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Big Data Analytics in Agriculture

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Preface

Real-time inflow of data through Internet of Things (IoTs), drones, remote sensing, robotics, nanotechnology and crowd-sourcing have turned "Big Data" a buzz word. Like other sectors, agriculture too has the concept of big data enshrined its definition and coverage of complex biological entities and processes. Amongst its various possible applications, the identification of genotypes for higher yield and stress tolerance; assessment and monitoring of soil, crop, animal and environment health; precision agriculture; input control; demand projections and delivery of weather advisories and other farm services are prominent ones.

With a plenty of technological innovations, it is possible to bring in significant changes in farming with the application of Big Data Analytics via Use-Adapt mechanism. The application of Big Data Analytics in agriculture has potential to develop technologies to achieve the goal of sustainable and smart agriculture. Future developments are to be centered on Internet of Things (IoT) in which all kinds of devices are connected and interact with one another through local and global wireless network.

This policy paper provides a historical perspective on Big Data and its applications in agricultural research and development for better understanding of the challenges and prospects that agriculture is contemplated to confront in the near future. I, on behalf of the Academy, thank Dr Rajender Parsad for synthesizing and presenting the opinions, comments and suggestions of the participants in the form of this document. My special thanks to Mr Akhilesh Srivastava and Dr J. Jayasankar for their valuable comments on the document. I am also grateful to all the participants for their contributions. My sincere thanks to Drs P.S. Birthal and Malavika Dadlani for their editorial support.

(Trilochan Mohapatra)
President

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Big Data Analytics in Agriculture

"Digital Transformation is not about the evolution of devices (though they will evolve), it is about the integration of intelligent data into everything that we do." IDC- International Data Corporation (2018)

1. INTRODUCTION

The data, of late, has been compared with the oil, one of the most important natural resources on the earth. Access to data provides a significant advantage to corporate giants like Alphabet, Amazon, Facebook and Microsoft. It fuels growth by introducing new products and services. Such accumulated data is increasing at a phenomenal rate and is expected to rise from 33 zettabytes (1 zettabyte = 1 trillion Gigabyte) in 2018 to 175 zettabyte (IDA, 2018) in 2025. The cost of data storage (per GB per month) is less than US $ 0.025 (in Amazon Cloud services). The availability of computing power is further making it possible to handle data explosion. Google had introduced Tensor Processing Unit (TPU) in 2017, which can perform up to 128000 operations per cycle as compared to Graphics Processing Unit (GPU, 10000 operations per cycle) and usual central processing unit (CPU, 10 operations per cycle). Thus, better processing, storage and availability of data for complex analytics reduces the cost of storage and high-performance computing. The industries which have embraced the new phenomena are significantly benefiting from these. The impact will be visible in every sector — be it business, research, governance and agriculture. It will transform the agri-food ecosystem, including research, education, extension, farming, and agri-business. To benefit from data science, the National Agricultural Research and Education System (NARES) of India needs to align its agenda with the emerging trends in it.

A timeline of developments that brought "Big Data Analytics" to the fore is briefly presented as follows:

1944: Fremont Rider, Wesleyan University Librarian	Speculated that the Yale Library in 2040 will have "approximately 200 million volumes because of information explosion"
1980: Sociologist Charles Tilly: the first person to use the term Big Data	"none of the big questions has actually yielded to the bludgeoning of the big-data people": discovered by Oxford English Discovery folks
1990: Peter Denning	"It is possible to build machines that can recognize or predict patterns in data without understanding the meaning of the patterns"
1997: Michael Cox and David Ellsworth	Used the term "big data" for the first time in print in an article in the ACM digital library
1998: John Mashey, Chief Scientist at SGI	"Big Data… and the Next Wave of Infrastress." used in various speeches and is credited for coming up with term Big Data
2001: Doug Laney, Meta Group (Gartner)	"3D Data Management: Controlling Data Volume, Velocity, and Variety."
2005: Tim O'Reilly	Published article on What is Web 2.0?' that set off the Big Data race
2005: Yahoo	Hadoop was created by Yahoo built on the top of Google's Map Reduce

2. BIG DATA ANALYTICS

The ‘Big Data’ is a term, which originally denoted the data which could not be fitted into/handled by the memory of a single computer server. However, the term now implies not only the size (volume) but also the flow (or velocity), type (or veracity), and analytical methods (machine learning as compared to hypothesis based) served by it (data-based products as compared to decision- making). In the literature, the term ‘Big Data’ is defined in terms of many V's but with emphasis on 5Vs — **V**olume (size in terabytes/petabytes); **V**elocity (flow or data in motion); **V**ariety (types such as structured, unstructured, text, voice, video, etc.); **V**alue (worth of data in terms of relevance) and **V**eracity (quality or trustworthiness of data). The Consultative Group for International Agricultural Research (CGIAR) in its Leveraging Big Data document defines big data as harmonized, interoperable and contextually integrated datasets and publications from multiple disciplines relevant for agricultural research and development goals {(CIAT and IFPRI (2016)}. The term ‘Analytics’ denotes systematic analysis of data to uncover patterns, interpretation and communication applying statistical tools. The outcomes of the traditional analytical tools have led to the introduction of features such as the predictive search and recommendations (Amazon/Netflix). Voice recognition tools such as Google Assistant and Alexa powered by big data and artificial intelligence have proven the potential of Big Data Analytics in every walk of life.

Usefulness of the artificial intelligence is unfolding in several domains. Deep learning algorithms are able to predict cardio-vascular risk factors with 70% accuracy using retina scan data (Poplin, 2018). It is expected that the accuracy may increase over time with more data. Thus, a simple non-invasive procedure such as retina scan can cut down discomfort/cost, and at the same time can predict accurately risks to human health. In agriculture, several start-ups in India have been applying ‘image processing with Big Data and Artificial Intelligence’ for grading agricultural produce with more than 90% accuracy. The time taken for this process is only around 2 minutes. Bhar et al. (2019) presented status and prospects of artificial intelligence in Indian agriculture.

Several of the existing applications of ‘Big Data’ are in the food and retail sectors. Relying on the consumer preferences, the retail giants like Walmart predict demand for food and beverages and manage their stocks accordingly. The customer sales data are used for building robust predictive models and decision-making, and hence result in reduction in wastage and an increase in customer satisfaction. Increasing awareness of the customers about food quality and environmental concerns are compelling food manufacturers and distributors to compulsorily indicate the place of origin, standards followed, animal welfare ratings and price of the products on the labels.

3. BIG DATA IN AGRICULTURAL RESEARCH AND DEVELOPMENT

Agriculture and allied activities in India engages to nearly 45% of the country’s population and contribute 19.9% to the gross domestic product (GDP). The continuous improvements in agricultural sciences have turned India self-sufficient in food, and even an exporter of some foods like rice and buffalo meat. India no longer worries about the famines or temporary shortfalls in food production. The growing population, expected to be around 1.6 billion by 2050, with increased purchasing power and changing dietary habits throws a different challenge to India’s food production system (Singh, 2019). The problem now is to address the challenge of increasing food production in a sustainable manner with judicious use of inputs and minimum damage to environment. Apart from research, policymakers have been searching for other means of achieving this goal, particularly the application of 'Information Technology'. It is expected that with increasing advances in statistical sciences and private investments in its application tools, Indian agriculture may leapfrog towards digitization. However, the country need big data tools and techniques to solve the complex problems of agriculture and agro-based manufacturing and services.

There are several areas of agriculture where the data volumes are expected to increase rapidly. These include the increased use of sensors and other devices to monitor moisture, physical and chemical properties of soils and biotic and abiotic stresses at the farm level. The net cultivable area in the country is around 141 million hectares fragmented into landholdings of varied sizes. More than 86% of landholdings are of size less than or equal to two hectares. Even if a miniscule fraction of cropped area (say 10%) adopts the Internet of Things (IoT) the data generated would be huge.

Mechanization of various farming operations, particularly of harvesting, is increasing at a rapid pace due to shortage of labour, and the sensors available in harvesting machine may generate valuable information for application in the next growing season. Regional or local crop planning using the Geographic Information System (GIS)/remote sensing tools is another potential application of big data science. Personalized advisories to farmers are also becoming increasingly popular and are expected to produce data that can be analyzed using text analytical tools to improve upon advisories. The language processing and ontological tools can be put to mutually beneficial machine learning algorithms thereby creating a seamless pathway of communication on both sides making a supervised expert response nearly automated.

In research, plant phenomics is an area for precise quantification of the responses of plants to different stresses for identification of superior genotypes and genes. Similar to MRI or CT-Scan diagnostics of human health, the phenomics uses non-invasive sensors and advanced image processing computational programmes to non-destructively characterize plants in the near real-time. Recently, a national facility for phenomics has been established at the ICAR-Indian Agricultural Research Institute, New Delhi. Such facilities (of smaller scale) are also available at a few other Institutes and State Agricultural Universities.

Genome data is another area of application of 'Big Data Analytics'. Agricultural researchers are continuously generating genome data of important plants, animals, and microbes. Advanced Super-computing Hub for Omics Knowledge in Agriculture (ASHOKA), at the ICAR-Indian Agricultural Statistics Research Institute, New Delhi, has opened up new avenues to practice data-driven science in biological computing or computational biology.

A generic categorization of kinds of data that gets generated while research and developmental agencies are in operation would yield the following:

- Scientific/Experimental/Survey Data/ Lab/Field
  - Small experimental dataset, for example, AICRP trial data
  - Diagnostic; animal health; fish effort and catch
  - Production and productivity; soil and water

- Geo-referenced data
  - Weather data, although big, but still can be handled by usual means
  - Remote-sensing imageries of different resolution/cycles can be big data
- Sequence/Genome data: Big data
- Live stream of images/data: may be big data
  - Phenomics; Sensors on fields and crops; GPS and sensor units on tractors/machines
  - Unmanned aerial vehicles (UAV) or drones
  - Radio Frequency Identification (RFID): based traceability systems; acoustic signals
  - Administrative data
  - Service records
  - Academic data coming from the Universities; Recruitment data
  - Agricultural farm records (revenue departments), subsidies, credit details (financial institutions), input supply and use (agri-business industries)
  - Agriculture, Livestock, Fisheries Census data
- Socio-economic data
  - Commodity and market data
  - Price and sales data
- Social media/Internet/Government schemes
  - Extension services through social media
  - PM Kisan Portal, Direct Benefit Transfer, Soil Health Card, Crop Insurance, Kisan Credit Card, Kisan Call Centres
- Open Government Data Platform: https://data.gov.in

At the Indian Council of Agricultural Research (ICAR) the biggest challenge is to manage research data and transform these into usable knowledge and products. ICAR has come up with research data management guidelines in 2014 and currently these are in an implementation phase at its research institutions. The KRISHI – Agricultural Knowledge Resources and Information System Hub for Innovations— is an initiative to collate and distribute knowledge resources at one place. The KRISHI portal (https://krishi.icar.gov.in) is being developed as a centralized data repository system of the ICAR. It contains technology, data generated through experiments/ surveys/ observational studies, geo-spatial data, publications, learning resources, etc. Besides, several customized services can be built around the KRISHI portal. This needs to be amalgamated and updated with real-time data collected through sensors, satellites and cameras for artificial intelligence for real- time decision- making in agriculture.

Although the institutional and informal sources of information, which qualified as data, had always been well-documented and identified from time to time, the legally or ethically binding instruments which should have made deposition and populating of such data at regular intervals were always delayed. With fast developments in data science, India too has taken initiatives towards this direction. The following policy frameworks/guidelines of data management may be helpful for Big Data in agriculture

- Government of India Policy: National Data Sharing and accessibility Policy, 2012. Available at https://data.gov.in/sites/default/files/NDSAP.pdf
- CGIAR Open Access and Data Management Policy (October 2, 2013), mainly on information products
- ICAR Open Access Policy (September 13, 2013). Available at https://icar.org.in/node/5542
- Guidelines for Research Data Management in ICAR Institutes: Approved on March 12, 2014 and circulated on September 21, 2014. Available at http://www.icar.org.in/files/ICAR-Guidelines-Research-Papers-2014.pdf
- The Information Technology Act, 2000. Available at https://www.meity.gov.in/writereaddata/files/itbill2000.pdf
- Guidelines for acquiring and producing Geospatial Data and Geo-spatial Data services including Maps. Available at https://dst.gov.in/sites/default/files/Final%20Approved%20Guidelines%20on%20Geospatial%20Data.pdf
- Policy on Open Application Programming Interfaces for Government of India. Available at https://www.meity.gov.in/writereaddata/files/Open_APIs_19May2015.pdf
- Personal Data Protection Bill introduced in Lok Sabha on December 11, 2019

With many policy/guidelines in place regarding data management, the access and sharing by the formal institutions that handle the information, the emphasis had been lopsided or at basic level. This could have been justified at their respective times of conception as the developments would not have warranted a more comprehensive holistic policy, which is not the case now. Therefore, what is required now is single policy covering all aspects of data management, data access, data retention and data sharing.

4. BOTTLENECKS

The availability of information and application to solve practical problems differ across industries. To find or record retina scans from a large number of patients may be comparatively easier. However, the data from agriculture/agricultural research are not readily available in machine readable formats and can be time consuming or can be even costlier to collate. The four categories of Big Data usage by Davenport (2014) are given below:

Data Availability	**Extensive**	Underachieving	Big Data Competitors
	Limited	Disadvantaged	Overachieving
		Limited	**Extensive**
		←Data Use→	

Traditionally, in agricultural sciences the availability of data is limited because of the small number of experiments from which these are collected and collated. Agricultural research is at a disadvantage due to this limitation. Availability of data from farmers can become huge if collected and stored through an informed transparent automated process. The data could probably pertain to crop calendar like seasonal crop records collected by revenue departments, subsidies, credit details (financial institutions), and input supplies (agri-business industries). This points towards the huge potential for farmer-centric applications of big data science. However, the lack of coordination, interoperability in applications and poor investment in digital data capture are major bottlenecks, and proper rectifications are needed to uncover the potential.

Satellite-based remote sensing data has been in vogue to estimate area under crops for quite some time now. This has also proved useful in monitoring crop growth, stresses, and environmental pollution. The spatial and temporal coverage of remote sensing data can be of varying degrees of exhaustiveness depending upon the position of the satellites and swathes assimilated from them. The recent breakthroughs in drone technology provide high-resolution data over time but with limited spatial coverage. Thus, mixing of the low-resolution, low-temporal, and high-spatial coverage data from remote sensing with the high-resolution, time-varying and low-spatial coverage data from drone technology can generate valuable insights into several biophysical constraints that agriculture confronts and possibly their solutions. Such studies, however, require significant efforts and funding support. Similar combinations of sensor-based resource identification and quantification technologies, which are already in vogue in fisheries, can be ramped up by such admixture of telescopic resolution imagery.

The availability, standards, accessibility, security, sovereignty, quality, authenticity and disambiguation of agricultural data is a challenge. The central and state governments own a large chunk of data (e.g., landholdings, research data, crop sown area and survey data). Knowledge amassed over several decades is available with the agricultural research institutions. Lately, the Government of India has initiated an Open Data initiative through Open Government Data Platform, https://data.gov.in, for sharing data. Yet, many datasets are not easily accessible. Creating and maintaining Computing Environment (hardware, software, storage, bandwidth, connectivity and cyber security) is a challenge for the government institutions. More importantly, there is an acute scarcity of trained human power. Lack of coordination and investment in digital data capture and their utilization is a big challenge.

Cloud-based information systems are also being developed to provide real-time decision support. Compared with the existing decision support systems (DSSs) that are modeled after a human-in- loop decision process; the next generation Decision Support and AUTOMATION System (DSAS) would have a feature of a fully automated decision process— from data acquisition to data analysis and decision synthesis to control field devices based on the recommended decision. This is the right time to start working on these aspects.

5. POTENTIAL APPLICATIONS OF BIG DATA SCIENCE IN AGRICULTURE

Some of the specific fields of agriculture where the Big Data Analytics can play an important role are as follows (a reference may also be made to USDA, 2013):

- **Faster technology development and adoption:** Using sensors and automated tools for data capturing along with application of appropriate analytical tools, it is possible to reduce technology generation time. This requires collaboration among experts from plant breeding, agronomists, engineers, statisticians, modelers and computer specialists. Through social media the extension professionals can promote faster adoption and also extract feedback for technology refinement and assessment.

- **Plant breeding:** Traditionally, it takes 7-8 years from the initial crosses to commercial releases of crop varieties including 3-4 years of their field evaluation. The time period is even longer for perennials and tree crops. The challenge here is to ensure that the material is suitable for a region and yields an economically viable solution to farmers. The efforts are being made to collect data from individual fields, plants and leaves, and use machine learning/deep learning approaches to predict performance of crosses under different weather conditions.
- **High throughput field phenotyping (HTFP):** Here big data analytical allows rapid scanning of large scale field evaluation of crosses which can replace the tedious and subjective ratings used by plant breeders. This can be used both in breeding nurseries as well as field experiments for collecting spatial and temporal information through sensors, drones or satellite imageries. The assessing crop growth over a season provides valuable information. The HTFP in conjunction with weather information and management practices can lead to new insights into genotypic-environment interactions.
- **Bioinformatics:** High throughput sequencing, genome assembly, proteomics and metagenomics are other applications of Big Data. Agricultural researchers are continuously generating genome data on important plants, animals and microbes. Infrastructure, data sharing policies, and parallel and grid computing are required for developing de-Novo assemblies, identification of genes responsible for different traits. ICAR has initiated some studies for database creation and prediction by mining genome/proteome sequences using machine learning algorithms. Development of genomic data warehousing, parallelization of workflows, SNP resources for animal species, genomic resources for various crops/ animals and other transcriptomes resources need to be taken up.
- **Precision farming:** It involves analyzing intra- and inter-site variability with geo-tagged data to apply site-specific management practices to minimize input-use and cost of production. Precision farming is pursued in developed countries. The software solutions provide customized advisories to farmers including remote management, cloud storage and satellite imageries. Another area of agriculture where the Big Data can make a significant dent is the harvest machines. Harvesting machines are common for wheat and rice. Sensors attached to a harvesting machine can provide valuable information on moisture, soil temperature and crop yield. All the data are geo-tagged, and the inter- and intra-plot variability at plant level can be easily obtained through an analysis of such data. Thus, site-specific management practices are very much possible at farmers' fields. Operationalizing it will involve seamless merging of data varying in time, space, frequency, scale and units (e.g. hyperspectral data, geo-referenced, harvest, nutrients, weeds, pests and disease information, biomass, remote sensing, sensors data) and proper analytical tools and techniques. Simply put, this kind of model leaves a high frequency trail based analysis of all scalable, quantifiable and palpable aspects of farming. Precision farming based on Big Data Analytics can help optimize the use

of inputs leading to sustainable production with lower costs and environmental pollution.

- **Crop planning:** Looking from the other side of the prism, crop planning had always been a classical big data problem where the analysis of different types of data, including the soils, water, weather, market demand and price forecasts are required. Big data analytics is also helpful in Mega Environment Mapping of Crops
- **Quality assessment:** Price discovery for farmers at market level based on quality using image recognition of different crops is another potential area for big data analytics application.
- **Grading and marketing:** Technologies are now available using image analysis to assess quality of fruits, vegetables and spices through mobile applications. These solutions bring transparency and standardization to quality assessment in grading and may help better price realization by the producers.
- **Customized farm advisory services:** Customized farm advisories for planning, management practices and identification of insect pests and diseases are in a pipeline. For example, a farmer is interested to know before sowing what is the best possible yield in his/her field/village, how different it is from the best at state, national and global levels, and why. This gap analysis will enable farmers to understand and plan for higher yields. Generation of sowing schedules and contingency plans; predicting phenology and suggest agronomic measures; crop-specific soil-test based fertilizer recommendations; agro-met advisories will be helpful for location-specific advisories. In fisheries science such advisories can form basis of a whole lot of livelihood options, ranging from backyard pond pisciculture to seaweed cultivation to open-sea mariculture for monitored identification of potential regions of wild capture fisheries.
- **Traceability:** Blockchain technology can be used to trace the product from farm to plate (Shekhar et al., 2017). This will ensure food safety. Also, e-ledger based transactions will help e-market interventions comparatively transparent and less speculative.
- **Sustainable resource management:** In case of marine fishery resources, the optimality and sustainability are the two ends of the managerial spectrum, often ending up as mutual tradeoffs. The use of real-time data will help bridging the gap between quantity of catch and its economic value, and a new paradigm shift will maximize fishers' profit within the safe limits of fish stocks. With many international bodies insisting on the vouchsafing of marine ecosystem and prodding towards catch certification such a learned analytical canopy on the fisheries dynamics will be pertinent and timely.

6. WAY FORWARD

The Big Data Analytics can play an important role in agricultural research and development. It is time for all to come forward and develop vision for application of Big Data Analytics in Indian agriculture. Some suggestions in this direction are as follows:

- **Bringing data together:** It would require breaking down silos and determining identity and security controls to achieve effective data governance. Data retention, data integration and data sharing policy guidelines across the domain are required.
- **Multi-disciplinary team:** Big data problems require involvement of expertise from different

fields – statistics, computer science, engineering along with domain knowledge experts for artificial intelligence (AI)/ Machine Learning (ML), Graph analytics, Natural Language Processing (NLP), augmented analytics, blockchain, recurrent neural networks, deep learning, etc. Hence, it is must to solve a problem as a multidisciplinary team.

- **Partnership/Collaborations** – It is essential to join hands with other academic institutions as well as private industry. International collaborations will also be required.
- **Infrastructure:** Establish/strengthen Big Data Analytics and Data warehouse platform for data management (Data fabric, persistent memory servers, forgetting insights).
- **Moving to cloud:** Cloud-based computing, wherein the services can be hired based on requirement, is one of the options. The charges for computing may be less as compared to establishment and maintenance cost. The organizations have to think of a hybrid model of on-site resources and On Site + Cloud Software as a Service.
- **Standard Community of Practices (CoPs):** are required across the system, defining data standards, interoperability protocols, security and privacy concerns; connecting with existing initiatives.
- **Showcase applications:** Identification of potential areas will be required where the big data science can be applied. These include establishment of Big Data Analytics and Data warehouse platform for data management, and development of web applications for providing location-specific, on-time and data-driven information/advisories, crop mega- environment mapping, crop planning; predicting phenology, generation of sowing schedules and contingency plans using AI /ML.
- **Capacity building:** Since Big Data Analytics is a field still evolving, the need for capacity building of scientific and technical personnel through trainings cannot be undermined. It may involve international collaborations.

To capture a sizeable chunk of the progressive steps listed above, the systems may have to go a long way to attain reliable quality data resources and include latest techniques like blockchain, recurrent neural networks and deep learning for getting further insights. Relevant quality data, and understanding the problem, context and analytical techniques are likely to be a key factors for successful application of Big Data Science in agriculture. Identification of relevant sources and quality data from historical datasets from research, socio-economic, markets, live-streaming datasets from sensors, robotics, satellite imageries, and bringing data from silos to useable and shareable formats are the key concerns.

7. RECOMMENDATIONS

The following recommendations emerged from the discussion:

- A national-level Seminar/Brainstorming/Workshop should be organized to *identify successful case studies, prioritize potential areas to work upon and to draw future roadmap for application of Big Data Analytics in agriculture*. It must ensure participation of all stakeholders involving the public and private entities, and international organizations. Some showcase applications, such as providing location-specific, on-time and data-driven information/advisories, crop mega-environment mapping, crop planning; predicting phenology, generation of sowing schedules and contingency plans, selection of mariculture sites, electronically-guided sustainable capture fisheries management, and robustly integrated market intelligence driven supply chain management, using AI /ML may be developed. Through this, a thorough landscape analysis may be conducted for assessing needs, gaps, promising platforms and technologies, defining data typologies and ecologies to use, identifying API-based platforms to enable interconnected datasets and operations. Through the discussions, multidisciplinary teams involving core statisticians, computer professionals, engineers, domain experts for AI/ML, Graph analytics, NLP, augmented analytics, e-ledger technologies (blockchain), recurrent neural networks and deep learning may be identified.

(Action: ICAR and NAAS)

- Establish an *'Innovation Centre or Center of Excellence for Big Data Analytics in Agriculture'* with adequate funding and trained manpower for facilitating collaborations among multidisciplinary teams. Big Data Analytics platform needs to be established/ strengthened for data management, including the data fabric and persistent memory servers. Cloud-based computing, wherein services can be used based on requirement, should be encouraged. Available infrastructure and resources such as cloud-computing initiative of MeitY (MeghRaj), ICAR Data Centre, ASHOKA, and Open Government Data Platform should be exploited, used and strengthened for the purpose.

  (Action: ICAR-Agricultural Universities (AUs), CGIAR organizations, MeitY, Govt of India)

- ICAR Research Data Management initiative should be strengthened, incorporating ontologies and similar meta mining tools wherever feasible. Standard Operating Procedures/Community of Practices (SoPs/CoPs) should be developed for defining data standards, interoperability protocols, security and privacy concerns, data capture, data storage, data transformation and data analytics along with suitable data governance mechanism and technical and business metadata management framework. There is also a need to develop standards and frameworks to harvest data from various data assets and identified sources.

  (Action: ICAR and AUs)

- Efforts should be made to compile data from the Directorate of Economics and Statistics (DES), Ministry of Agriculture and Farmers' Welfare; and Ministry of Fisheries, Animal Husbandry & Dairying with value addition for their integration with data from NARES. MOUs may be signed for sharing data among the Departments. As far as possible, mechanism for auto updates of data and visualization should be developed.

  (Action: DES, DA&FW, Department of Fisheries, DAHD and ICAR)

- A 'National Open Data Framework' should be established with metadata catalogue of all the major potential shared entities along with matrix for cross-linking metadata available across NARES. The framework for "Labeling" for any image or video-streaming data collection should also be initiated with a central server that can serve as a repository. The variability (in its totality), diversified nature, socio-economic profile and safety nets that the Government has put in place, in particular, the last mile delivery, for the small and marginal farmers needs a totally different approach and Big data analytics can serve the purpose. A document should be prepared and circulated to all science academies for developing a framework on Data Analytics to make the country a Global Hub on Data Analytics

(Action: MeitY, Ministry of Agriculture, NAAS and other Science Academies, ICAR and AUs)

- Efforts should be made to establish AgTech innovation center in Public-Private-Partnership mode on the lines of AgTech Unit being established by the North Carolina State University in collaboration with other stakeholders. "Ready use cases such as devices detecting micro-behaviour of cows feeding, ruminating, resting, detection of conditions indicating estrus, monitoring the tail movement of cows for timing the artificial insemination for female calf birth needs to be explored and rolled out for piloting in India under the AgTech Innovation Center."

(Action: Through Public Private partnership)

- Big data analytics and artificial intelligence require prescriptions from experimental data and, therefore, experimental data should always remain an integral component of agricultural research to understand the biological system. Therefore, improvement in methods /procedures of quality primary data collection and judicious blend/ amalgamation of experimental data, traditional survey data, historical data along with data from IoTs, drones, remote sensing, UAVs, smart phones, crowd sourcing, and administrative and government data needs to be thought of.

(Action: Meity, ICAR-AU, CGIAR)

- Identification of relevant sources of quality data from historical datasets from research, socio-economics, markets, live-streaming datasets from sensors, robotics, and satellite imageries needs attention. Bringing data from silos to useable and shareable machine readable formats should be the main focus. Understanding the problem context and selection of appropriate analytical techniques will be key factors for successful applications in agriculture.

(Action: ICAR, AUs, Open Government Data Platform)

- System dynamic approach needs to be used to understand each major generic domain of Indian agriculture (e.g., soil, water, crop, weather, socio-economic, associated environment) and derive useful information for crop management and livelihood enhancement. Integrated hybrid analytic platform should be established to understand dynamics of ecosystems in agriculture.

(Action: ICAR in collaboration with other Scientific organizations, NASF)

- Capacity building in big data analytics both in online and offline modes (overseas and within country) is also essential.

(Action: DARE, AUs, NAHEP)

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