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Blockchain-Enabled Machine Learning in Agriculture

Shreyasi[1], Rohan Kumar Raman[2*], Ujjwal Kumar[2], P C Chandran[2], Anup Das[2], Pawan Jeet[2], Banda Sainath[2] and Anil Kumar Singh[2,3]

ABSTRACT

The integration of blockchain and machine learning (ML) offers new opportunities to make agriculture more transparent, secure and efficient. Blockchain provides a reliable and tamper-resistant platform for recording agricultural activities, transactions and product information, while ML helps analyse data, identify patterns and support informed decisions. This article discusses the basic concepts, types and working mechanisms of blockchain, along with ML techniques used in blockchain-based applications. It highlights the potential of these technologies to improve farmers' income and livelihoods through transparent supply chains, timely payments, better access to credit, efficient crop insurance, verification of agricultural inputs and carbon-credit opportunities. A hypothetical dataset of 100 observations is also used to demonstrate the application of a Decision Tree classifier for identifying potentially suspicious agricultural records using IoT-based parameters. The illustrative example shows how ML-based analysis, combined with blockchain-enabled record keeping, could strengthen data verification and promote trust in digital agricultural systems.

Keywords: Blockchain technology; Machine learning; Smart agriculture

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INTRODUCTION

Blockchain is a shared, computerized record keeping system which cannot be modified or say is immutable. The concept of blockchain was introduced in the year 2008 Bitcoin whitepaper. Earlier Stuart Haber and W. Scott Stornetta (1991), Nakamoto developed the first decentralized blockchain system, which was implemented along with the launch of Bitcoin in 2009. A key feature of blockchain technology is that data is distributed across many computer systems, which makes it very difficult to alter. The transactions and tracking of assets are validated through a consensus mechanism to ensure agreement across the network. In blockchain technology, each transaction is grouped into blocks and afterwards, it is linked together to form a secure and transparent chain. This structure helps to maintain the integrity of data and a tamper proof record which makes it ideal for applications like cryptocurrency by recording financial transactions, verifying ownership and ensuring digital coins cannot be duplicated without approval from banks, as well as in supply chain management by replacing siloed databases with decentralized transparency, making it impossible to alter past transactions (Zheng et al., 2017). Nodes are considered as an important term that frequently use in blockchain. Actually, these are network of devices which form a blockchain's infrastructure. The blockchain's real-world applications are seen in the field of estate, finance, supply chain management, healthcare, agriculture etc.

Types of Blockchain

Based on utility, blockchain is commonly categorized into four types: Public, Private, Hybrid, and Consortium blockchains.

Public Blockchain- This is an open ledger that anyone can use to view, read, and add records. In this network, every node is able to see the records, check transactions, participate in the agreement process, and create new blocks.

Private Blockchain-In this network, only authorized users, nodes, and entities can take part. A central body or organization sets the rules, manages security, controls access rights, and defines the agreement process. Its design builds trust among users while keeping data confidential and operations efficient. It offers high efficiency and fast processing speed.

Consortium Blockchain- It is semi-decentralized, control is shared among a preselected group of several organizations, and no single entity runs it. It aims to balance the privacy of a private network with the openness of a public one. All network operations are carried out jointly by the organizations involved.

Hybrid Blockchain- It combines the strengths of public and private networks. Organizations can keep sensitive information and data in a closed, permissioned system, while using a public blockchain for open verification, transparency, and accountability (Johar et al., 2021).

[1]Computer Science and Engineering Manipal University, Jaipur
[2] ICAR Research Complex for Eastern Region, Patna
[3]Bihar Agricultural University (BAU), Sabour
[*]Corresponding Author E-mail: rkraman19icar@gmail.com

The working mechanism of blockchain in agricultural systems is illustrated in following steps and fig.1:

Step1: Transaction Request: A farmer or another user starts a transaction using a digital platform. It may involve buying seeds, fertilizers, or other inputs, selling agricultural produce, or receiving subsidies and insurance payments.

Step2: Creation of a Transaction Block: The transaction details are collected and stored in a digital block. The block includes information such as the transaction record, date, time, and a unique identification code.

Step3: Sharing the Block with Network Nodes: The new block is shared with computers connected to the blockchain network. These computers are called nodes, and they help check the transaction information.

Step4: Transaction Verification: The nodes check the transaction details according to the network's rules. The blockchain system uses a consensus method to decide whether the transaction can be accepted.

Step5: Reward to Nodes for Proof of Work: In a Proof of Work system, miners use computing power to solve a mathematical problem. The successful miner may receive a reward for adding the verified block to the blockchain.

Step6: Addition of the Block to the Blockchain: After approval, the new block is linked to the existing chain. This creates a record of the transaction that can be traced later and is difficult to change without detection.

Step7: Transaction Completion: Once the transaction is confirmed, the participants can check the recorded details. This helps farmers and other stakeholders track payments, agricultural produce, and related activities.

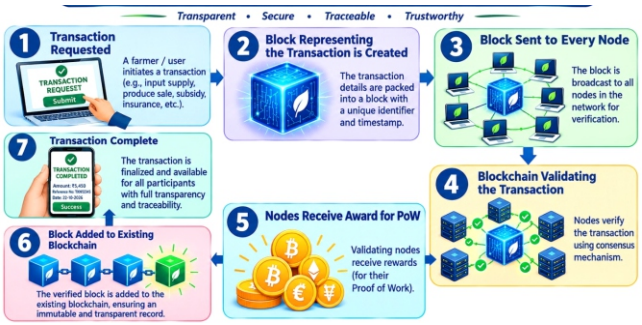


Fig.1. Flow Diagram of the Blockchain-Based Transaction Mechanism in Agricultural Systems

Blockchain algorithms and machine learning: -

Machine Learning (ML) is a branch of computer science in which systems improve their performance on a task by learning from data, rather than relying on step-by-step instructions written in advance. Instead of being told exactly what to do, the system identifies patterns in examples and uses them to make predictions or decisions on new, unseen data. The algorithms in ML try to identify patterns in historical data, to build models that perform tasks like recognizing images, certain languages and translating them or forecasting trends. ML is categorized into four parts such as supervised learning, unsupervised learning, semi-supervised learning and reinforcement learning. Blockchain work along with ML to ensure security, transparency and data sharing with trust. Machine learning strengthens blockchain systems by analyzing verified data to reveal hidden patterns, detect fraudulent activity, predict network behavior, and support automated decision-making. In this relationship, blockchain supplies a reliable and tamper-resistant source of data, while machine learning turns that data into actionable insights.

Machine learning methods applied in blockchain applications:

Machine learning (ML) and blockchain technologies can work together to make data sharing, model training and AI applications more secure, transparent and reliable. Different blockchain mechanisms help maintain trust among network participants without depending on a central authority. Some important methods are described below.

a. Consensus Algorithm: It allows all participating nodes in a blockchain network to agree on shared information, including machine learning model updates and training results, without depending on a central authority.

b. Proof of Work (PoW): It verifies blockchain transactions through complex mathematical problems solved by computers called miners. In ML, it can help verify contributions during decentralized model training. However, it requires high computing power and energy.

c. Proof of Stake (PoS): It selects validators based on the cryptocurrency they hold or lock as a stake. In ML, it supports secure sharing, training and exchange of AI models through decentralized platforms.

d. Practical Byzantine Fault Tolerance (PBFT): It enables network nodes to agree on valid information even when some nodes fail or provide incorrect data. In ML, it supports secure collaborative model training across IoT devices and distributed networks.

e. Hashing Algorithm: It converts data into unique digital fingerprints (hash values) to detect unauthorised changes. In ML applications, it helps protect datasets and verify the integrity and authenticity of AI models.

Role of Blockchain in Improving Farmers' Income and Livelihood

Transparent Agricultural Supply Chains: Blockchain ensures secure and traceable agricultural supply chains by recording farmer identity, crop origin, quality, storage, transportation and pricing, thereby improving transparency, preventing fraud and enabling farmers to receive better returns for quality-assured produce.

Smart Contracts for Direct Payments: Blockchain-enabled smart contracts automatically execute agreements upon fulfilment of predefined conditions, such as quality verification and product delivery, ensuring timely payments, reducing paperwork and disputes, and strengthening trust among farmers, buyers and agribusiness enterprises.

Improved Access to Credit and Finance: Blockchain maintains secure and verifiable records of crop production, harvest volumes, transactions and farm activities, helping financial institutions assess farmers' creditworthiness, lower verification costs and provide timely agricultural loans (Kamble et al., 2023).

Efficient and Transparent Crop Insurance: Integrating blockchain with IoT sensors, weather information and smart contracts enables transparent crop-loss assessment and automatic insurance claim processing, reducing administrative delays and ensuring faster compensation to farmers affected by adverse weather conditions.

Prevention of Counterfeit Seeds and Fertilizers: Blockchain-based traceability systems use QR codes and RFID tags to record input batch numbers, manufacturers, expiry dates and quality certificates, enabling farmers to verify product authenticity and avoid counterfeit agricultural inputs and related crop losses.

Carbon Credits and Additional Income: Blockchain technology can support transparent recording and verification of sustainable agricultural practices, including conservation tillage, efficient input use and crop rotation. Such traceable records may facilitate carbon-credit verification and trading, improve accountability and create additional income opportunities for farmers adopting climate-friendly practices (Giganti et al., 2024).

Illustrative Example: Integration of Machine Learning and Blockchain for Smart and Secure Agriculture

The integration of machine learning (ML) and blockchain can help identify suspicious agricultural transactions, improve data reliability and strengthen transparency in digital farming systems. The following hypothetical example demonstrates how a Decision Tree algorithm can be applied to detect potentially fraudulent records generated through IoT-enabled agricultural monitoring.

Data Description: A hypothetical dataset comprising 100 observations was taken to illustrate the proposed approach. It included farmer identification, farm characteristics, environmental conditions, crop performance, sensor alerts and blockchain transaction information. The dataset contained the following variables:

Table 1. Description of variables used in the illustrative dataset

Variable	Description	Unit/Type
Farmer ID	Unique identification code assigned to each farmer	Categorical
Farm Size	Total cultivated agricultural area	Hectares (ha)
Soil Moisture	Soil water content recorded by sensors	Percentage (%)
Temperature	Environmental temperature during observation	°C
Rainfall	Total rainfall during the observation period	mm
Fertilizer	Quantity of fertilizer applied per hectare	kg/ha
Crop Health Score	Indicator of overall crop health	0–100
Sensor Alerts	Number of abnormal notifications generated by IoT sensors	Count
Blockchain Transactions	Number of agricultural transactions recorded on the blockchain	Count
Yield	Crop production per unit of cultivated area	Tonnes/ha (t/ha)
Fraud Flag	Target variable identifying suspicious or legitimate records	Binary (0 = Non-fraud; 1 = Fraud)

Farmer ID was retained for identification purposes and excluded from model prediction. The fraud flag represented artificially assigned labels for this illustrative dataset, rather than independently verified instances of actual fraud.

MATERIALS AND METHODS

The study employed a Decision Tree classifier following the CART methodology to categorize agricultural records into legitimate and potentially fraudulent transactions (Breiman et al., 1984). The target variable, Fraud Flag, was encoded into two categories: 0 for non-fraud and 1 for fraud. The 100 observations were randomly partitioned into training and testing datasets, comprising 80% (80 observations) and 20% (20 observations), respectively.

Model development was based on the Gini impurity measure, which helped determine the most informative variables and appropriate threshold values at each branching point. The algorithm progressively divided the dataset into smaller groups to improve classification accuracy and generate interpretable decision rules. The final tree highlighted sensor alerts, soil moisture and rainfall as important parameters for identifying potentially abnormal agricultural records.

RESULTS AND DISCUSSION

The Decision Tree model identified sensor alerts, soil moisture and rainfall as the key variables for classifying suspicious agricultural records. The model generated the following illustrative decision rules:

Table 2. CART-based decision rules for agricultural fraud classification.

Decision rule	Conditions	Classification
Rule 1	Sensor alerts < 3 and soil moisture < 58%	Non-fraud
Rule 2	Sensor alerts < 3, soil moisture ≥ 58% and rainfall < 113 mm	Non-fraud

Decision rule	Conditions	Classification
Rule 3	Sensor alerts < 3, soil moisture ≥ 58% and rainfall ≥ 113 mm	Fraud
Rule 4	Sensor alerts ≥ 3	Fraud

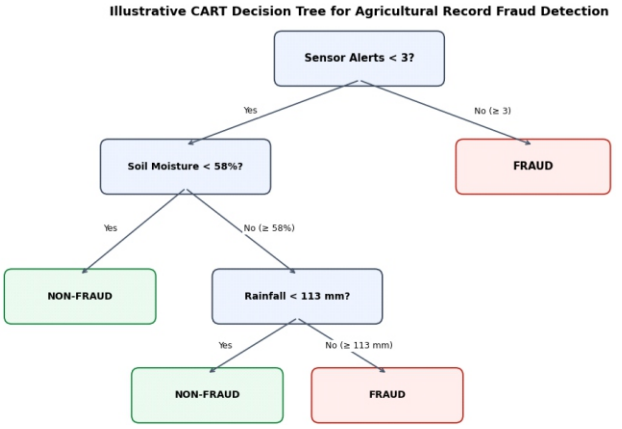


Fig. 2. CART-based decision tree illustrating the classification of potentially fraudulent agricultural records using IoT sensor alerts, soil moisture and rainfall parameters

The Decision Tree identified sensor alerts, soil moisture and rainfall as important indicators for detecting potentially fraudulent agricultural records. Integrating ML with blockchain can strengthen data verification, transaction transparency and security in smart agriculture.

CONCLUSION

Blockchain and machine learning offer complementary opportunities to improve agricultural transparency, data security, traceability and decision-making. Their integration can support farmers through better market access, timely payments, financial services, crop insurance and sustainable income opportunities. The illustrative Decision Tree approach further demonstrates the potential of ML to identify suspicious agricultural records, contributing to more reliable and secure digital agriculture.

OpenAI was used to assist in improving the language, grammar, clarity and readability of the manuscript and in preparing illustrative figures and images.

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