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Enhancing livelihoods in farming communities through super-resolution agromet advisories using advanced digital agriculture technologies

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ABSTRACT

Agricultural production in India is highly vulnerable to climate change. Transformational change to farming systems is required to cope with this changing climate to maintain food security, and ensure farming to remain economically viable. The south Asian rice-fallow systems occupying 22.3 million ha with about 88% in India, mostly (82%) concentrated in the eastern states, are under threat. These systems currently provide economic and food security for about 11 million people, but only achieve 50% of their yield potential. Improvement in productivity is possible through efficient utilization of these fallow lands. The relatively low production occurs because of sub-optimal water and nutrient management strategies. Historically, the Agro-met advisory service has assisted farmers and disseminated information at a district-level for all the states. In some instances, Agro-met delivers advice at the block level also, but in general, farmers use to follow the district level advice and develop an appropriate management plan like land preparation, sowing, irrigation timing, harvesting etc. The advisories are generated through the District Agrometeorology Unit (DAMU) and Krishi Vigyan Kendra (KVK) network, that consider medium-range weather forecast. Unfortunately, these forecasts advisories are general and broad in nature for a given district and do not scale down to the individual field or farm. Farmers must make complex crop management decisions with limited or generalised information. The lack of fine scale information creates uncertainty for farmers, who then develop risk-averse management strategies that reduce productivity. It is unrealistic to expect the Agro-met advisory service to deliver bespoke information to every farmer and to every field simply with the help of Kilometre-scale weather forecast. New technologies must be embraced to address the emerging crises in food security and economic prosperity. Despite these problems, Agro-met has been successful. New digital technologies have emerged though, and these digital technologies should become part of the Agro-met arsenal to deliver valuable information directly to the farmers at the field scale. The Agro-met service is poised to embrace and deliver new interventions through technology cross-sections such as satellite remote sensing, drone-based survey, mobile based data collection systems, IoT based sensors, using insights derived from a hybridisation of crop and AIML (Artificial Intelligence and Machine Learning) models. These technological advancements will generate fine-scale static and dynamic Agro-met information on cultivated lands, that can be delivered through Application Programming Interface (APIs) and farmers facing applications. We believe investment in this technology, that delivers information directly to the farmers, can reverse the yield gap, and address the negative impacts of a changing climate.

Keywords: Livelihood, Indian agriculture, Agro-advisory, Digital technology, Marginal farmers, Transforming agriculture

The world's population is expected to reach 10 billion by 2050 and the agricultural sector must increase crop production to ensure global food security (FAO, 2017) (Ericksen *et al.*, 2009). However, the agricultural sector faces numerous challenges, with a changing climate, variable monsoons, small land holdings and declining soil quality.

In developing nations, traditional farming systems often dominate. These farming systems evolved over thousands of years as a result of the lessons learned from regional farming techniques (Pulido and Bocco 2003). Practices changed slowly, where farming systems developed using local insight and locally available technology. Farmers in developing countries generally use

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regional, customary, or landrace varieties of both minor and major crops (Jackson *et al*., 2007). Furthermore, traditional agricultural practices are still widely employed and these systems provide sustenance to 1.9 to 2.2 billion people globally (Singh and Singh, 2017). However, these systems are under threat. Urbanisation, lack of space, deforestation, water shortages and climate extremes are challenging these traditional systems faster than they can naturally adapt. There is an urgent need to modernise these farming systems, boost productivity, build resilience, and maintain the global food security for nearly a third of the world's population (Subeesh and Mehta, 2021).

Modernisation of traditional farming systems is complex. One of the emerging areas of modernising farming is use of information and communication technologies to provide effective Agro-met advisories to enable the farmers for an informed decision making. The Agro-met Advisory Service has been established to provide farmers with intelligence about the prevailing weather conditions and forecast climate to protect standing crops from potential weather anomalies. The Agro-meteorological Advisory Services provide a crucial service to farmers and contribute to weather information-based crop/livestock management strategies and operations dedicated to enhance crop production and food security. The service provides insight into current crop conditions, weather forecasts, identifying weather-related stresses (droughts, floods, cold and heat waves, etc.), weather-based farm management advice, distribution of Agro-met advisory bulletins, etc. The service can answer specific questions from farmers, and can respond to feedback from farmers. These advisories services provide important data on all agricultural operations, from land preparation to harvesting, based on weather forecasts. The capacity to provide accurate, timely weather forecasts has the potential to reduce the impact of erratic weather on food production, maximize resource utilisation and minimise losses caused by harsh/abnormal weather conditions (Hansen, 2002a; Venkataraman, 2004).

Agricultural technology and climate information are advancing rapidly. Advances in remote sensing, earth observation, crop modelling, climate forecasting mean technological insights can be provided quickly to farmers via digital tools such as mobile phones. These advancements mean there is an opportunity to enhance the services that Agro-met provides, to address real world problems that farmers face.

The review identifies the limitations of traditional south Asian production system that also exists in India. India has 159.7 million hectares of arable land (second largest after the US) with all the 15 prominent climates existing across continents and 46 out of 60 soil types in the world (Mohapatra and Rout, 2021). Indian subcontinent experiences extreme climatic events because of geographical and hydroclimatic conditions that affect the hydrological cycle (Mall *et al*., 2006). Climate change has emerged as a serious threat to the livelihood of Indian farmers (more than 80% are marginal and small farmers), who are still poorly informed and prepared to face recent changes in climate and its impacts on agriculture (Das *et al*., 2022). The review was conducted following the recommendations from the recently concluded Australia-India Council funded pilot-project held during 2017-2021 that focused on issues in the Birbhum district of West Bengal, India where climate change induced stresses threatened the existing production system.

Indian agriculture is rapidly transforming with the technological infusion and policy reforms. India's take on tackling climate change issues in agriculture has been encouraging but yet to be sufficed. Therefore, we evaluate the scope of smart technological intervention that may lift productivity, enhance food security and build in the economic resilience for the region. There is an urgent need to translate climate data into information that farmers can use. It is necessary to link climate information with available technologies and best agricultural practices. Small farmers require actionable information that is tailored to their location and crops (Chattopadhyay and Chandras, 2018). Thus, this paper highlights the use of existing and new remote sensing-based capabilities from space and airborne platforms to measure relevant soil, water and nutrient status, and combine these with weather forecasts using artificial intelligence and machine learning (AIML) approaches, to produce a high spatial resolution decision support system (DSS) for agriculture.

INDIAN PRODUCTION SYSTEM

In India, agriculture has been practiced since 9000 BCE (Bowman and Rogan, 1999). Despite of remarkable growth of Indian agriculture with food grain production increasing from 51 million tons (Mt) in 1950/51 to over 314 Mt in 2022, and ranking second in agricultural production in the world, the country faces serious production risks due to climate change. Typically, double monsoons occur, where extreme rainfalls occur from June through September due to southwest monsoon (summer monsoon); northeast monsoon (winter monsoon) affects India's east coast during November and December. Farmers developed systems to exploit this rainfall pattern, and to grow food and non-food crops in three main cropping seasons, viz. kharif (June-October), rabi (November-February) and zaid/summer (March-June) (Baber, 1996). Rice is the principal food grain and major crop occupying approximately 34% of the overall cropped area and grown mostly as *aman* rice in kharif season (sown in rainy season- July/August and harvested in winter); on availability of irrigation, *rabi* rice/ *boro* rice (sown in winter and harvested in summer) and pre-*kharif*/ *aus* rice (sown in summer with pre-monsoonal showers and harvested in autumn) are also grown. Wheat is the second major crop cultivated by the farmers in rabi season; oilseeds and pulses are also grown as rabi season crops. *Kharif* crops (rice, maize, jowar, millet, arhar, soyabean, groundnut, cotton, etc) are grown with the onset of monsoon in different parts of the country. The major *rabi* season crops are wheat, barley, mustard, sesame, potato and peas, most of which are grown with availability of irrigation. With availability of irrigation farmers cultivate crops like rice, corn, cucumber, melon, tomato, and some coarse cereals sown in March and harvested by June.

Rice is the most important crop during the *kharif* season in the Eastern India, covering about 26.8 million ha area, out of which about 11.7 million ha is kept fallow after harvesting of *kharif* rice. Farmers keep the areas fallow mainly due to lack of irrigation, late harvesting of long duration *kharif* rice, moistures stress at the time of sowing/ waterlogging and excessive moistures due to early/ late withdrawal of monsoon, and nuisance like stray cattle, etc (Kumar *et al*., 2019). Rice-fallow is a mono-crop rice based production system in India and mostly (82%) concentrated in the eastern states, which need an improvement in productivity and cropping intensity through appropriate technological interventions and suitable policy reforms.

Agriculture has played an important role in the Indian economy and is the dominant source of income in rural areas (Ahluwalia, 1978). India is the largest producer of pulses and jute and second largest producer of rice, wheat, cotton, fruits and vegetables in the world. However, Indian agriculture continues to face the challenges of increasing productivity, profitability and resilience at the backdrop of increasing population, depleting natural resource base, aggravating climate change and reducing farm income (Mohapatra *et al*., 2022). Lifting agricultural production enables a greater portion of that region to engage in non-agricultural activity. This in-turn improves the overall livelihoods and standard of living for that region (Bellu, 2018). Therefore, the economic prosperity of a region is intrinsically linked to agricultural productivity.

There are many barriers related to lifting productivity. For example, many of the farmers depend on their Indigenous Technological Knowledge (ITK) for predicting weather, planning their crops and their management practices. However, the digital revolution has opened new windows for Indian farmers (Mohapatra and Rout, 2021). Weather forecasts, and decisions related to those forecasts are not widely used by the marginal farmers. Yet, weather data can help the farmers in the selection of variety, sowing and harvesting operations, scheduling of irrigation and optimal water use, adaptation to the adverse weather events such as low temperature, frost, heavy rainfall at critical crop stages, nutrient management through fertilizer application, plant protection measures such as pesticide, fungicide spraying schedules, feed, health and shelter management for livestock (Chaudhari *et al*., 2018). Productivity improvements would be possible, if weather forecasts, and the decisions related to those data were better communicated to farmers with modern digital technology.

CONSTRAINTS IN EXISTING PRODUCTION SYSTEM

India has achieved self-sufficiency in food grains production after the Green Revolution (Abrol and Sangar, 2006); however, this system has brought a host of environmental challenges (e.g., loss of soil fertility, waterlogging, ground and surface water pollution, intensified pests, and diseases) and socio-economic problems (e.g., increased farm input prices, regional disparity) (Cummings, 2019). At the same time, climate change exacerbates existing problems, is challenging the current production systems and poses a significant threat to Indian agriculture (Rao *et al*., 2016). Recent studies showed a dramatic change in the weather parameters such as temperature, frequent heat waves, droughts, extreme precipitation events, and intense cyclonic activities (Ray *et al*., 2019; Rohini *et al*., 2016; Sharma and Majumder, 2017). Thus, significant yield loss in India is associated with the frequent droughts since 1966 (Auffhammer et al., 2012). The crop water demand has been found to upsurge with the prolonged warming and thus will be requiring more irrigation (Venkateswarlu and Singh, 2015). Low agricultural water productivity from 10 water guzzler crops (like rice, wheat, maize, chickpea, arhar, groundnut, rapeseed-mustard, sugarcane, cotton and potato occupying more than 60% gross cropped area) has been a concern for improving cropping and irrigation intensity (Sharma *et al*., 2018). Three major crops- rice, wheat and sugarcane occupying 40% of gross cropped area consume more than 80% of irrigation water available in the country. In the rice based cropping system in irrigated areas, rice-wheat cropping pattern has been pointed out a major reason for lower water productivity. In India, the overall efficiency of surface and groundwater irrigation ranges between 30-65% and 65-75%, respectively (Sharma *et al*., 2018). At the same time, over-exploitation has already led to a substantial decrease in the groundwater level; even those areas with increased precipitation due to climate change, would need excessive groundwater extraction if irrigated agriculture is extended (Zaveri *et al*., 2016). Guiteras (2009) found that in the short run (2010–2039), climate change would lower the yields between 4.5-9%, whereas, in the long-run (2070-2099), it will drastically reduce the yields at least by 25% in the absence of adaptation.

Ultimately, climate change directly affects farmers while the climate and agricultural production system changes will affect food security (Soubry *et al*., 2020). The combined effect leads to farmer distress, localised inflation, and has far-reaching economic consequences. Currently, the annual average crop losses due to extreme weather reduce India's annual GDP by 0.25 (Singh *et al*., 2019). Besides, climatic stressors exacerbate farmers' debt burden and cause emotional stress that has led to suicide (Carleton, 2017). Thus, climate change and the associated hardships are the major concerns for India, as because 85% of the farmers have low financial resilience (Singh *et al*., 2019). There is an urgent need to develop India's agricultural production systems to cope with the changing climate. Greenhouse gas mitigation and intervention strategies will not reverse this trend, so direct engagement to adapt agricultural systems to the new reality is essential (Klock and Nunn, 2019).

India is a diverse country with variable land holding capacities, thus farmers' perceptions and adaptations are also likely to differ spatially. Therefore, to achieve sustainability, there is a pressing need to create a constructive and comprehensive knowledge base for decision-making by identifying and integrating the heterogeneous information on farmers' perceptions and adaptation actions.

SUCCESSES OF AGRO-MET ADVISORY SYSTEM (AAS) AND GAP AREAS

Weather forecasts and weather-based Agro-met advisories help in growing the economic benefit to the farmers by suggesting suitable managing practices according to the weather conditions (Vashisth *et al*, 2013). Every Tuesday and Friday, AAS bulletins are distributed to 636 districts based on the medium-range weather forecast. State Composite bulletins (23) and National AAS bulletins were also issued parallelly. There are efforts to prepare AAS bulletins for all the districts. As a result of this, NCMRWF (National Centre for Medium Range Weather Forecasting) has developed a forecasting system for objective medium-range location-specific surface weather elements (Maini *et al*., 2004). Location specific weather forecasts for six parameters: maximum and minimum temperature, humidity, precipitation, pressure, wind speed, and wind direction. A T-80 collected data on precipitation, cloud cover, wind direction and velocity, and minimum and maximum temperature twice per year with a resolution of 150 km x 150 km for the general circulation model. These forecasts were again subjected to statistical and synoptic interpretation by experts, and 5-day quantitative forecasts were issued twice per week to AAS units. AAS units converted these forecasts into farm-level advisories and disseminating them to farmers in their native language via mass media (Rathore, 2013).

The India Meteorological Department (IMD) is responsible for collecting and analysing meteorological data. Districts have adopted AAS since 2008. The local district AAS is provided to farmers to utilise the information provided by the NCMRWF and IMD regarding medium-range weather forecasts. All India Coordinated Research Project on Agrometeorology (AICRPAM) undertook a pilot project in 2010 to generate and circulate micro-level AAS through its 25 cooperating centres spread throughout the country in order to enable growers' capacity development for climate resilience (Vijayakumar *et al.*, 2017). Micro-level agro-advisory service also provided the weather data twice a week to the farm grower through the subject matter specialist of KVK or individual farmers received advisories directly via mobile telecommunication networks (via SMSs), announcements were made over the village public address system (loudspeakers), and weekly posters were displayed in prominent locations in some villages and on walls/ blackboards (Lobo *et al*., 2017). For the benefit of the Indian producer, IMD has published Agro-met brochure in different Indian regional languages such as Hindi, English, Assamese, Bengali, Gujarati, Kannada, Malayalam, Manipuri, Marathi, Nepali, Punjabi, Tamil, Telugu, and circulated for wider publicity (Chattopadhyay and Chandras, 2018).

The weather has a significant impact on agricultural productivity. For efficient planning and control of agricultural operations, weather forecasts across all time scales are desirable. Farmers became aware of the potential advantages of employing weather-based agrometeorological information to minimize losses due to unfavourable weather conditions, consequently enhancing yield, quantity, and quality of agricultural products, thanks to the development of reaction strategies (Maini and Rathore, 2011). Weather-based advisories are directly related to farmers' traditional knowledge (Patt and Gwata, 2002). If weather and climate predictions can influence a farmer's decisions regarding important aspects of farm management, then the forecast is more valuable from their point of view (Everingham *et al*., 2002; Gadgil *et al*., 2002; Ingram *et al*., 2002). Therefore, it becomes crucial to relate to farmers' needs (Hansen, 2002b), comprehend their requirements, and provide the forecast with an inappropriate spatial and temporal range (Hammer *et al*., 2001; Hansen, 2002b). Crop losses can be reduced by implementing real-time contingencies in crop management based on weather forecasts. Numerous studies have revealed that perceived behavioural control factors, followed by attitude and subjective norms, had the greatest impact on farmers' intentions to adopt (Arunrat *et al*., 2017).

NEW TECHNOLOGIES FOR TRANSFORMING AGRICULTURE

In the nexus of current agricultural challenges, space-based solutions seem to be a lucrative option as decision support tool for sustainable production, early warning system to food insecurity and insurance or credit products. In the last few decades, due to major improvements in remote sensing data acquisition, processing and interpretation, space technology is becoming an indispensable tool for farming sector. Multispectral, Hyperspectral, Microwave, Thermal or LiDAR imaging from multiple platforms involving drones or satellites with high spatio-spectral fidelity are paving the way for space technology applications. Today global agriculture is progressing towards the concept of Agriculture 4.0 (Rose and Chilvers, 2018) encompassing a wide variety of futuristic, potential game-changing technologies (Klerkx and Rose, 2020). Besides, the emerging field of Artificial Intelligence (AI) is pushing boundaries beyond imagination. Improvements in precise information collection, understanding of underlying cause and overall predictions coupled with automated decision making through AI are some of the immediate benefits of AI in the field of digital agriculture (Smith, 2020). Scope of different AI and ML techniques for retrieval of useful information related to precision agriculture using remote sensing data have been realized in irrigation water management (Mendes et al., 2019), nutrient management (Zeraatpisheh *et al*., 2019), plant protection (Behman *et al*., 2015) or yield monitoring.

Different optical and thermal remote sensing based vegetation indices such as Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Shortwave Infrared Water Stress Index (SIWSI), Degrees above non-stressed canopy (DANS), Degrees above canopy threshold (DACT), Crop Water Stress Index (CWSI) have been used by researchers to detect water stress in vegetation (Ballester *et al*., 2018, DeJonge et al., 2015, Egea *et al*., 2017; Ahmad *et al*., 2021). Satellite based evapotranspiration (ET) estimates provides useful insight into crop water demand for irrigation scheduling (Verstraeten *et al*., 2008). Soil moisture retrieval in optical-thermal region of the electromagnetic spectrum using Land-surface Temperature-Vegetation Indices (LST-VI) "triangular" or "trapezoidal" space has also been employed in optical trapezoid (OPTRAM) model (Sadhegi *et al*., 2017). Rejuvenation of degraded soil health due to heavy nutrient mining and improper blanket application of fertilizers without considering plant need could be achieved through Site Specific Nutrient Management (SSNM) based on 4R nutrient stewardship concept (Bruulselma *et al*. 2012). A wide diversity of research work has been carried out to estimate soil properties in spatial scale using soil reflectance spectroscopy either proximally through hand-held spectrometer (Dalal and Henry, 1986; Ben-Dor and Banin, 1994) or remotely using satellite or drone based images. In soil a variety of chromophores including clay minerals, organic matter, water and iron oxides affect the shape of soil reflectance spectra directly and predictive modelling through selection of sensitive wavebands can help in their spatial mapping (Ben-Dor, 2002). Remote sensing data coupled with GIS and GPS techniques provide a new paradigm in identifying spatio-temporal dynamics of plant biotic stress due to disease attack (Pethybridge *et al*., 2009) as compared to conventional field scouting based disease scoring (Nutter *et al*., 2006). Integration of different geospatial thematic data layers pertaining to environmental variables linked to stress response in plants is found to be effective in discerning the stimulus-response relationship and predicting pathogen population density in spatial scale (Nutter *et al*., 2002, 2010). In diseased plant increased reflectance in the visible range or the red-edge shift to shorter wavelengths is reported due to presence of discrete necrotic or chlorotic lesions on leaves (Moshou *et al*., 2011) while senescence or limited growth decreases the canopy reflectance in the NIR region. Digital infrared thermography also has potential for disease detection because of its direct effect on plant transpiration (Oerke *et al*., 2010). Besides The Internet of Things (IoT) based insect pest warning systems (Saleem *et al*., 2021), high definition video monitoring system (Cheng *et al.*, 2017) or computer vision (Larios *et al*., 2008) and advanced ML algorithms like deep learning or support vector machines for pattern recognition (Couliably *et al*., 2022) are emerging as potential field for pest monitoring system. Low altitude imaging through UAVs and use of IoT based sensors along with different ML techniques have also been increasingly used for pest damage detection (Gao *et al*., 2020).

The incorporation of technology for agricultural growth is an urgent necessity. The Internet of Things (IoT) has enormous potential to revolutionise agriculture automation, and it is already performing miracles in the field (Matta and Pant, 2019). The combination of the IoT and artificial intelligence (AI) produces powerful systems that can surpass human decision accuracy.

All data produced by a satellite are processed for the extraction of the desired information. There are many methods, algorithms and procedures to derive fundamental data for agrometeorological applications from remote-sensing. For efficient utilization of resources in agriculture, GIS and remote-sensing (RS) technology must be integrated. Products derived from remote-sensing are particularly attractive for GIS database development because of its cost effective, wide coverage in a digital format that can be directly entered into a GIS. The process of integration usually includes the following analytical procedures: data acquisition, data processing, parameter retrieval, data analysis, data conversion, integration into process models, error assessment, and final product presentation.

A leading agrometeorological weather service, using advanced data collection and analysis tools like remote-sensing and GIS, must be equipped with sophisticated devices, but above all must have efficient and trained staff. In developing countries, there remains a risk that using limited resources (high-level agrometeorological personnel and funding) on the development of highly specialized and complex products will not serve the needs of agricultural decision-makers. The problems and priorities of agrometeorological services need to be defined first. Methodologies come second, but will be essential if they are made available and applied properly.

The platform for remote-sensing can be either fixed or moving, terrestrial or operating from different altitudes, and it can be either manned or unmanned. Considering the operating time, the platform can be classified as temporary, semi-permanent or virtually permanent. These aspects are important in order to understand the quality and quantity of the information available to the agrometeorological service.

Thus, smart interventions were needed for sustainable efficient management of soil moisture and nutrient to assure economic crop return aiming to enhance the farm-life. The fortified intervention successfully demonstrated the benefits of climate smart agricultural practices in two small-holder village communities. Here, excess rainfall water normally lost was captured, and was applied through climate-smart practices and a collective approach to resources. It was aimed to diversify agricultural production, increase in profitability, and increase the labour market participation of women.

Many studies have been carried out globally using remote sensing for agriculture and crop yield estimation. There is still a paucity of dedicated applications of remote sensing for soil health monitoring and soil health based crop yield estimations (Pointing and Belnap, 2012; Van Der Heijden *et al*., 2008).

In recent years, Indian Space Research Organization (ISRO) has made significant progress using satellite remote sensing applications in agriculture especially generation of agro-met products (Nigam *et al.*, 2021; Bhattacharya, 2007), crop inventory using AI/ML (Das *et al.*, 2021 and yield estimation (Bhattacharya *et al*, 2011, Tripathy et al., 2021, Kumar *et al*., 2021) at various scales. With the major development in relation to the atmosphere and climate, improved simulation of tropical cyclone track with regional 3DVar initialization was evaluated using Weather Research and Forecasting (WRF) model. It was evident that the 3DVar runs are superior in simulating the track movement of all the four cyclones and hence the same could predict the landfall position more realistically. Recently, on the aspect of integrating of hyperspectral imaging and 3D laser scanning for crop discrimination and biophysical modelling, application of drone based hyperspectral imaging in agriculture was evaluated to aid the application of drone based hyperspectral imaging in agriculture.

POSSIBLE PATHWAY OF DIGITAL TECHNOLOGY DIFFUSION FOR SMALL AND MARGINAL FARMERS

When India launched the satellite IRS 1C in 1995 with a resolution of 6 m, it had the distinction of having the highest spatial resolution among all operational civilian remote sensing satellites in the world at that time. This world-class technological capability in remote sensing was a result of favourable organisational and institutional factors that nurtured innovation. Since India is still largely agriculture and natural resources dominated economy, a generic technology that could be used in many sectors related to natural resources has the potential to accelerate the economic development process. Satellite remote sensing emerged as a successor of aerial remote sensing during the 1960 s with the Explorer, TIROS (Television Infrared Observation Satellite) series, Corona, and later with Landsat missions, among others. Though Indian remote sensing technology has improved leaps and bounds, but its technological intervention remains limited for the benefits of the average Indian farmers.

Farmers and other rural players can also be benefited from weather-based advice services (Chipeta, 2006). In India, there have been numerous efforts to issue crop advisories depending on the weather. The National Centre for Medium Range Weather Forecasting (NCMRWF) under the Ministry of

Earth Sciences (MoES), Government of India had been providing Agrometeorological Advisory Services (AAS) to the farming community based on location-specific medium-range weather forecasts to the districts under different agro-climatic zones (now called Integrated Agrometeorological Advisory Service) (Maini and Rathore, 2011). The operation of an advisory system is explained by the interrelated factors of governance, financing mechanisms, skills and qualifications of advisors and managers of service providers, and the method by which advice is provided, which is characterised by the advisor's service relationship with the farmer (Faure *et al*., 2011. The quality of advisory services is determined by (i) the accuracy and relevance of the advice's content, (ii) the quality of the partnerships formed and the feedback effects generated, (iii) the timeliness and outreach of the advice, and (iv) the effectiveness of service delivery and other economic performance indicators (Birner *et al*., 2009). In agricultural point of view, machine learning and Artificial Neural networks are the furthermost extensively applied methods in research related to mechanization in agriculture (Jha *et al*., 2019). There is a need to develop robust algorithms that determine the crop productivity (in terms of yield) in heterogeneous agricultural systems since most of the research focused on scales that match satellite footprint (Karthikeyan *et al*., 2020).

Remote Sensing is an important method for describing both temporal and spatial properties observed from earth surface characteristics for spatially separated variables (Kneubuhler, *et al*., 2014; Pande *et al*. 2017; Pande *et al*., 2019). Tomar *et al.*, 2014 studied the prediction of soil physical and chemical properties useful for special emphasis on agricultural land and ecological management in India. Ustin *et al*., (2006) used non-destructive and well-organized computational wavelet transformation techniques, but the current view of agriculture, forestry and other areas under the climate change scenario is critical to soil health. Wavelets convert methods and satellite data was easily classify the soil chemical properties (Wang *et al*., 2010; Peng *et al*., 2012; Pande, 2020). Models for real-time monitoring of soil factors outlook for soil physical and chemical properties prediction have been developed (Ines *et al*., 2013). Hongyan Chen *et al*., (2011), viz., have developed three predictive models. Useful for predicting soil chemical properties, linear, polynomial, strength, nonlinear.

The size of operational holdings in India is continuously declining with every successive generation. The situation has raised serious question on the survivability of these small holders (Pandey *et. al*., 2010). On the other hand, the rapid increase in population coupled with substantive increase in incomes and purchasing power has led to increased demand for quality food and agricultural products. According to the XII plan Working Group, "The small and marginal farmers are certainly going to stay for a long time in India — though they are going to face a number of challenges". Therefore, what happens to them has larger implication for the agrarian sector in particular and the entire economy in general, which has an implication on people's livelihood." Being smallholders, these farmers suffer from some inherent problems such as absence of economies of scale, access to information and their inability to participate in the price discovery mechanism. The participation of farmers is observed to be restricted by limitations like poor vertical and horizontal linkages and limited access to market, training and to finance (Fernandez-Stark and Bamber, 2012).

The challenge is to optimize benefits through effective and efficient means of aggregation models. The instrument of Farmer Producer Company (FPC), registered under Companies Act, is emerging as the most effective means of Farmer Producer Organization (FPO) to cater to the needs of farmers at the grass root level. FPCs offer a wide range of benefits compared to other formats of aggregation of the farmers. FPC members are able to leverage collective strength and bargaining power to access financial and non-financial inputs and services and appropriate technologies leading to reduction in transaction costs. Members can also collectively tap high value markets and enter into partnerships with private entities on equitable terms. Its main activities consist of production, harvesting, processing, procurement, grading, pooling, handling, marketing, selling, export of primary produce of the members or import of goods or services for their benefit. It provides for sharing of profits/benefits among the members.

The Department of Agriculture and Cooperation, Ministry of Agriculture and Farmer Welfare, Govt. of India has identified farmer producer organization registered under the special provisions of the Companies Act, 1956 (As amended in 2002), now Companies Act, 2013, as the most appropriate institutional form of aggregation of farmers. The main objective of mobilizing farmers into member-owned producer organizations, or FPCs, is to enhance production, productivity and profitability of agriculturists, especially small farmers in the country.

Successful examples of producer companies in India (Paty and Gummagolmath, 2018) are:

i. Jagannath Crop Producers' Company Ltd., Odisha, Chetna Organic Agriculture Produce

ii. Company (COAPCL), and Chetna Organic Farmers' Association (COFA), Telangana,

iii. Pashusamvardhan Producers Company Ltd., Maharashtra,

iv. Dhari Krushak Vikash Producer Company Limited, Gujarat,

v. Rangsutra in Kerala,

vi. Vegetable Growers Association (VGAI), Narayangaon Pune

vii. Sahyadri Farmer Producer Company, Nasik

viii. PAAYAS Milk Producer Company, Jaipur

ix. Savithribai Phule Goat Farming Producer Company

x. Maahi Milk Producer Company, Gujarat

xi. Nachalur Farmer Producer Company, Tamil Nadu

These companies are creating benefits in farm and non-farm sectors. For example, Sahayadri farms revolutionized the farming of smallholder farmers by quickly transforming into a movement of farmers through the smart accurate weather forecasts for disease and pest control, early warning to farmers and avoid losses. A large number of producer companies have been registered across 24 states on the initiative of Small farmers Agri-Business Consortium (SFAC). NABARD and National Horticultural Board (NHB) are also promoting incorporation of producer companies.

With a view to improve the condition of small and marginal farmers and to double the income of farmers, Government of India realigned its interventions from 'production-centric' approach to 'Farmers' income-centric' initiatives, with focus on better and new technological solutions.

The recommendations of several studies undertaken recently in India include (i) ensuring timely availability of inputs, (ii) an increased focus on measures to enhance the productivity - especially of small and marginal farms, (iii) adoption of modern agricultural practices, (iv) optimal use of inputs, (v) choice of the right crops through macro and micro-level planning, (vi) availability of near real-time information on prices and markets, (vi) enhanced efficiencies in the post-harvest operations like storage, logistics and food processing, affording the farmer a greater role and share in the value chain, diversification, and above all, addressing the issues relating to information asymmetry across the entire agricultural cycle. Such long and complex agenda call for a concerted action both on the policy and implementation fronts, towards bringing Green Revolution 2.0. Digital technologies can bring revolution to Agriculture and allied sectors by 'doing more with less'. The MoAFW (Full form) aspires that the Initiative on Digital Ecosystem for Agriculture (IDEA) would place the farmer in the centre of the agriculture ecosystem leveraging open digital technologies.

National e-Governance Plan in Agriculture (NeGPA) is modified to support Digital Agriculture activities (Anonymous, 2021). The committee on Doubling Farmers' Income (DFI) appreciated the role of digital technologies such as (i) Remote Sensing, (ii) Geographic Information System (GIS), (iii) Data Analytics, (iv) AI/ML, (v) Internet of Things (IoTs), (vi) Block Chain (vii) Mobile, to be used in IDEA. Such technologies aimed to enable farmers towards need-based input management and also balancing demand driven product inflow-outflow relation. Digitial agriculture is also aiming in creating a federated farmers' database by compiling information of the farmers from various databases available with the Government and linking them with land records under 'Agristack'. These will provide farmers with recommendations on seeds to buy, best practices on yield maximization, weather updates, agricultural credit and crop insurance doubling farmers' income.

CONCLUSION

Application of advanced digital technologies can help enhancing livelihood of the farming communities by addressing the emerging issues on agricultural systems towards insecurity on food and farm economy. Agro-met services can deliver the need-based valuable information benefitting the end-users at the field scale in reducing the yield gap.

- For operational technology diffusion, the digital interventions should be rooted through FPCs using the farmers' databases linked to digital land records of evolving 'Agristack' for providing services of super-resolution advisories to small and marginal farmers of India.
- Development of FPC-specific Decision Support System (DSS) on GIS or cloud platform with 'Android App' is the need of the hour to facilitate farming community to have better access to information and make right decisions for better economic gain.
- Consorted efforts among agricultural scientists, data scientists, technology providers and FPCs are needed to find out the type of specific information at farm-scale need through digital technology, organize research and provide solutions towards these.

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