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SYSTEMATIC REVIEW

Systematic Review on the Application of Nanotechnology and Artificial Intelligence in Agricultural Economics

Revisión Sistemática sobre la Aplicación de la Nanotecnología y la Inteligencia Artificial en la Economía Agrícola

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ABSTRACT

The convergence of nanotechnology and artificial intelligence (AI) represents a transformative force in agricultural economics, offering innovative solutions to longstanding challenges such as productivity inefficiencies, environmental degradation, and unsustainable resource use. This study presents a systematic literature review (SLR) aimed at synthesising theoretical frameworks, applications, and economic implications associated with these technologies in agriculture. A structured search strategy was developed using Boolean operators to combine key terms related to nanotechnology, AI, and machine learning. Comprehensive searches were conducted across six academic databases—Springer, IEEE Xplore, ACM, Science Direct, Wiley, and Google Scholar—complemented by manual and snowballing techniques. From an initial pool of 840 records, 55 studies met the inclusion criteria after rigorous screening and eligibility assessment. Findings indicate that nanotechnology enhances nutrient delivery, pest control, and crop monitoring through nanosensors and nano-fertilisers, while AI facilitates data-driven decision-making, yield prediction, and resource optimisation in precision farming. Despite promising results, challenges such as high initial investment, technological complexity, and limited access for smallholder farmers remain significant. The review concludes that the integration of nanotechnology and AI can improve agricultural efficiency, economic viability, and environmental sustainability. However, targeted investments, capacity-building, and interdisciplinary collaboration are essential to bridge the gap between innovation and implementation in developing economies.

Keywords*:* Agricultural Economics; Artificial Intelligence; Nanotechnology; Precision Farming; Smart Agriculture; Sustainability; Systematic Review; Technology Adoption.

RESUMEN

La convergencia de la nanotecnología y la inteligencia artificial (IA) representa una fuerza transformadora en la economía agrícola, al ofrecer soluciones innovadoras a desafíos persistentes como la ineficiencia en la productividad, la degradación ambiental y el uso insostenible de los recursos. Este estudio presenta una revisión sistemática de la literatura (RSL) orientada a sintetizar los marcos teóricos, las aplicaciones y las implicaciones económicas asociadas a estas tecnologías en la agricultura. Se desarrolló una estrategia de búsqueda estructurada utilizando operadores booleanos para combinar términos clave relacionados con la nanotecnología, la inteligencia artificial y el aprendizaje automático. Se realizaron búsquedas exhaustivas en seis bases de datos académicas—Springer, IEEE Xplore, ACM, Science Direct, Wiley y Google Scholar—complementadas con técnicas manuales y de bola de nieve. De un total inicial de 840 registros, 55 estudios cumplieron con los criterios de inclusión tras una rigurosa evaluación de elegibilidad. Los resultados indican que la nanotecnología mejora la entrega de nutrientes, el control de plagas y el monitoreo de cultivos mediante nanosensores y nano-fertilizantes, mientras que la IA facilita la toma de decisiones basada en datos, la predicción de rendimientos y la optimización de recursos en la agricultura de precisión. A pesar de los resultados prometedores, persisten desafíos importantes como la elevada inversión inicial, la complejidad tecnológica y el acceso limitado para los pequeños agricultores. La revisión concluye que la integración de la nanotecnología y la IA puede mejorar la eficiencia agrícola, la viabilidad económica y la sostenibilidad ambiental, aunque se requiere inversión específica, desarrollo de capacidades y colaboración interdisciplinaria.

Palabras clave*:* Economía Agrícola; Inteligencia Artificial; Nanotecnología; Agricultura de Precisión; Agricultura Inteligente; Sostenibilidad; Revisión Sistemática; Adopción de Tecnología.

INTRODUCTION

The emergence of nanotechnology and artificial intelligence (AI) has opened new frontiers for innovation in agriculture, particularly in addressing long-standing limitations of conventional farming practices. Initial efforts to integrate nanotechnology into agriculture originated in developed countries, driven by growing concerns that traditional farming methods were reaching their limits in enhancing productivity and could not adequately restore degraded ecosystems.(1) These early initiatives demonstrated the potential of nano-agriculture in improving input efficiency, crop protection, and environmental sustainability. Inspired by these advancements, developing nations have also begun exploring the application of nanotechnologies in their agricultural sectors.(2,3,4,5)

Despite significant public investment and global interest over the last decade, the pace of development in agricultural nanotechnology remains modest. This sluggish growth can partly be attributed to the complex and variable nature of farm environments, which differ significantly from the controlled laboratory conditions where many nano-based solutions are initially developed. Nonetheless, the potential applications of nanotechnology in agriculture remain extensive, from targeted delivery of fertilisers and pesticides to smart sensors for real-time monitoring of soil and crop conditions.(4,5,6,7)

At the same time, the integration of artificial intelligence into agriculture has brought about a transformative shift in how farm operations are managed and optimised. Since the 1980s, technological innovations have increasingly influenced agricultural practices, with AI tools enabling predictive analytics, resource optimisation, and data-driven decision-making. However, such advancements have also introduced economic complexities.(7,8,9) The high capital investments required for precision agriculture, such as establishing AI-driven orchards or deploying nanotech-based systems, demand rigorous financial planning. Improper investment timing or lack of cash flow management can lead to economic instability, especially for smallholder farmers.

Moreover, while technological innovation promises higher yields and sustainability, it can paradoxically contribute to market disequilibria. For instance, rapid output growth facilitated by AI and nanotech may outpace demand, leading to depressed market prices and farmer incomes. Additionally, environmental challenges such as the disposal of agricultural wastewater and biosolids, particularly on rice farms, raise concerns about economic feasibility, ecological safety, and long-term viability. Issues such as heavy metal contamination, increased production costs, and regulatory pressures to land-apply effluents necessitate integrated economic and technical approaches.(2,3,5,6)

In light of these dynamics, this paper presents a systematic review of the theoretical foundations, practical applications, and economic implications of applying nanotechnology and artificial intelligence in agriculture. The aim is to synthesise existing literature to identify opportunities, challenges, and gaps at the intersection of technological advancement and agricultural economics. By critically examining how nanotech and AI influence cost structures, productivity, environmental sustainability, and farmer livelihoods, this review provides a comprehensive outlook on how these innovations can be harnessed effectively within the agricultural sector.

METHOD

Conducting searches in online repositories constituted a crucial phase in executing the systematic literature review (SLR) on the *Application of Nanotechnology and AI in Agricultural Economics*. This process began with the formulation of a structured search string developed under established SLR protocols. The search string utilised a combination of key terms and their synonyms, integrated using Boolean operators. Specifically, the query applied was: ((NM sustainability OR NM safety OR nanosafety) AND (artificial intelligence OR AI) AND (machine learning OR ML)).

Using this search string, comprehensive searches were carried out across six well-established online repositories: Springer, IEEE Xplore, ACM, Science Direct, Wiley, and Google Scholar. These platforms were selected due to their broad coverage of scholarly literature in technology and applied sciences. In addition to database searches, manual techniques and snowballing—guided by the methodology—were employed to ensure the inclusion of all relevant studies. This combined approach yielded a total of 840 records.

Following identification, an initial screening phase was conducted to remove irrelevant or duplicate studies. A total of 110 duplicate records were excluded, alongside 30 records that were removed for other reasons, such as language constraints or being outside the scope of the review. This left 700 records for screening. During this phase, 520 records were excluded after reviewing titles and abstracts, mainly due to a lack of relevance to agricultural economics or insufficient methodological rigour.

Subsequently, 180 reports were sought for full-text retrieval. Of these, 10 reports could not be retrieved due to access issues. The remaining 170 reports were assessed for eligibility based on predefined inclusion and exclusion criteria. As a result, 115 reports were excluded for reasons such as absence of economic analysis (n = 60), lack of relevance to agriculture (n = 35), or unreliable methodology (n = 20).

Finally, 55 studies met all eligibility criteria and were included in the final review. These studies provide a robust and comprehensive basis for understanding the intersection of nanotechnology, artificial intelligence, and agricultural economics (figure 1).

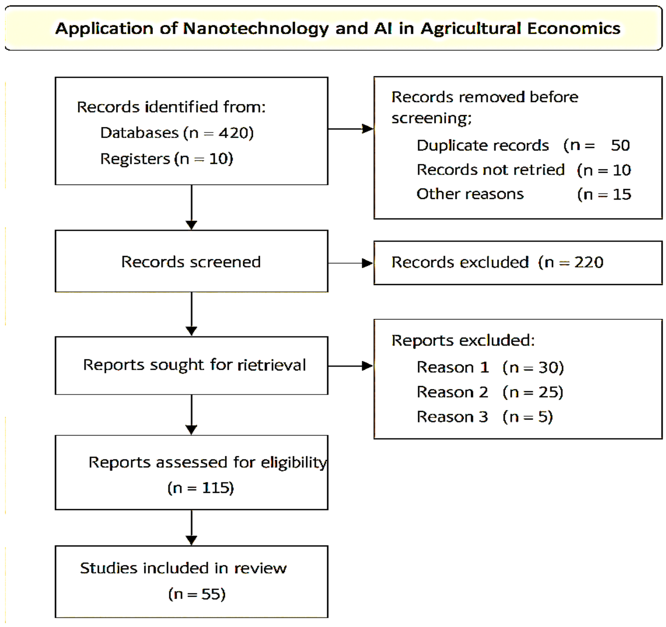

Figure 1. PRISMA Flow Chart of Literature Review

RESULTS

Artificial Intelligence in Agriculture

The latest developments in AI- and nanotechnology-based applications have advanced human conditions to the upper extreme level. Now, new disciplines are focusing on their combinations, creating huge potential for striking technological and socio-economic implications. The most notable among these blends of humanitarian technologies are applications in agricultural economics.

"In 2018, a research trend on using AI systems to monitor the lands and their applications impacts was identified. However, the remarkable research developments were missing up to the middle of 2020". So, a project was conducted to fill the research gap. The study investigated the state-of-the-art blends of AI-based actions in agricultural economics, and its outcomes were incredible. A large number of scientists have concerns about the specific topic (81,9 %), and the available AI instruments were satisfactory for the examination. As a result of the study, 45 widely known and accessible articles related to AI applications for monitoring agricultural land and agricultural economics impacts were identified and highlighted. Numerous articles could be found valuable for the scientists, technocrats, and researchers who are researching AI systems to perceive and analyse the agricultural aspect. The study involved an investigation of research publications in the topics related to AI operations, applications, and impacts on agriculture.[5,8,9,10]

Integration of Nanotechnology and AI

Nanotechnology and AI have revolutionised various processes across different disciplines. In agricultural economics, AI focuses on reducing environmental disaster severity, preparing for climate change, managing water, and using cost-effective technologies in precision farming. Nanotechnology applies to seeds, fertilisers, pesticides, herbicides, irrigation systems, solar power, and forecasting.[7,10,11,12,13]

Nanotechnology in agriculture is a new concept that implies advanced nanotechnology applications in agriculture, such as using nanomaterials for optimising nutrient use efficiency, modelling methods for metagenomic analysis, and nanosensors for monitoring soil microbiota. Processes like internalisation, uptake, distribution, and release of nanometals and ontogenies in plants are analysed to understand plant-nanometal interactions.[2,5,14,15,16,17]

Agricultural production is reliant on the supply of essential nutrients that must be proactively managed for both economic and environmental reasons. Almost 75 % of total fertiliser-N and P are not utilised by plants and jeopardises the environment. It can be speculated that AgNP fertilisers were available as ionic forms through the ionic release of AgNPs in the test systems. High nutrient concentration also supports the dissolution of AgNP. The ionic free Ag ions are taken up by plant roots in response to ion depletion and are effectively transported to the shoots.[7,9,10,11,12,13,14,15]

The advantages of incorporating nanotechnology in agricultural practices are the enhancement of properties and functionalities such as agrochemical delivery, sensitive detection, managing plant vital processes, etc. AI is a very broad science that combines using computer algorithms, mathematical, and statistical models with amassed data. The most common applications in agricultural economics and policy are resource allocation, yield production predictions, fair trade, search for solutions about reducing environmental disaster severity, application of instruments in the water management for agriculture, dealing with the need for climate change with appropriate modeling, low-cost instruments, and the use of economic resources in precision farming with the help of instruments and modeling.[7,9,12,16,17,18,19,20,21,22,23]

Impact of Nanotechnology on Crop Yield

A key focus and application has been on the impact of nanotechnology and artificial intelligence on agricultural economics. Market power, control of food safety and waste, and the impact on the impacts on crop yield with the advance of technology, such as the soil sensors, could be studied as a model.[9,14,23,24,25,26,27,28,29,30] In the future, advances in the two technologies, like the integration of joint use and more applications in the field, are needed in the agricultural economic field. This application and results could provide some contribution to the new data and perspective in agricultural economics using the technology and methodology. The applications of nanotechnology are increasing every year, and these emerging applications represent the potential to create a new set of possibilities for the scientific understanding of agricultural systems. Researchers are using nanotechnology to address a variety of issues that are relevant to crops, the natural environment, and cropping systems.[1,31,31,32,33]

But as novel technologies and products, applications to agricultural systems are not widespread. In particular, the application of nanomaterials to crop fields is currently limited since it raises many socio-economic and environmental questions. From these observations, a short primer on the needs and means for research on the sustainable use of nanotechnology in agriculture is provided. A range of emerging issues is described, including those related to health and the environment, as well as possible paths for research progress. The interests from the various applications of nanotechnology could be divided into two typical models.[4,7,35,36,37,38,39] One is the diæusion of nanoparticles from the original place to the surroundings and plants, and the second is the direct introduction of nanoparticles through spraying or watering the plants. In the real ðeld, however, these two models can overlap. Nanoparticles used in the field, as pesticides, are used to avoid sideward, lateral drift of nanopesticides; lateral drift is far more environmentally hazardous than drift that is only in the downward direction. How the drift of nanomaterials changes with different formulations can be tested in a novel way using foil sprays on a petri dish arrayed on 23 diĩerent soil types, covering a continuous range of sand, silt and clay loams. The nanoparticles can be measured after several days, using standard methods.

AI-Driven Decision Making in Agriculture

The key to agricultural technology is modernising farming operations and becoming a more profitable, sustainable, and efficient facility. With the advancement of AI, precision farming employs this computational intelligence for difficult, timely decisions, technique integration, and operational security. AI-driven decision frameworks for site-specific weed elimination in cereals can lead to broad-spectrum and cost-effective weed management. It is the actual 21st-century technology for the agriculture sector to make precise decisions and work with a high level of precision.[40] AI is valued because it can not only make decisions but also make predictions. As well as making judgments, it can aspire to 'anticipate.' As a result, in unpredictable circumstances, machines will respond and operate. Today's challenges, sustainability concerns, integration, time pressure, quality ambits, and operational safety to applying agitation or field procedures in agriculture to a high level can often be viewed as an optimization dilemma. Importantly, most applications are inherent and impact-dependent; therefore, they incorporate a high level of complexity. However, the same situations are

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ideal in terms of AI integration. They operate with a high level of exactness and, if sufficient data is used, in unpredictable environments equally well.

As a key pillar of precision farming, AI encompasses a range of applications which allow farmers decision-making in a timely manner, from site-specific crop management through to machine health monitoring and yield prediction. Thus, a wide selection of frameworks developed in this field is depicted. Every day, IoT sensors and Unmanned Aerial Vehicles collect millions of data points, constituting big data where the data are assembled to the cloud and thereafter analyzed by AI/ML algorithms. This focuses on the AI-driven decision-making part and elaborates on some of the latest frameworks. On the other hand, AI applications on machinery health monitoring and yield prediction are also presented. With AI, farming machines are becoming self-conscious and able to detect minor damages or deviations from safe operation, whereas yield maps help farmers to optimise treatment rates and improve the economic effect of crop protection measures.(2,3,4,5,33)

Economic Implications of Nanotechnology

Acknowledging the fact that nanotechnology is an emerging area of science and having activities in various new fields, agricultural economists have started to implement it for the betterment of agriculture. Nanotechnology may provide new avenues for the agricultural subsectors to play a vital role in overcoming the existing constraints. The manipulation of matter at the atomic and molecular level has opened the gate of new scientific advancement, mostly in the areas of medical and engineering sciences. As the field is advancing rapidly, it seems timely for social scientists to inquire whether it holds any direct or indirect implication for agricultural economics.(15,17,21)

Unexpectedly, financial allocation for research and development of the technologies that may have disproportionate advantages towards farming has been increasing. Since the early 1990s, consultative research has gained momentum for evaluating pooled technologies, like biotechnology and agrochemical input-based plant protection programs. The impact assessment of subsequent technologies, followed by participatory research, has shown enormous benefits from such farming interventions. Determining the economic consequences of converting normal-sized forms of materials into the nanometer range is a big challenge. Given the multiple applications of nanotechnology, a small measure implemented in industrial sectors might have strong spillover effects on agriculture.(5,6,7,8,9,10,11)

This review critically explores the emerging issues and possibilities of the economic implications of nanotechnology for agriculture. Broad areas for the intervention of nanotechnology in agriculture, including production, storage, packaging, processing, textiles, and a thorough exploration of forest and herbal science, are elaborated. Agricultural production systems may adopt nanotechnological intervention for the improvement of the efficiency of use of nutrient use. Detection of insect infestation in crop plants is a growing challenge in the era of free trade and biotechnological applications. Random adaptations of pests and diseases are witnessed worldwide with the ongoing changes in the climate system. Diplomacy-based surveillance systems have thus attained limits.(2,3,4,5) The development of light-based insect detection systems has been feasible with imaging techniques utilising the property of chlorophyll reflectance. Scalable-orbit components like sunlight, sky-view, and camera-based close-range image sensors can capture the radiation from plant foliage. These spectral signs can then be analysed with the in situ portable devices for triggering the action of agrochemicals.(33,35,40,41,42,43,44,45,46)

Cost-Benefit Analysis of AI Applications

The recipient of the agricultural digital revolution was the farmers. Farming, which is costly and frequently leads to cash losses, has become risky. Bayer, for example, with the Drip-By-Drip application, allows acting on the tasks based on the daily weather forecast for irrigated land. A comprehensive evaluation of the cost-distribution of AI applications will yield an examination of the practical feasibility of combining individual AI applications. Risky areas of land are determined by the Drip-By-Drip AI system in the research domain. The assistance of this technique throughout the growing cycle and at harvest, the cost shares of Stock and Drops, concerning this AI system, are calculated. Cost-shares can be compared to ecosystem service gains and existing modifications discussed. Ensuring that findings are of a likely concern, the most costly choice regularly occurs in other midpoint areas.(23,25)

Challenges in Implementation

Foresight and patience are essential for the successful application of a complex technology such as nanotechnology in what appears to be an even more complex, knowledge-poor agricultural environment. Data generation in the field of agricultural research is time-consuming and expensive. The success of an operation predictably becomes risky when, in each situation, many variables occur and interact.(25,26) A farm production system is dominated by several variables. The relationship between the nanomaterials and the nature of the complex is not fully understood yet. In this context, for nanotechnology to be successful, it is recommended that natural processes be simulated more effectively.

Guo et al.[14] studied several points relevant to eventual agronomic interventions of nanomaterials with model mathematical procedures. For plant productivity and better environmental security, the objective must be to improve the nutrients used.[27,28,29] Nutrient management is partly based on the practice of plant cultivation on the ions present in the plant-available from within the soil system.[2,3,4,5,9] Among them, nutrient transportation in soil-plant systems depends on many factors; these are related to the ion exchange, adsorption-desorption, and solubility-precipitation reactions. Such processes must be encouraged by nanomaterials. Nanomaterials designated for such purposes must focus on simulator action to ensure the availability of plant nutrients in the manner required. These actions are probably based on the attachment of these nanomaterials to the clay mineral particles in the size of the encapsulated state.

Another issue that needs to be studied is the recent increase in environmental concern about the stable development and the remediation of soils contaminated with pesticides, heavy metals, and radionuclides.[28,29] There are many findings in this area, although there seems to be increasing concern and emphasis on some descriptions and potential obstacles. Much more thought must be done on such a complicated and multi-faceted issue. Ultimately, it can be argued that, to some degree, agricultural production systems in the third decade of the 21st century are problematic. These systems are heavily based on water, likely over-supplemental irrigation almost globally. More changes can be found in the formulation of the inputs, which are especially subject to capital restoration of external demand.[30]

However, all the things that are harmful to the system need to address the major problems of this system that lead to over-dependency problems, and it is recommended to look for the effect and effectiveness of technology in the broadest sense, including nanotechnology. Developing promising countries can expect much higher dividends, especially in the most enjoyment of poor countries. In contrast, the productivity of input usage is so poor that it can be expected that the most benefit will take place in countries that have passed the Millennium Threshold.[27,32] This is particularly the case for water, a commodity that probably results in global conflict. Africa-led investments are high; there has been much investment in the past few decades, with social and ecological problems. Thus, the positive effects of agriculture-focused nanotechnology can reach much farther than the current typical boundaries of research and application. On the other hand, there are many development concerns that this topic could cause environmental and health concerns, which are indicative of the questions that should be investigated and considered about management now.[33]

Future Trends in Agricultural Economics

Give me a field where you need to apply technology, and I'll give you the name of a company that can do it. Thus begins the conversation on how math and algorithms can make it rain, literally. The interesting thing is that it won't just rain itself, it will rain in such a way that the farmer has a better crop yield, and that crop yield puts more money in the farmer's pocket. The trick is in the analysis of hordes of data to figure out ways in which something man has no control over, the weather, can be controlled. This computation-heavy task is handled by relatively simple means: setting up a system which takes as input the farmer's type of soil, what he has grown in the past, what he's planning to grow this season, current irrigation and weather conditions among others.[34,35]

This system then synthesises and crunches all the (un)stated information through a machine-learning algorithm and provides a schedule telling the farmer when and how much to water. And by doing so, a farmer in a remote county has an anticipated return of at least twenty percent on his investment this year. Over the past few decades, the field of risk management has developed a series of computational, statistical and mathematical models to aid the assessment, avoidance and acceptance of certain types of risks.[3,5] These models have been successfully applied to hardware-driven concerns like bridge or Aeroplane design, which have clear and strong mathematical relationships between forces exerted, stress exerted and possible breakage. Unaided modelling of software-related risks seemed insurmountable for a long time, as software defies physical representation, and its emergent properties are difficult to calculate. However, a recent discovery of the existence of non-random patterns in some software systems looked like a promising thought-to-form ahead road for people wanting software to worry less about modelling of potential cybernetic risks, offering viable options.[35]

Technological Barriers to Adoption

Technological barriers to its adoption as an emerging new technology for producing many economic and social innovations are also of importance in any country. Small and less-developed countries, through the adoption of any new technology, try to accelerate their pace of development. Mostly, this pace is as fast as their resources and capacity permit. Sometimes, therefore, in anticipation of exaggerated expectations, less consideration is given to the constraints the new technology or innovation would face in the future. The technology's choice, acquisition, diffusion and utilisation by peasant farmers are by themselves time-consuming matters.[3,5] This, in part, stems from the local learning by doing and learning by using of several different techniques and management of resources in the countryside and on the farm. More importantly, local adaptations and innovations do not belong to industrial entrepreneurship and are often slow to come. This may well be the case for the new promising technologies such as biotechnology, information technology and other modern technologies combined with highly mechanised and computer-oriented agriculture on a very large scale to compete with the export crop production of large farms in the developed countries.[36]

Investment and Funding Opportunities

It's expected that farmers and researchers are both excited to implement technologies in agricultural economics that involve artificial intelligence (AI) and nanotechnology. AI is seasoned in decision-making processes, especially in the presence of inconsistent data on crop load, pest attack, fertilisers, groundwater levels, horticultural knowledge, and market trends. Nanotechnology is best suited for storage and crop yield enhancement. It deals with the physical, chemical, and biological properties of structures at the nanometer scale (10–9 m). The most likely current and future applications in agriculture include pesticide protection, genetic engineering and biologicals, intelligent sensing, and nanoimaging.[37]

Conventional pest protection methods consume a vast array of chemicals, and a high percentage of pesticides can penetrate plant tissue, including the translocation of ineffective absorption. Nano-based pesticides can be heavily loaded on carrier materials with a high surface area and adequate retention power. The current standard for diagnosing plant diseases is primarily based on imaging. [38,39,40] Nanoparticles generated by quantum dots and superparamagnetic materials can significantly advance imaging technologies.[35] The environmental footprint of technological developments in the agricultural sector is a severe consequence of global climate change and risks to life on Earth. Yet, recent nanotechnological and AI advances show the potential for mitigating these consequences. For instance, nanoherbicide formulations boost the efficiency but decrease the amounts needed by up to 60 %. Moreover, through the use of UAVS and AI, the search, detection, and eradication of pests in fields have been revolutionised.[40,41,42,43]

Education and Training Needs

Foresight and patience are essential for applying nanotechnology in agriculture because the generation of data in most agricultural fields is time-consuming and expensive, and the success is uncertain because a large number of variables are involved in farm production systems. Successful applications of nanotechnology in agriculture might come into reality when the natural processes are simulated with greater scientific sophistication. Nanotechnology applications could make the soils 'clever' to improve the efficient nutrient use for greater productivity and better environmental security. Nutrient management with nanotechnology should rely on two important parameters. The first being, ions must be present in plant-available forms in the soil system; and the second, nanomaterials must facilitate processes that would ensure the availability of nutrients to the plants.[44]

Nanotechnology applications could reduce the impact of current adverse impacts of agriculture, such as overdependence on supplementary irrigation, vulnerability to climate and extreme weather conditions, and overall poor input and energy conversion in the current agricultural production system. It would also enhance the productivity of agriculture in particularly common crop production systems in developing countries, relying on the agricultural surplus water due to the unavailability of water during the reproductive phase of crops. As the potential benefits of some of these practices suggest, both in terms of crop water use efficiency and productivity gains, it is also likely to encourage the expansion of area under HYV and other irrigated crops. And because of the very nature of the problems that Indian agriculture is facing, the application of nanotechnology should be anticipated, as it is becoming an increasingly topical of active research concern globally. From an ethical perspective, there are also obstacles to a requirement that everyone will be a consumer first as human trials become prevalent.[45]

There is a skeletal workforce equipped with comprehensive, interdisciplinary knowledge and skills in both AI and nanotechnology. Relevant education and training in this regard are still in their infancy. Tertiary level curriculum on science and engineering would have to tailor towards what is known now as converging hi-tech areas of nano-technology, bio-technology and AI. But facilities to develop such skills are only available in a handful of developed countries and just a few institutions within them. Currently, nanotechnology and knowledge in AI are almost like "black boxes." Very few researchers in this regard can appreciate what is inside these black boxes, including their wider impact on economic systems. for researchers in agricultural economics to adapt to forging collaboration with and gain knowledge from the AI and nanotech research sector. So, it is imperative to have a research agenda in FARO that would develop the discipline as well as the knowledge base for it to deal with. At the same time, there would have to be a strong, coordinated push on nanotechnology and AI training and education to enhance national capacity.[46,47,48]

CONCLUSION

This systematic review demonstrates that the integration of nanotechnology and artificial intelligence (AI) holds significant potential to transform agricultural economics by improving productivity, sustainability, and decision-making efficiency. Nanotechnology applications, including nano-fertilisers, nanosensors, and controlled agrochemical delivery systems, can enhance nutrient use efficiency and environmental stewardship. Simultaneously, AI-driven tools support precision agriculture through predictive analytics, crop monitoring, and resource optimization.

However, the adoption of these technologies is hindered by challenges such as high implementation costs, limited awareness, technological complexity, and insufficient infrastructure—particularly in developing countries. The socio-economic implications of these innovations remain underexplored, and concerns over environmental safety and health impacts persist, especially in the case of nanomaterials.

For these technologies to deliver equitable benefits, a coordinated approach is necessary—one that includes policy support, investment in infrastructure, targeted training, and interdisciplinary research. By bridging the gap between innovation and practical application, nanotechnology and AI can significantly contribute to sustainable agricultural development and economic resilience. Further research should focus on field-level implementation, cost-benefit analysis, and the development of inclusive models that address the unique needs of smallholder farmers. These insights will be vital for scaling innovations that are economically viable, socially acceptable, and environmentally sound.

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