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Smart Farm Mechanization for Sustainable Indian Agriculture

by

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Abstract

Indian agriculture is undergoing transformation due to technological revolution, sprawling urbanization, modern cultivation techniques, and climate change. These changes offer unique challenges and opportunities to transform agriculture to smart, more productive, economically remunerative, socially equitable and environmentally sustainable through adoption of smart mechanization technologies. In this paper, the approaches and strategies are highlighted for sustainable mechanization of Indian agriculture. The smart farm mechanization includes application of sensors, controllers, Internet of Things (IoT), artificial intelligence (AI) and robotics. The research work in the areas of precision agriculture, digital farming, precision irrigation, AI powered machinery, user friendly mobile applications, etc. has gained momentum in India during the last decade. The emerging smart agriculture mechanization combines precision farm with management tools (GPS/GNSS, DSS, VRT), end user applications (platforms, mobile, machines, Agri-bots), data solutions (data IoT, information, tech empowered tools), etc. These technologies not only make farm machinery smart and efficient but also help in saving inputs such as seeds, fertilizers, chemicals, water and energy for sustainable agriculture.

Keywords: Agricultural Mechanization, Artificial Intelligence, Digital Agriculture, Mobile App, Precision Agriculture.

Introduction

Indian population is expected to reach 2.2 billion by 2050. At the same time, biotic and abiotic stresses, degrading and depleting land and water resources and climate change are major challenges for sustainable agricultural production and productivity. To meet food security of increasing population, India needs to increase its annual food gain production to 333 million tonne by 2050 against 285 million tonnes in 2018-19 (Kapur et al., 2015; DARE-ICAR Annual Report 2018-19, 2019). For this, the farms will need to increase their output by 17% as land for agricultural production becoming a scarce resource. Over the years, Indian farming system has not given an expected remuneration to farmers besides its remarkable growth in food-grain production and processing sectors. However, agriculture remains a principal means of livelihood for over 58% of the rural households and 86% of small and marginal land holdings (Mehta et al., 2019). In addition, as per World Bank estimates, half of the Indian population will be urban by the year 2050. It is estimated that the percentage of agricultural workers of total work force will reduce from 54.6% in 2011 to 25.7% in 2050. This highlights the need to enhance farm power availability and farm mechanisation level in the country (Mehta et al., 2014; NITI, 2018).

Agricultural mechanization is an important symbol of agricultural modernization. The agricultural equipment is the carrier of agricultural modernization and thus an important tool used to promote agricultural mechanization. The level of economic development has a positive impact on the mechanization level. As India's economy has diversified in recent years, the contribution of agriculture as a proportion of GVA has decreased from 18.2 in 2014-15 to 16.5 in 2019-20. The demand for food in Indian market is growing considerably which requires increasing agriculture production. The level of farm mechanization in USA, Russia, Brazil, China and India has been reported as 95, 80, 75, 60 and 45%, respectively. However, the level of mechanization is inversely proportional to contribution of agriculture in the countries GDPs (World Bank Indicators, 2013; Mehta et al., 2019). Therefore, there is a need for further promotion of farm mechanisation. It is estimated that global market of agricultural implements and machinery is worth around US$ 200 billion in 2019 and Asian countries are contributing more than 60% to total demand (Kapur et al., 2016; FICCI, 2019).

Presently, the farm machinery in India are being primarily used for production of field crops like cereals, pulses and oilseeds crops. The agricultural mechanization is at an early stage in India and growing at 7.5% per annum in spite of challenges of small land holdings, cropping pattern, market prices of crops, minimum support price (MSP) and government policies and legislations. The ignorance of these challenges will exaggerate the redundant labour force, low return against inputs for yield and ultimately decrease the enthusiasm of farmers in agriculture. Due to lower probability of increase in net cultivated area and scarcity of agriculture labour in the near future, Indian agriculture may require energy intensive agriculture with higher input use efficiency, better soil health management practices and value addition to produce in production catchments.

Within Indian ecosystem, labour-intensive farm activities are automated, stakeholders (farmers, labours, manufactures, etc.) and decision makers across the value chain are more connected with one another, and information and data, physical products, service and touch point experiences will be united as one integrated solution that solve users/stakeholders needs. In such a complex and rapidly evolving environment, it will be difficult to achieve clarity on what are the biggest emerging opportunities and need of farm machinery manufacturers and service providers to create commercially successful propositions. It will enable the agricultural machinery manufacturing industries for sustainable production in country.

In this paper, the rapidly changing environment in mechanization of Indian agriculture is studied and suggested the approaches and strategies to make Indian agriculture smart based on opportunities in following areas.

Smart Farming

Smart farming is a management concept using recent technologies such as precision agriculture and digital agriculture to improve quality and quantity of farm produce as well as input use efficiency. These techniques are well supported by artificial intelligence for weather prediction, detection of pest and diseases, site specific application of water and nutrients, optimize crop planning for maximizing yield and profit.

The applications of new technologies viz. precision agriculture, digital agriculture and artificial intelligence (AI) are heralding the start of a new revolution in agricultural production. The recent and emerging technological development such as Internet of Things (IoT), drones and robots, are accelerating changes around the agricultural mechanization across the world. Taken together and deployed effectively, these emerging trends and technologies have the potential to usher in a new golden age of smart agriculture.

Precision Agriculture

Precision agriculture (PA) technologies can help to meet new challenges by applying the right inputs (seeds, fertilizers, chemicals, water, etc.), in the right amount, at the right place, at the right time, and in the right manner. The importance and success of precision agriculture lies in these five "R". Presently, research on precision agriculture is at initial stage and developed technologies are in laboratories in India. The PA technologies such as sensors (soil nutrient, temperature, fertility, and moisture gradients), guidance systems (often enabled by GPS, GNSS, RFID), variable-rate input technologies (VRTs), automated machinery (automatic control and robots) and advanced imaging technologies (including satellite and drone imagery) have been developed to map the variability and manage at field level. A few potential precision agricultural technologies such as fixed rate seed drill, low cost SPAD meter, spectral reflectance (NDVI) based fertilizer applicator, uniform rate sprayer, real time soil moisture based sprinkler irrigation system, automatic irrigation system for rice and automatic yield monitor for indigenous combine harvesters have been developed and tested at ICAR-Central Institute of Agricultural Engineering (CIAE), Bhopal (Chandel and Agrawal, 2019).

The low cost SPAD meter has been developed for indirect measurement of chlorophyll content of leaves in the field crops (Anonymous, 2017a). It is a compact handheld and portable unit and can be plugged to OTG enabled android smartphone for display and data logging of SPAD values. Two row on-the-go variable rate spectral reflectance based urea applicator for top dressing has been developed for rice and wheat crops (**Fig. 1**). It is 5.5 kg in weight and has swath width of 4 m. The NDVI based variable rate fertilizer application system resulted in 8-15% savings in application of urea fertilizer in wheat and rice crops in areas with spatial nitrogen variation (Anonymous, 2016). The GPS based variable rate fertilizer applicator has also been developed. The application accuracy of the applicator ranged from 89.3% to 98.1% at various discharge rates for 8 × 8 m size grid (Mehta, 2015; Chandel et al., 2016).

An ultrasonic sensor based spraying system, sensor-based system for sugarcane bud cutting and planting, tractor-implement monitoring system, automatic depth and draft control for fuel economy and image based herbicide applicator have been developed and tested at IIT, Kharagpur. The percentage saving of chemical by tractor operated ultrasonic sensor-based pomegranate sprayer was 25-30% and 45-50% with turbo nozzles and hollow cone nozzles, respectively as compared to whole field spraying system (Mehta, 2015). Further, Punjab Agricultural University (PAU), Ludhiana has developed an optical sensor (Yara) based fertilizer application system, an automatic EC and pH mapping system and a batch type yield monitoring system for indigenous combine harvesters. The real-time uniform rate spraying system has been developed at ICAR-CIAE, Bhopal. It helped in uniform application of chemical and reduced loss of chemicals during turning at head lands (**Fig. 2**). The results of these precision technologies are encouraging, however, their adoption on large scale is lacking due to high cost of these machinery.

Digital Agriculture

Digital agriculture (DA) consists of a wide range of technologies, most of which have multiple applications along the agricultural value chain. These technologies include cloud computing/big data analysis tools including block chain and smart contracts, the Internet of Thing (IoT), digital communications technologies (mobile phones) and digital platforms (e-commerce, agro-advisory apps, e-extension websites). The government of India has planned to digitize farming system for sustainable agriculture productivity. Agricultural research institutions, universities, and other organizations are working on digital farming to solve various agriculture related problems. IIT Bombay in collaboration with Japan has developed a Geo-ICT and WSN based DSS for agriculture/environment assessment. Under the Information Technology Research Academy (ITRA) project at IIT Kharagpur, work has been carried out on applications of IoT and UAVs in smart farming. The Coordinated Programme on Horticulture Assessment Management using geoiNformatics (CHAMAN) was initiated in 2014 for area assessment and production forecasting of 7 major horticultural crops on pilot basis using sample survey methodology and remote sensing technology across 12 states. The project "Forecasting Agricultural Output using Space, Agro-meteorology and Land (FASAL)" based observations is one of the successful initiations under digital agriculture and is an AI-powered IoT-SaaS platform for horticulture crops. It has raised $1.6 million in seed funding to build a world-class solution for two core problems of horticulture farmers to manage irrigation and diseases/pests. The sensor array can be installed in field by farmers in less than 15 min and measures multiple dynamic variables, including micro-climate, soil and crop conditions. It uses machine learning (ML) to transform the sensor data into farm level predictions, which help farmers anticipate various risks and reduce input costs by optimising crop protection, irrigation and crop nutrition. The introduction of a low-cost, mobile phone-based agricultural extension system among 1,200 farmers in the state of Gujarat had a positive and significant effect on agricultural yields and efficient input use in cotton cultivation. As a result of using this service at a cost of less than $10/year/farmer, farmers' marginal net income increased by approximately $100/year/farmer and yields increased by 8.6% for cotton and 28.0% for cumin crops (Anonymous, 2019). On the other hand, digital technologies involved in e-commerce platforms, e-exten-

Fig. 1 NDVI based variable rate urea applicator for rice and wheat crop

Fig. 2 Sensor based real-time uniform rate spraying system

sion services, warehouse receipt systems, block chain-enabled food traceability systems, tractor rental apps, etc. fall under the umbrella of digital agriculture.

Marut Dronetech, a start-up, has developed an intelligent and autonomous drone for spraying application in agriculture. The drone collects data, analyses them and generates disease map of a particular field with the help of RGB (red, green, blue), hyper, multi-spectral cameras and powerful sensors. Drone takes the payload with it and sprays the targeted areas using a predefined route. The start-up is presently working with input manufacturers and Farmer Producer Organisations (FPOs) to provide services (Kurmanath, 2019). It has already covered about 2,000 ha of crops by targeted spraying of pesticides in Telangana and Andhra Pradesh states.

Artificial Intelligence in Agriculture

Using artificial intelligence (AI) platforms, one can gather large amount of data from government and public websites. Presently, artificial intelligence (AI) based on machine learning (ML) is not extensively used in Indian agriculture for automatic data collection, analysis, decision making and controlling the various tasks using different algorithm and mathematical models. The AI offers vast opportunities for advance application in agriculture. The use of AI with computer vision and robotics is able to build next-generation agriculture equipment those can identify defects in fruits and vegetables, detect stresses in crops, assess nutrient deficiencies in soil, reduce chemical application and harvest high value crops. There is a growing interest in applying AI to develop smart farming practices to minimize yield losses in crops by early warning.

AI based agricultural machinery is becoming more and more intelligent. AI based sensors have become basic components on autonomous tractors, self-propelled machinery and implements. Within PA and digital agriculture based applications, AI based automated data acquisition will have the highest priority. Microsoft in collaboration with the International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Hyderabad has developed an AI Sowing App powered by Microsoft Cortana Intelligence Suite including Machine Learning and Power BI. The App sends sowing advisories to participating farmers about the optimal date to sow. The best part is that farmers do not need to install any sensors on their farms or incur any capital expenditure. They only need a feature phone capable of receiving text messages. These AI-based sowing advisories led to 30% higher yield per hectare (Microsoft News Center India, 2017).

Precision Irrigation

Globally, agriculture accounted for 90% of freshwater consumption for irrigating 20-30% of agricultural land of which contribution of surface water and ground water was 60% and 40%, respectively (Chaturvedi et al., 2013; Smilovic et al., 2015). India has 18% of world population, and 4% of world's fresh water, out of which 80% is used in agriculture. Of the net sown area of 140.1 Mha, only 68.4 Mha is net irrigated area (DARE-ICAR Annual Report 2018-19, 2019). With advent of climate change and increase in demand of water for other competitive uses such as domestic and industrial use, water available for irrigation will be limited in future. The conventional surface irrigation methods such as border, check basin and furrow have low efficiency (30-60%). In addition, they have limitations of uniform distribution of irrigation water in terms of space and time, higher seepage and percolation losses and affected by soil type and topography of the land. Precision irrigation methods such as drip and sprinkler irrigation minimize water loss as water is carried through closed pipelines and delivered at desired rate resulting in higher conveyance and application efficiency. Therefore, there is a huge potential to bring more area under irrigation in India.

The Government of India implemented the National Mission on Micro-Irrigation (NMMI) scheme to enhance water use efficiency in the agriculture sector by promoting appropriate technological interventions like drip and sprinkler irrigation systems and encouraging the farmers to use water saving and conservation technologies. The scheme in this form continued up to 2013-14 and is being continued as centrally sponsored scheme on Micro Irrigation under Pradhan Mantri Krishi Sinchayee Yojana (PMKSY). The scheme has benefitted the farmers in term of enhanced productivity and reduced cost of electricity and fertilizers consumption. The average productivity of fruits and vegetables increased by about 42-52% and fertilizer usage reduced by 28%. Besides, the scheme has also succeeded in reducing the irrigation cost by 20-50% and electricity consumption by 31%. Moreover, this led to increase in water use efficiency by 50-90% and farmer's income by 42%. Given its higher efficiency and ease of implementation within months as compared to conventional irrigation projects which need years to create infrastructure to implement, micro-irrigation system can go a long way in addressing the issues faced by country and agriculture sector. The integration of micro-irrigation with watershed projects particularly for utilization of harvested water as aimed under PMKSY too are likely to result in an efficient utilization of available water resources in agriculture with significant savings of water for extending the irrigation facilities to un-irrigated areas.

The indicative costs per hectare of

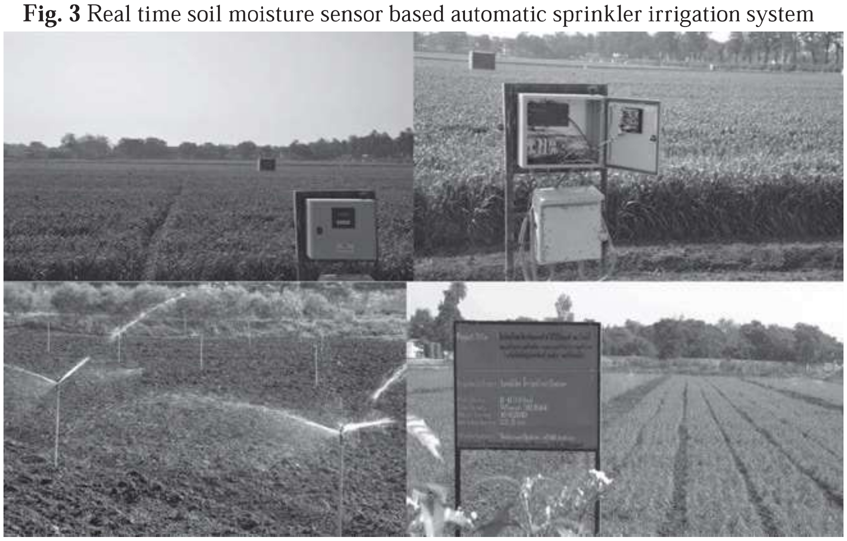
drip, micro and mini sprinkler irrigation systems are Rs. 25,000-75,000, Rs. 58,000-68,000 and Rs. 85,000-95,000 (One US \$ ≈ 74 Rs.) , respectively depending upon type of crop/spacing/material used and source of water (Anonymous, 2017b). Small and marginal farmers are often not looking at saving of water, energy and fertilizer due to high initial investment of these systems. Therefore, reducing manufacturing cost of the products and/or material replacement or increasing life of system are a few areas for further research.

The sensors available for monitoring of different soil and climatic parameters such as soil moisture and temperature for automated irrigation system are costly and not robust. The number of sensors per unit area and their placement are also important and provide soil moisture data at a particular point at a depth (**Fig. 3**). The wetted area of different micro-irrigation systems need to be considered to provide representative data to decide about number of sensors per unit area for irrigation scheduling. The variable rate irrigation application can be designed considering soil heterogeneity. The yield mapping and/or traditional soil sampling can help to identify different soil zones according to their physico-chemical properties. However, electro-magnetic induction (EMI) or near-infrared (NIR) system can be used on a field to map spatial soil variability.

The biotic as well as abiotic stresses of plants can be assessed using high resolution imagery. Satellite data, use of unmanned aerial vehicles and drones can be used for procuring high resolution thermal and RGB images for spatial soil moisture mapping/plant water stress monitoring which can be used as inputs for activating an automated irrigation system. These techniques can lead to precision and site-specific irrigation overcoming field variability and soil heterogeneity. The potential of near-surface remote sensing as a scalable platform for collecting high-resolution plot-specific data in addition to local images captured using smart phones can be used in supporting crop damage insurance, crop modelling, and extension for building resilience to yield risk and maintaining sustainable food security in smallholder agricultural systems (Madramootoo and Morrison, 2013).

The real time irrigation scheduling using sensors can be achieved using Wireless Sensor Network (WSN), IoT and AI based technologies. Currently, automation is being practiced using embedded system and micro-controller with the help of solenoid valves in a few Indian farms. However, these are limited to research level and/or small scale. The research in future should focus on development of irrigation scheduling using techniques such as machine learning, deep learning and artificial intelligence. The compact and robust sensors can also be developed using nano-technology having high accuracy.

Fig. 3 Real time soil moisture sensor based automatic sprinkler irrigation system



Solar Powered Irrigation

The success of government policies and programs such as PMKSY, National Water Policy, National Mission of Sustainable Agriculture etc., is limited due to India's energy crisis leading to widespread power outages and unscheduled interruptions across rural and urban India. As micro-irrigation systems are operated at standard operating pressure (98-392 kPa), pumps are required to generate desired pressure irrespective of source of water. In India, it is estimated that about 21 million pumps are electricity operated and 8.8 million pumps are diesel engine operated, while only 0.13 million are solar powered pumps. The unscheduled power outages in India also affect the timing and supply of irrigation water to field crops. Although diesel engine operated pumps allow more flexibility as compared to electrical pumps (AC power), but availability of diesel and its cost are the major constraints (Garg, 2018).

The solar irrigation system consists of solar cells, electricity generator and pump. In this, solar energy absorbed by cells (panel) is converted into electrical energy by generator and fed as input to motor driven pump. The Government of India through Kisan Urja Suraksha evm Utthaan Mahabhiyan (KUSUM) scheme has planned to provide solar pumps where grid electivity has not reached. The Ministry of New and Renewable Energy of Government of India has launched the scheme to provide subsidy to farmers on installation of solar irrigation pumps

(SIPs) for their farms. Under the scheme, the farmers will have to spend only 10% of total expenditure to acquire and install a solar pump and 60% of cost will be borne by government and the remaining 30% will be given as loan by the bank as credit.

The solar pumps not only irrigate the farms but also generate safe energy. Farmers can also sell extra power to power supply companies to generate extra income. However, high initial investment and variable yield (discharge) as per the solar radiation are some of the issues for their large scale adoption. The up-front cost of solar pumps, heavily subsidized supply of electricity to the rural sector, poor after-installation maintenance support and lack of awareness of the benefits of solar pumps prevent most of Indian farmers from shifting from less efficient and unsustainable modes of irrigation to solar water pumps.

Smart Phone Based Apps

Number of smart phone users in India are likely to get double (401 million) by 2020 as compared to 199 million in 2015. With an increasing trend in growth in digital services, Indians downloaded more apps (12.3 billion) in 2018 than residents of any other country except China. This was due to reduction in data cost by more than 95% as compared to 2013. Large number of mobile apps related to agriculture and allied areas have been developed. These apps support weather forecasting/warning, disease and pest management, market updates, crop insurance and payment gateway individually or in combination. Further, these apps can be connected to data acquired from drones, cameras, satellite images for forecasting/predicting plant diseases at an early growth stage.

ICAR-CIAE, Bhopal has developed web-based app to suggest machinery package for different cropping systems of India. The app suggests farm machinery package based on agro-climatic region, state, district, cropping pattern and power source. The apps also recommend an estimated cost of farm machinery package, list of manufacturers and their addresses. An Android smartphone based app 'KRISHI Yantra' has also been developed (**Fig. 4**).

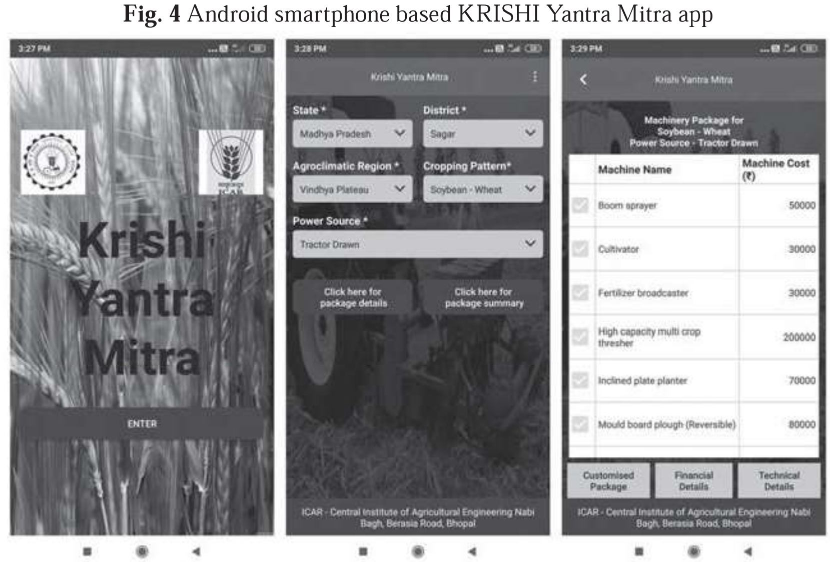
The app 'Kisan Suvidha' provides information on weather updates, 5 days' weather forecast, soil information, market prices, location of cold storage system and godowns, etc. The app "CHC Farm Machinery" has been developed for farmers to avail custom hiring services from the nearest custom hiring centre (within 50 km radius). The "Bhuvan Hailstorm" app helps to estimate losses in crop yield due to hailstorm. The information on location (latitude and longitude), crop details and photographs are required by the app as inputs.

Strategies for Smart Farm Mechanization

Present Indian agriculture is highly labour intensive whereas smart agriculture is all about machines and technologies. The Department of Agricultural Cooperation and Farmers Welfare (DOAC & FW) and Department of Agricultural Research and Education (DARE) of Government of India are engaged to enhance technical cooperation among state departments of Agriculture/Agricultural Engineering, State Agricultural Universities (SAUs), research institutes and associate members of NARS as well as other interested NGOs, through extensive exchange of information, sharing of knowledge and promotion of R&D and agri-enterprise development in the areas of sustainable agricultural mechanization, in order to attain the nationally agreed development goals.

The research institutes of Indian Council of Agricultural Research (ICAR), SAUs, IITs, NITs and other private organizations are involved in development of technologies based on precision agriculture (PA), digital agriculture (DA) and AI through different projects such as the National Agricultural Innovation Project (NAIP), Consortia Research Platform on Farm Mechanization and Precision Farming (CRP on FMPF), AICRP on Farm Implements and Machinery, etc. These institutes are applying modern tools and techniques for application of sensors and robotics in planting, rice transplanting, auto-guided tractor, drone-based spraying with

Fig. 4 Android smartphone based KRISHI Yantra Mitra app



the help of AI, etc. It is vital that these centres should focus on the stakeholders' interests to ensure that research concepts (farming methods and machinery) may not remain at the prototype stage.

The themes of PA, DA and AI in agriculture can be applied across disciplines and may bring a paradigm shift in how we see farming today. The following strategies will not only enable farmers to do more with less but also help to improve quality and ensure faster go-to-market for crops.

1. Promotion of digital farming and precision agriculture technologies in addressing issues related to sustainable farming through research & development and financial assistance.
2. Need for increased application of precision agriculture and smart agriculture with involvement of private sector for farm mechanization.
3. The potential of vertical farming may be harnessed by next generation drones enable with advanced navigation technology and AI.
4. The advancement in agri-bot will directly address the challenge of labour drain and further unlock productivity potential.
5. Establishment of an interactive digital platform to allow farmers full access to information and technology databases, expert systems and DSS for web based agro-advisory, skill development, machinery management and financial assistance.
6. The agriculture should shift focus from productivity per unit area of land to irrigation water productivity. The applications of ground-based sensors and remote sensing data at high spatial and temporal scales can be integrated for forecasting and allocation of irrigation water.
7. Promotion of an app-based farmer-to-farmer aggregation platform, which bridges the demand and supply gap of machinery or equipment by connecting owners of tractors and farming equipment with those who require their services.
8. Human resources development of scientists and technical manpower in smart agriculture technologies such as AI, precision agriculture and digital agriculture.
9. The drudgery prone and repetitive farm operations such as weeding, spraying and harvesting of costly fruits and vegetable can be enabled with AI, leading to improved accuracy and productivity.
10. The data captured/generated by drones can be used to implement crop insurance schemes to evaluate/verify crop damages claims. Farmers can make insurance claims by capturing drone feeds as evidence.

Conclusions

There are four recurring themes for sustainable smart agricultural mechanization in India.

1. Farm power and agricultural machinery are essential inputs if sustainable agricultural production and productivity are to be increased and managed to feed India's burgeoning population.
2. The intensification of crop production must be sustainable. Its environmental footprint (carbon and energy) must be as low as possible and in any case lower than the rate of natural renewal.
3. Top-down solutions are rarely efficacious. All stakeholders need to be considered from the outset and the private sector must lead the development process on the field.
4. A holistic, value-chain approach is necessary for agricultural mechanization, going beyond green production through precision agriculture and digital agriculture.

If agricultural mechanization efforts are to succeed in India, there is an urgent need for all stake holders like farmers, manufacturers, supporters, planners or decision makers, to understand and contribute to smart agricultural mechanization efforts across the entire farming system. There is also a need for regional research & development complex and centres of excellence that can guide national policy towards sustainable agricultural mechanization. The large agricultural tractor and machinery manufacturing sector in India requires incentives for the manufacturing of equipment for sustainable mechanized agricultural practices.

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