collected along with straw. Ali (2020) developed an integral dust separation system for straw reapers which helps in enhancing the quality of wheat straw by reducing the dust concentration and eliminates the extra operation for dust separation.

IV. Future Mechanization Pathways Through Climate-Smart Technologies

Presently, technology plays the role of a feeder to agriculture. New approaches in farm mechanization to maximize productivity are required for a paradigm shift in agriculture. One approach is to utilize accessible IT in the context of smarter equipment, to raise and achieve energy outputs more effectively than before. On the other hand, precision farming has been proven to be effective, it's time to switch on to the new generation equipment/mechanization. Although the existing human operations are effective across larger fields, still there is an immense potential for growing the size of autonomous system services which can contribute to improved efficiencies. Therefore, it is time to follow realistic precision approaches in farm machinery along with other steps to improve agricultural productivity of restricted cultivated land under changing climate and depleting natural resources to feed the burgeoning population (NAAS, 2016). This will entail urgently required measures to encourage agro-service providers through farmers' cooperatives/custom hiring centers/machinery banks in order to receive the benefits of farm mechanization from small and marginal farmers. In the sowing machinery or conventional seed drills, existing furrow openers need to be improved to reduce both the inter-row and intra-row variability of seed rate. Mechanical paddy transplanting should be boosted by developing a mechanized method of sowing mat type nursery in field itself. Also, the transplanting of vegetable and horticultural crop is expected in the near future. Besides this, a boom floatation, design of the nozzle, sprayer electronics and computer control such as VRT can be improved according to the region and crop. Sugarcane requires more energy inputs among all other agricultural crops and expected to be mechanized in sowing, weeding and harvesting according to regional characteristics through precision farming. The introduction of autonomous AI architecture enhances the ability to create a whole new range of farm machinery based on smart machines that can do the operations in precise manner. Adaptation of these technologies should match the complexity of real situations and environmental conditions and climate-smartness in farm production scenario. Farm mechanization also solves the challenge of shortage of farm labour during peak cultivation seasons such as sowing and harvest. Most of the farmers have been continuing with locally available low quality and inefficient farm machinery such as plough, cultivator, harrow, seed drill, sprayer, thresher etc. These machinery leads to avoidable wastage of scarce input and natural resources. Appropriate farm machinery management offers solution through 3C's approach namely cooperative, custom hiring and contract farming.

IV.1 Mechatronics

Mechatronics refers to a synergistic combination of mechanics, electrical, electronics, computer and control. Mechatronics has many useful applications in farming system. Its components, such as actuators as well as sensors, play vital roles in sowing, cropping, fertilizer application along with monitoring of vegetation. Present and future mechatronics are being developed based on the technological developments required to enhance and make human life easier and sustain the world. Use of mechatronics with IoT in the agricultural field is going to push the limits of engineering streams beyond the conventional confines. Some of the application of mechatronics can be used in automatic seeding mechanisms, pesticiding and weeding operations. Mechatronics assist the metering mechanism in seed drill/planter can address many of the inefficiencies experienced in a mechanically driven seed metering device and have the potential to increase productivity and yield rates dramatically on both no-tillage and rotary-tillage lands. The mechatronics based system observed good seeding uniformity among all seeding technologies with quality of feed index, missing index, multiple index and precision index in range of 90-98, 0-11, 07 and 1-22 %, respectively under speed of 1.0 to 16.0 km/h (Gautam *et al.*, 2019).

There are some other technologies to assist humans for efficient work in farm operations. One is a lightbar (LB) and another satellite navigator (SN) both are GPS derived products placed in front of the tractor operator or the cabin. Also, Magar *et al.* (2014) observed that Indian agriculture has potential to use SN which can enhance agricultural productivity. The risk of overlapping areas or missing areas is reduced with this technology, as it is a climate-smart approach to cope up with climatic calamities.

IV.2 Robotics

In recent years an application of robots in agriculture has grown tremendously, overcoming some of the challenges and complications of this field. Onwude *et al.* (2016) examined the use of agricultural mechanization and its emerging developments and drawbacks for large-scale applications from the point of view of service robotics. Increasing level of agricultural technological advancement in field and crop mapping, soil sampling, mechanical seeders and harvesters in farm robots. Also, Kester *et al.* (2013) revealed the future trends and likely

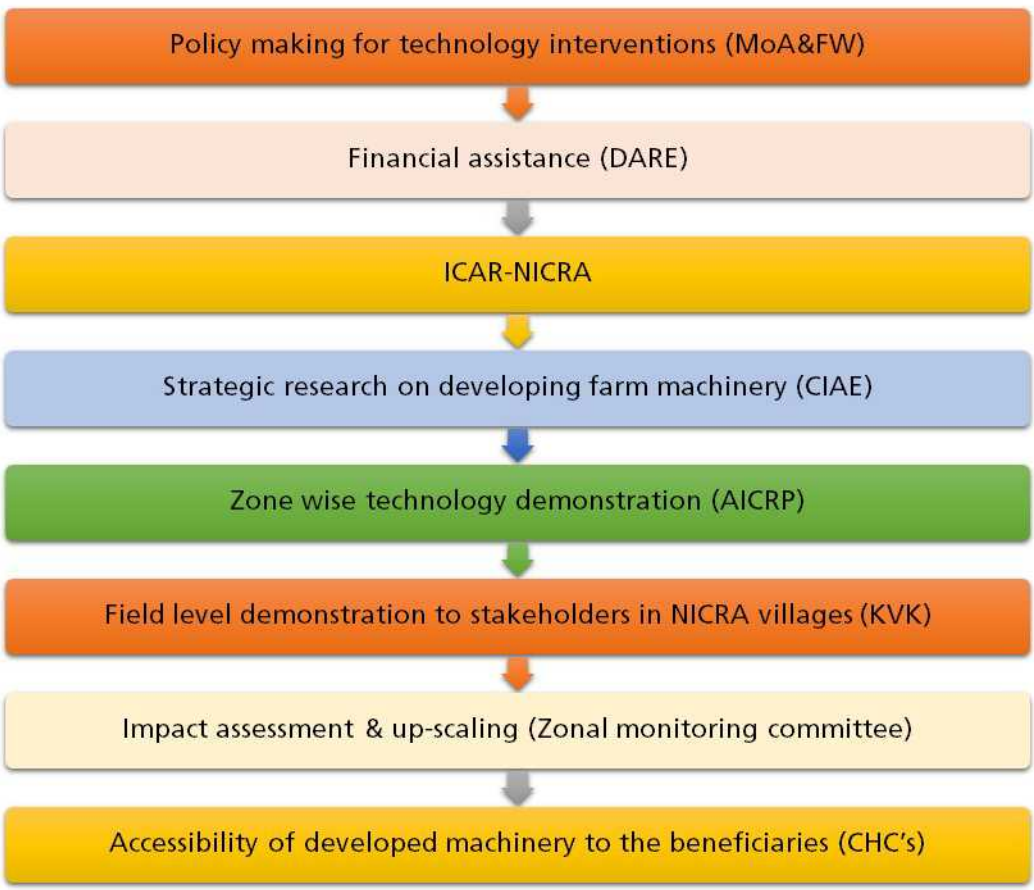


Fig. 11: Flow Chart of an Action Plan for Climate-Smart Mechanization

introduction of automatic agricultural machinery. The results of this study demonstrate a growing interest in autonomous and semi-autonomous workload reduction systems: tillage, seeding and harvesting.

There are some restrictions on the performance of aerial robots, such as cloud presence, lengthy data delivery times, need for unique approvals and most relevant rewards of certain products subject to adoption. In contrast, the UAVs can be effectively deployed on the farm which can carry multiple sensor for various purpose. For it to become a cost-effective alternative it does not require very stringent permissions. Small, mobile, integrated, compact robots one benefit of modern robotics is their ability to build on low-cost, lightweight, and intelligent parts. Due to their prevalence in consumer electronics, such as mobile phones, gaming consoles and mobile computing (laptops, tablets, etc), high quality cameras and embedded processors can be built into many platforms at very low cost. The use of collective and cooperative actions in a robotic fleet offers the opportunity to distribute activities across multiple platforms and thereby reduce the damage done to the soil or existing crops by heavy traditional agricultural platforms. Multiple data sources can also be used by the robotic fleet to calibrate the mission, reduce waste and focus on areas of greater need, potentially reducing fertilizer costs and impact on the environment.

IV.3 Artificial Intelligence

Artificial Intelligence (AI) refers to human intelligence simulation with machines that are often programmed to think like humans and imitate their behaviour. Also, it includes development of computer or mobile based software capable of intelligent behaviour which is compatible to the user. The agricultural operations would be highly correlated with the AI in future. It would lead to creating self-learning algorithms and helps automation in agricultural practices. A number of farm operations will be performed via applications and processes developed around AI. Presently, this technology is at a nascent stage with time and capital investment, all above discussed farm operations will be automated, leading to enhanced input use efficiency and reduction in cost of production. In order to mitigate agricultural production losses, there is a need to develop climate-smart technologies in future, it is vital to keep the small and marginal farmer in mind. Also, private and custom hiring organizations can uphold climate-smart agriculture mechanization.

Tractor in the farm operation is the prime mover that requires a skilled person to operate it efficiently. The farm operations are highly affected by the climate and the environment during the working hours and non-working hours as well. At this instance, the driverless tractor or unmanned farm tractor can work to cope up climate calamities. Tractors will be driven without an operator and specialised farm equipment able to plough, sow, plant, spray and weeding in the farm. Some of the leading tractor manufacturing industries have developed unmanned tractors based on artificial intelligence (Kumar *et al.*, 2018; The

Hindu, 2019). This intervention can bring the tractor at an unprecedented level of intelligence in farming operation and also farm tractor mechanization would reach to new and redefine height in India. This state-of-the-art technology is equipped with attractive features such as; auto steer, auto-headland turn, auto-implement lift, skip passing, and safety features like; geo-fence lock and remote engine start stop. These modernizations in tractor through artificial intelligence will lead to higher food production, productivity, more income and lesser health hazard to the farmer which can feed the rising needs of increasing population.

IV.4 Strategies for Climate Change

Single farming practice does not suit in all conditions for effective crop management. Practices in crop management need to be tailored and location-specific to increase production, profitability and reduce adverse environmental effects. Such activities would also focus on the judicious and productive use of inputs to achieve higher efficiency and profitability through climate-smart technologies. Adoption of the technology is likely to take place in planned steps. Most farmers and food producers would need innovations that can be slowly implemented alongside and within their present system of production. Promotion of conservation agriculture would conserve the natural resources in a better way by avoiding excessive soil movement through carbon sequestration. Direct seeding of rice, as well as sowing of other crops can be done on the raised bed for a higher degree of precision along with conserving the natural resources. Judicious use of chemicals should be done through introducing electrostatic spraying technology in various crops which will offer high efficacy and low drift. This reduced environmental degradation. Mechanical weeders should be deployed with improvement instead of weedicide application. The fertilizer application should be based on the requirement of soil micronutrients for which soil should be tested, micronutrients and fertilizers should be given at right amount at various depths for enhanced input use efficiency leading to the productivity of crops. Liquid urea can be applied in the soil where there is mulch condition such as straw. Use of laser land leveller, micro-irrigation methods such as drip and sprinkler should be promoted for precise use of valuable water. In addition to improving precision in currently manufactured and used farm equipment/machinery in India, attention must also be paid to the principles and practices of precision farming. In research and development, efforts need to be made to increase precision in farm equipment (NAAS, 2016). The decision support system for tractor selection and tractor implement combination should have appeared in the top while purchasing both. However, a capacity-building programme is much needed to impart the knowledge of the selection of appropriate farm machinery corresponding to farm size and crop type. Existing, improved and newly developed climate-smart machinery should be demonstrated for popularization and priority in providing financial assistance to the farmers. Also, keeping in the view of farm size there is a need to establish farm machinery banks at clustered of 2-4 villages and interconnection within them (DACFW, 2018). There is a need to transform the green revolution into an evergreen revolution. This will trigger through farming systems approach that can enhance productivity from the existing natural resources such as land, water and human power resources. Presently, variability in soil-related characteristics has been excluded from whole-field management approaches which seek to apply inputs for crop production uniformly. At present, development of indigenous and affordable farm machinery is needed to avoid over-application or under-application and also devices for precise application of inputs is a challenge. In case of crop residue management, there is a need for an all-round aggressive approach from the scientific community as well as the government in terms of subsidy to cope up burning of residue. Also, an increase in awareness and responsibility for environmental issues. Action plan for the climate-smart mechanization enhancement is given in Fig. 11.

V. Conclusion

Climate-smart based mechanization is an agricultural development paradigm extensively promoted in developed countries to transform agriculture under a changing climate. Adopting climate-smart agricultural equipment i.e., zero till drill, No-till drill, laser land leveller, combined tillage practice and controlled traffic system for seedbed preparation will decrease the GHC, remove carbon from the atmosphere and store it in the soil, reduce soil disturbance and reduce use of all agricultural inputs. Mechanization in sowing or transplanting is highly required. It brings timeliness in operation, precision, cost-effectiveness, resources and inputs use efficiency and resource conservation of soil and water. In spite of many challenges in implementing mechanical weed management, there is tremendous scope for exploring robotic weed control system. More research is needed on inter and intra row weeding for various field crops. Micro and mechanized farming systems help to reduce water wastage, as the market is experiencing tremendous demand from emerging nations. Irrigation system can also be automated using real-time clock, moisture sensor, temperature sensor and humidity sensor along with irrigation supply system and system controller. The negative consequences on environment corresponding to excessive N fertilizer, need new technological interventions to improve nutrient management. The use of remote sensing to control dose and timing of N fertilizer can protect environment and permit best management of crops to enable sustainable agriculture. The new state of art technologies allows farmers to ensure the efficiency of crop inputs such as water or chemical fertilizers which can lead to enhanced productivity with better product quality. The harvesting and threshing operation is most important and critical in farm operations. Combine harvesting gives lesser carbon footprint than harvesting and threshing of crops when done separately. Addition of Straw Management System (SMS) or other mechanical components improve the performance of combine harvesting of crops resulting in slight increase in carbon emissions that are offset or nullified by the high quality threshed grain from the combine and finer straw output from the combine that is decomposed in the field rapidly. Management of crop residue needs attention on a priority basis and awareness among the farmers need to be created. Farm machinery developed need limited initial handholding by the government to enable ready acceptance and quick adoption by the farmers in order to tackle the crisis of climate change.

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