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Chapter 12: Future perspectives on the integration of digital technologies in Agritech

12.1. Introduction to Agritech

Agritech is a collective term for those technologies and innovations related to functionally specialized to improve the quality of the act of raising animals and growing plants. As the interest in Agritech is accelerated due to shifting world demographics to urban farming, the increasing necessity of closed loop ecosystems to reduce the risk of potassium and phosphate depletion, more economically viable sustainable agriculture, climate change mitigation, food distribution networks powered by sensor technologies to solve the carbon footprint issue, as well as vertical agriculture systems to make use of the vast building footprint that cities provide, we see the merging of themselves into a variety of disciplines addressing these challenges including genetics, food science, synthetic biology that are revolutionizing the very idea of food and food grown from the soil, precision farming or modern agriculture progressively replacing old-world heavy and expensive ag equipment, renewable energy sources to power closed loop ecosystems, advanced materials for paperbased biodegradable integrated circuits for affordable and easy to manufacture sensors, robotics and machine learning, storage technologies to reduce and better plan the cold chain (Kamilaris & Prenafeta-Boldú, 2018; Liakos et al., 2018; Kamilaris & Prenafeta-Boldú, 2019).

Despite being considered a traditional industry dealing with stable practices over hundreds of years, Agritech is providing some of the most interesting coverage as both society and technology mature towards making the term sustainable a tangible reality. The convergence of a new generation of startups, researchers leveraging the new technological fabric that is becoming mostly available combined with changing businesses and practices provide radically new perspectives as the impact of Climate Change is both real and taking place now, thus challenging the current model of extravagance and excess and its large negative externality on the environment as well as food shortages. In this chapter, we present an overview of Agritech, some stimulating questions, an encompassing outline of all aspects of Agritech, some illustrative examples, and point toward new directions and open questions, exploring subsequently the technologies, the business aspects, and the relationships within (Tzounis et al., 2017; Wolfert et al., 2017).

12.1.1. Overview of Agritech Fundamentals

Agritech, also known as agricultural technology or agtech, refers to a wide range of activities, including science, engineering, information technology, and economic activities. The objective of these activities is to identify, evaluate, and solve problems associated with agriculture. Specific activities in the domain of agtech are characterized by the application of a series of converging digital technologies, such as the Internet of Things, big data, artificial intelligence, blockchain, autonomous machines, drones, robots, sensor-related technologies, augmented and virtual reality, and so on. The integration of these technologies in the whole value chain of agricultural production can contribute to tackling crucial problems associated with modern agriculture, such as the need to increase and maximize production yield with lower inputs while protecting the environment and natural resources, and ensuring food quality and safety.

The global agricultural industry, particularly commercial agribusiness, is probably one of the oldest ones in the world, but digital technology has largely been absent from this industry, until recent times. Agriculture has largely followed the principles of mechanization, introduced in the 18th and 19th centuries, for its development and modernization. The introduction of digital technologies in agriculture is therefore a relatively recent phenomenon, and binding on the historic evolution of both digital technologies and the agricultural industry, focused mainly on areas such as the mechanization of production, and chemical, biotechnological, and demographic issues. The potential of agtech to transform existing agricultural production processes is huge, however, both in terms of increasing efficiency and productivity, and in terms of sustainable development.

12.2. Current State of Digital Technologies in Agriculture

The deployment of digital technologies in agriculture is already today transforming the industry around the globe and will play a crucial role in tackling the daunting challenges of our time such as climate change, food security for a growing world population with rising diets, and the socio-economic welfare of both farmers and rural communities. Corporate and institutional investments into digital solutions, new product offerings and partnerships in the agritech sector are growing rapidly. However, the majority of farmers have not yet adopted available data platforms to their full extent to increase productivity and mitigate environmental impacts dynamically.

The increasing availability of low-cost devices to monitor soil, water, and crops by using smart and drone-based sensing technologies and satellite imagery is a strong driver of soil and crop health monitoring in precision agriculture applications today, especially in developed countries. Significantly enhancing data foundation and toolkits for data analytics offer semiconductor, communication, and sensor companies, AI and monitoring software developers. On the other hand, it is not easy to be successful with the rollout of data platforms to be developed, provided that aggregate data is available from farmers who apprehend remote sensing with their privacy loss, concerns related to reliability risk, as well as commercial exploitation risks. Additionally, precision agriculture tools do not solve the underlying challenges of macro-scale soil and natural resource degradation. Therefore, advanced tools should be implemented alongside larger programs to collectively transition farming to regenerative and precision techniques while at the same time enhancing the return on investment for the developments of all agricultural stakeholders involved.

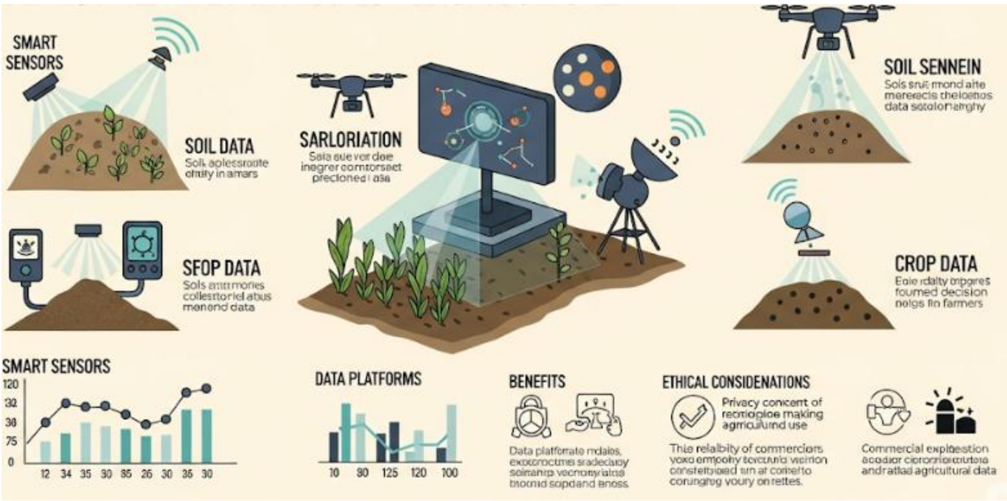

Fig 12 . 1 : Digital Agriculture: Transforming the Fields

12.2.1. Current Digital Landscape in Agriculture

The transformation driven by digitalization is revealing how far agriculture can be from the average economy in terms of technology adoption. The penetration of digital is still small today, but it typically runs at ever-increasing and accelerating speeds. As digital technologies contribute to process reengineering, they are increasingly applied to activities traditionally considered the forte of the ingenuity of human beings such as precision farming, pest and disease predictions, data collection, analysis and prediction, knowledge sharing, trust building, and labor recruiting. These applications of digital technologies may be developed directly by farmers or, more often than not, they are set by innovative start-ups or incumbent companies, which together with large customers, such as agrifood multinationals and supermarket chains, act as ecosystem orchestrators.

Yet, why are the results of digital technologies still disappointing? The availability and the potential power of digital tools depend on what cloud computing brings to the industry: a nearly limitless computing capacity; data-analyzing algorithms, using machine learning technology, that astonish observers with their ability to predict; data sharing capabilities afforded by the platform economy, which allow easy data gathering from thousands of users and machine-to-machine exchanges with machinery operated in the field; and the rapid decline in tools' prices, which allows farmers to save on investments in new hardware and software in the years to come. However, what renders the impact of digital technologies so frustrating is that many activities and processes in agriculture are difficult to standardize or pool on platforms as a result of distinctive localized natural factors or the personalized skills of the farmers.

Digital technologies promise the delivery of more precise answers to production needs, data that are more accurate in regard to what needs to be done or in what time, and plant disease and pest forecasts that are more correct. But farmers are often disappointed by the poor precision of the algorithms they use. Some respond to these signals by abandoning the technology and returning to judgment-based actions.

12.3. Emerging Digital Technologies

The contributions of digital technologies to the transformation of the agricultural sector are myriad, and with the continuous advancements in technologies the future of agri-tech sector also looks promising. The sophisticated digital technologies, in synergistic combination, are capable of solving many of the uncertainties, complexities, scale or performance challenges faced by agriculture. The latest advancements in the digital technologies such as artificial intelligence and machine learning, big data analytics, the internet of things, blockchain technology, high-speed communication networks, robotics and autonomous systems, nanotechnology, remote sensors, satellites, unmanned aerial vehicles, gene-editing tools, and synthetic biology can be leveraged to further reinvent agri-tech.

Artificial intelligence is one of the most revolutionary technologies of the time. It has enormous potential to resolve numerous issues in agriculture. The development of AI in the 20th century has been marked by many milestones and breakthroughs. AI comprises a group of transformative technologies that could enable computers to behave more intelligently like humans, which include machine learning and deep learning. AI is one of the few technologies that could resolve scale challenges in agriculture, especially for countries where millions of small farms form the backbone of agriculture. AI finds application in smart crop protection, automated machinery, and smart irrigation systems and resources management. The continued enhancements in AI are expected to improve the computer learning algorithms, resulting in better productivity, faster and more accurate data processing, availability of predictive and prescriptive analytics for the agri-tech companies.

The agriculture ecosystem is increasingly becoming highly digitized, whereby multiple entities are generating enormous amounts of data. An average farm is expected to produce over 1.2 million gigabytes of data every year. Data generated can vary widely in terms of origin, form, and volume. The use of different devices such as robots, automated tractors, drones, satellites, and cameras for data collection and the growing investments in the precision agriculture software and hardware by various market players are enabling agricultural data generation at scale. Farmers, food processors, and companies are collecting and generating different types of data for diverse purposes. As the demand for agricultural produce is expected to grow, managing this farm-generated data and utilizing it in the right manner will become essential to achieving better productivity and sustainable farming. Big data analytics presents immense opportunities for modern agriculture, with data-driven predictive and prescriptive analytics expected to help farmers produce more with minimal adverse impact on the environment.

12.3.1. Artificial Intelligence

Artificial Intelligence (AI) is on the verge of making significant inroads into the global agricultural industry with optimism. It is already being put to use to make smart-seeding sustainable, smart-irrigate, crop-health monitoring, climate prediction, and yield prediction. In the future, AI will be applied to various agrarian exercises/data from various places at various times such as smart-farming, rotational grazing, precision-beef, and precision-dairy systems to increase the industry's adaptability and resiliency. Even farming system modeling is being influenced by AI. AI anticipates that it will increasingly disrupt the farming and distribution of foods sectors in the future. Some people think that an incredible amount of data generated on many different aspects of food security will allow AI algorithms to contribute to managing what has become an increasingly globalized food supply system.

There appears to be broad consensus that food security, climate change mitigation, and adaptation to climate change are key priority areas for future developments in the application of AI for the agrifood sector. These issues include how to increase agricultural production to meet a still-growing population while reducing agriculture's environmental footprint. It is generally accepted that achieving these objectives will require the innovative and strategic use of new technologies. An important part of this process, and the focus of this paper, is the role of AI applied to agriculture, especially as it relates to climate change and how to meet future demands for food more sustainably and with fewer external input.

12.3.2. Big Data Analytics

Advancements in technology, such as the Internet of Things (IoT), have made it possible to collect large amounts of data on agricultural operations. This data, often referred to as "big data," can include information on things like soil composition, animal health, market conditions, labor management, and climate conditions. We argue for the need for big data analytics in agritech. We emphasize that this data will not be valuable unless data collection and usage is managed with a strategy in place. These strategies can include local data ownership and control along with data sharing and collaboration protocols and enable sustainable and responsible data management. These criteria are needed if the objective of agritech is equitable solutions that benefit all players in the agritech ecosystem, and that do not simply become new ways to extract value from agricultural and rural communities. We raise other questions while also providing examples of successful agritech solutions. Big Data refers to data that is too large, fast, or complex to be handled by conventional data-management tools within a given timeframe, e.g., the 3 Vs: Volume, Velocity, Variety, Viscosity, Variability, and Complexity.

Big Data analytics is the process of examining large datasets containing a variety of data types to uncover hidden patterns, unknown correlations, and other valuable business information. Big Data analytics can allow various technology and business elements to be integrated to generate new value. Because of the number of people employed in traditional agriculture, and because of its economic significance in developing countries, Agri-tech stakeholders, particularly policymakers and R&D institutions, face challenges associated with Big Data in Agriculture. Further, big data analytics bring together various technology and business methods in collaborations together with analytics that can change agriculture in multiple ways.

12.3.3. Internet of Things (IoT)

It is forecast that there will be more than 64 billion connected IoT devices by the year 2026. The rise of the IoT-based smart agriculture tools in the market enables the collection of massive amounts of data about crops, soil, and the surrounding environmental conditions. Thanks to edge computing technology, data can be processed in real-time locally in the devices without having to transfer to the cloud. These smart devices bring new dimensions to what and how these types of data are collected. Comparison to previous types of agricultural tools with sensors and cameras neither connected nor autonomous, these smart devices are capable of collecting data continuously, autonomously, and in real-time. The new dimensions of the data help the agriculture stakeholders enhance and speed up research that requires the data to be collected in high temporal and spatial resolution with high accuracy and reliability. With the foundation of the high quality of data collected from IoT devices and new potentiality, advances of new technologies to process these types of data including big data analytics, artificial intelligence, and geospatial technology will in turn help the IoT devices become more sophisticated with machine learning techniques. IoT devices play an important role in fostering sustainable agriculture. As IoT devices allow collecting data in high spatiotemporal resolution, the sustainability of agriculture will be improved through better decision-making of the stakeholders from the data collected. Smart decision-making on the farming practices such as irrigation management, fertilizer management, pesticide management, and harvest time management guided by data from smart devices will help reduce greenhouse gas emissions, water usage, and the uses of chemical fertilizers or pesticides while increasing crop yields and increasing the ability to adapt to climate change conditions.

12.3.4. Blockchain Technology

The integration of emerging digital technologies into modern agriculture allows for the transition towards precision smart agriculture integrated with more efficiency, sustainability, and resilience. Blockchain is an open distributed ledger comprising blocks of data that provides unique advantages in ensuring transparency and traceability of transactions while protecting unauthorized access and data manipulation. Blockchain technology provides secure and transparent storage for a variety of data products like sensors data, data analytics models, and farm management and production and commodity data. Blockchain technology comes along with the token economy that allows microtransactions through digital tokens that can stimulate farmers' engagement in the introduction of more sustainable methods of agriculture.

With proper design for incentives and rewards, blockchain technology can be integrated along with Internet of Things technologies for the purpose of strengthening resilience of smart agriculture against shocks, and disease outbreaks. Building an integrated architecture for the credit system and safety net using these technologies can both stimulate farm production and create a safety net for farmers. Moreover, blockchain technology adds resilience, sustainability, and safety to food systems around the globe by generating trust and cooperation between the various value chain actors thanks to the storage of immutable data about the traceability of agricultural commodities and food products along the supply chain. This type of integration of digital technologies allows for the protection of both consumers' health and farmers' income: the blockchain implementation will protect consumers against health consequences associated with food fraud while the proper use of funds allows farmers to either achieve some of their development goals or provide some emergency support.

12.4. Impact of Digital Technologies on Crop Management

Advances in sensor technology, communications, and computing are used to enhance farm efficiencies, resulting in a rapid growth in the application of digital technologies in agriculture. The ability to collect and utilize real-time data to inform and direct management practices is the foundation of a concept called precision agriculture. Precision agriculture uses technology in crop production, including sensors to monitor soils, crops, and pests; GPS to enable accurate data and map layering; and application equipment calibrated to apply or treat variable areas within a field. Instead of applying fertilizer and chemicals on a whole-field basis, unique fertilizer and chemical treatments can be applied to local areas of a field. This technology relies on the generation and variable-treatment of maps by overlaying different spatial and temporal data sources. Data used in this process includes yield monitor maps, terrain, soil service maps, aerial photographs, and block and field history maps. The use of yield monitors has accelerated the production of yield maps. Yield monitors were the first widely adopted technology utilized in precision agriculture.

In-Field Sensors can be added to tillage, planting, and agricultural machines and operate as part of the larger farm information system. These sensors can be used to make immediate management decisions or can be incorporated into management systems and algorithms to store and analyze data. Specified data about a specific field can push recommendations back to the field for use in making instant decisions that affect management practices, or the data can be stored for later analysis and decision making to affect subsequent applications of inputs. Yield monitors installed on combines can provide real-time yield estimates, allowing for immediate decisions about subsequent field operations.

12.4.1. Precision Agriculture

Precision agriculture originated from the need for more sustainable agricultural production processes meeting the needs for feeding an increasing world population in harmony with the environment. Precision farming allows the acquisition and integration of site-specific characteristics and data on crop-growing conditions and crop–soil–climate interactions during crop physiology in order to optimise input management. With the adoption of GPS supported guidance in agriculture, the process of site-specific data acquisition and integration was facilitated at lower costs. Recently, the era of large data has arrived, when large amounts of heterogeneous data on production processes, climatic variables, satellite images, etc. are available at a relatively low cost. Also, the development of low-cost ground-level sensor systems or UAV-based remote-sensing systems permits the detailed micro-scale investigation of crop traits and parameters.

The aim of precision agriculture is to develop site-specific crop management practices incorporating farmers' knowledge and recently developed advanced technologies derived from '-omics' technologies and remote-sensing techniques. The Hierarchical Modeling of Data was proposed to understand the relations of processes occurring at different scales such as climatic variables influencing background functions, site-specific characteristics of soil such as microbial biomass and its enzymatic activities, crop–soil–climate interactions during plant growth at different growth stages, and dynamics of crop traits as predicted by network modelling using recently developed information-based Index/Co-Index method-tools.

12.4.2. Remote Sensing

Remote sensing is widely regarded as one of the significant breakthroughs in precision agriculture, having greatly enhanced the capacity of farmers to make timely agronomic decisions. This technology preserves the capacity for a quick overview of a large area while simultaneously improving the capacity to manage heterogeneous areas at the within-field level. Remote sensing allows one to track developments in the needs of crops on a daily basis using a variety of sensors, from well-established ones, which operate in the optical and infrared spectra, to new microsatellites with multispectral sensors, including new and emerging small satellite constellations, drones with remote sensors attached, and next-generation commercial satellites. These sensors cover longer and shorter spatial scales: from approximately 30 meters, which is typically the best available with established remote sensing systems, down to 1-meter resolution or even submeter capabilities using UAVs.

Remote sensing is one of the more prominent precision agricultural technologies that are acquiring increased visibility and importance, contributing to the new phase of technology-led agricultural development in the future. Remote sensing differs from physical site-based sensing in two important ways. First, most importantly, the technology permits both large-scale coverage and visualizing land use dynamics through time rapidly. Second, it allows the collection of repeated time series data on a given location or land use. Through continuous image data covering regions over time, remote sensing allows significant expansion to revisions of regional and global crop forecasts as well as improved construction of simulation models for crops and land resources.

12.5. Digital Technologies in Livestock Management

Traditional livestock production systems may provide a wide variety of food products. Nevertheless, these systems are often resource intensive, resulting in a high environmental impact. Digital technologies can facilitate animal monitoring, optimizing nutrition and waste management, while enhancing animal welfare and improving biosecurity. These could be considered as "clever" solutions and could develop new agrifood business models, such as alternative proteins from cells. These aspects are compounded by a growing global demand for food products of exceeding quality and safety standards. Animal husbandry is considered one of the most resource-consuming sectors of the entire food system. Digital technologies have emerged in agrifood systems that have the potential to increase the sustainability of animal agriculture.

The impact of digital technologies on the improvement of productivity and efficiency as well as the monitoring and improvement of animal health has been modest to date. The adoption of digital technologies in animal husbandry is related to specific characteristics of the sector, such as vertical integration of the production chains, economies of scale, and concentration of decision-making in a small number of companies. The functions supported by these available technologies and solutions and the potential of these technologies to contribute to the main technology challenges are presented. By this mean the chapter will frame and structure the discussion along three main enabling domains: wireless communications, sensor networks, and genomics. In doing so, it underlines both areas of maturity and technical gaps too, identifying thus a roadmap of challenges and opportunities.

12.5.1. Wearable Devices

Livestock farming is a practice as ancient as humanity itself. Initially, animals had no clear owner but favoured the fields and deposits of cereals and legal tender created by humans to barter with other groups. The desire of some farmers for an easier and less risky life was the origin of the domestication of wolves as scavengers of the food scraps of men and their herds. Wolves then underwent generations of selection that allowed them to coexist with people, creating a bond that eventually led to their transformation into an ancestral type of dogs. From the desire to obtain tender meat without the risks involved in hunting large mammals, either the natural selection of those who were less skittish, which made it easier for hunters to approach, or the search for a less fearful type of ancestors of current wild boars was initiated. It is often said that agriculture allowed humanity to move from a nomadic way of life to a sedentary one; however, this would not have been possible without the domestication of some mammals and birds for meat production but, above all, for milk and eggs, which allowed our ancestors to have an energy intake all year round while their plants matured.

Historically, livestock farming has been somewhat hit-and-miss, with disorders in animals that manifest themselves in clinical cases dictated mainly by the lack of specialists or poor detection of pathologies when present. Veterinarians have been responsible for interpreting the symptoms presented by animals and establishing a diagnosis of the ailing individual or group of animals. In the last decade, there have been numerous technological advances in the study of animal health and welfare that make it possible to have numerous variables that can serve as physical indicators of such welfare, which allow auto-diagnosis, preferring prevention to cure. Wearable devices for livestock usage allow to automatize data collection and analysis from animals in a continuous way in real-time, freeing the farmers from collecting information manually from the animals, helping to increase their productivity by improving the efficiency of their farms, providing them also with an early warning system for possible incipient pathologies.

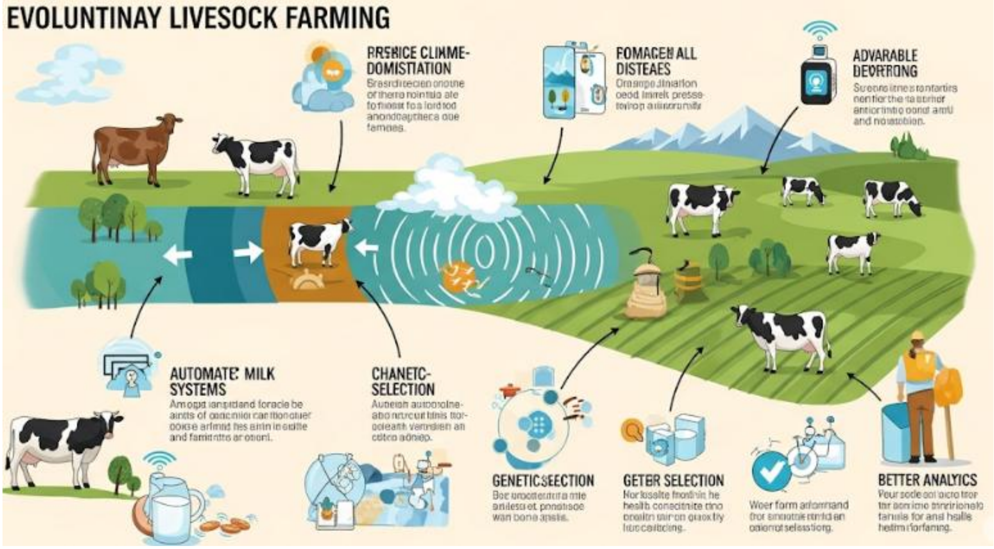

Fig 12 . 2 : The Evolution of Livestock Farming

12.5.2. Genomic Technologies

Genomic technology refers to DNA- and RNA-based technologies, where states and levels of their expressions (genomes, transcriptomes), function (epigenomes), or structure (chromosomes) are the subjects. In this case, genomic technology allows to check the genetic predisposition of the living organism for the given phenotypes. Genomic predictive ability can be utilized on different levels: in population selection, as a prediction of the genetic predisposition on the level of the individual; for biological research, as prediction of mutations associated with a given function or phenotype in a given population.

From up to middle 2010s, there were two types of genomic phenotype prediction tools on the market: array-based and sequencing-based genotyping tools. The throughput and costs for genotyping were significantly improved due to the next-generation sequencing technology. For example, to date, genotype information for single-nucleotide polymorphisms is available due to sequencing of more than one hundred bovine individuals.

Traditionally, SNP genotyping is used for many applications. The need for individual SNP assays for validation is still there; however, it is not such a limitation as it was in up to the mid-2010s. The challenges to commercial Bovine SNP array-based genotyping tools include sequencing based, imputed, and reduced-representation whole-genome SNP genotype arrays. The imputation activity is geared toward improving accuracy of either chip or sequencing tools. Interpretive application needs and accessibility have grown with the availability of the low-to-mid dosages of polymorphisms in gene-rich regions, more types of variant data, and diverse populations/chip designs and user-friendly tools from outside commercial service organizations.

12.6. Sustainability and Digital Innovations

One of the key aims of digitalization in agriculture is to enhance productivity and to produce more from the same amount of land and resources. This is particularly important in light of the growing food demand, as Europe and the rest of the world have to produce 70% more food by 2050. However, in addition to increased agricultural productivity, digital innovations also need to improve the sustainability of agriculture. This trend is particularly prevalent among a growing number of technology-seeking consumers, who are more willing to switch brands based on their values and attitudes toward the brand. Environmental sustainability is seen as one of farmers' most important concerns. Digitalization may help to address these challenges by providing farmers and other food system actors with ways to measure the impact of their actions on different aspects of sustainability, optimize the use of different resources to minimize the environmental impact, or choose from a range of alternative practices that have a lower negative impact on climate change and other aspects of sustainability. The digital technologies increasing the efficiency of agricultural resource use include a range of precision agriculture technologies, precision farming applications, and farm management decision support systems. Internet-connected sensors can help farmers optimize their use of water and other resources by providing real time information on weather, disease outbreaks, soil and crop-related data, as well as the status of equipment or machinery likely to malfunction. Farmers can also use decision support systems to make better choices compared to traditional farming decisions based on heuristics or "rules of thumb." Precision agriculture innovations also help farmers manage animal welfare better by enabling animal health surveillance, monitoring, and diagnostic systems, as well as animal tracking technologies that may allow early detection of disease onset.

12.6.1. Resource Efficiency

In globalization’s technological progress, productivity is key for economic development. In response to multiplying pressures from markets, society, and regulators towards uplifting or maintaining standards in sustainable practices, firms have opted for digital innovation. In most cases, this is to reduce environmental impact. Digital improvement increases efficiency across different value-generation processes including logistics, production, and product monitoring through predictive maintenance, smart enabling systems, and analytics. These sophisticated data technologies have the potential to make resource and energy use extremely efficient. With that, they may substantially reduce the impact of business operations as well as the greater economy on climate change and environmental degradation.

Electronics development, design, and manufacturing, through innovations in devices, are accelerating changes towards a new circular electronic economy where material resource recovery is pursued. With its business models, the impact of different technologies on global supply and resource disturbance is being tackled making the development of consumer electronics more efficient in all aspects including energy use and supply of rare and composite materials. Decision support technology is being developed to enhance the fulfillment of companies’ renewed corporate responsibilities by embedding sustainability-driven decision criteria into qualitative analytics for sustainable product and service innovation. Furthermore, design solutions are shifted from incurring energy during product use only to optimizing overall product lifecycle energy use, from production through use to end-of-life. Going even further, digital technologies may influence product design consideration in the more distant future including the hybridization of product lifecycle energy use through the combination of sustained product energy consumption and local energy generation.

12.6.2. Waste Reduction

Waste generation is pervasive in every stage of the supply chain for agribusiness. Therefore, agribusiness has to explore smart strategies to reduce overall waste generation otherwise they will not achieve economic and environmental sustainability. In the field of digital technologies, the Internet of Things technologies, especially related to tracking and monitoring, are paving the way to tackle inefficiencies and help agribusiness reduce waste. For instance, the introduction of RFID tags in the logistics of perishable products is a clear application to minimize the spoilage at this stage of the supply chain. Other examples include predictive analytics to improve inventory management at distribution and retail levels.

Concretely, the adoption of IoT solutions at a global scale enables real-time visibility of resource flows throughout the supply chain. These applications increase the alignment between supply and demand hence helping agribusiness reduce the amount of surplus that has no demand. B2B solutions include enhanced visibility for transporters regarding the throughput of other transporters, which reduces the chances of surplus for perishable food. B2B applications also are being developed to coordinate retailers' actions. On the contrary, B2C solutions aim to transfer responsibility to customers through optimal interface design and incentives to facilitate their monitoring over their own consumption. Users are encouraged to disclose their food preferences, allowing retailers to adjust and optimize production, hence decreasing food waste.

12.7. Challenges in Implementing Digital Technologies

Digital technology integration in agriculture has become increasingly critical for future food security. However, challenges remain, particularly for developing nations. Despite a generally favorable attitude toward digital tools across countries, sectors, and demographics, adoption didn't follow due to numerous inhibiting factors. Novel technologies have significant market-entry costs and time frames of return on investment that prevent adoption. Governments and financial organizations can alleviate these costs through financial instruments that encourage early adopters of these technologies. Another barrier mentioned is that governments do not commit to investment in digital infrastructure.

A resounding call for investment in ag-specific digital infrastructure to enable future novel technology integration in the agri-food sector is reported, below balance targets at farm and field scales of existing digital technologies with support for innovative tools. We conclude, summarizing the discussion, by emphasizing the need for technological specialists and interdisciplinary groups composed of agronomists, data scientists, economists, and implementing communities to jointly work on tools that fit the economic, environmental, and social criteria of farmers. Lack of adequate infrastructure is a barrier that is common to more widespread challenges associated with technology integration. Although demands for digital resources are high, available resources are not set up adequately for the needs of farmers and integrated across diverse geographic areas or horizon work that spans more than one growing season. Data privacy concerns are expressed as barriers to active participation, especially for market-oriented farmers.

They mention unease in exposing information to local experts or policymakers on production decisions or possible crop damages due to adverse weather events, risking their market positioning and delaying accurate use of valuable local-specific data. The discussion on these barriers should be kept as general and not too influenced by the positioning of individual advantages advocated by a single stakeholder or another.

12.7.1. Infrastructure Barriers

Although digital technology can play a pivotal role in moving agritech towards Industry 4.0, the burden of legacy supply chains may become a major barrier to its effective uptake. Physical infrastructure in rural areas where most agriculture is conducted is generally poorly developed compared to urban spaces; broadband internet and reliable electricity are indispensable to successful implementation of the digital technologies. It is recognised that deployment of sensors, drones, harvesters and other robotic technology for food production processes rely on constant and uninterrupted internet connectivity. Unlike urban spaces that have moved ahead with private sector investments, rural areas have traditionally relied on governments to invest in broadband internet connections which has proven challenging.

Electricity shortages cripple efforts to introduce modern agritech solutions in rural areas. These shortages, which are widely common globally, are more profound during periods of crop production, creating bottlenecks especially in the uptake of mechanization and adoption of AI-based solutions applied to automate certain manual processes such as crop harvesting. The urgency of the electricity shortages varies according to the uniqueness of country. For example, in India, while the states of Punjab and Haryana are likely to witness massive losses to the wheat harvest crop claimed to be by a manpower shortage exacerbated by police action following social unrest, it is in West Bengal that millions of tonnes of paddy still remain unharvested.

12.7.2. Data Privacy Concerns

Despite the substantial benefits presented by digital technology integration in agritech, data privacy concerns represent one of the most significant factors affecting farmers' willingness to participate in digital farms or precision machineries. Technology can provide useful advice and intelligence, but these are usually based on sensitive data, especially in variable rate applications, particularly when prescriptions are generated and applied remotely. Farmers are rightfully concerned about what happens to their data once they commit their information. For instance, how is it protected by companies? And will their data become a commodity used to create systems that might harm their businesses? A lack of interest by agrifood and service suppliers to establish long-term data sharing and data use agreements with the farming community is a barrier to farmers' acceptance of digital technology and precision ag. In this regard, farmers are stressed and anxious about unforeseen changes to their private data, especially regarding the dreaded sale of their private data to operators.

Given the current state of agricultural data privacy legislation, it is widely accepted that farmers now carry most of the risk associated with data misuse, and some feel that their only recourse is to either refuse to give consent for data collection or refuse to engage in data-rich activities altogether. Farmers prefer a model where they are compensated upfront for their data. Understanding the possible uses and collection of both farmers' production data and the already available large underlying datasets that describe some aspects of specific regions is essential for farmers so they can modify and validate some of their perspectives regarding agronomics digitalization and big data use. Subsistence to common clarification about what exactly goes on with their data is probably for farmers a better alternative since big data use and data sharing as a commodity will only become more common in the immediate agricultural future. A balance needs to be struck between farmers' willingness to share data with the industry and the industry's desire for access to data assets, as both parties will need to benefit from the process.

12.8. Future Trends in Agritech

Agriculture is changing nowadays, incorporating many of the processes and developments on technology from other sectors. The agritech sector, focusing on the use of technology to drive and or accelerate agricultural production processes is rapidly becoming a high-demand field, incorporating from AI, UAV, and robotics systems, to the use of blockchain and smart contracts for managing land sharing, crop sharing, and product tracking and distribution. Autonomous farming promises to incorporate a variety of technology to not only reduce the manpower required to produce food but increase the safety, efficiency, and availability of the resources needed for these production processes. Autonomous tractors, drones for crop monitoring, spraying, monitoring for pests, integrated systems using ML and AI for tracking and anticipating the food supply process and meeting demand fluctuations, and maximizing production efficiency are but a few of the autonomous farming solutions being developed. These solutions, when integrated with autonomous harvesting systems can change drastically the food production systems we now think of as normal. Vertical farming revolves around concepts used in biology and hydroponics, optimizing the use of space and environmental conditions to maximize crop growths. This optimization can also be achieved by using integrated monitoring and management systems based on AI and IoT devices, controlling and monitoring the conditions required to maximize output while also limiting negative impacts on the environment, such as chemical or energy waste.

Many of the concepts and ideas seen in other sectors of the economy and business are now making their way to agritech. The rapid pace of these changes is not only due to the increasing demand for better and more efficient use of resources and for food but also the current, alarming state of the environment. The optimization of resource utilization, such as water and chemical consumption, energy use, and carbon footprint generation, are all issues that are also being addressed. Circular economy is a major paradigm shift that is being introduced in the agritech sector, changing concepts of supply and demand around business processes, and favoring internal cyclical processes that allow industries to limit waste generation and develop secondary production processes that reuse the waste generated.

12.8.1. Autonomous Farming

A common and rapidly growing trend in the treatment of work in almost every sector is toward the automation of processes: a shift from manual or remote control to the use of technician labor to program, install, test, set, and maintain automated flows. Agritech is going the same way, which means there will be an increase in automated and eventually autonomous farming systems. Already now there are numerous types of autonomous devices available and specific types of automation are incorporated in many farm operations, and this is an important part of the development of smart farms. In the future, autonomous farming will offer management systems allowing farms to be fully unattended. Acceptable performance is determined by the needs and interests of the farm managers, who set the economic or performance thresholds. Generally, such an organization of farming with the development of technologies in smart farms will probably result in many operations being just remotely monitored. Work systems which will not adapt or develop along these lines will likely demotivate students to enter the sector or lead them to think that operating farms is not a sustainable medium- to long-term career. Farming automation and the increased use of robotics are necessary second-order scenarios in the development of smart farming and digital farming. Digitalization and platforming will produce a move toward data and information supra-systems on the basis of which technology change and systems to optimize the efficiency and sustainability of farming will be implemented. This process, especially in the development of cleaning and cultivation mechanization in vegetable crops, is liable to mitigate the demand for human labor but also generate dilemmas: reduced employment opportunities in rural areas, less income for laborers in activities, rising farming labor costs that are hard to predict, and accelerated sector consolidation through land accumulation.

12.8.2. Vertical Farming

The urban population is growing faster every day, especially in the developing world; therefore, the allocation of land for agriculture is decreasing. Climate change is already putting stress on certain types of crops in many parts of the world, leading to a hunger crisis in some of them. Vertical farms have proven to be a solution to many of these problems, but technological challenges remain. Vertical farming is a method to grow crops in controlled conditions, indoors or outdoors, using high-rise structures. Vertical farms use the resources at their disposal in a very efficient way. Water is reduced thanks to hydroponic and aeroponic systems, where farmers can recirculate the same water, which also has nutrients, thus avoiding waste.

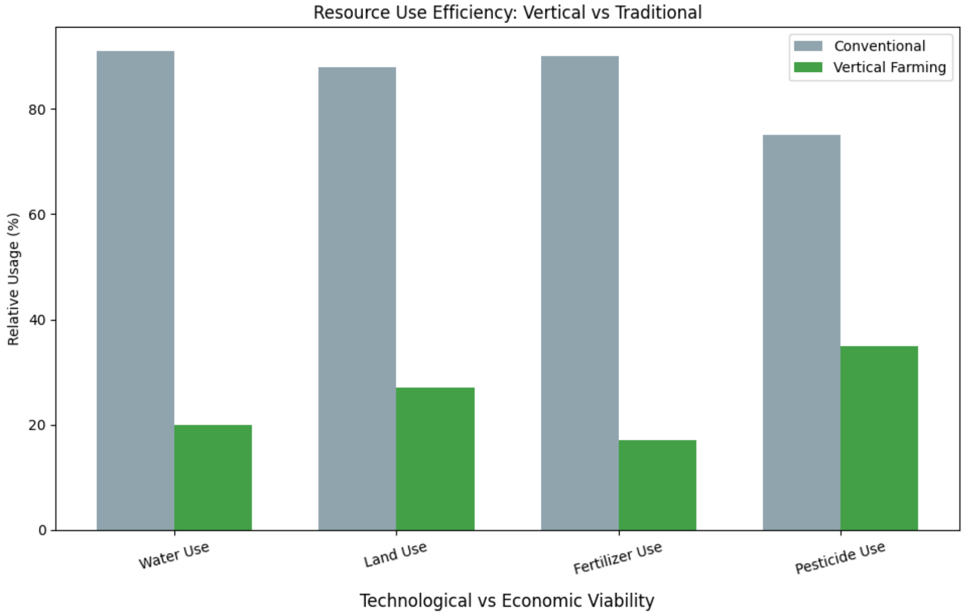

Fig 12 . 3 : Resource Use Efficiency: Vertical vs Traditional

There have been substantial technological developments, but the challenges for vertical farming are mainly of an economic nature. Technical solutions have been proposed to optimize energy and labor consumption. New materials with improved optical and thermal behavior, production systems, and sustainable business models will help reduce costs in vertical farming. Also, growing demand for local fresh produce will boost the market and pave the way to maintaining technological development in the field. The feasibility of vertical farming is based on its efficiency in resource use and its potential to eliminate the dependency on seasonality and weather. Vertical farming can also be the answer to developing food production in space.

In addition, vertical farming is now available in many forms worldwide, from Mega factories to small modular and mobile solutions. Many governments are proposing regulations to make vertical farming a viable alternative, but there are still very important issues to overcome regarding energy consumption and the products' final price to sell. Also, the implementation of new technologies in food production may leave a whole part of the population behind, because of their relation with the artisanal production methods, and make them unfriendly.

12.9. Conclusion

As already highlighted throughout this essay, the fast and furious evolution of science and technology has brought us unparalleled opportunities, as well as challenges, for the near future. The pandemic made crucial the research and development of digital technologies that were mainly absent in the agritech state of the art and markets. The aftershock of this world event set in motion a new wave of investment in the agritech sector and fueled the development, testing, and adoption of digital innovations, with a focus on how they can potentially improve agricultural systems' sustainability and resilience. Tackling one of the most fundamental issues of our world and of our species, namely feeding the increasing population by ensuring food security without hampering the ecosystem to which we depend on for providing the resources by means of which food supplies are generated, this new wave of innovations has been particularly active in the provision of technological solutions for precision agriculture, improved traceability, enhanced supply chain management, and estimated forecasting of extreme weather events.

Looking ahead, it could be possible to continue this narrative of technological and economic convergence across sectors and industries. By looking at other verticals that experienced a higher digitalization and technological integration pace, new technological solutions, and business models could emerge that lower the entry, development, and marketing costs for start-ups, attracting the attention of the incumbents again. Collaborations among different actors of the agriculture value chain, from farmers to agribusinesses, and from technology providers to laboratories, could press forward the research and testing phase, ultimately paving the way for new technological solutions to be implemented in live settings. Further, collective actions toward transparency could boost the ability to collect, assess, and analyze the information flow around an agricultural product all along the supply chain, hence reducing the liability of being a pioneer in the use of new tools and technologies.

12.9.1. Summary and Future Outlook for Agritech Innovations

Digital technologies hold unprecedented potential to transform agritech innovations by increasing efficiencies across the food ecosystem. This space is seeing investments pouring in from a variety of investors – ranging from global agritech leaders to venture capitalists and private equity firms aspiring to build the next big decacorn and billionaire exit through digital disruption. Offering unparalleled ideas and business models, agritech innovations utilizing digital technologies have attracted interest and investments from across sectors be it agricultural implementation, AI-based insights, farmer-centric commerce, or analytics for supply chain and market information, to name a few. Despite challenges in terms of technology adoption at the ground level, venture capital money is betting on agtech ideas to improve this process. As governments, venture capitalists, private equity and global players take positions in the agritech sector, it is poised to usher in the next Green Revolution through disruptive digital technologies.

Digital technologies like Artificial intelligence, Analytics, Blockchain, Big data, Cloud computing, Internet of Things, drones, robotics, and digital payments are enabling the acceleration and enabling of agritech innovations. This paper discusses the implications for these technologies in building innovations across the agritech value chain ecosystem starting from agricultural inputs, implementation, practices, productivity, and farm gate, supply chain, and warehousing for post-harvest management with digital disruption in marketplace access. As the planet moves towards becoming a 10 billion population world by 2050, balancing food security for all is a challenge. It is imperative to leverage the potential of the digital age to evolve holistic agritech solutions to meet this challenge.

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