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Automation and Digitization in the Seed Sector: Offline to Online

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Authors' contributions

This work was carried out in collaboration among all three authors. The authors read and approved the final manuscript.

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ABSTRACT

As automation has become an integral part of today's world, the Internet of things (IoT) and Machine learning (ML) offers a platform for tracking and controlling different environments remotely with the help of sensors, controllers and the internet. Today IoT and ML are taking over control of agriculture industries and playing an important role in smart farming. The literature highlights the potential use of IoT and ML in agriculture and even in seed sector which is feasible for surveillance and monitoring from sowing to harvesting and similar packaging operations. In this review, we have highlighted the use of IoT applications with remote sensors such as temperature, humidity, soil moisture, water level sensors and pH value providing an idea of automation in seed sowing, seedling development and yield, which displays precision as well as practical utility to cope with difficulties in the field. It also addresses the digitalization in seed distribution and market systems. Some notable prospects by ML in the seed industry *viz*., seed tracking and smart storage system has also been stated.

Keywords: Internet of things; machine learning; seed industry.

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1. INTRODUCTION

“According to recent data, 9.6 billion people will inhabited the planet by the year 2050. But many countries like India still use the traditional way of farming. Here, the farmers are reluctant to use advanced technologies because of either the lack of knowledge, heavy cost, or because they are unaware of the advantages of these technologies. Lack of knowledge of soil types, seed quality, weather, improper use of pesticides, problems in irrigation, erroneous harvesting, and lack of information about market trends led to the loss to the farmers or adds to an additional cost” [1]. “Lack of knowledge in each stage of agriculture leads to new problems or increases the old problems and adds to the cost of farming.Overall, losses in the agriculture processes starting from seed selection to selling of products/seeds are very high. As per the famous saying “*Information is the Power*”, keeping track of information about the seed source/type [2,3], soil conditions [4], environment [5] and market [6], may help farmers to take better decisions and alleviate problems related to agriculture. Technologies like IoT and ML can be used to get quick and valid information that can be easily processed” [7].

“Based on precision information and technology, the agricultural system is designed to improve the agricultural processes by precisely monitoring each step to ensure maximum production with minimized environmental impact. The beginning of an agricultural process is seeding where the seeds are becoming plants. However, the seed sector is forced to utilize automation and digitization in order to feed this enormous ever growing population. These technologies are erasing issues like extreme weather, soil conditions, climatic changes, and environmental damage while also assisting us in meeting the demand for more food” [8].

Till now the IoT and MLhave disrupted many industries and the seed industry isn't an exception. “It is anticipated that ML and IoT are going to play a considerable role in increasing the ongoing agricultural productivity to cater to the growing food demand. The market size of these technologies in agriculture was initially valued to be at $16,330 million in 2017. However, it is projected to reach $48,714 million by 2025. The global IoT in the agricultural market is predicted to grow at a CAGR of 14.7% from 2018 to 2025. It is due to reduced technology costs as a result of currently operating R&D in IoT and an attempt by the government to boost the quantity and quality of agricultural production” [9].

2. AUTOMATED SEED PRODUCTION TECHNIQUES

2.1 Climatic Conditions

When it comes to seed production, the climate is quite important. Furthermore, incorrect climate knowledge substantially reduces the quantity and quality of seeds that are produced. However, we can now access real-time weather information through IoT and ML technology. The seed production fields have sensors installed that gather environmental data that is utilized to select the best seed crop that would thrive in the given climatic circumstances. The sensors that make up the smart farming ecosystem are incredibly accurate at detecting real-time meteorological conditions including humidity, rainfall, temperature, and more [10]. There are several sensors available to detect all of these factors and configure them in accordance with our needs. These sensors keep an eye on the surrounding weather as well as the state of the seed that was sown and the seedlings that were later established. An alarm is delivered if any unsettling weather is discovered. The requirement for human presence during unfavorable weather conditions is eliminated, which eventually boosts output and enables farmers to gain incredible agricultural benefits [11].

2.2 Smart Greenhouse

With the use of IoT and ML, weather stations can now automatically change the climate based on a specific set of instructions. “IoT and ML use in greenhouses removes the need for human interaction, which lowers costs and boosts accuracy throughout the process. For instance, creating modern, affordable greenhouses utilizing IoT sensors driven by solar energy. These sensors gather and send real-time data that can be used to precisely track the state of the greenhouse in real-time” [12]. “With the aid of the sensors, automatic and intelligent irrigation can be carried out while water usage and greenhouse conditions are monitored via emails or SMS warnings. Information on the pressure, humidity, temperature and light levels will be provided by these sensors” [13].

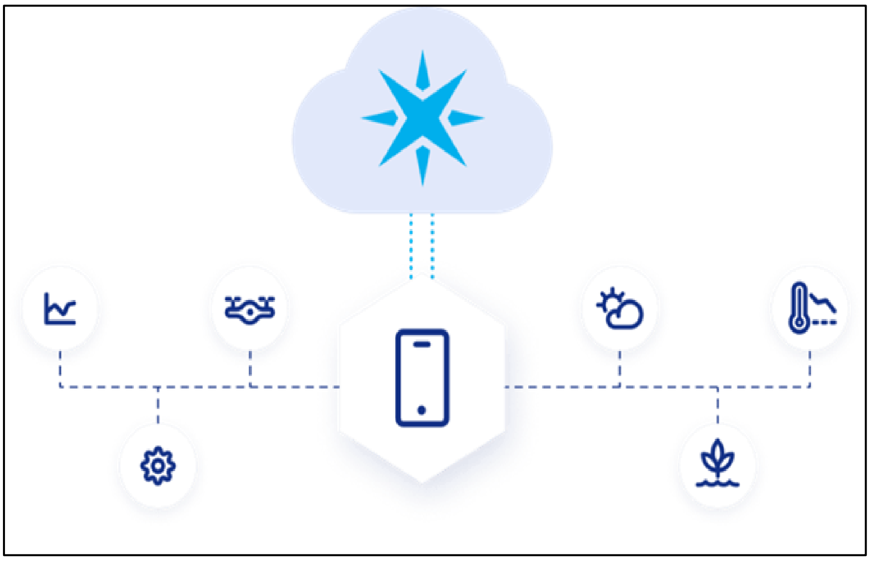

Fig. 1. Monitor climate conditions with an edge-to-cloud platform
(https://www.particle.io/agriculture/)

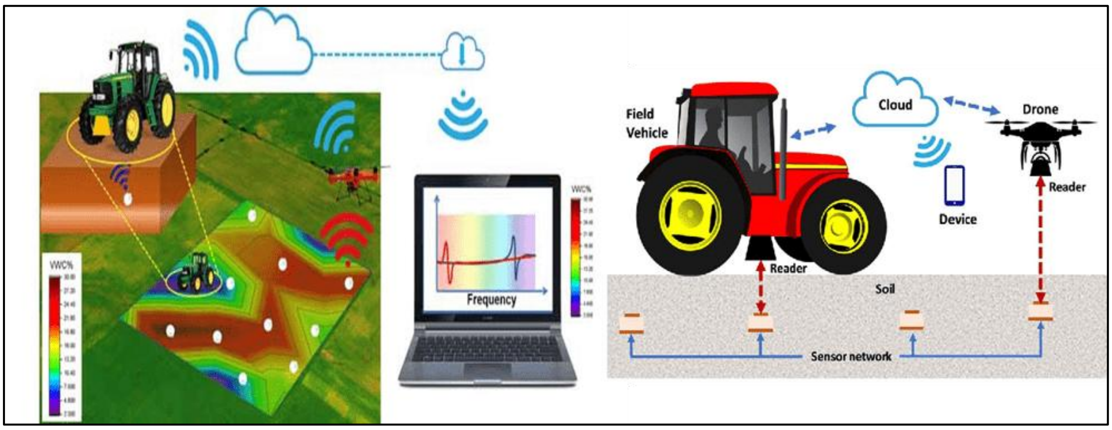

Fig. 2. Battery-Less Wireless and Chip less Sensor Tag for Subsoil Moisture Monitoring [14]

2.3 Wireless Subsoil Health Monitoring by Biodegradable Chip Less Sensor and Analysis of Soil Condition

Fully Degradable Intelligent Radio Transmitting Sensor (DIRTS) that allows remote sensing of subsoil volumetric water using drone-assisted wireless monitoring. The device consists of a simple miniaturized resonating antenna encapsulated in a biodegradable polymer material such that the resonant frequency of the device is dependent on the dielectric properties of the soil surrounding the encapsulated structure.

The simple structure of DIRTS enables scalable additive manufacturing processes using cost-effective, biodegradable materials to fabricate them in a miniaturized size, thereby facilitating their automated distribution in the soil.DIRTS provides a new stepping stone toward advancing precision agriculture while minimizing the environmental footprint. The chip less sensor tags are designed to endure and operate through the agricultural cycle that comprises seed sowing, crop growth, fertilizing, and harvesting. At the onset of the crop season, furrows of suitable depths can be created to distribute the sensor tags alongside the seeds with the help of a seed planter such that each seed has a sensor tag in its vicinity to monitor the soil health parameters surrounding the seed.

Liakos et al. [15] and Sharma, et al. [16] presented "a soil management survey with the application of ML techniques for the prediction or identification of soil properties (estimation of soil temperature, soil drying, and moisture content). The categorization and estimation of the soil attributes help farmers in minimizing the extra cost of fertilizers, cut the demand for soil analysis experts, increase profitability, and improve the health of the soil, whereas Suchithra and Pai [17] suggested pH values and soil fertility indices classification and predication model using ML".

2.4 Seed Bed Based on IoT

The IoT is the greatest solution for agricultural issues like seedbed resource optimization, decision assistance, and seed breeding monitoring. Wireless Sensors Network (WSN) implementation in seedbed monitoring (SM) will maximize control of air temperature and humidity, soil humidity, air capacity, and luminance while minimizing seed breeding time and maximizing the number of seeds developing into seedlings that can be prepared for transplantation.

One advantage of the automated seed breeding monitoring system is that it can give real-time feedback on a variety of variables that influence seed breeding. Higher yields and reduced costs are made possible through the data gathering and monitoring of many variables. Each sensor only receives what is necessary for its specific region, and for the right amount of time and duration [18].

Fig. 3. Seed bed controlled by smart phone
(https://www.instructables.com/Raspberry-Pi-Powered-IOT-Garden/)

Fig. 4. Automatic seed sowing system

2.5 Precision Planting

"One of the most well-known IoT applications in the seed industry is precision farming. By using smart farming applications including seed planting, vehicle tracking, field observation, and inventory monitoring, improves precision and control in farming practice. Precision farming aims to assess data produced by sensors and respond appropriately. With the use of sensors, precision farming enables farmers to collect data, analyze it, and make quick, informed decisions. One can analyze soil conditions and other relevant parameters with the use of precision farming to improve operational effectiveness. Not only that, but it also checks the current operational status of connected devices to monitor water and nutrient levels" [19].

2.6 Seed Sensor System for Seed Count and Seed Spacing

A seed sensor system determines the position of the seed relative to the seed tube as the seed passes the sensor. The position of the seed as well as the speed of the planter and the position of the seed tube above the planting furrow are used to calculate the trajectory of the seed into the furrow from which the seed spacing is predicated. By sensing the seed in both X and Y directions in the seed tube, the sensor is better able to determine multiple seeds as well providing more precision to the seed population.

2.7 Smart Irrigation Module

"IoT and machine learning, utilize adequate water for the irrigation process which is possible through smart agribot. The soil moisture sensor is used to get moisture data, and as per the microcontroller programming, it automatically regulates the motor of a water pump. Agri-bot is controlled from anywhere as it is connected through the cloud system. The bot runs for a specified time, then plants the seeds and covers the field area. The soil moisture status will be identified and displayed on the board. The technicians will gather and handle the information got from the sensors. When a limited moisture level of the soil is reached, the water will automatically supply for proper seed plantation. This will be helpful to farmers, and nursery experts as the utilization of automated smart seed planters replace the conventional techniques for the irrigation process and make a revolutionary change" [20].

2.8 Harvesting Seed Robotics

"Utilizing agribots to pick crops is solving the problem of labor shortages. Working the delicate process of picking filled pods these innovative machines can operate 24/7. A combination of image processing and robotic arms is used by these machines to determine the pos/seed to pick hence controlling the quality. Greenhouse harvesting also finds applications with these bots for high-value crops. These bots can work in greenhouses to aptly determine the stage of crops and harvest them at the right time" [21].

3. AUTOMATED HYDROPONIC SYSTEM

Hydroponic based seed production has quite a lot of advantages over the traditional soil-based systems. In future one can think that hydroponics would become main stream over the time. Advantages include lower water use, better nutrient delivery, ability to harvest seed easily and sooner making it more effective.

The Fig. 5 depicts the system architecture and design of the Intelligent IoT-based Hydroponics system. There are three parts to this system. The Arduino is the first component, which captures data from sensors such as pH, humidity, light intensity, temperature, and water level in a hydroponic tank and sends it to the microcontroller. The second part is the Raspberry Pi3 which got the Deep Neural network fitting model which has been trained in the cloud based on the data set collected. The fitting model in the Pi3 would make an intelligent choice when providing the output decision, which is then given to Arduino in order to activate the proper control system pertaining to activating the fan, lighting, and other devices [23]. On top of that, it's smart too, which means that it features an array of sensors and intelligent controls that one can monitor or influence via the corresponding Smart Phone App.

4. AGRICULTURAL DRONES

"Agricultural drones have nearly completely revolutionized agricultural operations as a result of technological improvements. The assessment of seed production fields for crop health, crop monitoring, planting, crop spraying, and field analysis uses ground and aerial drones. Drone technology has transformed the seed sector by giving it a high rise and a makeover with adequate strategy and planning based on real-time data. Drones equipped with thermal or multispectral sensors locate the areas that need irrigation, fertilizer, etc. adjustments. While harvesting, drones also keep an eye on crop plants with diseased and off-types. Sensors determine the vegetation index once the crops have begun to grow and show their state of health. Eventually, the environmenta impact was lessened by intelligent drones. The results have been such that there has been a massive reduction and much lower chemicals reaching the groundwater" [24,25].

5. SEED STORAGE BASED ON IoT

"In order to reduce the amount of seed wasted during storage, proper warehousing techniques are needed to safeguard the product/seed and ensure that it reaches the farmers who need it. IoT can help improve this method by continuously monitoring and tracking the seed produce that enters the warehouse. IoT system consists of a microcontroller and various sensors that can collect information such as temperature, humidity, and seed quality and post this information to the person who monitors, while also taking appropriate steps to ensure that the seed is stored at optimum environmental conditions" [26,27].

6. SEED TAGGING USING RADIO-FREQUENCY IDENTIFICATION (RFID) TECHNOLOGY

Real-time item traceability and addressability by RFIDs is the innovative technology of integrated RFID and mobile computing is fast being used for integrated traceability systems. It provides a model of communication which would harness the capabilities of RFID technology and mobile technology to provide agricultural vendors and institutions to track the seeds purchased by farmers from them (the RFID-tagged seed bags) to find how they are being used for cultivation and get feedback from the farmers about the health of the crops after seed utilization and provide various advisories to them if required. Also, the RFID data accumulated over a period of time can be used for analytics and a fuzzy approach to analyze the data using the concentration of the seed purchasers in particular areas which would enable the vendors to establish an effective network of their customers.

7. AUTOMATED MONITORING OF SEED GERMINATION CHAMBER

The humidity and temperature factors are under automatic control. Additionally, it monitors seeds using image processing. When compared to tests conducted under uncontrolled conditions, results from germination experiments conducted under controlled conditions indicate outcomes with positive growth patterns. Monitoring the seeds without interrupting the temperature and humidity level by opening the germination chamber reduces a positive result to the decrease of non-germinated seeds (Fig. 9).

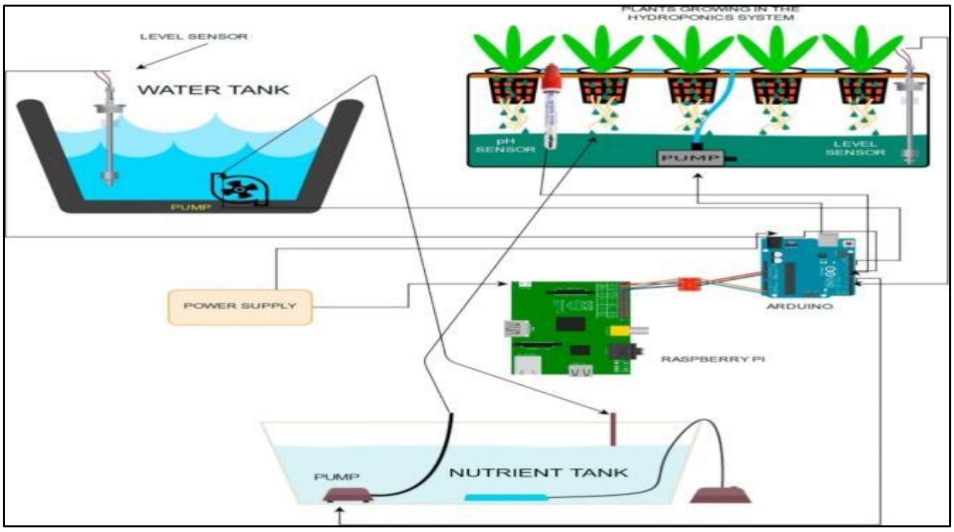

Fig. 5. Hydroponics based on IoT (adapted from Mehra et al. [22])

Fig. 6. Real-time field monitoring by drones
(PC: https://intellias.com/collecting-and-analyzing-drone-imagery-for-crop-monitoring/)

Fig. 7. Monitor seed storage with connected sensors (PC: https://www.tsgcinc.com/)

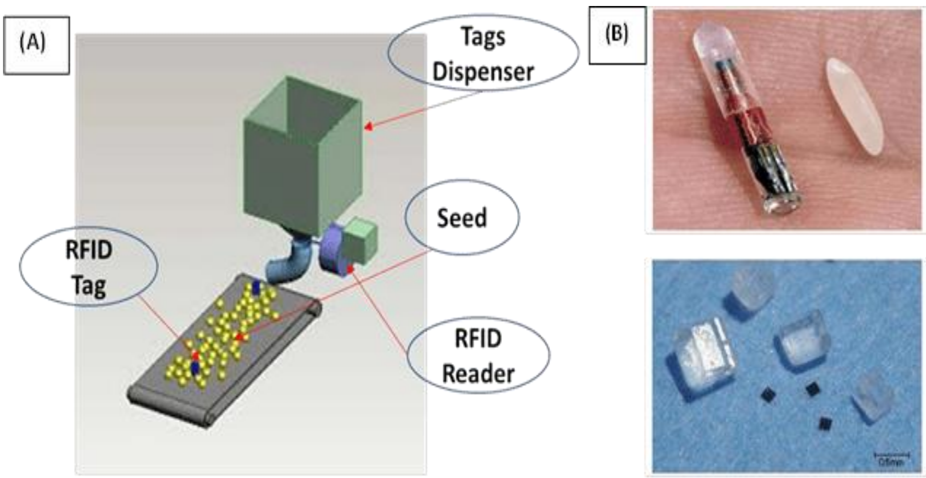

Fig. 8. (A) RFID tracking technology for seeds, (B) Examples of RFID tags whose size is comparable to the size of rice (modified from Hornbaker et al. [28])

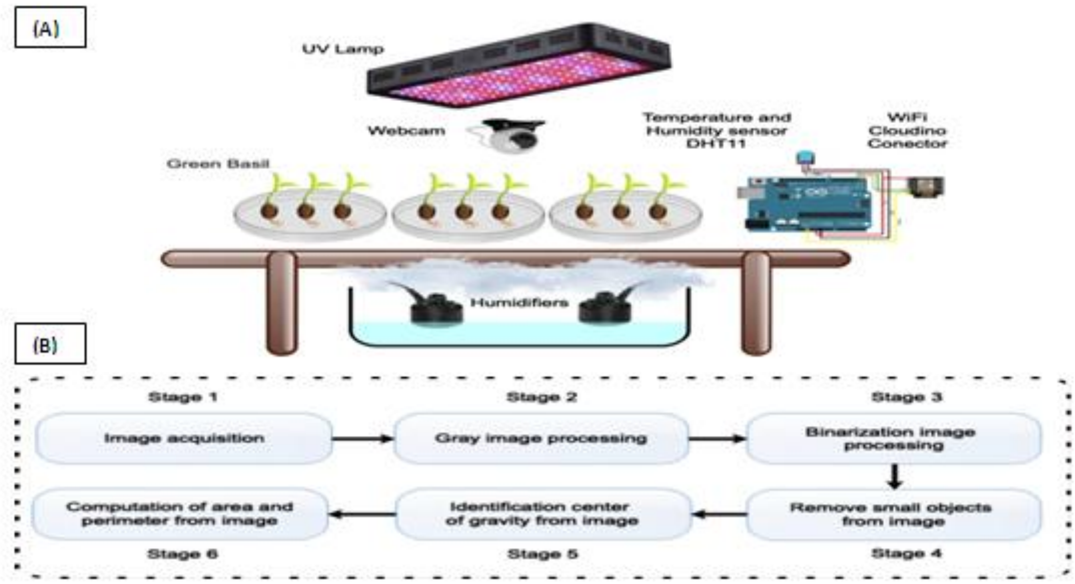

Fig. 9. (A) Overview of seed germination Chamber experimental. (B) Proposed Methodology for the image processing system [29]

Additionally, its application shows how the controller's functionality enables the variables to be established in the reference suggested for the seed. As a result, the data is delivered to the cloud, which makes it easier to store the data so that it may be shared in real time by using the platforms. Finally, it can be validated by the user to get germination monitoring data remotely over the Internet. This work also lays the foundations for future work to implement a screening method in the discovery of optimal germination conditions of unknown wild seeds, or of new seeds obtained by breeding techniques.

8. DIGITALIZING SEED CERTIFICATION AND SEED MARKET

A number of countries have already digitalized their national seed certification systems. These initiatives provide opportunities to build on this capacity to develop an international network, but also present new challenges in terms of the interoperability of existing seed systems. When the Schemes first started exploring digital solutions for certification, blockchain technologies stood out because of their potential to improve efficiency, decentralize the storage of transaction information, provide greater transparency and traceability, and help build trust. The Organization for Economic Cooperation and Development (OECD) Seed Schemes began working closely with OECD's Blockchain Policy Centre to better understand the opportunities and challenges the technology presents.

Digitally Enabled Seed Information System (DESIS) aims to provide an automated version of the seed balance sheet. Agencies/Farmers/Seed growers will be able to place their requests and seed producers to post their seed supplies with unique logins. The platform also aims to help to aggregate and manage breeder, and foundation seeds, as well as certified and labeled seeds, and build a digital inspection system and QR code-based seed certification system. The system will also include an offline seed catalog where users can view seed characteristics, compare seeds and select released and registered varieties available. Users can also generate seed quality reports on batches of seeds. It can be made accessible through a mobile website or android app where users can operate in English and other languages.

Going digital in the seed system has most of the time proven to be beneficial. Research done in many countries, including India has found positive results. Digitalization increases inclusion, efficiency, and innovation while reducing transaction costs. Linking farmers directly with seed suppliers and buyers improves the seed market system and digital platforms are opened up for more people engaged in seed business who previously might have been restricted either due to lack of easy access to the market or due to linkage between buyers and sellers or many other socio-economic barriers. The whole processes in the seed value chain become more efficient as works become faster, cheaper, and more convenient. Though initial setups for digital systems seem to be expensive, they become worthy as transaction costs gradually lower, improving the overall economy. The problem of middlemen which is a major problem in analog systems reduces as farmers become aware of the market price and so can make an optimal decision for their products. This also enhances the knowledge of farmers, and breeders about the possible risks during production and also awareness about the quality of seeds which will eventually decrease the use of low-quality seeds and seed materials that result in lower productivity and food insecurities. Real-time information on seed demand and supply by all the stakeholders can be accessed and the problem of late access to quality seeds decreases.

But as two opposite sides of a coin, digital systems too have some limitations out of which some may improve while others may not. While introducing a digital system, the inclusion that we aim for may not be achieved. As digital systems need knowledge to operate, instead of including, it may exclude less skilled manpower or they may not become competitive which in turn may increase the social gaps. Similarly, most of the rural areas in the country do not have access to internet facilities enough to support such new technologies which again makes the urban areas and farmers/producers there more privileged. Small-scale producers may not be able to invest in advanced digital technologies which again results in disturbance in the economy and price dispersion. And even after going digital, still, there isa lot of work that has to be done manually like the decision-making process which is vital.

While we get to know about some possible problems that we may face, there isroom for improvement and prevention. Inclusive packages should be brought by the Government of Nepal that may include policy reforms, skill development training, workshops to teach technologies, and extension programs including knowledge about a new system. Internet facilities should be made available in rural areas too and while we develop easy internet, SMS facilities may be alternative to include farmers from rural areas. To make the system more effective, reforms in policies and legislation according to the need of the time is equally important.

To sum up, there is a need of digitalizing the seed sector, taking in account the limitations that it may come with. As the productivity of crops is largely varied by the use of quality seeds at right time, it is important that farmers get access to it and it is more important for farmers to be secured in the field which can be ensured more by going digital. With all areas covered up, digitalization in the seed sector in a country like ours will turn out to be effective and promising for improving the overall yields and seed business in the country.

9. DIGITALIZATION OF SEED SYSTEM

While working toward solving the gap between supply and demand in the Odisha state seed system, the International Rice Research Institute (IRRI) has developed a digital tool “SeedCast” through deliberation with the Odisha state seed corporation (OSSC) and Government of Odisha. This comprised pre-registered network users who represented more than 3,500 retailers (seed dealers) of the entire state. “SeedCast- a customized version for the region, is an information and communications technology-based solution that combines a mobile application (or app) and a web portal. This supports seed demand estimation in a very dynamic, updated and real-time manner across seasons. The key users of these apps are seed dealers, village agriculture workers (VAWs) and farmers. The dealers and VAWs, once registered through the app, can raise their product demand estimates. Passing through several automated and digitized fast review systems, the demand reports generated serve as critical market information and a decision-support tool for the institutions that are responsible for seed production, provisioning or distribution. Primarily aimed at leading public seed institutions, the demand reports help them in producing, procuring and supplying seeds of farmers’ choice and get collated through the most connected ground agents, such as dealers and VAWs” [30]. “Farmers using the app have access to critical information, such as varietal profiles and varietal selection options for their farms, as well as stock or supply information for the varieties available in the state. Initially, including all key varieties in the state, this app can be expanded to include newer products as they come in. It also can include multiple crops and their varieties. It is intended to help the seed suppliers (Odisha state seed corporation) to plan their production, inventory management as well marketing or distribution patterns well in an advanced and in a more targeted manner. These reports are envisaged to act as decision-making tool for getting the right product to the right markets. These reports also can be used to help state policy makers to notice and decide on investment patterns around multiple agriculture, especially varietal promotion programs driven by client needs and choices for better adoption and impact" [30].

10. DATA ANALYTICS

The storage capacity of a traditional database system is insufficient for data collection. The end-to-end IoT platform and cloud-based data storage are crucial components of the smart agriculture system. In the IoT world, sensors are the main means of gathering data on a massive scale for storage and processing platforms in the seed production area. Using analytics technologies, the data is analyzed and converted into useful information. The analysis of weather, soil and crop conditions is made easier with the aid of data analytics. By utilizing the gathered data and technological advancements, better decisions may be made. We can obtain information on the status of the crops in real time by using IoT devices to collect data from sensors. With the aid of predictive analytics, we can get knowledge to improve harvesting-related decisions. IoT has aided the seed sector in maintaining crop quality and soil fertility, which has improved product volume and quality [31].

11. CONCLUSION

Due to lack of constant and reliable communication network infrastructure, an IoT and ML face implementation challenges in seed sectors placed in remote or less developed regions. But many network providers are making it possible by introducing satellite connectivity and expanding cellular networks. Particularly, seed growers and farmers need to utilize information and communication technology for all stages of seed production, including post-harvest storage, processing, sales, and certification to produce high quality seeds. Machine learning benefits seed growers at every stage including soil management, crop management, disease detection etc. The use of Internet of Things (IoT) applications with remote sensors such as temperature, humidity, soil moisture, water level sensors, and pH value will give an idea of automation in seed sowing, seedling development, and yield, which displays precision as well as practical utility to cope with difficulties in the field. In order to bypass out-growers, distributors, wholesalers, or retailers and to supply high-quality seeds directly to farmers and seed producers, the system is also capable of managing a blockchain-based seed distribution system as well as sale of seeds by the farmers in online portal.Data generated by various sensors are of paramount importance and require to be managed and analyzed using machine learning and deep learning-based approaches to foresee upcoming challenges in farming practices. As a result of seamless end-to-end intelligent operations and improved business process execution, quality seed is processed faster and reaches farmers' fields in the shortest possible time so that farmers can make use of the monsoon.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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