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APPLIED INFORMATION TECHNOLOGIES IN AGRICULTURE

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Abstract: This paper examines the possibility of transitioning towards sustainable food production, considering the accelerated growth of the world population and increased demand for food on one hand, and the consequences that the previous approach has had on the biosphere and sociosphere at a global level on the other hand. The first part of the paper presents alarming and precise data and facts that require an ultimate paradigm shift, this time based on the most powerful technological and scientific methods and practices to date. The second part establishes the relationships between the concepts of Agricultural Social Network (ASN), Agricultural Value Chain (AVC), new digital technologies and approaches, with the need for transition towards Society 5.0, where a balance between economic progress and a society tailored to human needs is established. In the third part, the technologies on which the new concept of "precision agriculture - PA" relies are identified, and a case study of the Agrosens digital platform is provided as a good practice example to support agricultural producers. Finally, the last part demonstrates, through the concrete example of Project Provenance Ltd., how the application of new technologies can connect processes and actors in Supply Chain Management (SCM) to establish transparency, efficiency, traceability, and other performance measures necessary for effective and responsible SCM. This enables the implementation of corrective actions and measures to promote responsible production, distribution, and consumption of food or other widely used products.

Keywords: food production, agricultural value chain, blockchain, supply chain management, Society 5.0.

Introduction

There is no doubt that today's agriculture cannot feed the population of tomorrow. Predictions suggest that the world's population will increase by 2 billion by 2050, resulting in approximately 9.7 billion people to feed. The increasing demand for food, along with the exploitation of natural resources, changing dietary habits, climate change, biodiversity loss, inadequate management, and competing agricultural systems, are all driving the need for agriculture to find new ways to improve efficiency. In simple terms, agriculture must be sustainable in the face of population growth, social development, industrialization and climate change adaptation. Consequently, new solutions must be sought to optimize and enhance the efficiency of the agricultural and food chain. On the ground, a chain reaction is initiated due to the rising demand for agricultural production. Expanding arable and agricultural land indefinitely to increase yields is not a sensible approach; instead, the focus should be on optimizing efficiency within existing areas. Agricultural practices aimed at boosting yields are often carried out, but they frequently have negative effects. An all-too-common mistake is the excessive or inadequately controlled use of pesticides, herbicides, and other chemical compounds. These substances can directly impact soil quality and the health of consumers through the consumption of contaminated products or polluted water. The consequences extend beyond humans, affecting the entire ecosystem by introducing excess micro and macronutrients that can harm flora and fauna in rivers and lakes. Heavy metal contamination, resulting from pesticides in water from deep wells and industrial sources, poses a significant threat as well. Additionally, agricultural practices also endanger the air. Animal farms contribute substantial amounts of CO2 and methane, two of the three main greenhouse gases, while nitrogen oxides indirectly result from emissions from agricultural land and crop cultivation. Many of these negative environmental impacts can be mitigated through timely information and farmer education. To address these challenges, it is crucial to bridge the gap between science and agriculture by integrating new digital technologies. This integration should aim not only to increase productivity but also to optimize production outcomes, protect the environment, and achieve social justice

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through fair food distribution (Fróna, D., Szenderák, J., Harangi-Rákos, M. 2019). Implementing digital technologies can significantly improve the complex and efficient management of agricultural processes.

Materials and methods

Agriculture plays a crucial role in the global economy as it provides food, raw materials, and employment opportunities. The increasing demand for food, climate change, and the necessity for sustainable agricultural practices involve an ever-growing number of stakeholders, forming a complex Agricultural Social Network (ASN), especially in the wake of the global COVID-19 crisis (Tombe, R.; Smuts, H., 2023). Traditional agricultural production is not economically or ecologically sustainable. Climate change and extreme weather conditions are significant contributors to global hunger and food insecurity. The high volatility of food prices, market manipulation, counterfeiting, and fraud have become prevalent in the liberalized agricultural market over the past decade. Inadequate food supply can lead to riots and social unrest, which not only have economic and social impacts but also raise ethical and political concerns (Fróna, D., Szenderák, J., Harangi-Rákos, M. 2019).

The utilization of advanced digital technologies such as the Internet of Things (IoT), big data, data mining and analytics, systems integration, smart sensors, robotics, ubiquitous connectivity, augmented reality, machine learning, blockchain, and artificial intelligence is revolutionizing the management of food production systems and supply chains in agriculture. This digital transformation enables the seamless flow of information throughout the agricultural value chains (AVC), encompassing farmers-producers, processors, advisory and regulatory services, traders, and consumers (Tombe, R.; Smuts, H., 2023). Digitizing the agricultural value chain (AVC) is crucial in addressing the various challenges associated with managing food systems, from the initial stages of production in the field to the final consumption at the fork.

Due to the factors mentioned above, the management of the agricultural value chain (AVC) faces significant challenges, as does supply chain management (SCM). SCM needs to establish a robust control and management system capable of dealing with supply and demand fluctuations, perishable products, logistical complexities, food fraud (counterfeiting and fraud), and stringent food safety standards. The digitization of AVC can introduce innovative digital systems to enhance productivity, food security, supply chain management, knowledge sharing, and the income of indigenous communities collaborating through different agricultural social networks (ASNs).

The concept of Society 5.0 merges digital technologies with social innovation to foster a human-centered society. Society 5.0 comprises technology, systems, and people, and emphasizes the interactions among these elements to promote the digital economy in the agricultural sector. Society 5.0 envisions a harmonious integration of cyberspace and physical space, aiming to balance economic progress with addressing social issues (Tombe, R.; Smuts, H., 2023) Consequently, to ensure inclusivity and empower individuals and communities through the integration of digital technologies, stakeholders must collaborate and create digital economy solutions that drive sustainable development within the agricultural value chain (AVC).

Digitalization practices and challenges in agriculture

The term commonly used to describe the application of information technologies in agriculture is "precision agriculture" (PA). According to various factors drive or hinder the adoption of digitalization practices in agriculture. These include competitive and contingent factors, socio-demographic factors, and financial resources. Research has shown that key parameters influencing the adoption of digital tools in agriculture are the size of agricultural land and the education level of farmers (Perpaoli et al. 2013). Farmers' education is often linked to their age and their willingness to adopt and trust computerized tools. In practice, the United States of America stands as the global leader in this field, mainly due to significant investments in applied innovation, research, and development at academic and scientific levels. The US has made notable progress, particularly in the concept of carbon farming. This involves implementing well-organized systems that provide subsidies to farmers for employing various techniques to capture CO_2 from the air and store it in the soil. This approach is more advanced compared to the rest of the world. The European Union also has a strategy to reduce greenhouse gas emissions through the Carbon Agriculture Initiative, implemented as part of the European Green Deal, alongside its Farm-to-Fork and Biodiversity strategies[1]. On the European continent, the Dutch agricultural system stands out as a prime

[1] European Comission, Technical Guidance Handbook: Setting up and implementing results-based carbon farming mechanisms in the EU (2021), Brussel, 2021.

example of efficient modern agriculture.

Education on digital practices in agriculture is not only relevant to the well-being of plants, animals, and the environment but also extends to the operation and maintenance of machinery used in farming, such as combine harvesters. These high-capacity and multifunctional machines significantly enhance efficiency, but their operation requires specialized knowledge and skills. However, due to the high cost involved, such advanced machinery is not commonly found in underdeveloped countries. In animal husbandry, automation has been widely embraced, primarily through the implementation of various sensors. Mature solutions in livestock farming include automated milking and feeding systems, climate and atmosphere control, animal identification and tracking, calving detection, and manure removal, among others. These advancements in automation have brought notable improvements to the efficiency and management of livestock farming.

Proximal monitoring tools, which are placed directly in the field and provide real-time data on crop conditions, have a higher likelihood of adoption by farmers. On the other hand, satellite imaging technologies are globally used but are still in the early stages of development and are primarily applied in developed countries due to their significant financial requirements. This represents a novel approach to collecting large amounts of data and applying various data processing methods to enhance monitoring capabilities. However, satellite imagery is rarely utilized to evaluate the impact of agricultural practices on crop yield and well-being. Unlike sensor readings, satellite image processing is not a direct service to farmers. In practice, satellite images usually need to be processed by powerful computers and made accessible to end-users through a platform or server (Kubitza at al. 2020).

An exemplary case of good practice in this regard is Argosense, a platform developed by the Biosense Institute from Novi Sad, Serbia. It is designed not only as a source of plant health indices and environmental data but also as a space for farmers to socialize, exchange best practices, and facilitate communication among various stakeholders, including farmers, the food industry, agronomists, retailers, insurance companies, and policy makers. Agrosense is a digital platform empowered by cutting-edge technologies such as sensors, yield monitors, drones, soil sampling probes, the Internet of Things (IoT), big data analytics, and artificial intelligence. It provides farmers and agricultural companies with the means to monitor crop conditions and plan agricultural activities[2]. Available as a web or Android application, Agrosense enables easy and swift data entry into the system, granting agricultural producers instant access to various field data. This includes location-specific weather forecasts, satellite crop indices that describe plant growth and photosynthetic intensity, water and nutrient availability, soil analysis summaries, crop photos, and the latest information on the occurrence of diseases and pests in the vicinity of the field.

Agricultural data is inherently diverse, encompassing various formats, types, intentions, data collection methods, and protocol devices. This necessitates the seamless integration of data, processes, and systems. Thus, effective platforms are needed to facilitate communication and information exchange among farmers and other stakeholders within Agricultural Social Networks (ASN). These platforms aim to support appropriate activities that enhance agricultural practices, increase productivity and profitability, ensure food quality and safety, and ultimately meet consumer needs. In addition to blockchain technologies, which provide transparency, traceability, and data security on a decentralized network, especially in supply chain management (SCM), the Internet of Things (IoT) and smart sensors play a crucial role in connecting the physical and virtual realms. Furthermore, the combination of Edge and Cloud Computing enables the analysis of big data using artificial intelligence techniques. These technological advancements contribute to the efficient processing and utilization of agricultural data, fostering improved decision-making and sustainable practices in the agricultural sector (Tombe, R.; Smuts, H., 2023).

Similar to other sectors that have embraced digitalization, the digital transformation of agriculture necessitates the interoperability of digital systems and technologies. This entails the operationalization of standardized data formats within an established ethical and legal framework. Only through this approach can all stakeholders within the Agricultural Social Network (ASN) collaborate effectively, exchanging data and information pertaining to agricultural practices, markets, pricing, and distribution channels. Interoperability, when combined with the utilization of decentralized blockchain platforms like Ethereum, opens up new opportunities for smart agriculture. These possibilities encompass enhanced financial accessibility through decentralized finance (DeFi), novel organizational structures and management through Decentralized Autonomous Organizations (DAOs) and smart contracts, as well as the inclusion of agricultural populations previously excluded from ASN. It also enables them to access broader digital markets at regional and global levels.

[2] https://agrosens.rs/#/app-h/about

Blockchain and Supply Chain Management

It's surprising how little the average consumer knows about most of the products they use every day. Before reaching the final consumer, goods traverse a wide and predominantly unseen network involving sellers, distributors, transporters, warehouse facilities, and suppliers who participate in the design, production, delivery, and sale of these goods. However, the production, exchange, and utilization of material products carry numerous potential negative consequences, including environmental damage, child labor exploitation, unsafe working conditions, fraud, counterfeiting, and substantial waste of valuable materials at the end of a product's life cycle.

The establishment of comprehensive "chains of custody," which verify the origin of each product or material, remains fragmented and susceptible to fraud and errors, even among certified companies. Blockchain-based applications have the potential to enhance supply chains by providing infrastructure for registering, certifying, and tracking goods transferred between remote parties within the supply chain who may lack mutual trust.

Through blockchain technology, supply chain participants can ensure transparency, traceability, and accountability. This enables the verification of product origins, ethical sourcing, fair trade practices, and compliance with safety and quality standards. By leveraging blockchain, the supply chain ecosystem can be strengthened, fostering increased trust and efficiency while mitigating the negative consequences associated with the production and distribution of goods.

Without delving into the intricate details of blockchain technology, we can say that "blockchain" is an immutable irreversible linear chain of cryptographically hashed "blocks" on which transactions are recorded. This linear history of time-stamped events is verified and stored in a decentralized DLT-based manner, and network nodes "witness" transactions and reach consent on which transactions are considered regular through a consensus e.g "Proof of Work" algorithm (Bjelajac, Ž., Bajac, M. 2022). Each transaction's data recorded and validated on the blockchain is immutable and irrevocable, accessible for inspection by anyone or authorized auditors.

In the realm of food production and processing, a precise and up-to-date blockchain-based register is expected to aid in identifying various aspects of a product, including information regarding the origin and composition of raw materials, processing facilities, storage conditions, transportation, manufacturing and expiration dates, and more. Consequently, during situations such as outbreaks of infections, adulteration, or fraud, details can be obtained regarding how and where the food was grown and who inspected it.

By creating a "digital passport" or "digital avatar" of physical products, blockchain not only provides reliable information but also ensures transparency regarding a company's business footprint. Through its design, blockchain enforces the transparency, security, authenticity, and auditability necessary for establishing traceability of the chain of custody and product attributes. This, in turn, empowers customers to access high-quality information, enabling them to make more informed choices.

As a result of implementing blockchain technology in the supply chain, a multi-layered system of supply chain validators emerges, and the choices made in the market determine which business practices thrive and survive, and which ones fade away. This new system, serving as a source of interconnected, secure, and unalterable information, enables smarter and more informed purchasing decisions in supply chains and among end consumers. It also ensures the sustainability and viability of economic activities on both the biosphere and sociosphere.

The information architecture for the certification and chain of custody system on the blockchain takes takes into account the following stakeholders[3]:

1. Raw material producers (e.g. cattle breeders).
2. Producers of the final product (e.g. manufacturers of processed food)
3. Registrars, organizations that provide credentials and unique identities to stakeholders (e.g. accreditation services, Agency for Business Registers).
4. Standardization organizations, which define specific rules and standards (e.g. Fairtrade, ISO).
5. Certifiers and auditors, typically separate entities responsible for incpecting raw material producers and final product manufacturers to verify compliance with certain standards).
6. Buyers of product throught the supply chain, including end consumers.

Transactions involving supply chains often deal with multiple actors who transact based on concealed information or with a lack of knowledge regarding the product's origin. Corporations can use the Blockchain to identify these multiple layers that are often linked to human and natural resource exploitations, environmental footprints, and waste productions and gain a more transparent supply chain as a result (Ly, P. 2018). Project Provenance Ltd has developed a decentralized blockchain-based dApp that collects and verifies a product's provenance and other attributes in real-time, providing it with a "digital

[3] https://www.provenance.org/whitepaper

passport" that can be tracked along the entire supply chain until it reaches its destination.

This architecture consists of a series of modular programs distributed on the blockchain and independently controlled. However, because they operate within the same blockchain system, they can seamlessly communicate with each other. These programs include[4]:

1. Registration, standardization, and certification modules: These programs handle the of participants, establish standards, and certify compliance with those standards.

2. Production module: This module specifies the input goods and tracks their transformation through the production process, from sources such as bull farms to the final packaged meat found on supermarket shelves.

3. Labeling module: This module establishes a link between the digital and physical worlds through unique cryptographic QR codes or NFC tags. These tags connect the origin of the material, ingredient, or product to its physical counterpart.

4. Linking module: Physical goods and materials are identified and linked to their digital representation on the blockchain using serial numbers, barcodes, digital tags like RFID and NFC, or genetic tags. These tags uniquely identify a physical asset and its digital counterpart.

By utilizing smartphone applications, customers can aggregate and access reliable real-time information, enabling them to make informed purchasing decisions. This technology can be implemented through discreet and removable labels easily verified via QR codes read on smartphones, holograms, or RFID tags embedded in brand labels. These features allow product owners to prove the authenticity of their products at any time by accessing blockchain data via tokens[5].

All these systems rely on tracking the attributes of material things not only during their creation but also during their use. This comprehensive record of a product's life cycle can significantly impact the afterlife of goods and contribute to broader initiatives such as the circular economy.

One specific aspect, particularly relevant in more developed countries, is food waste management. It is estimated that approximately one-third of all food produced is wasted, with a significant portion being discarded directly from consumers' plates. In response, the EU has implemented a strategy to reduce food waste, which includes measures such as identifying and prioritizing target groups, improving the food management chain, implementing food donation strategies, and enhancing food labeling to prevent waste. Some of these actions legally obligate stakeholders to reduce food waste.

Educating society on how to effectively manage food waste is a crucial part of these efforts. This includes activities such as sorting, selecting, and recycling food waste, which have proven effective in reducing waste across many EU countries. Many strategies also promote food waste education in schools to foster an understanding of food quality assessment, raise awareness of the impact of food waste on climate change, and encourage individuals to adopt responsible behaviors towards food.

Conclusion

Technological development has always been the primary catalyst for paradigm shifts. During Third Industrial Revolution, which introduced the Internet and propelled the world into the Information Age, it was anticipated that the inherent connectivity of this technological innovation would bring people closer together and diminish alienation. However, a paradoxical situation unfolded – people became more interconnected than ever before, and communication became increasingly effortless, yet the process of alienation between individuals persisted and intensified (Filipović A., Bajac, M., & Spaić, I., 2022). Despite numerous strategies and agendas that were implemented, it became evident that the biosphere and sociosphere were unable to withstand the impact of the existing neoliberal paradigm. The economic model, driven by the pursuit of maximizing utility from technical, human, and natural resources, prioritized capital accumulation rather than meeting human needs. The technologies associated with the Fourth Industrial Revolution, such as quantum computers and artificial intelligence, have the potential to offer new prospects for improving the overall quality of life for citizens. However, they also raise concerns about the potential emergence of a totalitarian dystopia with uncertain consequences. One of the most prominent figures associated with the World Economic Forum (WEF), Yuval Noah Harari, emphasized in his speech that the automation of jobs through the implementation of AI systems often results in job losses and the emergence of a cohort of "unemployable and useless" individuals. He argued that while people in the past feared exploitation, in the 21st century, the fear will shift towards a sense of uselessness. Being considered useless is perceived as far worse than being exploited.

[4] https://www.provenance.org/whitepaper

[5] https://www.provenance.org/whitepaper

Precision agriculture (PA), in conjunction with the concept of smart cities, plays a pivotal role in the transition from an information society to the notion of Society 5.0. This transition involves an unprecedented connection between cyberspace and physical space. Establishing sustainable production, ensuring equitable distribution, and shaping consumer behavior are critical factors for the success of this concept. Therefore, further research necessitates an interdisciplinary approach with a greater emphasis on social and human sciences such as social psychology, anthropology, and philosophy. This approach aims to ensure that the implementation of cutting-edge technologies genuinely leads to a social organization in which every individual can live an active and fulfilling life.

Conflict of interests
We have no known conflictof interest to disclose

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