Precision Agriculture to Digital Agriculture:

A Literature Review

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Abstract

This paper tries to capture the evolution of Digital Agriculture based on the foundations of precision agriculture. The review of literature around the development of precision agriculture reveals that the data captured in the precision agriculture processes, if effectively used, can support extensive agronomic decision making. With the advent of artificial intelligence and machine learning (AI/ML), predictive and prescriptive analysis of even huge amounts of data is now possible. Digital Agriculture seeks to combine the power of AI/ML and data from precision agriculture to deliver decision support systems to farmers and in other aspects of the agricultural value chain. The prerequisites for Digital Agriculture to realise its full potential are business models that demonstrate clear economic benefits for the farmers and user-friendly design.

1.0 Introduction:

Ours is a Columbia University project in partnership with The Energy and Resources Institute (TERI) titled, "Towards a New Indian Model of ICT-led Growth and Development". The project examines the potential for a new Information and Communication Technologies-led model of growth and development in the Agriculture sector in India and seeks to make recommendations for India to continue to leapfrog the development process using ICTs in key sectors including agriculture, among others. In the course of the project, we have come out with working papers relevant to agriculture and technology. This paper is an attempt to review the literature around precision agriculture and its development to what is now termed digital agriculture. We begin with a brief history of the development of precision agriculture along with a description of the technologies that constitute precision agriculture. We also describe the implications of precision agriculture and future possibilities. The reasons affecting the uptake of precision agriculture and limitations of precision agriculture are also captured. The development of digital agriculture on the foundation of precision agriculture is also reviewed before the conclusion.

2.0 Existing Studies on Precision Agriculture:

2.1 Mulla and Khosla (2015), note that the terms site-specific and precision farming were introduced into scientific literature by John Schueller from the University of Florida. He helped organize an important symposium on this topic at the 1991 Annual Meeting of the American Society of Agricultural Engineers (ASAE) in Chicago. According to Schueller, "the continuing advances in automation hardware and software technology have made possible what is variously known as spatially-variable, precision, prescription, or site-specific crop production." In their paper they review the following aspects of precision farming

- Soil Sampling, i.e., where the soil is tested for precise fertilizer application resulting in grid sampling recommendations
- Geo Statistics and GIS quantifies soil spatial variability and allows Map interpolation and reclassification for soil fertility data
- Farming by Soil, is a concept, which was first developed by Pierre Robert and actively promoted by him in the early 1990s, for which he is often regarded as the father of precision agriculture. His research notes that anomalous reflectance patterns from row-cropped fields were associated with soil series boundaries and he actively advocated geographic soil and crop management database system for improving farm management
- Variable Rate input (Fertilizer, herbicide, irrigation) applications phase in precision agriculture was a logical progression to the developments of the concepts listed above. It involved Machinery development and field testing for variable rate fertiliser applications
- Site Specific Farming and Management Zones: Management zones in precision farming

were also defined around the same time and the concept has persisted to the present day, but both the concept and definition has broadened since David Mulla from Washington State University offered the first definition in 1991: “Each management zone should ideally represent portions of the field that are relatively similar and homogeneous in soil fertility status so that a different uniform fertilizer recommendation can be made for each zone.”

- GPS allows real time location monitoring
- Automated Tractor Navigation and Robots has been one of the most intense areas of research and implementation over the past 30 years because it can improve fuel efficiency, reduce human effort and drudgery, eliminate machinery overlaps etc. Japan is a leaser in adoption of all types of autosteer navigation technology.
- Yield Mapping: The paper finds that there has been a lot of technology development and field testing but “the focus on spatial and temporal variation in crop yield tends to overlook an important issue”, which is that for precision technologies like variable rate input applications, crop response, and not crop yield is the critical factor with the result that defining management zones based on differences in crop yield is not an efficient approach
- Remote Sensing: The application of satellite imagery to precision farming was limited during the 1990s due to technological limitations like limited spatial resolution and high return frequency. However, since then, remote sensing technologies have a come a long way with hyperspectral remote sensing and a growing interest in unmanned aerial vehicles (UAVs) as a platform for remote sensing in precision farming to assess different relevant crop parameters successfully. Governmental restrictions on their usage, light payloads, low power, and limited flight times are some of the current limitations of UAVs.
- Proximal Sensing of soils and crops

In conclusion, the authors note that the economics of precision farming is still a work progress as technologies and management techniques improve. However, the major factor that continues to influence the economics of precision farming is commodity prices. They find that increased commodity prices, which result in higher economic profits for farmers, also result in greater investment in new technologies including precision farming. They also find that the decline in commodity prices slow down and reverse the adoption of precision farming.

2.2 Strobel (2014), while noting that the development of precision agriculture technology started in the 1960s, lists the 5 major tools of technology out of the several tools used in precision agriculture, namely:

1.yield mapping, 2.guidance and global positioning systems (Global National Satellite System, GPS), 3.variable rate technology (VRT), 4.con- trolled traffic farming (CTF), and 5. Geographic information systems (GIS)

Further, through the use of such precision technology, a databank with many years' worth of constructive information and of huge economic worth is created. Farmers appreciate the value of this data but are also apprehensive about its uses once it is freely available; it can be used for selective marketing of inputs, or to manipulate prices and other such uses which may be detrimental to farmer interests. Thus the question about data privacy and ownership of such data arises. The most common ways of ensuring data privacy is through confidentiality agreements but that has its limitations. To ensure continued protection to the data from precision agriculture and protect farmers' interests, the author suggests legislative and policy changes to prevent the leak of data produced by precision agriculture to maintain privacy, and to retain ownership of data in the hands of the farmers. In this regards, Personal Information Protection Electronics Document Act (PIPEDA) of Canada and Health Insurance Portability and Accountability Act, or HIPAA of the US are suggested as templates, which should be followed.

2.3 Ullah A. et al, survey the technologies and challenges in precision agriculture. They begin by identifying a greater need for efficiency in current farming methods to be able to meet the goal of feeding an ever-growing population, which the FAO expects to reach 9.2 billion by 2050. They proceed to list different technologies, challenges and state-of-the-art methods based on artificial intelligence and image processing for efficient precision agriculture. They mention artificial neural networks (ANNs) and fuzzy logic controllers for regulation of temperature and humidity in artificially conditioned greenhouses and UAV based pest controllers and sprayers as some of the solutions.

2.4 Zhao C. et al, 2016, describe methods for acquiring spatial information about farmlands using remote sensing techniques towards the requirements of decision making in precision agriculture. They note that to achieve the goals of precision agriculture, high-density, high-speed, and low-cost supply of spatial information on crops, soil, and environmental conditions is necessary. They list remote sensing techniques to estimate chlorophyll in crops, Nitrogen in crops, water content of crops and crop LAI (leaf area index). They also list the data that can be captured using sensors and calculators in tractors and reapers. They note that "Acquisition of crop yield data in the plot and plotting the spatial distribution diagram are the starting points of precision agriculture and also the basis for achieving scientific regulation of input and making decisions about crop production. " Combine harvesters carry commercialized yield estimation systems like the "AFS system (CASE, USA), the FieldStar system (Massey Ferguson, UK), the GreenStar system (John Deere, USA), and the PF system (Ag Leader, USA)", which capture data through which the crop yield of each plot at each spatial location is obtained and is used to map the spatial distribution diagram of yield. They also describe an automatic soil sample collection system consisting of a sampling device and a recording device to determine soil nutrition and fertility. However, in their paper, significantly, they also identify cost efficiency as the greatest barrier to the implementation of precision agriculture and argue for the development of fast and low-cost methods to acquire spatial information on farmlands. They view the recent developments in airborne and space borne remote sensing as a potential means for the efficient and low-cost acquisition of farmland information needed in precision agriculture. At the same time, they make it clear that remote sensing data cannot be directly applied in agricultural decision and suitable models are needed to interpret the collected information to provide support for farmland production management.

2.5 Yang C., et al, (2016) study precision agriculture in large scale mechanized farming. According to the, the central concept of precision agriculture is identification and management of within field variability with the aim to improve farm input efficiency, increase farm profits, reduce environmental impacts and improve sustainability. They list 4 steps for automatic implementation of the concept of precision agriculture (1) measuring spatial variability; (2) analyzing data and making site-specific recommendations; (3) implementing the variable-rate application (VRA) of farm inputs; and (4) evaluating the economic and environmental benefits. Thus in their opinion, "A broader view of precision agriculture would include more than VRA. It is more about helping farmers better manage their operations and correct inadvertent errors using sensing and control to automate and more precisely carry out field operations. "

As far as adoption of precision agriculture is concerned, they are clear that any new farming practice is adopted only for economic gains and precision agriculture requires a high initial investment cost which may not be immediately compensated in the initial years of adoption and thus despite technological advances and potential benefits, the global adoption of precision agriculture is slower than expected. Owing to these challenges they recommend 3 broad areas for further work:

1. Development and integration of low-cost variable-rate components (i.e., sensors, controllers, and actuators) into/with existing fertilizer application equipment

2. Development of low-cost and easy-to-use tools to determine site-specific fertilizer application rates and create prescription maps so that field profitability can be enhanced more effectively with minimum inputs; and

3. Long- term systematic studies on the economic feasibility and environmental impacts of variable-rate fertilization.

2.6 The report of the Scientific Foresight project 'Precision Agriculture and the future of farming in Europe (2016) is a comprehensive document on the contemporary status of precision agriculture in Europe. According to this study, there is a wide range of enabling technologies for PA.

Some techniques of Precision Agriculture applied in EU:

- Automatic machine guidance with GPS
- Automatic guidance and contour cultivation on hilly terrain
- Automatic guidance of fertilisers and pesticides based on geographic information and at requisite distance from water ways in the field including section control of sprayers and fertiliser distribution
- On-the-go manure composition sensing and depth of injection adjustment
- Soil texture map
- Weed maps for weed detection and patch herbicide spraying
- Multisensor optical detection, Airborne spores detection , Volatile sensors for early and localised pest or disease detection and treatment
- Crop vegetation index based on optical sensors
- Soil nutrient maps
- Crop vegetation index to determine crop biomass

Such available PA technologies, the report states, are used for "object identification, geo-referencing, measurement of specific parameters, global navigation satellite systems (GNSS), connectivity, data storage and analysis, advisory systems, robotics and autonomous navigation." Further, although a lot of progress has been made in PA development and implementations of PA practices already exist in arable, vegetable and dairy farming, yet the full potential of PA has not yet been harnessed. Some of the implications of PA for European Agriculture as analysed are mentioned below:

- Competitiveness of EU farming will increase with PA technologies because farms can produce 'more with less' with large farms benefitting the most
- Farm sizes will increase because of the required know how and investments in PA technologies. Thus, the number of farms will go down.
- Farm jobs will decrease due to replacement of low skilled workforce by PA technologies
- Skilled jobs (specially in ICT) and relevant services will see a rise in demand
- The opportunities and market size for sensor industry, IoT, ICT services, food processors, logistics and retail will grow
- Agriculture will become multi functional due to increased focus on farming due to PA technologies
- PA can impact demographics and rural development because it can create new business opportunities in rural areas and thus affect the movement of people from rural to urban areas
- Positive impact on food security; sensor based monitoring systems and Decision Support Systems (DSS) can provide farmers and stakeholders with better information, early warning on the status of crops and animals and improve yield forecasts. This also

improves food safety and transparency of agri-food chains

- Enhances sustainable production and helps in climate change and action. Natural resources and other input use is rationalized to allow more production with less; thus farmers, environment and society, all benefit from PA. Also stakeholders can detect effects of climate change on agricultural production earlier and easily and take necessary action.

It also notes that there has been wide development and reach of internet and internet enabled services like cloud based data storage services, GIS systems, data analysis software, wireless communication via e.g. 3G, 4G and other networks, smartphone applications that can provide farmers with specific information such as on weather conditions, status of crops, heat detection and movement of animals, and give management advice. Inspite of all these developments, they find that only 25 % of EU farms use technologies, which include a PA component. They proceed to suggest certain policy options, which can be adopted for increasing the uptake of PA.

- New business models
- Promoting PA towards trend-setters and the next generation
- Issuing an annual report on PA uptake
- Building the appropriate infrastructure for keeping and attracting young farmers
- Robust 5G internet infrastructure in the European context which can facilitate:

    - Live mapping of soil moisture;
    - Variable rate fertilisation (including N-sensing);
    - Precision planting;
    - Data-centric farm management;
    - Connectivity to wind-farms;
    - Access to world markets.

3.0 Literature Review indicating shift to Digital Agriculure

3.1 Shamshiri R., et al (2019), list the following use cases of Digital Agriculture:

- Sensor-based field mapping
- Wireless crop monitoring
- Climate monitoring and forecasting
- Stats on farm production
- Wireless equipment monitoring
- Predictive analytics for crop and livestock
- Livestock tracking and Geo-referencing
- Smart logistic and warehousing

The identify Wireless and Sensing Technologies, Positioning Technologies, Data Analytics Solutions, Mobile Applications and Web based solutions as the main technologies used by the above use cases. Further, they state that AI, Smart and wireless sensors, IoT, UAVs, Big Data, Virtual Farms, Automation, Agricultural Robotics, Deep learning and Precision Management are the building blocks of Digital Agriculture. Thus Digital Agriculture provides tools and methods for sensing the environment, information processing and precision acting. As more and more data is collected from the farm and analysed, future harvest yield and livestock performance can be projected that will enable farmers to plan better and enhance productivity and revenues.

3.2 A DLG (German Agricultural Society) position paper (2018) reviews priorities to achieve the full promise of digital agriculture. They view PA to mean optimizing growth conditions by means of sensory analysis and precise application technology and Smart Farming as the further development of PA that contributes chiefly to supporting decision making due to the complex nature of information processing which can only be achieved through automation.

Thus, Digital Farming, according to them, combines the “consistent application of the methods of “Precision Farming and Smart Farming”, internal and external networking of the farm and use of web-based data platforms together with Big Data analyses”.

They feel that through greater use of sensory analysis within the context of the ‘Internet of Things’ and remote sensing data, farmers would be able to respond better to unforeseeable natural phenomenon such as weather conditions, biotic and abiotic factors in agricultural production processes. They also cite literature to state that profitability analysis tools enjoy the top priority among digitization tools closely followed by applications for machinery control, for Big Data analyses and for transferring data to public authorities.

In conclusion, they argue that digitizing should maintain the entrepreneurial autonomy of farmers towards productive, sustainable and fail-safe agriculture while strengthening and expanding the role of agriculture in human and social development.

3.3 Salam A. (2020), in his study identifies the Main Barriers to Digital Agriculture Technologies Adoption. According to the study, among the major issues in adoption, first is return on investment. The cost of digital agriculture equipment and services is still higher than their benefits. Thus naturally interest is low due to economic reasons. Secondly, digital agriculture technology business is mostly targeted to the big farms and thus smaller farm owners are excluded. Thirdly, enormous data is generated due to the application of digital technologies on the farm but there is a lack of decision tools. Thus, interception of this data and decision making become very time consuming for the farmers. Fourth, farmers prefer the educated guess based on their own experience rather than trust the sensing (in situ and remote), yield maps, and soil maps based recommendations. To add to the above, “the cost and availability of specialists for complex equipment, lack of manufacturer support, difficulty in putting up encompassing high value, precision portfolios are the limiting factors for precision business”, the paper adds. Because of the above barriers, the digital agriculture business is not profitable.

3.4 Shepherd M. et al (2018) note that digital technology in agriculture has its roots in the concept of PA. While PA has evolved with the use of GPS, proximal and remote sensing methods and variable rate technologies (VRT), the next challenge for PA is to harness the potential of the collected data to support decision making. This is possible because of the growing ability of computers to utilise technologies to convert precise data along the value chain into actionable knowledge to drive and support complex decision-making on-farm and along the value chain. This aspect distinguishes the ‘digital agriculture’ from PA and enables the shift ‘from precision to decision’.

The authors note that although there is a general assertion that digital technologies have potential to truly transform agriculture, they believe, for the potential to be truly realised, the technology has to be implemented on a large scale. But the experience from history is that it is a slow process. They cite examples from Dutch studies (only 20% of dairy farmers have on-cow sensors a specific purpose but other sensors are hardly adopted), only about 20% of farmers in the USA have adopted VRT even inspite of wide availability and some other instances are also mentioned.

They define digital agriculture as the use of detailed digital information to guide agricultural decision making all along the agricultural value chain and not limited to farm or production processes only. It includes the use ‘big data’ (high-volume, variable source data), to produce actionable knowledge. Thus, it also offers “the potential for an ‘almost direct link’ between consumer and food producer” which is recognized as ‘smart farm- ing’ in literature, i.e., a development that emphasizes the use of ICT in the farm management cycle. Thus, the concept of digitalisation of agriculture is similar to business digitalization with both enabling, improving and/or transforming operations and/or functions and processes, by leveraging digital technologies and digital data for decision making.

They view the developments in particularly 3 areas which would provide a great thrust to Digital Agriculture

i. Sensors: Ever decreasing size and costs of sensors can facilitate cost-effective data collection.
ii. Telecommunications and Data Storage: Advances in telecommunications along with decreased costs of both data transfer and storage is a positive externality for Digital Agriculture
iii. Analytics: Analytical ability of computers is increasing exponentially and can offer almost real time analysis, which increases the ability of AI to deliver predictive and prescriptive solutions.

In effect, they argue that digital technologies and their interconnectedness through the Internet of Things offer immense potential for agriculture from the upstream to downstream in the entire value chain However, they are also clear that embedding digital agriculture, and equitably sharing its potential benefits requires significant agricultural system changes and critical socio-ethical and technical issues to be resolved.

3.5 Rose et al (2016) investigate the factors affecting the uptake and use of decision support tools (DST), by farmers and advisers in the UK. Software-based DST play an important role for evidence-based decision-making in agriculture to improve productivity and environmental outputs. The fifteen factors identified in their research, listed below, provide insights into the characteristics on an effective decision support tool.

Core Factors:

1. Performance expectancy, i.e., does the DST tools in question perform a useful function and work well

2. Ease of Use, i.e., how easy is the interface of the tool to use by the end user

3. Peer Recommendation, to encourage peer to peer knowledge exchange

4. Trust, i.e., is the tool evidence based and the users trust it

5. Cost, i.e., the cost –benefit ratio of the tool should be beneficial and initial cost should not be prohibitively high

6. Habit, i.e., does the tool match closely with existing habits of farmers?

7. Relevance to User, i.e., the tool should have the ability to say something useful about individual farms

8. Farmer adviser compatibility, i.e., the tool should facilitate farmer advisers to encourage client uptake

Modifying Factors:

1. Age, i.e., the tool should be compatible to farmers of different age groups

2. Scale of business, meaning the tool should be suitable for different scales of farms

3. Farming Type, i.e., the tool should be useful for different farming types

4. IT Education, meaning the tool should not require specialized IT skills to operate

Enabling factors:

1. Facilitating Conditions, meaning that farmers should not have to face additional tasks, or their existing devices should be easily integrated along with the DST used

Driving factors

1. Compliance (Legislation): the tool should not create impediments in compliance in any ways and should ease and facilitate compliance for the farmers

2. Level of Marketing, like any product, marketing definitely plays a role in DST too.

4.0 Conclusion

The literature surveyed tries to capture the evolution of digital agriculture based on the foundations of precision agriculture. A lot of data gathered in precision agriculture could not be put to good use due to limitations of the models of PA; the advancement of technology has made it possible to use such data for decision making and a rapid advancement to the digitization of the entire agricultural value chain. The key takeaways from the literature reviewed are:

- Economic aspects and business models: Digital Agriculture solutions have to necessarily keep economic gains for farmers in mind so that the farmers invest in and adopt Digital Agriculture business models. This is absolutely important and if the technologies and business models do not substantiate effective and tangible economic gains, adoption of digital will lag far behind the potential.
- Design aspects: Technology is rapidly advancing and is poised to only grow further. The challenge and opportunity lies in the domain of design to harness the growing power of technology to design keeping, inter-alia, the ease of use, performance expectations and skill levels of the end-user in focus.

Thus, at current levels of technological research and development, this decade can herald a conclusive shift towards Digital Agriculture with the right environment in terms of design and business models being the only prerequisite.

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