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The Impact of Innovation on Sustainability in Agriculture: A Literature Review and Opportunities for Future Research

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THE IMPACT OF INNOVATION ON SUSTAINABILITY IN AGRICULTURE: A LITERATURE REVIEW AND OPPORTUNITIES FOR FUTURE RESEARCH

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Abstract

Agriculture has evolved dramatically over the past few decades, principally due to advances in machinery. Another evolution is at hand due to technological advances such as artificial intelligence, sensors, etc. These emerging technologies are anticipated to enhance not only the productivity of agriculture but also its sustainability. The past century has seen an increasing focus on sustainability, also called sustainable development. Research indicates that agricultural systems and human development are irrevocably connected since agricultural systems are the principal channel to produce food for society. Almost all recent definitions of sustainability place emphasis on an ecological perspective. That is, the idea that there is an intimate relationship between human society, the economy, and the natural environment. In other words, humans must coexist amicably with the natural universe if there is a desire to "persist, adapt, and thrive" forever on Earth. Therefore, a common model of sustainability illustrates the interrelationship between three Es, namely, the environment, economy, and social equality (or equity). This paper aims to understand better the role of innovation, how natural and technological approaches contribute to economic and sustainability objectives in agriculture, and pathways for future IS research in the agriculture domain.

Keywords: Sustainability, agriculture, agroforestry, lifestyle, permaculture, technology, case study

1 Introduction

Sustainability or sustainable development, from the Latin sustinēre (a combination of the words sub, 'up from below' and tenēre, 'to hold'), is a contemporary idea with an extensive history which denotes the act of maintaining, sustaining, supporting, enduring, or, restraining (Caradonna, 2014, p. 7; Spindler, 2013). Rural cultures, since antiquity, show evidence of having understood and implemented sustainability. Agriculture systems are presently the primary channels for society's food production. The impetus to confirm that adequate food is provided by these systems has led to agriculture becoming the chief user of land, using almost a third of the earth's total surface area, excluding Antarctica and Greenland (Dudley & Alexander, 2017). Relatedly, agriculture is the single largest contributor to loss of biodiversity due to its transformation of natural ecosystems into ranches and farms; extension of management in longstanding cultural landscapes; discharge of pollutants, as well as greenhouse gases (GHGs); and related impacts to the value chain, such as, usage of transport and energy, and wastage of food (Dudley & Alexander, 2017). These have resulted in calls for a "reformed, sustainable approach" to agriculture (Robertson, 2015) or sustainable systems for agriculture. Sustainable agriculture systems denote systems with the capacity to persevere (Robertson, 2015) and integrates three principal goals namely the health of the environment, economic viability, and social equity (Brodt et al., 2011).

The diversity of research related to agriculture's impact on sustainability indicated that some themes were recurrent namely, the use of natural agricultural approaches and the use of technology. Although agriculture is one of the prime instances of the interface between humans, nature, and technology, innovation in agriculture has typically been associated with only technology. Specifically, its development, utilization, and application (Andrade et al., 2020). However, there are some explorations of innovative practices such as, syntropic farming and permaculture, which highlight a change in focus towards the interaction between humans and nature. Permaculture, specifically, is an alternative agroecology movement and consequently is an "international movement and ecological design system" (Ferguson & Lovell, 2014, p. 252). The advent of permaculture can be traced to the 1970s where it was proposed as a "practical *in situ* approach" to fashioning human communities that were cooperatively sustainable (Suh, 2014). This approach differs from industrial systems of agriculture principally in its use of small-scale polyculture and its dependence on renewable energy sources and soft technology which is in contrast to the characteristic yearly market-dependent monoculture and heavy utilization of energy sources which are fossil-based of industrial agriculture (Suh, 2014). The use of fossil fuels may be direct such as, fertilisers, or indirect such as, electricity (Anand, 2014). On the other hand, Syntropic agriculture was developed by Ernst Götsch, a Swiss farmer in the 1980s. It is a form of agriculture that contains components present in most forms of agroecology such as, no usage of chemicals, usage of technologies with no- or low-impact, and a design with a robust basis on ecological succession. However, this approach differs from other agroecological practices as it is centred on syntropy. Syntropy is used not only for interpreting life mechanisms but also decision-making concerning field management (Andrade et al., 2020). The implementation of permaculture in agriculture has been found to resemble, rather closely, other alternative approaches to farming such as, organic or biodynamic farming, agroecology, or agroforestry, movements which have traditionally supported the creation of agroecosystems which use resources efficiently and are free from pesticides. Such agroecosystems prefer local cycling of nutrients (e.g., utilising compost, animal or green manure) and support biological control by nurturing an elevated extent of biodiversity to maintain plant and animal health (Morel et al., 2019).

Sustainability has been a topic on business agendas for several decades, from the time when the enterprises realize their impact on and responsibility towards the environment. This "going green" movement has become popular since the companies have realized that they can reduce pollution and increase profits simultaneously (Levina, 2015). In the last few decades, information systems (IS) and information technology (IT) have changed human behaviour profoundly and therefore have the potential to support the shift to a sustainable society. Even so, IS and IT pose a great threat to sustainability issues

(Ijab & Molla, 2011). We respond to this threat to sustainability issues by examining more IS focussed research papers like Richard Watson and colleagues (Watson et al., 2010) paper who initiated discussion on a subfield of Information Systems (IS) that acknowledges the probable role of IS in decreasing consumption of energy and consequently carbon emissions, namely energy informatics. Also, we are taking a novel approach of combining IS based technology approaches with natural approaches to minimize the threats to sustainability.

Consequently, with a focus on innovation, this paper aims to measure the impact of how natural approaches and technological approaches can be used to derive sustainability outcomes in agriculture. The following overarching research questions were formulated to inform the study: To what extent has literature already explored the impact of innovation on sustainability in agriculture?; Which dimensions of innovation are analysed in this area of research?; How can future researchers contribute to this literature?

The remainder of the paper is organised as follows: first, a brief overview of the methodology used by the study is provided followed by a review of the literature related to the chief concepts of interest to the paper is performed. A discussion of sustainability in agriculture is first provided followed by a discussion on sustainability in information systems. This is followed by a discussion on innovation in agriculture. The impact of innovation on sustainability in agriculture is then examined. This is followed by a discussion of the findings of the review. Finally, the opportunities for future research and conclusions are also provided.

2 Methodology

The methodology utilised by the study was a non-systematic review of the literature. In this regard, relevant academic papers and publications were considered because they addressed important aspects of the subject under concisderation. The researchers utilized different database systems such as Elsevier Products, Emerald eJournals, JSTOR, Sage Online Journals, Springer, Taylor & Francis Online, Wiley Online Library, Google Scholar, IE University Library, etc., to locate suitable literature for inclusion in the study. Studies were also found through database searches using these search terms in different combinations. The subsequent literature review included studies that were considered significant for this research.

3 Sustainability

This section discusses sustainability in agriculture including aspects such as, frameworks, principles and goals, and approaches. The following section also discusses sustainability in information systems (IS) considering that it is the science of the digital technologies.

3.1 Sustainability in agriculture

Sustainable agriculture signifies an “integrated system of plant and animal production practices having a site-specific application that will, over the long term, satisfy human food and fiber needs, enhance environmental quality and the natural resource base upon which the agriculture economy depends, make the most efficient use of non-renewable resources and on-farm resources, and integrate, where appropriate, natural biological cycles and controls, sustain the economic viability of farm operations, enhance the quality of life for farmers and society as a whole” (Kremsa, 2021, p. 114). Sustainable agriculture has also been defined by the Food and Agricultural Organization (FAO) of the United Nations as the “management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such development conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable” (Oberč & Arroyo Schnell, 2020, p. 5). Initially, the understanding of sustainable agriculture was of a system of farming that replicates natural ecosystems (Gomiero et al., 2011). Overall, the aims of sustainable agriculture can be understood to be as follows: "preserving the natural resource base, especially soil and water, relying on minimum artificial inputs from outside the farm system, recovering from the disturbances caused by cultivation and harvest while at the same time being economically and socially viable" (Gomiero et al., 2011, p. 13).

3.1.1 Frameworks for sustainable agriculture

The Food and Agriculture Organization (FAO) of the United Nations developed a framework to support decision-making as regards the probable effectiveness of certain land management practices on sustainability, termed the Framework for Evaluation of Sustainable Land Management (FESLM) (Smyth & Dumanski, 1994). This working definition of sustainable land management (SLM) as provided by this report is as follows:

"Sustainable land management combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously: maintain or enhance production/services (Productivity); reduce the level of production risk (Security); protect the potential of natural resources and prevent degradation of soil and water quality (Protection); be economically viable (Viability); and socially acceptable (Acceptability)."

The use of the following eight principles have also been reported in the development of the FESLM (Smyth & Dumanski, 1995):

1. The evaluation of sustainability is for defined types of land usage;
2. The evaluation of sustainability pertains to specific areas of land;
3. Sustainability pertains to a specified period of time;
4. Assessment is performed in terms pertinent to the physical, economic, biological, and societal background of the involved areas;
5. The evaluation of sustainability involves multiple disciplines;
6. Understanding of the processes and practices related to the current land use, if any, and its present suitability should be established prior to recommending any changes based on sustainability evaluation;
7. Scientifically valid procedures and data are the basis of evaluation together with a choice of sustainability conditions and indicators which suggest awareness of both causes and symptoms; and
8. Initiation of fresh or amended practices will be performed on an experimental scale at first with careful monitoring of their consequent progress.

Hill and Macrae (1996) utilised their "Efficiency/Substitution/Re-design" framework to scrutinise and categorise probable strategies pertaining to the transition to more sustainable forms of agriculture. The efficiency stage on the farm is exemplified by modifications in traditional systems that lower utilisation and misuse of rare and expensive resources. For example, by grouping fertilizers, observing pests, ideal siting of crops and scheduling of operations. Replacement of products and procedures that are dependent on resources and disruptive to the environment by one more nonthreatening to the environment takes place in the substitution phase. More recently, the Sustainability Assessment of Farming and the Environment (SAFE) framework (Van Cauwenbergh et al., 2007) is designed for three spatial levels: parcel, farm, and a higher level (e.g., landscape, region, or state). The overall objective of this framework is to assess sustainability in agriculture. The objective is progressively attained by consecutively defining principles, criteria, and indicators. Another framework (Le Gal et al., 2010) is based on three sub-systems namely: biophysical, technical, and decisional. The basis of their framework is the assumption that an agricultural production system combines productive activities at the level of the farm utilising resources already available of the farm or provided by the environment. A later sustainability framework was also provided by the FAO (2014). Overall, the different frameworks to explain or direct sustainability in agriculture involve facets such as decision-making (FESLM); strategies for transitioning to forms of agriculture which are more sustainable ("Efficiency/Substitution/Re-design"); assessment of sustainability (SAFE); different sub-systems (Le Gal et al., 2010); and themes/indicators of sustainability (SAFA). However, it appears that there is no corresponding empirical research related to the evaluation of their appropriateness and effectiveness which is an opportunity for future researchers. Similarly, while several approaches to sustainable agriculture are suggested (Hill & MacRae, 1996), the status of their implementation again appears to be something for future researchers to pursue. With our research paper, we aim to fill in this research gap by capturing on-ground farm level insights when sustainability framework and solutions are implemented.

3.1.2 Principles and goals of sustainable agriculture

Sustainable agriculture does not signify a fixed group of processes. Moreover, it is different from organic agriculture since it may or may not continue to use agrochemicals (synthetic fertilizers and pesticides), albeit minimally if at all. Nevertheless, conservative practices (e.g., rotation of crops, cohesive pest management, natural methods of fertilization, least possible tillage, biological regulation) are completely incorporated in management of farms (Gomiero et al., 2011).

The FAO offers five principles for sustainable agriculture. These principles encapsulate the three essential pillars of sustainable development namely, environmental, social, and economic sustainability. Accordingly, the principles are to enhance efficiency in resource utilisation, to safeguard, defend, and develop natural ecosystems; to safeguard and develop rural livelihoods and societal welfare; to improve the resilience of individuals, neighbourhoods, and ecosystems; and to foster robust governance of both human and natural systems (Oberč & Arroyo Schnell, 2020). The European Commission also provides distinct goals related to sustainable agriculture. That is, ensuring that farmers receive a fair income, enhancing competitiveness, re-evaluate the supremacy in the food chain, action for climate change, care of the environment, safeguarding terrains and biodiversity, promoting generational regeneration, lively rural zones, safeguarding quality of food and health (Oberč & Arroyo Schnell, 2020). Similarly, Julia Pretty (2008) offered various principles relating to agricultural sustainability. They are to: "(i) integrate biological and ecological processes such as nutrient cycling, nitrogen fixation, soil regeneration, allelopathy, competition, predation and parasitism into food production processes, (ii) minimize the use of those non-renewable inputs that cause harm to the environment or to the health of farmers and consumers, (iii) make productive use of the knowledge and skills of farmers, thus improving their self-reliance and substituting human capital for costly external inputs, and (iv) make productive use of people's collective capacities to work together to solve common agricultural and natural resource problems, such as for pest, watershed, irrigation, forest and credit management" (Pretty, 2008, p. 451).

The discussion in this section highlighted the different goals for sustainable agriculture as submitted by many institutions. However, it appears that there is a lack of empirical evidence tracking and reporting the progress of these goals.

3.1.3 Approaches to sustainable agriculture

Approaches pertaining to sustainability may be both substantive (e.g., resource sufficiency and functional integrity) and non-substantive (e.g., promotion of social action). In general, sustainable agricultural programs use human, economic, and biological resources to develop technology and societal establishments. Further, they typically use other agricultural sciences and agronomy to study and propagate techniques and tools for utilisation by farmers. Alternatively, they assist decision-making by utilising applied social sciences and fulfil the resident challenges of rural communities using social organisations (Thompson, 2007). Different approaches to sustainable agriculture have been discussed in literature. These include agroecology; nature-inclusive agriculture; permaculture; biodynamic agriculture; organic farming; conservation agriculture; regenerative agriculture; carbon farming;

climate-smart agriculture; high nature value farming; low external input agriculture; circular agriculture; ecological intensification; and sustainable intensification.

3.2 Sustainability in information systems

Watson et al. (2010) indicated that the scope of environmental sustainability is not limited to a single organization. Instead, ecological sustainability can be developed through an awareness that ecological problems are completely and symbiotically interrelated. All elements of a system for energy supply and demand are incorporated into their proposed integrated framework which has an IS at its core. They suggest that suppliers are of two types: energy suppliers and service suppliers. Both these types have a shared need for information to regulate the flow of their resources. On the demand side, they suggest that providing consumers with information related to their use of energy can result in usage patterns being modified and overall consumption being reduced. Technologies in an intelligent energy system can be of three types: sensor networks (i.e., set of spatially distributed devices that reports the status of a physical item or environmental condition), flow networks (i.e., set of related transport elements that helps the progress of uninterrupted matter (e.g., air, oil, electricity, and water) or discrete objects (e.g., containers, packages, cars, and people), and sensitized objects (i.e., physical goods owned or managed by a consumer and which have the capacity to detect and convey data regarding its usage). The information system links the other components to offer a comprehensive solution. IS researcher Wolfgang, Karsten and Konstantina makes the case for IS research to play an active role in delivering a smart sustainable mobility ecosystem that is beneficial to users, mobility providers, and the environment (Ketter et al. 2022).

George et al. (2021) explored the contribution of digital technologies in dealing with climate change and supporting sustainable development. They highlighted the sustainability imperative which signifies the commitment of businesses to elaborate environmental goals either voluntarily or in response to pressure from governments, investors, and others. On the other hand, is the digital imperative which is related to the rapid digitalization resulting from a multitude of novel technologies such as, artificial intelligence and machine learning (AI/ML), the Internet of Things (IoT), and blockchain, which have given rise to a digital toolbox of solutions that have disrupted existing circumstances. Consequently, George et al. (2021) defined digital sustainability "as the organizational activities that seek to advance the sustainable development goals through creative deployment of technologies that create, use, transmit, or source electronic data" (George et al., 2021, p. 1000). They added that the "digital nature of these activities enables them to be less constrained by geographic boundaries and enhances scalability leading to higher impact. In addition, the objectives guiding these activities focus on the creation of socioecological value as an integral part of an economic proposition, thereby disarming the trade- off between profit and purpose" (George et al., 2021, p. 1000). The technologies typically utilised in digital sustainability activities include blockchain (distributed ledger technologies), Artificial Intelligence/Machine Learning (AI/ML), Big Data Analytics, sensors and other IOT (Internet-of-Things) devices, mobile technology and applications, and other telemetry tools like satellites and drones (George et al., 2021). Moreover, George et al. (2021) note that high scalability and ecosystem coordination are characteristics of digital sustainability activities. Corbett et al. (2011) proposed that the sustainability measurement principles offer a significant mechanism for building the required links between disciplines. The principles are uniformity, transferability, integrability, accuracy, transparency, granularity, and scope (range and inclusion). In another study, Corbett (2013) explored how carbon management systems (CMS), a category of green IS, could be designed and utilized to encourage employees to implement behaviors that were ecologically responsible.

Overall, it could be seen, however, from the review of IS and sustainability that there is a need for empirical research to evaluate the effectiveness of the contribution of IS to sustainability in specific sectors like agriculture. Also, there is limited IS work focussing on IS for the agriculture sector. This is a gap that needs to be addressed through future research.

4 Innovation in Agriculture Sector

To access the impact of innovation on sustainability the focus is on the natural and technological approach aspects of innovation in agriculture.

4.1 Natural approaches

Although agriculture is one of the prime instances of the interface between humans, nature, and technology, innovation in agriculture has typically been associated with only technology. Specifically, its development, utilization, and application (Andrade et al., 2020). However, there are some explorations of innovative practices such as, syntropic farming and permaculture, which highlight a change in focus towards the interaction between humans and nature. Syntropy, conceptually, is complementary to entropy. That is, while entropy governs the physical and mechanical worlds, syntropy rules the biological world. Also, while entropy is associated with dissipation of energy, syntropy pertains to concentration of energy (Andrade et al., 2020).

Agroecosystems are “communities of plants and animals interacting with their physical and chemical environments that have been modified by people to produce food, fiber, fuel and other products for human consumption and processing.” Relatedly, agroecology is the “holistic study of agroecosystems including all the environmental and human elements. It focuses on the form, dynamics and functions of their interrelationship and the processes in which they are involved” (Altieri, 2002, p. 8). Syntropic agriculture was developed by Ernst Götsch, a Swiss farmer in the 1980s. It is a form of agriculture that contains components present in most forms of agroecology such as, no usage of chemicals, usage of technologies with no- or low-impact, and a design with a robust basis on ecological succession. However, this approach differs from other agroecological practices as it is centred on syntropy.

Permaculture is a form of agroecology that evolved in response to rising fears regarding the adverse effects of industrial agriculture. The debate regarding the feasibility of shifting from industrial agriculture to other approaches to agriculture which have the capacity to offer a wide range of ecosystem services while simultaneously generating produce for human utilization resulted in what is termed the “agroecological transition.” This transition can be considered to be a “complex, multi-sector project, operating at multiple temporal and spatial scales and involving diverse constituencies” (Ferguson & Lovell, 2014, p. 252). Permaculture submits rational practical principles to generate living spaces that are independent, robust, and fair (Morel et al., 2019). Twelve principles were defined by Holmgren (2011) for permaculture design. These principles provide the foundations of a reflective process of design (Holmgren, 2011). The principles are: “(1) observe and interact, (2) catch and store energy, (3) obtain a yield, (4) apply self-regulation and accept feedback, (5) use and value renewable resources and services, (6) produce no waste, (7) design from patterns to details, (8) integrate rather than segregate, (9) use small and slow solutions, (10) use and value diversity, (11) use edges and value the marginal, (12) creatively use and respond to change” (Morel et al., 2019, p. 565).

Allied with its principles, the practices associated with permaculture include the following:

- Applying a systems approach, and terminating the loop as regards supplies and nutrients: harvesting of rainwater, composting;
- Employing ecosystem amenities and biodiversity: nitrogen-fixers (clover), pollinators (insect houses, flowers), bats and birds (food, water features, habitat), etc.
- Placing emphasis on production: substituting grass and lawns with crops that are productive, cultivating perpetual food plants;
- Fostering nourishing soil: no ploughing, mulching, no artificial or chemical pesticides or fertilisers, cover crops;

- Putting agroforestry into practice, connecting with the layering method: trees provide a cover and shelter along with fruit or nuts, food and habitat are produced by shrubs for wildlife, soil erosion is prevented through ground covers and vines;
- Animals utilised for various functions, encompassing: management of land, production of food and fibre, management of fertility, and safety. For example, pest populations can be reduced by free-range chickens together with turning the soil, managing weeds, etc. Controlled grazing and silvopasture are other practices;
- Hugelkultur: interring wood to enhance retention of soil water;
- Controlling flow of water through keyline design;
- No pruning for some followers (originating from natural farming)

It could be seen that the literature related to permaculture placed greater emphasis on permaculture principles rather than exploring the efficacy of the implementation through empirical research. This is a gap that needs to be addressed through future research.

4.2 Technological approaches

A World Bank report (Deichmann et al., 2016) highlighted the instantaneous private benefits generated by digital tools for individuals as these can not only facilitate easier communication between family and friends but also provide access to different information sources and modes of leisure. Extending this to the wider context, technology has been proven to improve economic opportunities, assisted with livelihoods, and aided in delivery of services. Regarding agriculture, the use of ICT (information and communication technology) showed considerable savings as regards time and cost for extension services in the context of African small-scale farmers (Aker, 2011). Again, the usage of precision tools such as, GPS (global positioning systems), monitoring through satellite and drone, and information related to meteorological conditions that is progressively itemised and promptly available, have become essential to contemporary large-scale agriculture (Oliver et al., 2010). Interventions using digital technology have been reported to enhance market transparency and farm productivity, and facilitate efficient logistics (Deichmann et al., 2016). Specifically, information can play a key role in the context of productivity on farms as it can help change farmer behaviour and prevent loss (via early warning systems) due to climate-related shocks. Digital tools serve as the basis for early warning systems and utilise information from different sources such as, traditional surveys and satellite imagery. While these digital tools can be utilised in all sizes of farms, more technologically advanced farms can utilise state-of-the-art precision farming systems. The underlying logic for such systems can combine different satellite images and remote sensing data for a specific section of a farm to offer detailed information such as, soil status, level of ground water, rain water precipitation, etc., for growth. Associated tools include sensors (for condition of soil), detectors (for detection of precipitation), and systems for irrigation optimization (Deichmann et al., 2016). Moreover, precision farming systems have been demonstrated to aid environmental sustainability. This is due to their continuous monitoring of natural resources and the appropriate taking of action before the occurrence of drought or nutrition depletion (Deichmann et al., 2016). AI, specifically, has found application in various aspects of agriculture and consequently many applications were either specially developed for this area or were adopted and adapted from other industries for farming(Popa, 2011).

Eli-Chukwu (2019) draws attention to the use of various AI techniques in different facets of agriculture such as, soil management to predict soil texture and the characteristics of soil moisture. Relatedly, Verdouw and colleagues (2021) studied how smart farming can be advanced by digital twins. They proposed a conceptual framework based on the Internet of Things-Architecture (IoT-A) for designing and implementing digital twins. The framework was used and validated in five use cases applicable for smart farming namely, arable farming, dairy farming, greenhouse horticulture, organic vegetable farming and livestock farming, as included in the European IoF2020 (Internet of Food and Farm 2020) project. The authors submit that the case-specific control models offer tangible understanding regarding how the smart farming systems of the use cases could be enhanced by digital twins (Verdouw et al., 2021). Bacco and colleagues (2019) also performed a synthesis of existing research related to smart farming and reported the use of sensing techniques, Farm Management System (FMS)/ Farm Management Information System (FMIS) systems connected to robotic solutions, and unmanned vehicles to support autonomous operations. Additionally, they reported various software systems designed to support agricultural production through IoT-based monitoring and/or leveraging Decision Support Systems (DSSs). Areas where remote sensing systems could be used included weeds mapping, soil organic carbon, yield prediction, plants growth, crop water stress, plant height, crop cover, real-time crop conditions, phenotyping, and chlorophyll measurement (Bacco et al., 2019).

Oliver and colleagues (2010) presented an approach to integrate knowledge of farmers, tools of precision agriculture, and crop simulation modelling to assess management options for patches that perform poorly. Their survey of nine cropping fields located in Western Australia revealed that farmers have robust awareness of the spatial coverage and rank performance of areas that perform poorly, in contrast to NDVI or yield maps. Additionally, they found that there is a broad spectrum of soil constraints, physical and chemical, to crop outcomes in such areas, some of which can be enhanced to increase outcome potential, and others where inputs to crops such as fertiliser can be matched better to poor outcome potential. Precision agriculture technologies (PATs) include Variable rate nutrient application, Variable rate pesticide application, Variable rate irrigation, Variable rate planting/seeding, Machine guidance (driver assistance or auto-guidance), Precision physical weeding technology, Controlled Traffic Farming (system that confines all machinery loads to permanent traffic lanes) (Balafoutis et al., 2017). The term smart farming signifies the use of information and communication technology (ICT) in agriculture. Efficient production processes are supported by data obtained and analysed using ICT techniques. This has motivated scientist, practitioners, and firms to strive to achieve the aim of advancing and inspiring the usage of pioneering technologies to support farmers. The European Union (EU), for instance, suggests that the most pertinent technologies and techniques to be thoroughly utilised are satellite imagery, agricultural robots, sensor nodes for data collection, and Unmanned Aerial Vehicles (UAVs) for aerial imagery, etc. (Bacco et al., 2019). Smart farming has also been described as the use of "supplementary technologies to agricultural production techniques to help minimize waste and boost productivity" (Navarro et al., 2020, p. 3). Smart farms utilise technological resources that aid in different phases of the process of production, such as plantation monitoring, management of soil, pest control, irrigation, and delivery tracking (Bhagat et al., 2019). Such technological resources include, temperature, humidity, luminosity, pressure, unmanned flying equipment, ground chemical concentration, video cameras, global positioning systems (GPS), agricultural information management systems, and communication networks, among others (Stočes et al., 2016).

Another line of thought highlights the challenges associated with digitisation of farming. For example, Bacco and colleagues (2019) provide insights regarding the technical and non-technical challenges associated with smart farming (Figure 1).

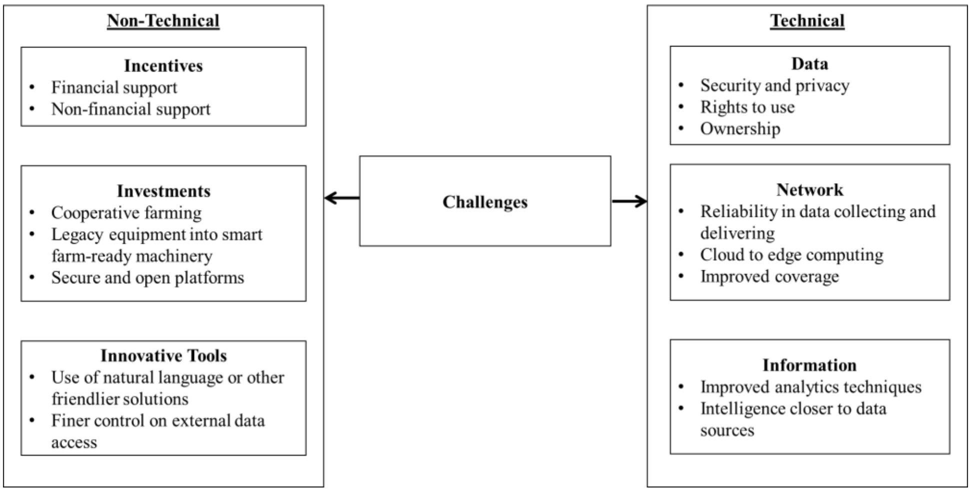

Figure 1 Challenges with smart farming (Bacco et al., 2019, p. 9)

Visser and colleagues (2021), in another study, determined that digital farming is frequently accurately inaccurate. This is perhaps due to Big Data's granularity and enormous volumes which are incorrectly associated with extreme precision. Consequently, they highlight the threat of a 'precision trap,' that is, an inflated confidence in the accuracy of Big Data that progressively results in a loss of safeguards (farmer observation, analogue data, etc.) on farms. The threat of precision taps grows with algorithm complexity, with changes from concurrent evaluation and guidance towards estimating, and with enhanced distance of farmers from field operations. Additionally, Visser and colleagues (2021) highlight a developing 'precision divide.' This refers to the uneven distribution of precision advantages stemming from the rising divide in algorithms between farmers concentrating on staple crops who are well-supplied by technological innovation and farmers growing other crops who have to manage with algorithms which are far less developed or suitable (Visser et al., 2021).

There are also some associated challenges of the use of AI in agriculture such as, accuracy, response time, requirement for Big Data, implementation approaches, high costs of data and technology and lack of flexibility (Eli-Chukwu, 2019; Giri et al., 2020). Nevertheless, Eli-Chukwu (2019) submits that there is considerable potential for AI in agriculture due to the immense growth anticipated in agricultural production to support the growth in the human population.

5 Impact of Innovation on Sustainability in Agriculture

5.1 Impact of syntropic agriculture and permaculture

Syntropic agriculture has been argued to be scalable and has been increasingly adopted in Brazil and other countries. It has been successful in achieving productivity targets while also supporting succession and regeneration of native ecosystems (Andrade et al., 2020). The impact of permaculture on sustainability has been studied by many researchers. Janzon (2018) performed a critical reading of literature related permaculture using the lens of John Dryzek's understanding of sustainable development. This study found while permaculture and sustainable development agreed on particular facets such as, holistic, anthropocentric, inclusive, and cooperative. However, they differ profoundly from the perspective of ideologies and images as regards the ideal appearance of a prospective, sustainable universe, such as need for economic growth, acknowledgement of limits to growth, and low extent of reform. Janzon (2018) therefore concluded that the likelihood of permaculture being used to support sustainable development was poor. From the perspective of sustainability, permaculture, with its emphasis on nature and its cooperative- applications, deals well with environmental and societal goals. As regards economic sustainability, however, the approach is not universally considered to be scalable and hence it may not be compatible in regard to contributing to considerable and consistent production of food. Nevertheless, it does have certain merits as regards teaching self-sufficiency in communities (Oberč & Arroyo Schnell, 2020). McLennon and colleagues (2021), relatedly, highlight that permaculture promotes natural ecosystems as multi-functional and places emphasis on self-sufficiency and self-regulation. The use of a combination of modern agricultural technology and data sciences (e.g., AI and ML) in this regard can help in realising sustainable food security due to their philosophy of reducing production inputs together with lowering the environmental footprint.

5.2 Impact of digital technologies

Watson and colleagues (2010) suggested the use of IS to create a society that is environmentally sustainable. Relatedly, the potential of precision technologies for agriculture to improve the sustainability of the environment has been highlighted. For example, these technologies have been promoted by Bayer Crop Science division as having the capacity to deliver farming practices with greater environmental soundness while simultaneously increasing farmer productivity (Clapp & Ruder, 2020). In particular, three principal arguments are provided by supporters regarding the positive impact, from a sustainability perspective, of these technologies. First, precision technologies are "climate smart" as they can be implemented in ways that enhance crop performance in less adverse climatic conditions together with easing carbon emissions. For instance, digital farming facilitates decision-making as regards utilisation of seeds and chemicals based on the condition of the soil and patterns of weather to increase yield. Additionally, no-till agriculture, which isolates carbon, can be facilitated by the technology. Moreover, it promotes wiser application of fertilizer, lowering carbon emissions and contamination from runoff. Similarly, gene-editing of crops can be performed to introduce traits that tolerate severe climate and withstand diseases that may increase with change in climate; and also reduce wastage of food and allied carbon emissions (Clapp & Ruder, 2020). Second, precision technologies can decrease toxins from use of agrochemicals along with the allied issue of resistance to herbicide in weeds. Third, precision technologies can enhance farming efficiency and productivity, which reduces the strain on natural resources and furthers farmer incomes while reinforcing goals associated with both economic and environmental sustainability (Clapp & Ruder, 2020). Other researchers (Lakshmi & Corbett, 2020) highlight that AI is predominantly utilised to improve efficiency and productivity in agriculture with environmental sustainability concerns taking lower priority. In this context, sustainability pertains to enhancing productivity without adverse impact to environments whilst simultaneously generating, if possible, environmental and societal benefits.

6 Findings and Opportunities for Future Research

It could be seen that the overall concept of sustainability has received considerable attention in research. Evidence of this could be found in the interpretation of sustainability and transition theories. Also, in the use of IS approaches to support sustainability research. With specific regard to sustainability in agriculture, the presence of several conceptual frameworks together with reporting on the principles and goals of sustainable agriculture reveal the global significance of this area. Additionally, literature provides considerable insights regarding approaches to sustainable agriculture such as, agroecology, climate-smart agriculture, regenerative agriculture, and agroforestry. From the perspective of innovation, it could be seen that innovation in agriculture through the use of natural approaches and digital technologies also received significant consideration in literature. The impact of these innovations on sustainability was also studied.

It could be seen that permaculture is one of many approaches to sustainable agriculture and involves practices such as, applying a systems approach, using ecosystem amenities and biodiversity, agroforestry, use of animals, promoting soil nourishing, regulating water flow, among others (Oberč & Arroyo Schnell, 2020). The implementation of permaculture, however, involves the buy-in and participation of many layers of participants including farmers and non-farmers (Fadaee, 2019). While permaculture practices can be inferred to promote sustainability, they are not typically considered to be scalable which impacts their economic outcomes (McLennon et al., 2021; Oberč & Arroyo Schnell, 2020). On the other hand, syntropic agriculture is reported to be scalable (Andrade et al., 2020) and is being used in certain countries.

Also, digital solutions have been reported to be beneficial with regard to market transparency, farm productivity, efficient transportation, and quality control (Deichmann et al., 2016; Mironkina et al., 2020). Precision farming systems, and digital platforms, devices, and technologies (e.g., RFID, robotic devices, sensors) (Deichmann et al., 2016; Mironkina et al., 2020; Neethirajan & Kemp, 2021a, 2021b) can utilise information from various sources such as, satellite imagery, GPS, and drones, to provide detailed information about a specific section of a farm including status of the soil, depth of ground water, rainfall, animal population, animal produce, disease outbreak, etc., (Mironkina et al., 2020; Oliver et al., 2010) which it can be inferred are useful for in improving the planning of crops and hence in the subsequent economic outcomes of a farm. The most popular underlying technologies appear to the AI (artificial intelligence), ML (machine learning), IoT (internet of things), cloud, and Big data (Abioye et al., 2022; Bacco et al., 2019; Neethirajan & Kemp, 2021b; Verdouw et al., 2021). As regards sustainability in agriculture, digital technologies are acknowledged to have the capacity to ensure the environmental soundness of farming practices by ensuring climate smartness and reducing toxins which can prospectively facilitate achievement of sustainability goals (Lakshmi & Corbett, 2020; Shankar et al., 2020; Vadlamudi, 2019). Simultaneously, their support for improving the efficiency and productivity of farming practices serves as twofold purpose by reducing the usage of natural resources and increasing farmer incomes (Clapp & Ruder, 2020; Lakshmi & Corbett, 2020; Linaza et al., 2021). There is a line of research, however, which also highlights the challenges associated with use of digital technologies in agriculture.

Challenges may non-technical aspects related to incentives, investments, and innovative tools. On the other hand, are technical challenges related to data, network, and information. Challenges frequently encountered appear to be technical in nature and include accuracy, response time, data volumes, requirement for Big Data, implementation approaches, high costs of data and technology, lack of flexibility (Bacco et al., 2019; Eli-Chukwu, 2019; Giri et al., 2020; Visser et al., 2021).

Based on the current literature review, there is a significant research gap related to sustainability and innovation in agriculture that needs to be addressed through future research. The review of literature related to sustainability and innovation in agriculture revealed the following gaps in research:

1. Though there are many frameworks to explain or direct sustainability in agriculture, evaluation of their appropriateness and effectiveness seem to be overlooked.
2. Various approaches to sustainable agriculture (Hill & MacRae, 1996) have been proposed, however, the status of their implementation appears to be under researched and underreported.
3. Goals related to sustainable agriculture have been submitted by many institutions (e.g., the European Commission). However, empirical evidence tracking and reporting their progress is not obvious.
4. Empirical evidence regarding the efficacy (or lack thereof) of different approaches to sustainable agriculture is limited.
5. Similarly, evidence of the efficacy of different innovations in agriculture also seems to be limited.
6. Research evaluating the impact of permaculture and digital technologies for sustainable agriculture is limited

Based on the research gaps listed in the previous section, Table 1 provides a summary of some research opportunities and associated research questions for future research.

Research Opportunity	Prospective Research Questions	Methods to Use
RO1 – Evaluating existing frameworks	How do the different frameworks compare with regards to sustainability outcomes in agriculture?	Empirical studies, Qualitative studies, Systematic literature

Research Opportunity	Prospective Research Questions	Methods to Use
related to sustainability in agriculture	Are the frameworks universally applicable for different sustainability approaches?	reviews and Field Experiments
RO2 – Evaluating, assessing, measuring implementation of approaches to sustainable agriculture	To what extent are the different approaches to sustainable agriculture implemented? Are some approaches more effective than others?	Qualitative Studies – Observations, Interviews, Focus Groups
RO3 – Evaluating, assessing, measuring goals related to sustainable agriculture	What are the goals of sustainable agriculture as reported by different global agencies? How are these tracked? What is their current status?	Surveys - Mix methods of qualitative and quantitative, Machine Learning tools
RO4 – Evidence of the efficacy of different approaches to sustainable agriculture	How do the different approaches to sustainable agriculture differ as regards their efficacy? What is the context in which they are most successful?	Qualitative Studies – Observations, Interviews, Focus Groups
RO5 – Evidence of the efficacy of different innovations for sustainable agriculture	How do the different innovations differ as regards their efficacy? Are there any specific conditions for their use?	Qualitative Studies – Observations, Interviews, Focus Groups
RO6 – Measuring the impact of permaculture and digital technologies for sustainable agriculture is limited	What are the impacts of implementing permaculture and digital technologies for sustainable agriculture?	Qualitative Methods Quantitative Methods including using Machine Learning tools

Table 1. Proposed Research Opportunities (ROs) for Sustainability in Agriculture

7 Conclusion

With the insights from the existing literature, it can be argued that innovation and sustainability can be achieved in agriculture through the use of natural practices such as, syntropic agriculture, permaculture and digital technologies. So while there are different frameworks to explain or direct sustainability in agriculture, it appears that there is no corresponding empirical research, specific to natural approaches and technological approaches, related to the evaluation of their appropriateness and effectiveness which is an opportunity for future researchers.

A key aspect of our findings also indicates that the while permaculture makes the farms sustainable and regenerative but effort and expenditure in setting up permaculture projects are high, and the rewards are much more long-term and sustainable. Organization can leverage the power of AI embedded IS systems to lower the usage of chemicals, lower the usage of water, drive efficiency in farm management operations and also improve farm yield. Green IT also can be an area that organization can explore to reduce carbon emissions and energy consumption across the farm-support IS systems.

It is acknowledged that this study has its limitations. First, the study's scope, purpose and associated research question and propositions were derived by the researcher based on his understanding of the topic. Second, this study did not use a precise methodology for the literature review such as, a systematic or semi-systematic approach. Consequently, the literature included in the review cover a broad spectrum and hence the outcomes of the research are more descriptive than providing a deeper analysis. Nevertheless, the paper has attempted to synthesize the present state of knowledge related to sustainability in agriculture, and also to summarise opportunities for further research.

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