NATIONAL SECURITY

A VIF Publication

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Wani P., Suhas, Mukund D. Patil and Dhirender Singh. "Strengthening Food Security through Technologies". National Security, Vivekananda International Foundation Vol.II (2) (2019) ISSN 2581-9658 pp. 170-190.

https://www.vifindia.org/sites/default/files/national-security-vol-2-issue-2-article-sfst

Article

Strengthening Food Security through Technologies

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Abstract

Securing food for 1.35 billion Indians and doubling the income of farmers by 2022, as stated by the government, are challenging tasks. India's performance is below average in all three aspects of food security: availability, affordability, and quality and safety. It is an irony that the nation with largest cultivable land in the world (142 million ha) is facing food insecurity in spite of wide agro-ecoregions that enable cultivation of land even for three seasons in the large area. A large population (58%) depends on agriculture for its livelihood but the contribution of this sector to country's gross domestic product (GDP) has declined continuously since 1950 and was 15% in 2018. Although, the country has transformed itself from dependency on imports to self-sufficiency still the challenge is to remove the farm distress in the country. Current farmers' field yields are lower by two to four folds than the achievable potential. In addition, the value realisation from the market is 30 to 35% only. This is because 59 % of the farmers in India do not get essential information from any agency. The major hurdles for achieving the goals set by the government are low investment in agricultural technologies, low adoption of key technologies by the farmers largely due to lack of knowledge/information, poor physical infrastructure, and involvement of large number of intermediaries in the value chains. Lack of awareness among farmers about good agricultural management practices is a key factor for stagnant productivity levels. The mind-set of all actors involved in agriculture needs to change so that they work collectively as a team instead of working independently in silos if the agrarian situation is to be transformed.

India stands at 76th position globally for food security as compared to 3rd position of the United States of America and 46th position of China. Affordability, quality and safety, and availability are the key factors considered for comparing the food security levels among the countries. Each of these interconnected factors also has a great impact on national security and largely depends on the agriculture sector. Five decades ago second Prime Minister of India Shri Lal Bahadur Shastri has underlined the priorities for the

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nation by announcing the slogan "Jai Jawan Jai Kisan". In fact, at that time India was fighting the battle on two fronts, one was on the line-of-control and another was in the farmlands of rural India. Unfortunately, the battle is still going on at both the fronts as still India has 282 million poor people and the country is fighting the stubborn malnutrition along with the challenges on borders with neighbouring countries.

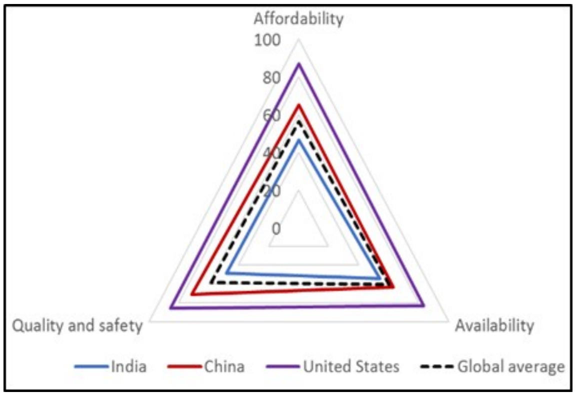

Figure 1. Global Food Security Index for India, China, and USA

Food security is achieved in two ways, producing food in the country or procuring food from other countries. A country like UAE is ranked high in food security index, even though it has less agriculture activity, thanks to large oil reserves which enables it to buy food from other countries. Oil-for-Food programme[1] by United Nations in Iraq might be one such example to bring food security. The countries with high-value resources (rich countries) are not only secure food through trade but also dictate the priorities of food production and food prices in developing countries. Moreover, these high-value resources are also at the center stage in a matter of national security. In fact, the USA has acknowledged that food insecurity is one of the reasons for terrorism and has brought an act for promoting global food security.[2]

Challenges

Securing food for 1.35 billion Indian is a challenging task. India's performance is below average in all three aspects of food security: availability, affordability, and quality and safety. It is a real irony that the nation with largest cultivable land in the world (142 million ha) is facing food insecurity in spite of wide agro-ecoregions that enable cultivation of land even for three seasons in the large area. So what are the key issues or challenges restricting Indian agriculture? The real challenge for India to improve food security is far from just mitigating climate change effects or improving agriculture productivity. In fact, the challenges of land degradation, water scarcity, and climate change are unequivocal throughout the world. Agriculture production may be increased by addressing these challenges, but the quality and affordability of the produce is also a major challenge. A large population (58%) depends on agriculture for its livelihood but the contribution of this sector to country's gross domestic product (GDP) is declining continuously since 1950 reaching to 15% in 2018 that widens the gap between haves and have-nots.

The important boosters for 1970's green revolution was improved seed and use of fertilizers. The relevance of improved germplasm and good management practices has become more critical, especially in the view of emerging issues of land degradation, water scarcity, and climate change. National and international crop improvement research institutes are working to enhance the genetic gains, defined as the amount of increase in performance of crop achieved annually through artificial selection. But, now the need is to enhance genetic gain at faster rate. The key ingredients to enhance the genetic gains are genetic diversity in breeding material with required phenotypic trait, selection intensity, the shorter breeding cycle, and good agricultural practices. Better crop produce through enhanced genetic gain with higher productivity and nutritional values will also improve the availability and affordability of food, especially in developing countries[3].

The primary sectors including agriculture, horticulture, livestock, fisheries, etc. need to play a key role in improving food and nutrition security in India. Although, the country has transformed itself from dependency on imports to self-sufficiency still the challenge is to remove the farm distress in the country. Current farmers' field yields are lower by two to four folds than the achievable potential. In addition, the value realization from the market is 30 to 35% only. Such a situation exists largely because 59 % of the farmers in India do not get any support for information from any agency.[4] In fact, a holistic solution to improve the primary sectors will have a greater and positive impact on food and nutrition security as well as income security as the farming community that constitutes a larger fraction of Indian population is also facing food and income insecurity. Improving the primary sector to produce more quality food by securing the profitability for the farmers will overall improve the food security status of India. The hope to reach towards the goal of food secure nation may rely greatly on 137 million farmers and their families in India. The government of India also realized that while improving the food availability in the country, the affordability of rural India needs to improve through increased income in farming. The major hurdles for achieving this goal are a low investment in agricultural technologies along with low adoption of science-led technologies by the farmers largely due to lack of knowledge/information as well as the poor physical infrastructure and involvement of large number of intermediaries in the value chains.

Transforming Agriculture through Integration of Technologies

The established understanding of high-tech interventions in agriculture includes communication network and devices, precision sensors with a telecommunication system, remote sensing data products, computing devices, and software for modelling, marketing and production trends prediction, etc. However, the integration of these technologies to provide technological solutions be it mechanization, soil fertility or water or pest management has not achieved to touch the lives of small and marginal farmers as much desired largely due to related departments/experts are working in silos. The government has not realized or scientific community in the country has not drawn the attention of the Government to applicability of these technologies in agriculture, thus the technologies have neither fully matured nor picked up by small and marginal farmers.

Crop Improvement Technologies

Evolving technologies are also being used world-wide for modernizing the crop improvement programs. For example, molecular and genomic approaches such as gene mapping and genome editing are being explored to understand the genetic variation, integrated system of precision sensors are being used for precision genotyping and phenotyping, and breeding cycle time is reducing by adopting integrated breeding approaches such as marker-assisted selection and doubled haploid development. The concept of team breeding (combination of multiple traits) and speed breeding (reducing the breeding cycle by increasing day light duration) are also required for ensuring the increased food production while the growing conditions are becoming tougher. All the activities required in breeding programmes are data driven. Large volume of data over time and space is generated through breeding program, but not being use effectively across the breeding teams. An integrated breeding management system comprising the data integration solution from gene bank cataloguing to release of cultivar is required at national level. The key technological advancement in the area of crop improvement are molecular marker technologies, next-generation genome sequencing technologies, IoT enabled platforms for precise and high-density phenotyping, and detailed models for crop growth simulations[5].

The other important technology in crop improvement is genetically modified crops. Globally, about 28 countries are using genetically modified crops such as maize, soybean, cotton, sugar beet, papaya, squash, canola, poplar, sweet pepper, and tomato. In India, Bt. Cotton is the only GM crop approved for commercial cultivation.[6] However, Bt. brinjal and Bt. mustard are two more GM crops developed in India are ready for field trials. Developing consensus regarding use of GM crops commercial cultivation in India may take longer time, but a much focus is also required on bio-fortification of crop to improve nutritional value in food grain. Mega project like Harvest Plus[7] are bringing national and international research and industrial partners to developed bio-fortified crops.

Natural Resource Management

The activities under natural resources management including farm- and land-based activities involve big data that vary with spatial and temporal scale. Though most of this information is digitized, the information is not being used into an integrated solution. Often, good information may be available in a complete form that very few could understand and use it for the planning process. Assistance from digital technologies could reduce the gap between laboratories and common individual and all the stakeholders. For example, anyone can use high -resolution aerial imagery of earth through Google Earth software.[8] All these imageries existed before Google developed the software, but were not accessible in a simple form. Similarly, volumes of information laying with research institutions and government departments are not being used effectively required for planning the natural resources management program as access to quality data is not there and planners may not be always in capacity to interpret the information as often such entities work in silos. Thus, often conventional methods are being used while planning the activities such as watershed development activity even without understanding the impacts of climate change, which consumes more time, provides partial solutions, and adds to the cost of specialists to analyse the data and provide a solution.

Integration of available information in a coordinated manner and building spatial data infrastructure for agriculture would be the stepping stone towards bringing efficiency in planning and implementation processes.

Integration of available information in a coordinated manner and building spatial data infrastructure for agriculture would be the stepping stone towards bringing efficiency in planning and implementation processes. For example, the Government of

India holds soil fertility information collected during countrywide Soil Health Mapping campaign (soil health card mission) and also a custodian of *Aadhar* database that include biometric information of Indian citizens. Integration of these datasets may help to award nutrient-based financial incentive to farmers for purchasing nutrients needed as per soil fertility report. Moreover, financial institutions are participating in the process of direct benefit transfer (DBT) to farmers' bank accounts. To achieve such integrated use of data rather than collecting the same data for different services, a centralized platform for data integration and service-oriented applications are required for agriculture.

A radical paradigm shift from existing input-output linkages to an innovative model is required to make agriculture as a profitable industry.

Adopting Good Management Practices

National and international research and extension institutions are continuously improving the management practices in agriculture, however, most of these technologies are not reaching to individual farmer. A radical paradigm shift from existing input-output linkages to an innovative model is required to make agriculture as a profitable industry. One such innovative model is 'farmers' producer organization (FPO)' where through collectivization small farmers can get the scale of operation and negotiating power with the inputs and service providers as well as farm produce buyers. Collective actions through FPOs provide a negotiation power to farmers and easy access for information dissemination to extension agencies. It also helps to maintain quality standards produce as the practices followed by the FPO members may be standardised as per the requirement. The FPOs will be the basic model, which need to be further strengthened through the advance technologies such as mechanization, weather-based advisories, block-chain technology for mapping the complete production cycle, and credit support.

Mechanization is one of the key ingredient that can bring efficiency in farming and reduce cost of agricultural operations like sowing/transplanting and harvesting. It was always a debate that mechanization in agriculture sector will take income away from agriculture labourer. But, it is also a fact that farming is facing labour shortage as most of the farming activities like sowing, harvesting, fertiliser application, etc., have to be completed in narrow time window. The advancement in sensor-based farming equipment is automating the farming application like sowing, fertilizer application, weeding, and harvesting. A FPO equipped with such high-tech tools can manage 1000s of hectare land efficiently with help of few skilled workers.

Another important piece of technology that will ensure the quality of farming produce is the marketing platform based on block-chain based technology. India's National Agriculture Market (eNAM) network is connecting agricultural marketing committees across the country through an online portal. The main objective of this initiative is to facilitate pan-India trade in agriculture commodities, providing better price discovery through transparent auction process based on quality of produce along with timely online payment.[9] The block-chain technology will further strengthen this initiative by keeping tamper-proof ledger of production cycle from seed to harvest. Though it will be distant dream to implement block-chain technology or sensor -based farming system for each farmer (138 million), this may be achievable through FPOs. If we consider agriculture as food producing industry, then FPOs are the companies to run that industry.

Spatial Data Infrastructure for Agriculture

Agri-Food Spatial Data Infrastructure (AFSDI) initiative by FAO[10] was started post -2015. Its main aim is to support comprehensive assessment and monitoring of food security and environmental sustainability and to support Country Governments and Organisations to achieve the Sustainable Development Goals (SDGs) through development of mechanism for increasing system coherence in the use and exchange of agri-food and geospatial data. Important applications of this initiative were the use of advanced geospatial technology to enhance smallholder livelihoods, establishing Land Resources Inventory (LRI), and assessment of agro-ecological feasibilities for crop planning. The primary objective of any SDI is to bring the data together on a single platform.

The basic requirement for successful implementation of any land- or farm-based programmes is to assess the problems and prospects in area-of-interest, which also include factors such as natural resources, physiography and socio-economic status. Advances in space research have enhanced the availability of spatial and temporal data. Electronic sensors, data loggers, portable electronic devices, internet and communication technology are vital in the programme planning, execution, monitoring, and evaluation. Processing of billions of data points in order to translate them into information and knowledge that benefit policy-makers, development investors, extension and development workers, and farmers have become feasible with the availability of advanced scientific tools, communication technologies and the combination of one or more of such tools[11]. But, integration of all tools and data through the system like AFSDI will play a very crucial role in planning, implementation, and monitoring of land- and farm -based programmes.

The core function of AFSDI is to store the data in a structured design, which eases the addition of new data and the availability of existing data. The type and volume of data required/generated in the primary sector are very diverse and very large, which definitely qualify for BIG data solution. List of some important datasets is given in Table 1. All these datasets are available with government institutions, but they are in different places, in different formats and connecting these datasets is not as easy as going for data collection. Thus, often, different institutions end-up in spending more resources on collecting the data that are already available. A common platform such as AFSDI is required to bring data together which also ensures data quality and accessibility. Implementation of such initiative is much more complex than the ongoing implementation of goods and service tax network. The ultimate stakeholders for AFSDI are going to be 137 million farmers.

Data Sourcing

Apart from the integration of existing data, innovations are also emerging from scientific communities which are helping to improve our ability to collect more quality data by spending less time and money. For example, paper-less mobile data collection tools are reducing the time and human resources required for data entry from paper forms to computer, which also provides near-real-time data streaming from the ground.

The real-time data stream is more important for several farm level decisions, such as efficient water management, areas sown, harvest times, quantities of a product available at locations, etc. The water management strategies, often, are response function of weather, crop growth, and available soil moisture. Thus, it is very important to have real-time data collection and availability, for example, real-time data stream from a network of weather stations, soil moisture sensors, water storage structures, and water level recorders across the country can be used to generate maps showing available water resources including soil moisture map. A network of IoT (internet of things) devices with precision sensors to measure biophysical parameters is an essential piece to keep AFSDI updated and serving the purpose. Indian Meteorological Department (IMD) is maintaining the network of automatic weather stations and rain gauges. But the density of these stations may not be sufficient for India, which provides a great opportunity to private companies, such as Skymet[12], to develop business as weather data providers.

Table 1. Sample list of datasets required for the agriculture sector

Data	Description	Source
Maps	Cadastral maps: This database includes information such as land parcel number, reference management unit, reference micro-watershed, owner of the land parcel (farmer), area, etc. Satellite imagery: high resolution (spatial and temporal) satellite images, digital elevation models, Soil maps: physical, chemical and biological properties, morphological and geological characteristics. Land maps: Slope, slope length, erosion, drainage, runoff, groundwater depth, flooding, surface fragment, rock-our crops, land use/land cover etc.	National/state remote sensing center. Public domain data from international scape agencies Survey of India National Bureau of Soil Survey and Land Use Planning
Hydrological data	Surface runoff, infiltration, evaporation, evapotranspiration, groundwater recharge, water tanks, quantities available in dams/tanks, sediment load, base flow, water quality, aquifer information, irrigation related data etc.	Water resource department Sourcing data from IoT devices

Drainage data	Rivers/streams (entire drainage), All water bodies both perennial and ephemeral (with names of major bodies), Canals, both perennial and ephemeral, Springs/ seepages.	National/state remote sensing center. Water resource department
Crop coverage	This database includes information such as reference land parcel number, reference management unit, reference micro-watershed, farmer data, area sown, sowing date, harvest date, etc.	National/state remote sensing center. Agriculture Department
Farmer data	This database includes information such as farmer name, village, taluk, district, contact number, adhaar number, etc.	Agriculture Department

Data-Driven Decision Support Systems for Primary Sectors

Agro-eco Region-based Planning

Soil-site suitability studies have provided the criteria to select suitable crops for a given piece of land. This helps to find out specifically the suitability of the land resources like soil-site characteristics, water, weather, climate, and other resources and the type of constraints that affect the yield and productivity of the selected crop. National Bureau of Soil Survey and Land Use Planning (NBSSLUP) has prepared a manual on soil-site suitability criteria for major crops[13]. In this assessment, the specific requirements of a crop are compared with the characteristics of land and suitability of the area for the crop is arrived based on the matching. If the land characteristics of an area match the requirements of the selected crop then the area is considered as suitable for the crop, otherwise, it is grouped as not suitable for the crop. The site-specific land resources database generated through SDI helps to establish the suitability of the resources to any selected

National Bureau of Soil Survey and Land Use Planning (NBSSLUP) has prepared a manual on soil-site suitability criteria for major crops.

crop for the area in a very objective manner, which was not possible earlier with general datasets.

The applicability of this approach to a large extent is limited due to unavailability of high-resolution spatial information of soil properties. However, this methodology is being piloted at the micro-watershed scale in the selected district of Karnataka state under a World Bank supported *Sujala* project. The crop suitability maps at a large extent have been successfully implemented by Tasmania using digital soil mapping to generate high-resolution soil maps[14] (Figure 2). The web application is available in the public domain[15] This tool is more helpful to policy-makers for devising the schemes/ programmes for promoting sustainable cropping pattern in the district/state/region.

Overall suitability rating		Unsuitable
Limiting Factor(s)	, pH, Stones, Slope	
Soil depth (cm)	>40cm	Well suited
pH (top 15cm)	<5	Unsuitable
Texture (% clay in top 15cm)	> 8.5%	Well suited
Elec. conduct. ds/m (top 15cm)	<4	Well suited
Depth to sodic layer (cm)	>30cm	Well suited
Drainage class	Well/moderately well drained	Well suited
Stones >200mm in top 15cm	>20%	Unsuitable
Slope (%)	>25%	Unsuitable

Figure . Crop suitability maps for Tasmania

Strengthening the Soil Health Card Scheme

Soil-test-based nutrient management is considered as one of the key initiatives for improving agricultural productivity. ICRISAT in collaboration with Government of Karnataka has worked together to address the issues of low crop yield through innovative strategies for implementing integrated nutrient management since 2005[16]. One key output from this project was soil fertility atlas for Karnataka state[17], which also resulted in policy decision for promoting the application of micronutrients in agriculture. The net profit accrued from the programme was about Rs 25.96 billion in seven years. The government of India also initiated a similar programme in 2015-16 with an ambitious target of reaching all 137 million farmers. The soil health card scheme was worth more than Rs. 5 billion over a period of three years, and was supported by Government of India under the National Mission for Sustainable Agriculture. Till now about 51 million soil samples have been collected across the country and 49 million soil samples have been analysed in public/private laboratories[18]. But, only 17 million soil health cards were 'dispatched' to farmers. Moreover, the adoption of the same methods for analysis and also the quality of data collected needs lot of improvement.

The few limitation or shortcomings identified in the soil health card schemes are lack of technical competency of existing state institutions for collecting and analysing the soil sample for every farmer (137 million), no standard protocols for quality control and assurance for such big data generation activity, and limited focus on training of farmers to bring soil health cards in actual use. The positive impact of soil-test based nutrient management on yield increment and cost reduction has been proved and adopted in large scale in part of India, however, taking this intervention to all the farmers may not be possible through conventional methodology. One such key and futuristic technology is hyperspectral remote sensing. The main difference between usual multispectral remote sensing data and hyper-spectral data is that multispectral data usually have 3 to 10 spectral bands ranging from visible to near-infrared regions, whereas hyperspectral sensors may capture hundreds of spectral bands. The higher spectral resolution obtained from these sensors is useful in the detection of several mineral deposits, such as nutrient composition in the soil. These technologies are being studied in India through network project on hyperspectral remote sensing, which needs to be given more focus with a target to strengthen soil health card scheme.

The other methodology for generating information on soil health status is digital soil mapping (DSM). Digital Soil Mapping (DSM) - or predictive soil mapping – provides an option to generate soil property surfaces at a fine resolution with some uncertainty of prediction. There are three steps in DSM: 1) collection of legacy soil data or field and laboratory measurement of soil properties and development of the base maps of available data including climatic information, land cover, terrain, and geological variables; 2) Estimation of soil properties by using quantitative relationship between measure point data and spatial maps prepared in the first step; 3) estimated soil properties further used to derive more difficult-to-measure soil properties such as soil water storage, carbon density, and phosphorus fixation[19]. Digital soil mapping uses field and laboratory observation method such as proximal soil sensing[20] and soil spectroscopy[21] as input to a predictive model that provides soil maps. Today, a global consortium is working together to make a new digital soil map of the world using state-of -the-art and emerging technologies for soil mapping and predicting soil properties at fine resolution[22]. Although, the DSM product has some prediction uncertainties, it provides the spatial information at much higher resolution and at less cost.

Efficient Management of Water

Agriculture is the largest consumer of fresh-water and utilises over 70% of the total amount in croplands. Moreover, inappropriate management of water resources and irrigation methods result in low crop yields and poor water use efficiency (WUE). To utilise the water resources more efficiently there is an urgent need to enhance WUE by enabling farmers to adopt need-based and efficient irrigation methods. A number of decision-making tools are available for simulation of water balance, crop growth and yield. Some of the tools/models are exclusively developed for designing irrigation scheduling. However, to run any tool/model values of certain parameters, such as soil type, crop, sowing date, available soil moisture, etc., are required to be provided. AFSDI loaded with all this information will able to run this model and provide the complete irrigation schedule as per the set-strategy.

The use of these data sourcing and modelling tools is mainly limited to the scientific community due to cost and complex parameterization. But, countrywide implementation of these technologies may be achievable through AFSDI initiative. Using such tool, farmers and other practitioners (stakeholders) should be able to decide suitable cropping system and cultivation intensity for their field and watershed or community scale and also could be potentially useful in large scale irrigation planning and management (for example, canal water release and water allocation).

Automation in drip/sprinkler irrigation system is improving the effective use of water and reducing the losses in irrigation practices. The key component of a fully automatic irrigation system is assured source of water and power, network of IoT sensors to measure soil moisture and weather parameters, crop water demand estimated based on models, and electronic valve for automatic operations. These smart irrigation systems are expensive and only available through irrigation companies, which may not be suitable for small holder farmers. However, it is very encouraging that large scale community based smart irrigation systems are being piloted through public private partnership[23]. As the scale of these project is large, remote sensing tools including drones and satellite may be effectively used for monitoring and decision making. Such kind of infrastructure is required to bring automation in irrigation practices, which saves water and also ensure equity in water distribution.

Risk Mitigation

The multi-faceted risks from biotic and abiotic sources including the market dynamics in Indian agriculture are also an important limiting factor for achieving food security. Data-driven technologies may provide actionable information to mitigate or even avoid the certain risk associated with climate, market, and production system. The weather-based advisories have helped farmers achieve optimal harvests by suggesting the best time to sow crops depending on weather conditions, soil and other indicators[24]. The Sowing Application (Sowing App) demonstrated by ICRISAT in collaboration with Microsoft utilizes extensive data including soil characteristics, rainfall over the last 45 years as well as 10 years of groundnut sowing progress data for Kurnool district of Andhra Pradesh[25]. This data is then downscaled to build predictability and guide farmers to pick the ideal sowing week. This Sowing App is being used by the farmers in selected districts of Andhra and Karnataka. A similar model can consume the data from AFSDI to present a progressive report on probable sowing period, which also is useful for designing the crop insurance product or even settlement of crop insurance claims. The conjunctive use of real-time data capturing, weather forecast, and crop growth simulation models can even provide yield forecast as actionable information to policymakers. In fact, Arable Labs Inc.[26] is providing new generation IoT devices that combine both weather and plant measurements as a solution to manage weather risk and crop health.

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Crop insurance is one of the schemes to mitigate the growing agriculture risks in agriculture, which is being implemented at various levels since 1972. A very first crop insurance scheme initiated by General Insurance Corporation of India in 1972 was on individual approach rather than the present Pradhan Mantri Fasal Bima Yojana (PMFBY) that considers village as a unit. The thought of implementing a crop insurance scheme with the farmer as a unit, similar to health/life insurance product design for the individual, was too early for that period. The important limitations observed during that era were a large number of land holdings, not able to assess the yield of all the farmers, vast diversity in the cropping system, a collection of the premium amount from a large number of farmers, etc. Over the period of time, the insurance schemes were evolved to address some problems like considering a cluster of villages as a unit for assessing the crop yield and linking loan taking farmers to crop insurance by default. Yet, Government is following the traditional methodology of crop cutting experiments that require more resources and which may not cover all crop fields. Geospatial technologies and advances in remote sensing can provide a solution, at least, for choosing the right location for crop cutting experiments. In fact, remote sensing products are being used to assess crop damage and settling insurance claims[27]. In addition to remote sensing technology like multi-spectral imageries taken from drones fitted with high-resolution cameras are helpful to assess the crop damages in real-time.

Monitoring and Evaluation

An effective monitoring and assessment tool is required to visualize the progress and impact of different interventions on agriculture productivity and income. Near real-time information collection and transfer is the critical aspect of a monitoring mechanism, which assists the decision makers to take appropriate actions. Mobile data collection tools are becoming an important resource for development programs for improving efficiency, accuracy, and pace of assessing the ground situation. Setting up the survey questionnaires and getting them filled, real-time data flow to the central server, and instant availability of clean data for the analysis are the important features of mobile data collection tools. The faster cellular technology and open source software development option has brought down the cost factor associated with the mobile data collection. Paper forms, camera, and GPS device are replaced by a single smartphone. There are several mobile data collection tools available for the Android platform.

The Open Data Kit is a set of three basic tools for creating a questionnaire[28], ODK collect a smartphone app available on Google Play Store, and ODK aggregate a data aggregation application. The forms as per requirements are prepared using ODK Build tools and uploaded them to ODK Aggregate server. ODK Aggregate may be deployed on a cloud server or on locally on a Tomcat server backed with a MySQL or PostgreSQL database server. The form uploaded on ODK Aggregate server is available for ODK Collect application installed on enumerators' mobile device. Data recorded using ODK Collect store on the mobile device until the filled form sent to Aggregate server. The open data kit has the option to record text, date, number, geo-coordinates, photographs, videos, multiple choice question, etc. A dashboard comprising the smart visualizations of key performance indicators (KPIs) backed by real-time data flow from the mobile data collector at field level will provide up-to-date progress report that will be helpful for taking decisions at various administration/policy level[29].

Big data analytics with machine learning (ML) and artificial intelligence (AI) are also being aggressively implemented to provide real-time actionable information. Several digital farming platforms are available in India to digitise complete value chain in the agriculture sector, which also ensures the traceability of produce from seed to food. A platform like CropIn[30] is specialised in digital farming right from geo-tagging of a crop field to keeping the records for compliances with good agriculture practices and practices followed at every step of value chain till that produce reaches to industries. However, these smart farming tools are being implemented through a few clusters of villages managed through contract farming, farmers' producers' organizations (FPOs), or industrial farms. Smallholder farmers are far away from these digital tools. An innovative partnership between government and private companies is essential to scale-up digital farming tools.

Communication Tools for Strengthening the Agriculture Extension System

Lack of awareness among farmers about good agricultural management practices is one of the important factors for stagnant productivity levels. Generally, farmers in developing countries are following traditional practices that are inadequate to sustain with changing climate and increasing population. The present extension system appears to be inadequate to address the challenges faced by the farmers in India in the context of changing climate scenarios. In India, the extension system has limited penetration below the block level due to lack of grass root level extension functionaries to work at the village level. However, public extension services would continue to play a critical role in technology dissemination to serve the large chunk of small farm holders besides other service providers.

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Farmers require information about improved farming practices, weather, insect/ pest control options, inputs suppliers, government schemes, machine hiring centres, credit facilities, storage and grading/processing centres, and markets. This information should come at the time when it is actually needed. Information communication tools have provided vital assistance to extension agents for supporting farmers' demands for information. However, large scale implementation of digital technologies for agriculture is required to support millions of farmers in India. The government of India and private companies are transforming the AES. The government has good human resources for agricultural knowledge generation, whereas private companies have a good feel of digital technologies. Based on this several technologies are being used for information dissemination.

Information communication tools have provided a wide range of options to assist extension agents as well as a farmer for getting up-to-date knowledge. The government of India and private companies are transforming the AES. There are several technologies are being used for information dissemination. For example, the Government of India has Kisan Call Centre (KCC) facility to satisfy information request as per farmers' demand in 22 local languages. Currently, all the information communication tools for disseminating agriculture knowledge are brought under one umbrella ***mkisan***[31]. The services provided through this website are Unstructured Supplementary Service Data (USSD) and SMS-based dissemination, Pull and Push SMS, Interactive Voice Response System (IVRS), KCC, and Android-based applications. Karnataka State Natural Disaster Management Centre is providing service to its subscribers in the state to receive daily weather update including alert about abnormalities in weather. In addition to Government, private companies are also providing innovative solutions for agriculture extension. For example, IFFCO Kisan Sanchar Limited has introduced voice messages for the agro-advisory system and Thomson Reuters introduced mobile-based integrated agro-advisory system 'Reuters Market Light'. Information updates obtained from such advisory system allow farmers to take a decision regarding various farm operation, which eventually helps the farmer to cope with climate change or changes in weather.

Instant messaging apps such as Whatspp, Hike, Line, Telegram, Viber, etc., have become very convenient tools of mass communication. Social networking tools such as Twitter, Facebook, Linkedin, etc., have already proved their importance in the social welfare sector. Microblogging tool such as Twitter has been used by many individuals as well as government agencies. The usual use of these applications is to let others know about one's experiences during daily life, however, most of the time users exchange the general information, jokes/quotes, interesting pictures, personal/official documents. The target user group for these apps is under the age of 30 years. However, these applications have been installed in most of the mobile devices by default.

Way Forward

India is a country of 137 million smallholder farmers living in 5.98 lakh (0.598 million) villages. Reaching out to such a large number of farmers with the right information at right time and in the right format is a herculean task. Moreover, small farm holders have multiple sources of family income such as crops (several ones), livestock, horticultural crops, fisheries, employment in rural areas and their information needs are complex. In order to increase (double) the farmers' income, technology-based, holistic and dynamic solutions need to be provided. There is a need to develop a devoted platform for agriculture in the country through public-private people-centric partnership (PPPP) for providing authenticated solutions/ advisories. Using technologies for recommending right crops/cultivars based on the agro-ecological potential of the region, considering the market demand and prices, soil test-based fertiliser recommendations, information about inputs suppliers, weather predictions and advisories, collective purchasing and sale through farmers producer organisations (FPOs), market information along with storage/processing facilities information and most importantly financial credit and risk coverage using new technologies such as GIS, RS, Crop modelling, IT services, machine hiring centres, water management, pest management etc. will transform Indian agriculture. Most importantly the mind-set of all actors involved in agriculture needs to be changed to work collectively as a team instead of working independently in silos. The existing silos holding the valuable and millions of datasets need to be blasted and bring all relevant datasets on a common platform to be used responsibly to benefit the small farmers at the state/national level. In our country, huge potential in agriculture needs to be harnessed using technologies to alleviate the farm distress through building consortia of public-private partnerships. Huge datasets sitting with different departments/agencies need to be brought out, quality checked and formatted to be used on the integrated platform to alleviate the farm distress. The government of India has made a good beginning initiating the programmes like soil health, eNAM, Farm Zone, integrated watershed management, aquifer mapping, groundwater monitoring, etc. which must be brought on an integrated platform. The platform needs to link-up researchers, policymakers, development investors, corporates and most importantly the small farm holders. A consortium of public and private institutions is very much essential to realize the conceptual framework of AFSDI.

Most importantly the mind-set of all actors involved in agriculture needs to be changed to work collectively as a team instead of working independently in silos…

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