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Narrative Review Article

Ethics-Centered Approach to the Development and Application of Artificial Intelligence in Agriculture

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Abstract

Introduction: Artificial intelligence (AI) is revolutionizing agriculture by enhancing precision farming, resource management, and productivity. However, the extensive use of AI raises significant ethical challenges related to privacy protection, data security, fairness, transparency, accountability, and environmental sustainability. These issues are critical given agriculture's direct impact on human health, food security, and natural resource conservation. This article explores the ethical considerations in developing and applying AI in agriculture.
Materials and Methods: This study employs a critical literature review and conceptual analysis approach to examine current ethical challenges and proposed solutions in agricultural AI. Key topics covered include privacy risks due to data collection and storage, inequities in access to AI technologies, algorithmic transparency problems, and accountability mechanisms.
Conclusion: AI has great potential to advance sustainable agriculture, but ethical use demands strong privacy protections, transparent algorithms, and fairness to prevent discrimination. Legal and ethical frameworks must guarantee accountability and protect social and environmental values. Involving diverse stakeholders and providing tailored education fosters trust, inclusivity, and equal access. Although challenges like regulatory gaps and knowledge disparities exist, collaboration and mutual respect can enable sustainable and ethical AI use in agriculture. This approach aligns AI with food security, environmental protection, and social justice, maximizing benefits and minimizing harm.
Keywords: Ethics, Agriculture, Technology, Responsible AI.

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INTRODUCTION

Artificial intelligence (AI), as one of the advanced and transformative technologies, plays a crucial role in the development and optimization of modern agriculture and has recently become one of the key tools for increasing productivity, reducing costs, and intelligently managing resources. One of the primary applications of this technology is the prediction and monitoring of climatic conditions. Intelligent algorithms, by analyzing vast amounts of meteorological and climatic data such as temperature, humidity, precipitation, and wind speed, can accurately forecast atmospheric changes and assist farmers in planning the timing of planting, growing, and harvesting crops. Moreover, the use of machine learning systems in the rapid and precise detection of pests and plant diseases has brought about a significant transformation. These systems identify signs of pest damage by processing images of leaves, fruits, symptoms of diseases, and can automatically issue necessary alerts, which may lead to reduced pesticide use and improved crop health. In the area of optimal

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resource consumption, artificial intelligence enables precise management of irrigation and fertilization by considering factors such as plant type, growth stage, soil condition, and weather. This not only results in economic savings but also plays an important role in conserving water resources and reducing environmental pollution. On the other hand, vision-based technologies and deep learning integrated into agricultural robots perform harvesting operations mechanized with high accuracy. By reducing the need for human labor, they contribute to increasing the speed and quality of harvesting. Overall, artificial intelligence, by automating processes, enabling precise data analysis, and creating predictive capabilities, has transformed traditional agriculture into smart and sustainable agriculture, paving the way for a profound revolution in global food security. However, unconsidered use of artificial intelligence technology in agriculture can lead to social, economic, and environmental harms [1]. This article aims to identify the most significant ethical issues associated with the use of artificial intelligence in agriculture and to explain how these concerns can be addressed to ensure responsible and sustainable application. While previous studies have often addressed single ethical aspects of AI in agriculture—such as privacy, fairness, or accountability—this paper introduces a comprehensive ethics-centered framework that simultaneously examines five critical dimensions: privacy and data security, equity in access, algorithmic transparency, accountability, and stakeholder participation. This integrated and multi-dimensional approach, particularly within the agricultural context, represents the main innovative contribution of the study.

MATERIAL AND METHODS

This article is based on a qualitative review of journal articles and academic studies focusing on the ethical challenges associated with the application of artificial intelligence in agriculture. The review primarily addresses key issues such as privacy, data security, fairness, transparency, and accountability within AI technologies relevant to the agricultural sector.

DISCUSSION

Privacy protection and data security

One of the fundamental and controversial challenges in the application of artificial intelligence is the issue of privacy protection and data security [2]. AI systems require vast amounts of data for learning, decision-making, and prediction, which often include personal, locational, behavioral, or even biometric information of individuals. In many cases, this data is provided to machine learning systems without users' informed consent or clear awareness of how it is collected, stored, and utilized. For instance, in smart agriculture, data such as land location, yield amounts, soil conditions, and farmers' management practices may be collected by private companies and exposed to potential commercial misuse [3]. Such instances not only violate the privacy of individuals or businesses but, if disclosed, can result in consequences including identity theft, discrimination, or unfair decisions based on inaccurate information. Data security is also continually exposed to cyber threats. Hacking of databases, unauthorized access to sensitive information, or contamination of AI-based systems can cause irreparable damages to individuals, companies, or even critical infrastructures. Addressing these risks requires robust legal and ethical frameworks [4,5]. To tackle these challenges, solutions such as data anonymization, the use of ethics-driven algorithms, obtaining informed user consent, restricting access to sensitive data, and the development of comprehensive national and international regulations have been proposed [6].

Although legal frameworks such as the general data protection regulation (GDPR) provide safeguards [4], their direct application to agricultural contexts in developing countries remains limited [3]. This reveals an ethical dilemma where farmers must balance the benefits of accurate AI-driven predictions with the risk of exposing sensitive farm-level data [6]. Such tensions show that data security is not only a technical matter but also a social responsibility, requiring continuous regulatory adaptation to local agricultural realities [7].

Equity in access

A key ethical challenge in AI is unequal access to the technology. This challenge can widen the digital divide between communities, countries, and different social groups. While AI promises to transform agriculture, access remains highly unequal: farmers in developed countries benefit from harvesting robots and predictive algorithms, whereas many smallholders in developing regions lack even basic connectivity [8,9]. Although AI is promoted as a poverty-reduction tool, evidence from developing regions shows that without investment in connectivity and localized innovation, these systems may unintentionally reinforce socio-economic inequalities instead of reducing them [10,11]. Access to AI-based technologies requires advanced infrastructure such as high-speed internet, powerful hardware, high-quality data, and specialized human resources—factors typically available in developed countries or among affluent segments of society but scarcely present in low-income countries or underserved regions [9]. Furthermore, AI systems are often designed based on dominant languages and cultural data (such as English and Western countries) which results in limited attention to indigenous, regional, and minority languages and cultures [10]. These inequalities are not only ethically unjust but also exacerbate poverty, underdevelopment, and dependency of weaker countries on powerful corporations and governments. If AI develops without consideration of social justice principles and equal access, it will deepen rather than reduce these gaps [11]. Therefore, addressing this ethical challenge requires policymaking at both national and global levels to ensure fair access to this technology. Such measures may include investment in digital education, development of communication infrastructure, promotion of AI translation and localization, support for indigenous innovations, and knowledge transfer to less privileged countries.

Lack of algorithmic transparency

A fundamental ethical challenge in AI is algorithmic opacity, known as the “black box” phenomenon [12]. In many AI systems, especially those based on deep learning and complex models, decisions are made by systems whose internal logic is incomprehensible to many humans. In other words, while we know what data is input into the system and what output is produced, the process in between—how data is analyzed, weighted, and decisions are made—often remains obscured. This paradox highlights that while AI can reduce human error, opacity in decision-making may institutionalize hidden biases [13,14]. Therefore, regulatory oversight in addition to explainability becomes essential [12]. Without such measures, the risk is not only lack of trust but also the reproduction of systemic discrimination in agricultural decision-making. The opacity prevents both users and developers from explaining why a specific decision was reached. This has several significant consequences. One is the erosion of public trust. Ordinary users and even experts are unlikely to trust a system whose decision-making process they do not understand. Another is the risk of perpetuating hidden biases and discrimination. Algorithms trained on historical data may

replicate or even amplify past inequalities without anyone realizing it. For example, if past data reflects discrimination against a particular group or approach, the system may reproduce the same pattern without providing a clear explanation [14]. A primary reason for algorithmic opacity is their complexity, particularly in deep learning models that operate with millions of parameters [15]. This highlights the importance of clear regulatory frameworks [16], particularly in addressing issues of accountability, which is elaborated in the subsequent section.

Accountability

Accountability is a core ethical challenge in artificial intelligence. Specifically, when an AI system makes a decision or takes an action that results in error, harm, or discrimination, who should be held responsible and answerable? Typically, responsibility for decisions and behaviors is attributed to a specific individual or institution, but in AI, due to the automated and complex nature of algorithms, this issue becomes ambiguous and multilayered [17]. AI algorithms sometimes make decisions based on big data and complex models without direct human intervention. Additionally, multiple parties are involved in the development and deployment of AI systems, ranging from software designers and developers to data providers, system owners, and end users. This dispersion of roles makes accountability unclear and complicates the process of assigning responsibility when problems arise [18]. The consequences of lacking clear accountability are severe. First, if agriculture suffers losses due to unfair or harmful decisions made by an AI system—for example, incorrect recommendations on fertilizer or irrigation usage—it becomes difficult for farmers to access legal rights and claim compensation [19]. Second, the absence of accountability may result in the failure to correct and update systems, causing similar errors to recur on other farms [20]. In some contexts, risk-sharing mechanisms can mitigate part of the damage caused by AI errors [17]. However, in many developing countries the absence of such mechanisms leaves smallholder farmers to bear the full consequences of algorithmic mistakes, raising serious issues of fairness and justice [19,20]. This makes accountability not only a technical requirement but also a matter of distributive justice in global agriculture. Numerous real and hypothetical examples illustrate this challenge. For instance, AI-based pest prediction systems have been reported to issue false alerts, encouraging unnecessary pesticide use, leading to financial losses, environmental damage, and product contamination [21]. Additionally, when drones are employed to assess crop health, errors in image analysis can result in healthy plants being mistakenly identified as diseased, prompting farmers to destroy crops or apply pesticides unnecessarily [22]. Such errors can cause loss of harvestable produce, environmental harm, and economic damage [20]. Therefore, in the absence of a clear accountability framework, it becomes difficult to determine whether the fault lies with the farmer, the algorithm developer, or the technology provider. Moreover, accountability is closely intertwined with other ethical challenges such as algorithmic opacity and data bias, because if decision-making processes are unclear or data are collected in discriminatory ways, identifying the source of errors and assigning responsibility becomes even more difficult [23]. Hence, accountability is not merely a technical or legal requirement in AI but a fundamental ethical principle that ensures emerging technologies are used for human benefit and social justice, with negative consequences being preventable and traceable.

Future solutions

Development of ethical and legal frameworks

One key solution for ethical AI development in agriculture is creating comprehensive ethical and legal frameworks that guide responsible, fair, and transparent use of AI technologies. These frameworks consist of a set of principles, values, laws, and regulations that define the responsible, fair, and safe use of AI technologies [24]. The importance of developing such frameworks is particularly pronounced in agriculture due to its close connection with human health, food security, natural resource conservation, and environmental protection. Any error or misuse in this sector can lead to widespread consequences. Therefore, ethical and legal frameworks should be designed in a way that not only facilitates technological development but also ensures that AI serves the interests of all stakeholders, including small and large farmers, society, and the environment [25]. Key components of these frameworks include privacy preservation and data security, ensuring that farmers' personal and sensitive information is properly protected and safeguarded against misuse [26]. Transparency and explainability of algorithms must also be prioritized, enabling users to understand how AI makes decisions and thereby build necessary trust [27]. Ensuring fairness and non-discrimination is another critical aspect. Furthermore, mechanisms for accountability and responsibility need to be established so that, in the event of errors or harm, the responsible parties can be identified and held answerable. Additionally, the frameworks should guarantee that AI is developed and applied in ways that support environmental sustainability and the preservation of natural resources without causing harm [28].

The role of various institutions in developing ethical and legal frameworks for AI is vital [29]. Governments and legislative bodies must enact comprehensive and clear laws that transform ethical guidelines into legal obligations with enforceable guarantees. Specialized agricultural and technological organizations are responsible for establishing technical and ethical standards and guidelines to facilitate proper implementation [30]. Moreover, active participation of farmers and other stakeholders in the development of these frameworks is essential to address their real concerns and needs. The benefits of establishing such frameworks are extensive. They increase public and user trust in AI technologies, leading to greater acceptance and wider adoption. These frameworks also improve decision quality by reducing the risks of errors, misuse, and discrimination. Furthermore, clear and harmonized frameworks can foster international cooperation and create a level playing field in agricultural digital markets. The development and implementation of ethical and legal frameworks do not hinder technological advancement; rather, they ensure sustainable, responsible, and human-centered progress [31].

Education and empowerment

An important solution to ethical challenges in AI for agriculture is educating and empowering users. Users include farmers, farm managers, experts, and other stakeholders in this field who must acquire the necessary knowledge and skills to use AI technology consciously and responsibly. This solution is vital because AI cannot be used ethically without users understanding its workings and limits. Appropriate education enables users to apply the technology in an informed and responsible manner, reduce the likelihood of errors and misuse, and play an active role in its improvement [32]. Educated users contribute to system enhancement by identifying and reporting problems and providing feedback to developers. This process increases trust in the technology, facilitating its sustainable acceptance and use. Educational content should cover fundamental AI concepts and the functioning of algorithms, the importance and sensitivity of data, and related

ethical considerations such as privacy preservation, fairness, transparency, and accountability [33]. Additionally, practical training on the proper use of AI systems in agriculture—including optimal resource management, problem identification, and error reporting—is a critical part of this process.

Training programs must be designed to match users' literacy levels and be delivered in local languages to ensure accessibility and comprehension. Methods of instruction may include in-person and online courses, interactive workshops, and the creation of simple, practical educational materials. Moreover, establishing support and advisory networks to address users' questions and problems plays a vital role in their empowerment. Collaboration among government agencies, the private sector, and educational organizations is essential for developing sustainable and broad-reaching training programs. Nevertheless, challenges persist, such as insufficient financial resources and infrastructure for training in rural areas, as well as disparities in literacy levels and access to AI technology [34].

Creating clear and comprehensible systems

An essential ethical approach in agricultural AI is designing transparent and understandable systems. Transparency means that users can easily comprehend how the system operates, based on which data and algorithms decisions are made, and how outcomes are produced. To ensure AI systems are understandable to users with varying levels of knowledge, simple user interfaces, clear explanations, and interpretable outputs must be provided. This enables even non-technical users to grasp system functionality and properly utilize its results [35]. In this regard, the development of approaches known as "Explainable AI" is of great importance. The goal is to design AI models so that their outputs and decision-making processes can be interpreted and reviewed by humans [36]. Here, designing interactive interfaces that allow users to ask questions and receive answers about the system's functioning is crucial. Moreover, in sensitive domains such as safe agricultural products, dispute resolution, finance, and education, stricter regulations should be enacted to mandate algorithmic transparency. Interdisciplinary education for developers, ethical evaluation of algorithms prior to deployment, and the establishment of independent bodies for review and oversight are additional strategies that can help mitigate this challenge. However, the complexity of algorithms and the large volume of data used may make transparency difficult. Therefore, close collaboration among software developers, user interface designers, technology ethics experts, and end users is essential to create systems that are both advanced and efficient as well as transparent and comprehensible [37].

Stakeholder participation

Active stakeholder participation is another essential approach for ethical AI development in agriculture. Stakeholders comprise farmers, experts, developers, policymakers, NGOs, and local communities. Participation ensures that AI technology is designed and implemented in a manner consistent with the real needs, values, and constraints of users and the agricultural environment [25]. Moreover, active stakeholder engagement increases technology acceptance, user trust, and guarantees adherence to principles of fairness, transparency, and protection of individual rights. It also facilitates obtaining feedback from those who practically use the systems, thereby improving decision-making quality and technology performance. Ethically, stakeholder presence not only helps identify and prevent potential discrimination and biases in algorithms but also ensures privacy protection, data security, accountability, and responsibility for possible issues [38,39,40]. Effective

participation can be achieved through methods such as consultation meetings, interactive workshops, surveys, focus group interviews, and online platforms that enable remote involvement. Implementing these approaches faces challenges like knowledge gaps, conflicting interests, and coordination difficulties, but building mutual trust and respect among stakeholders can largely overcome them. To provide an integrated overview of how the identified ethical challenges can be effectively addressed, a conceptual framework is presented in Table 1, which links each challenge to its corresponding solutions.

Table 1. Conceptual framework linking ethical challenges of AI in agriculture with corresponding solutions.

Ethical Challenges	Proposed Solutions
Privacy & Data Security	Development of ethical and legal frameworks; robust data protection regulations
Equity in Access	Education and digital literacy; infrastructure investment; knowledge transfer
Algorithmic Transparency	Explainable AI; interpretable models; user-friendly and comprehensible systems
Accountability	Clear responsibility mechanisms; legal oversight; monitoring and redress systems
Stakeholder Participation	Inclusive stakeholder engagement; participatory design; consultation and workshops

Practical applications and case studies

In addition to the conceptual and ethical challenges discussed above, it is important to demonstrate how artificial intelligence has been applied in real agricultural projects across different countries. These practical examples highlight both the potential benefits of AI and the ethical issues that must be considered. For instance, in India, the e-Choupal initiative has connected smallholder farmers to digital platforms and AI-based advisory systems, improving market access and increasing farm productivity [41]. In China, AI-enabled drones and machine vision systems are widely used for pest detection and precision spraying, reducing pesticide consumption while raising concerns about data ownership and privacy [42]. Similarly, greenhouse farms in the Netherlands, particularly in the Westland cluster, have integrated automation and AI-driven climate control systems that enhanced resource efficiency and optimized decision-making. However, these developments have also raised ethical concerns related to social inequality, labor precarity, and the consolidation of capital, which disproportionately affect smaller producers [43]. In Kenya, smallholder farmers have begun adopting AI-powered applications such as the Virtual Agronomist and PlantVillage. For instance, one coffee farmer reported an increase in yield from 2.3 to 7.3 tonnes in a single season, illustrating the transformative potential of AI in strengthening farmers' adaptive capacity to climate variability [44]. Nevertheless, the widespread diffusion of these technologies remains constrained by the digital divide, particularly due to inadequate infrastructure, poor connectivity, and limited digital literacy in rural communities [45]. In Brazil, the adoption of artificial intelligence in sugarcane production has optimized resource allocation, improved crop management practices, and enhanced economic outcomes by increasing precision in yield forecasting, soil nutrition management, disease diagnosis, and water utilization [46]. However, the opaque nature of deep learning models—where attribution maps often fail to align with expert judgment—raises accountability concerns regarding errors in fertilizer recommendations [47]. These case studies illustrate that while AI technologies offer significant opportunities to enhance productivity, sustainability, and resilience in agriculture, their ethical implications—including fairness, transparency,

accountability, and equitable access—remain critical. Integrating lessons from these projects strengthens the argument for comprehensive ethical frameworks and stakeholder participation in the design and deployment of agricultural AI systems.

CONCLUSION

A major concern is that if ethical frameworks are shaped mainly by wealthy nations, they may function as instruments of market control rather than global equity. Therefore, a context-sensitive and inclusive approach is required to ensure that vulnerable farming communities are not marginalized. This perspective emphasizes that responsible AI in agriculture must balance global principles with local realities to achieve fairness and sustainability. Without clear informed consent and robust security measures, the risk of data breaches, commercial exploitation, and erosion of trust increases substantially [1,39]. The absence of comprehensive legal frameworks in many regions worsens these risks, underscoring the urgent need for national and international regulations tailored to the agricultural context.

This article emphasizes the importance of developing integrated ethical and legal frameworks that balance data collection needs with privacy rights, ensure algorithmic transparency to enable users' understanding and trust, and promote fairness to prevent bias against marginalized groups such as smallholder farmers. Accountability mechanisms are indispensable to hold developers, policymakers, and users responsible for AI outcomes, fostering responsible innovation and minimizing harm. Moreover, the sustainable development of AI in agriculture demands active stakeholder participation throughout design and implementation phases. Involving farmers, agricultural experts, software developers, policymakers, and local communities ensures that AI solutions are grounded in real-world needs and challenges, increasing the likelihood of adoption and positive impact. Empowering users through accessible training programs, delivered in local languages and adapted to varying literacy levels, is also crucial. These efforts enhance comprehension and enable farmers to effectively and ethically engage with AI tools, reducing disparities in technology access and usage. While challenges such as coordination difficulties, knowledge gaps, and resource constraints remain, building trust and mutual respect among all involved parties can effectively overcome these barriers. This multi-faceted, ethics-centered approach ensures that AI technologies in agriculture not only drive technical innovation but also uphold social justice, environmental sustainability, and human dignity. The principal innovation of this work lies in advancing a holistic and multi-level perspective on ethical AI in agriculture. By explicitly linking ethical dimensions to practical agricultural applications and proposing combined legal, technical, educational, and participatory solutions, this study provides an integrated framework that is rarely offered in the existing literature, especially with specific attention to the realities of developing countries. In conclusion, this article advocates a responsible AI trajectory that integrates robust ethical and legal safeguards, fosters inclusive stakeholder engagement, and prioritizes education and transparency. By doing so, artificial intelligence can realize its full potential as a catalyst for equitable, sustainable, and human-centered agricultural development that benefits all actors in the ecosystem while mitigating risks and preventing harm.

ETHICAL CONSIDERATIONS

Ethical issues (such as plagiarism, conscious satisfaction, misleading, making and or forging data, publishing or sending to two places, redundancy and etc.) have been fully considered by the writer.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests.

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