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SECURING SOIL HEALTH: LEVERAGING BLOCKCHAIN TECHNOLOGY FOR RELIABLE SOIL SAMPLING & TESTING

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ABSTRACT
For efficient land management and harvesting, reliable soil testing and sampling is an essential component of agricultural techniques. The accuracy of soil data is at risk, though, due to problems like farmers using the same names and the frequency of inaccurate test results. Soil sampling and testing procedures may be made more secure and trustworthy with the use of blockchain technology, which is discussed in this study. Our proposed decentralized solution makes use of blockchain technology to avoid mistakes associated with shared names while also guaranteeing transparent record-keeping, immutable data verification, and safe farmer identification. Not only does our method ensure that soil test findings are genuine, but it also helps to build confidence among those involved in agriculture. Our case study illustrates how this technology may be put into reality and how it could transform soil management techniques. This, in turn, can lead to more sustainable agricultural results.

KEYWORDS: Blockchain, Data Integrity, Transparency, Security, Soil sampling & testing, Sustainable agriculture.

INTRODUCTION
The availability of vital nutrients and minerals including calcium, magnesium, phosphorus, potassium, and nitrogen is affected by soil health, which is critical to agricultural production and environmental sustainability. The need for trustworthy soil management procedures is growing in importance in response to the rising worldwide need for food. Important information about nutrient levels, pH balance, and possible pollutants can be gleaned by soil sample and testing. Nevertheless, conventional approaches frequently encounter problems including inconsistent data, manipulation, and a lack of openness, which undermine farmers' trust in their soil evaluations.

Here, blockchain technology stands out as a potential game-changer. Blockchain technology, which generates a distributed and unchangeable record, can improve the safety and reliability of soil data management. This technology presents a one-of-a-kind chance to guarantee that all parties involved in the agricultural supply chain have access to reliable, verifiable, and comprehensive soil testing data that include precise measurements of essential nutrients and minerals (Tang et al., 2024).

Soil sampling and testing procedures may be revolutionized with the use of blockchain technology, which is the focus of this article. Increased confidence among academics, farmers, and legislators are just a few of the possible advantages of incorporating blockchain technology into soil health management. Other advantages include more transparency and more reliable data. An agricultural future that is both secure and sustainable, with better soils that are rich in essential nutrients and minerals thanks to educated decisions made possible by blockchain technology, will be possible in the not-too-distant future (Ali et al., 2022).

Motivation

Soil sampling and testing is an important concern for farmers, despite the fact that healthy soil is crucial for environmentally responsible farming. This work tackles two important problems: first, the possibility of erroneous results undermining farming decisions; and secondly, the chance of document mix-ups among farmers with shared names, which might lead to misunderstandings over test results. A trustworthy and open system for documenting and confirming soil health data may be set up with the use of blockchain technology. This method eliminates chances of error, promotes confidence among stakeholders, and guarantees proper sample identification. Soil testing, educated decision-making and sustainable agriculture will all benefit from blockchain integration in the long run.

Contribution

By suggesting a blockchain-based system for soil testing and sampling, this research adds to the body of knowledge in agricultural technology. The study demonstrates how blockchain technology might offer a distributed, unchangeable database of soil health information by solving the typical problems associated with inaccurate or mislabeled documents. This method improves traceability by avoiding mistakes caused by farmers using the same name and by appropriately associating each sample with its source. Better soil management methods and more sustainable agriculture may be achieved through the study's other findings, which show how improved data integrity can provide farmers with trustworthy information. This work contributes to the larger objective of protecting soil health for future generations and enhances our knowledge of blockchain applications in agriculture.

LITERATURE SURVEY

Maintaining healthy soil is essential for environmentally responsible farming and managing ecosystems. Soil sampling and testing procedures could benefit from the new opportunities presented by blockchain technology, which aim to increase their transparency and trustworthiness. For the purpose of securing and validating soil health data, this survey examines previous research on soil health monitoring as well as blockchain applications in agriculture. Verifying the authenticity of soil testing and sampling results is critical for protecting soil health with blockchain technology. The transmission of soil data needs to be protected against any vulnerability, same like the problems discussed in (Singh & Singh, n.d.), where the security of communication networks is really important. The accuracy of soil health evaluations may be improved and made available to stakeholders and farmers by employing sophisticated methods for identifying malicious data sources. This convergence of safe communication and farming methods highlights the need to incorporate strong security measures into cutting-edge agricultural systems.

It is crucial to have strong security mechanisms in place while investigating the potential of blockchain technology for accurate soil testing and sampling. Because they tackle the difficulties of preserving secure communication in ever-changing settings, the ideas stated in (Kaur & Sran, 2012) especially pertinent. To make sure farmers get reliable information, we may improve the data transferred in soil health assessments by using comparable security frameworks. In light of this link, it is clear that cutting-edge security protocols must be part of agricultural technology in order to prevent data breaches and guarantee the validity of soil sample findings.

Monitoring of Soil Health

Numerous markers, such as organic matter, microbial activity, pH levels, and nutrient content, are included in the concept of soil health. Conventional soil testing techniques frequently have problems with data manipulation, sample integrity, and accessibility (Lal, 2015). Numerous studies have underlined the necessity of trustworthy monitoring methods in order to produce precise evaluations of soil quality (Karlen et al., 1997). Firstly, soil testing is crucial for farmers to make educated decisions since it affects both agricultural production and the longevity of the planet (McBratney et al., 2014).

Secondly, misunderstandings of soil health can occur due to problems with traditional methods of testing, such as unreliable sample methodologies, inaccurate data reporting due to human error, and an absence of traceability (Ul Hassan et al., 2020).

Blockchain Technology in Agriculture

A number of industries, including farming, have begun to embrace blockchain technology because to its irreversible and decentralized nature. According to (Kouhizadeh & Sarkis, 2018), it provides possible answers for making agricultural supply chains more transparent, traceable, and trustworthy.

Firstly, blockchain has several potential uses; for example, it has been the subject of research into its potential to improve supply chain visibility, food safety, and quality control (Tian, 2016). Better accountability may be achieved in the agricultural sector through the use of blockchain technology, which allows for secure transactions and the tracking of inputs and outputs (Lin et al., 2020).

Secondly, data integrity and security: In order to ensure that the information exchanged among stakeholders is reliable, blockchain technology offers a strong framework to protect agricultural data from manipulation and unauthorized access (Liu et al., 2021).

Integrating Blockchain with Soil Health Monitoring

A fresh perspective on the problems with conventional methods can be found in the application of blockchain technology to soil health monitoring. Current frameworks and ideas are covered in this section.

Firstly, soil data platforms built on the blockchain: According to (Zhu & Li, 2021), there is some study that suggests creating platforms that use the blockchain to gather and share information on soil health among farmers, agronomists, and lawmakers. Platforms like this may make data unchangeable and only available to authorized people, which boost confidence.

Secondly, pilot projects and case studies: Proof of concept studies for blockchain in soil health monitoring have started to surface. As an example, projects related to precision agriculture have investigated the possibility of integrating blockchain technology with Internet of Things devices in order to gather and manage soil data in real-time (Zhong et al., 2022).

Thirdly, smart contracts may automate soil testing methods, guaranteeing adherence to established norms and regulations. As a result, testing may be made more efficient with less room for human mistake (Vangala et al., 2021).

METHODOLOGY

Multiple critical phases are involved in integrating blockchain technology into soil testing and sampling procedures. Improve the reliability, transparency, and use of soil health management data with the help of this step-by-step guide on implementing a blockchain-based system. In order to establish a trustworthy and open system for soil testing and sampling, stakeholders must adhere to this comprehensive process in order to effectively use blockchain technology. This method improves data security and integrity while also providing farmers with the knowledge they need to make educated decisions, which leads to healthier soil and more environmentally friendly farming methods (Dey & Shekhawat, 2021). The use of blockchain technology to improve soil testing and sampling is illustrated in the figure 1. Firstly, think about what you want to accomplish by implementing blockchain technology (more data transparency, more reliable data, easier tracking, etc.). Collaborate with researchers, agronomists, farmers, and legislators to identify and learn about their needs. Consider scalability, security, and user needs when choosing a blockchain platform (such as Ethereum, Hyperledger etc.) Open and decentralized public blockchain vs. private, password-protected blockchain, think about your use case and make a decision based on that.

Make a set of smart contracts that govern how you take soil samples, run tests, and keep track of your results (Albaaji & Chandra, 2024). Data validation processes, sample collecting techniques, and testing methodology are all things that might fall under this category. Automate testing service-related tasks such data recording, outcome verification, and payment processing with smart contracts. Outline the steps to take while collecting samples, how often to do it, how to handle and transport them, and how to collect samples (e.g., random or grid sampling). Determine consistent ways of documenting soil test findings, such as pH, organic matter content, and levels of essential nutrients (N, P, K, Ca, and Mg). Create straightforward mobile and web apps that farmers and technicians can use to enter soil sample data and test results straight into the blockchain. Think about using Internet of Things devices (IoT) to automatically gather data (e.g., soil moisture sensors, nutrient sensors) and input it into the blockchain. To make sure that no one other than authorized users may access or change data on the blockchain, you should employ cryptographic techniques to safeguard data inputs. Make use of blockchain's decentralized structure to store data twice, on different nodes, making it more resistant to data loss (Mahalingam & Sharma, 2024).

Now set up robust authentication procedures, such as multi-factor authentication, to ensure that only authorized users can access the blockchain system. Assign various responsibilities and degrees of access and authorization to various stakeholders, such as farmers, researchers, and regulatory agencies. To evaluate the blockchain system in real-world situations, initiate a pilot program with a restricted sample of users. Find out what others think about the usability, usefulness, and potential improvement areas. Analyze trends in soil health, nutritional deficits, and geographical differences using blockchain data. Refine the blockchain system and fix any problems found during testing based on analytics and input from the pilot. Make available to the intended audience the soil sampling and testing system that is built on the blockchain. Hold training sessions to teach users how to make the most of the new system. Provide continuous technical assistance to resolve any issues that may arise. Always keep an eye on how the system is doing and how engaged its users are. Find out how well the safeguards for data integrity and security are working. Find out how the blockchain system changed soil health management methods, such as how accurate the data was, how decisions were made, and how happy the farmers were.

Stakeholders and farmers how blockchain technology may improve soil health management. To improve the information base and confirm the blockchain system's results, it is recommended to collaborate with agricultural research organizations.

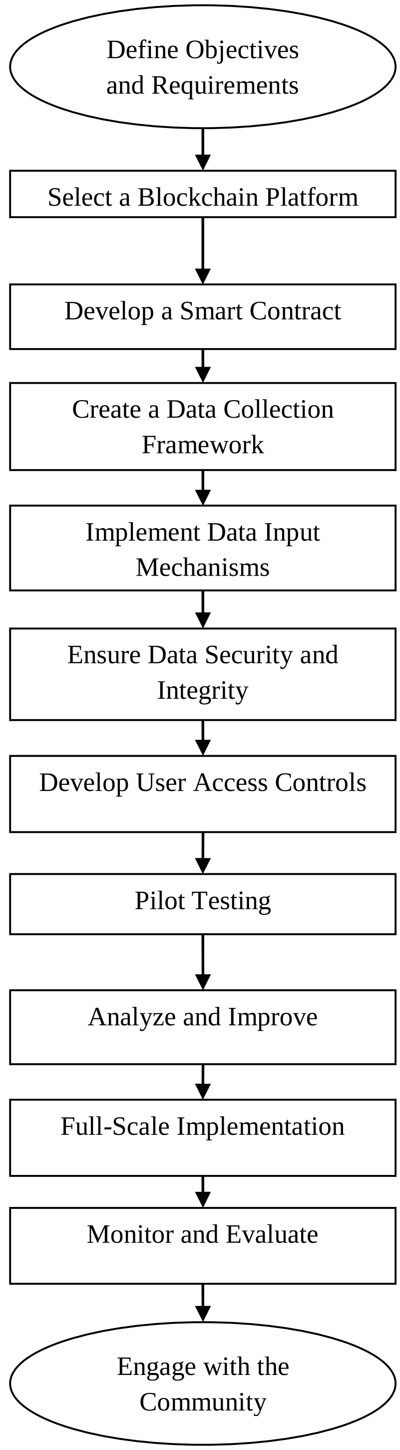

Figure 1.The use of blockchain technology to improve soil testing and sampling.

CONVENTIONAL Vs. BLOCKCHAIN-BASED SOIL SAMPLING & TESTING

The main distinctions between conventional soil sampling and testing and blockchain methods are as given in **Table-1**:

Table 1.Comparison between conventional and blockchain based soil sampling & testing.

Features	Conventional Soil Sampling and Testing	Blockchain Soil Sampling and Testing
Data Integrity	Manual data entry causes mistakes and discrepancies. Results might be skewed.	Data is entered on an immutable ledger and cannot be modified or erased, assuring data integrity.
Transparency	Limited transparency can cause stakeholder distrust by making data unavailable.	Creates a transparent record that farmers, academics, and regulators may access, building confidence and responsibility.
Data Security	Centralized data storage is susceptible to breaches, unauthorized access, and loss.	Uses cryptography to protect data. Decentralized systems reduce data modification and unauthorized access.
Automation and Efficiency	Manual data input, validation, and communication take time.	Smart contracts streamline data entry and validation, improving efficiency.
Traceability	Sample and outcome tracking is difficult, affecting quality control and accountability.	Each sample has a unique identification, and the blockchain records all operations (collection, testing, and findings) for total traceability.
Stakeholder Collaboration	Fragmented stakeholder communication causes inefficiencies and misconceptions.	Everyone involved may work together in real time on a shared platform, which improves communication and decision-making.
Cost Implications	Inefficiency, data inaccuracies, and a lot of human labor all contribute to higher expenses.	Implementation expenses may be greater, but efficiency and mistake reduction can save money over time.
Data Longevity and Access	Physical document degradation and inadequate record-keeping increase data loss risk.	A decentralized ledger secures data for long-term availability and loss prevention.

BASIC VERSUS ADVANCED SOIL SAMPLING AND TESTING

Blockchain technology improves basic and sophisticated soil sampling and testing. Basis sampling provides trustworthy insights with data integrity and openness. However, enhanced sampling offers in-depth studies, safe data management, and collaboration. Both methods can be used depending on soil health management goals, scale, and complexity (Lawrence et al., 2020).

Basic Soil Sampling and Testing

Soil pH, texture, and the three main nutrients (potassium, nitrogen, and phosphorus) are the main points of emphasis. Soil samples taken at a basic level are best used for broad evaluations in backyard gardens and small farms. These samples were obtained utilizing straightforward techniques, such as using hand trowels. It frequently makes use of composite sampling from a small number of randomly selected points across the field. Macro nutrients analysis, electrical conductivity, and pH are the usual components of these studies. In terms of soil fertility and overall health, it gives crucial information.

Basic Soil Sampling Using Blockchain

In order to guarantee immutability and quick access, it maintains basic test findings on a blockchain. It improves data trust by making test histories easily accessible. In most cases, the results are easy to understand and offer basic suggestions for amendments or fertilization based on them. Basic trend analysis is made easier with blockchain access to previous data. Lower expenses are usually the result of using simpler testing procedures and analyzing fewer parameters. Though it requires early investment, blockchain integration improves data management in the long run.

Soil Sampling and Testing Using Blockchain

By facilitating data access and verification for several users (farmers, extension agents), it encourages fundamental collaboration. Community agriculture efforts can benefit from it.

Advanced Soil Sampling and Testing

A thorough evaluation of the soil's micronutrients, organic content, microbial activity, and any pollutants is part of this process. Use it for precise farming, land reclamation, or in-depth studies. It makes use of complex methods such as depth-specific sampling, stratified sampling, and grid sampling. In order to gather data accurately and thoroughly, it may be necessary to use specialized equipment. Cation exchange capacity (CEC), organic matter content, microbiological health, and micronutrients (zinc, copper) are among the many factors it examines. It provides a comprehensive profile to help managers make educated judgments.

Advanced Soil Sampling Using Blockchain

The system records intricate datasets together with information (such as sampling techniques and environmental factors) on a distributed ledger. In addition to protecting data integrity, it allows for safe exchange and cooperation among many parties. Its findings, which frequently include sophisticated analytical methods, need the interpretation of an expert. Blockchain technology allows for detailed change tracking over time, which is useful for developing individualized management plans. The more extensive analysis and intricate sample methods used, the more expensive they are. The expenditure is justified by the value that blockchain delivers through improved data security and traceability.

Advanced Soil Sampling and Testing Using Blockchain

It promotes close cooperation among many interested parties, including as academics, agronomists, and government agencies. In addition to improving soil management as a whole, it makes data exchange easier for compliance, research, and policy creation.

BENEFITS OF UTILIZING BLOCK-CHAIN TECHNOLOGY

Soil sampling and testing with blockchain technology can save money by improving data integrity, operational efficiency, and decision-making. These benefits minimize direct expenses and promote sustainable and productive agriculture. The benefits of utilizing blockchain technology are illustrated in **Table-2**.

Table 2.Benefits of utilizing blockchain technology.

Advantages	Descriptions
Data Integrity and Accuracy	Automated procedures and immutable records reduce data entry mistakes using blockchain. This cuts error correction and retesting expenses.
Enhanced Transparency	Stakeholders trust outcomes more when sampling and testing data is clear and tamper-proof. This can decrease data authenticity issues and expenses.
Efficiency in Operations	Smart contracts can automate gathering and analyzing data for soil sampling and testing. The consequence is faster turnaround and lower labor expenses.
Improved Decision-Making	Farmers and land managers may make better soil management decisions using reliable, real-time data, thereby improving yields and lowering input costs
Reduced Need for Redundant Testing	Trend analysis without repeated testing is possible with blockchain's safe historical data storage. This reduces constant soil monitoring expenditures.
Collaboration and Shared Resources	Blockchain may help farmers, academics, and agricultural groups communicate. Sharing testing resources cuts advanced testing costs.
Increased Access to Funding and Support	Clear and reliable records can help offset testing expenses when applying for grants or sustainable practice financing.
Minimized Legal and Compliance Costs	Transparency and security can ease regulatory compliance and save audit and litigation expenses.

SOIL SAMPLING AND TESTING CHALLENGES

Farmers confront several soil sampling and testing issues, but this study discusses two typical ones. Farmers with shared names can mix up documents and test results, and they may receive inaccurate findings (Podder et al., 2024).

Blockchain technology to help farmers deal with the shared names

Especially for farmers with the same last name, there are substantial benefits to using blockchain technology for soil testing and sampling. By guaranteeing distinct identity, data integrity, and clear traceability, it offers a strong answer for farmers sharing a name (Nakasumi, 2017). Better agricultural results are supported by these qualities because they improve collaboration, decrease mistakes, and offer a dependable foundation for soil sampling and testing. Farmers may manage soil health and name similarities using blockchain. Blockchain can provide farmers digital IDs or wallet addresses. To avoid misunderstanding among farmers with similar names, samples are correctly defined to the relevant person. Each soil sample and its findings are permanently stored on a blockchain ledger. This ensures that farmer data is reliable and trustworthy, preventing outcomes attribution error. Blockchain records the whole soil sample and testing procedure. Farmers may trace their samples from collection to analysis to ensure accuracy and authenticity. Agronomists, extension agents, and regulators can safely access data. Despite name similarities, this collaborative atmosphere promotes communication and ensures everyone is on the same page. Unique identification and immutable records decrease sample processing and reporting mistakes. This is useful in busy agricultural environments when numerous samples are taken at once. Blockchain lets farmers view previous data tied to their ID. This helps monitor soil health and plan agricultural methods. Farmers may simply validate their soil test findings using blockchain to ensure they are using their own data. This is essential for appropriate agronomic decisions. Evidence of ownership and sample history increases accountability. This can improve best practices and compliance with regulations, benefiting farmers.

The use of Digital ledger technology for soil analysis is illustrated in the figure 2. Soil sampling using blockchain technology revolves on a basic idea with eight branches, or nodes, that stand for important benefits. Make a direct line from the main point to each advantage using arrows. Digital ID, which stands for unique identification, guarantees precise sample attribution. Ensuring data integrity with immutable records is crucial. Complete sample and result tracking is made possible with transparent traceability. Communication is enhanced by better cooperation that is utilized to share access for stakeholders.

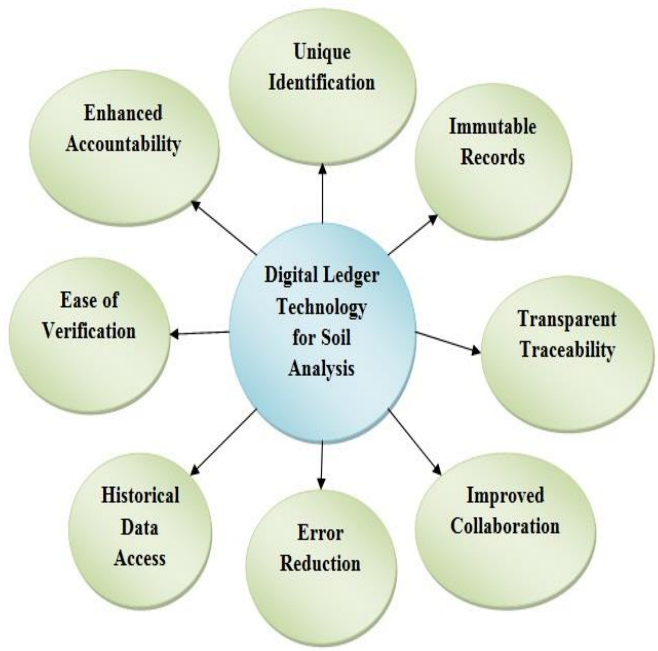

Figure 2.Illustration of the Digital ledger technology for soil analysis.

Reducing mistakes helps keep reporting errors and misunderstanding to a minimum. A description of long-term records for monitoring changes in soil health is provided by historical data access. Soil test findings should be instantly authenticated if they are easy to verify. Responsible practices are a direct result of increased accountability when it comes to establishing ownership.

Graphical depiction to help farmers deal with the shared names

Soil collection and testing present particular difficulties for farmers sharing a name; our smart contract seeks to alleviate those difficulties. Soil testing on the Ethereum blockchain is now more open and accountable thanks to the addition of unique farmer identities, which guarantee the correct attribution of each sample. Presented in figure 3 is a graphical depiction that is intended to assist farmers in dealing with the collective names.

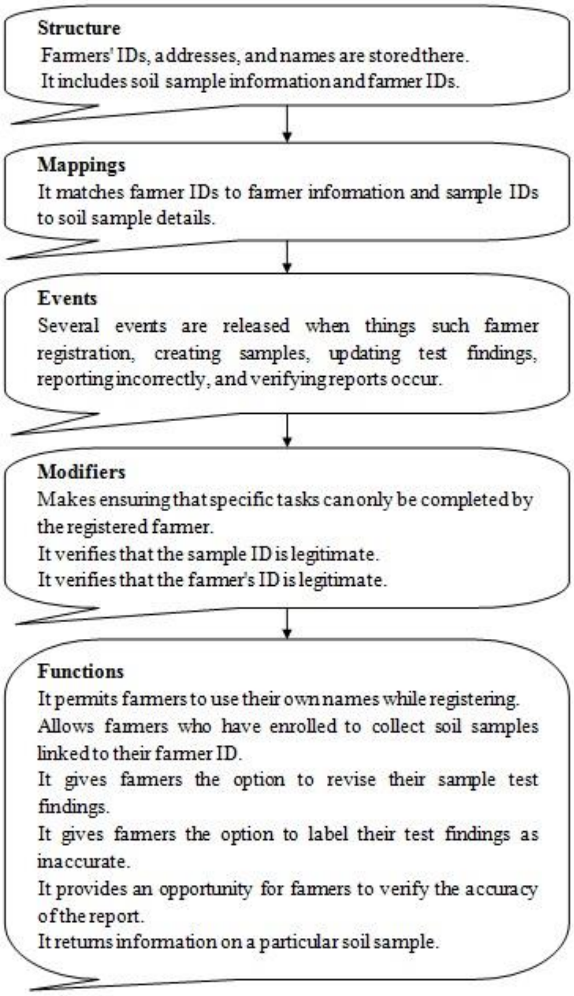

Figure 3.Graphical depiction to help farmers deal with the shared names.

Pseudo code for farmers deal with the shared names

START
Step1: Initialize Farmer and Blockchain Information
INPUT: FarmerName, FarmLocation, NumberOfFields, BlockchainNetwork

Step2: Define Blockchain Structure
DEFINE BLOCK as:
BlockNumber
PreviousHash
TransactionsList (contains soil sample data)
Timestamp
HashOfBlock

DEFINE Blockchain as List of Blocks

Step 3: Define Structure to Store Soil Sample Data
DECLARE List SoilSamples # A list to store sample records before blockchain entry

Step4: Define Naming Convention for Soil Samples
DEFINE FUNCTION GenerateSampleName(FarmerName, FieldNumber, SamplingDate):
RETURN FarmerName + "Field" + FieldNumber + "" + SamplingDate

Step5: Function to Add Block to the Blockchain
DEFINE FUNCTION AddBlockToBlockchain(SoilSampleData, Blockchain):
BlockNumber = GET Last Block Number from Blockchain + 1
PreviousHash = GET HashOfBlock from Last Block in Blockchain
Timestamp = CURRENT TIME

# Calculate the new block’s hash based on its data
HashOfBlock = GenerateHash(BlockNumber, PreviousHash, SoilSampleData, Timestamp)

# Create the new block with the soil sample data
NewBlock = {
"BlockNumber": BlockNumber,

"PreviousHash": PreviousHash,
"TransactionsList": SoilSampleData,
"Timestamp": Timestamp,
"HashOfBlock": HashOfBlock
}
ADD NewBlock to Blockchain

Step 6: Collect Soil Sampling and Testing Data
FOR each FieldNumber from 1 to NumberOfFields:
INPUT: SamplingDate (the date on which soil sampling is done)

```
SampleName = GenerateSampleName(FarmerName,
FieldNumber, SamplingDate)

# Input soil test results for this field
INPUT: SoilTestResults (e.g., pH, Nitrogen,
Phosphorus, Potassium, etc.)
```

Step 7: Store the Sample Data as a Transaction

```
SoilSample = {
"SampleName": SampleName,
"FieldNumber": FieldNumber,
"SamplingDate": SamplingDate,
"SoilTestResults": SoilTestResults
}

# Add this sample to the list of soil samples
(transactions) for the block
ADD SoilSample to SoilSamples
```

Step 8: Add Soil Sample Data to Blockchain

```
AddBlockToBlockchain(SoilSamples,
BlockchainNetwork)
```

Step 9: Display Blockchain for Verification

```
FOR each Block in BlockchainNetwork:
PRINT "Block Number:", Block["BlockNumber"]
PRINT "Previous Hash:", Block["PreviousHash"]
PRINT "Transactions (Soil Samples):"
FOR each Transaction in Block["TransactionList"]:
PRINT "Sample Name:",
Transaction["SampleName"]
PRINT "Field Number:",
Transaction["FieldNumber"]
PRINT "Sampling Date:",
Transaction["SamplingDate"]
PRINT "Soil Test Results:",
Transaction["SoilTestResults"]
PRINT "Hash of Block:", Block["HashOfBlock"]
PRINT "---"
# End of Pseudocode
```

END

Algorithm 1.For farmers deal with the shared names.

Blockchain technology to help farmers deal with inaccurate soil testing reports

When farmers get inaccurate results from soil tests, blockchain technology can be a huge help. It offers a solid foundation for fixing problems with inaccurate soil testing results. Blockchain technology allows farmers to verify their test findings, settle disputes, and make educated decisions by guaranteeing data integrity, transparency, and traceability. These benefits lead to more sustainable farming methods and improve the accuracy of soil health evaluations. There is no way to remove or change soil test findings once they are stored on a blockchain. Because these results cannot be altered, farmers may always go back to the original data when they disagree with the results.

All of the data from soil samples and tests can be seen on a transparent ledger thanks to blockchain technology. It is much easier to pinpoint the source of mistakes and hold individuals accountable when farmers are able to trace their samples from collection to testing. There is a way to correlate metadata (such as time, location, and testing techniques) with each soil test and assign it a unique identity. This gives farmers the chance to confirm the testing laboratory's reputation and the techniques followed, which guarantees that the data they get is reliable. The blockchain establishes an immutable record of transactions in case of a disagreement over erroneous reporting. To successfully address concerns, farmers might submit this information to testing laboratories or regulatory agencies. If a mistake is found, blockchain technology enables instantaneous changes that can be seen by everyone who needs them. Farmer decision-making is facilitated by the rapid delivery of correct information (Xiong et al., 2020).

Blockchain technology enables agronomists, testing laboratories, and farmers to communicate directly with one another. This encourages teamwork and makes sure everyone is on the same page, which lessens the chances of miscommunication that might result in inaccurate reporting. Soil data stored on the blockchain may be accessed by farmers, giving them the ability to put recent test findings into perspective. In the long run, this can aid in decision-making by revealing trends or inconsistencies.

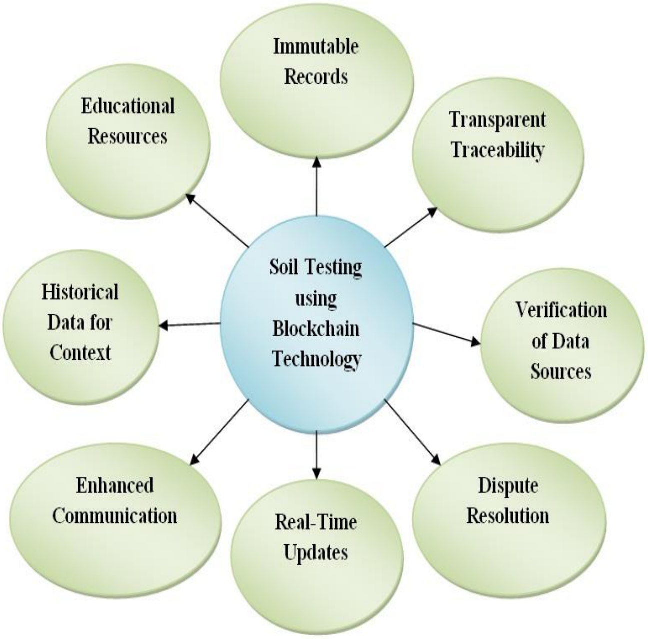

Figure 4.Illustration of the Soil testing report using Blockchain technology.

Soil test findings can be better understood by farmers with the use of instructional materials that can be integrated into blockchain platforms. Farmers can gain more agencies by gaining a better grasp of their reports and being able to independently spot problems. Blockchain technology for soil testing reports is illustrated in the figure 4.

Eight branches (or nodes) encircle the central circle, symbolizing the eight benefits of Blockchain technology for soil testing. Make a direct line from the main idea to each advantage using arrows. Data integrity is described by immutable records, which cannot be changed. Ensuring transparent traceability involves following soil samples from beginning to finish. In order to validate testing methods reliably, it is necessary to verify data sources. A transparent audit trail for conflict resolution is defined by dispute resolution. You may obtain the amended information immediately with a real-time update. Stakeholders are able to interact directly through improved communication. Access to long-term soil data analysis is made possible by historical data utilized for context. Methods for deciphering the findings of soil tests are detailed in instructional materials.

Graphical depiction to help farmers deal with inaccurate Soil testing reports

With the help of this smart contract, farmers may generate samples, edit test findings, disclose errors, and check the accuracy of their soil testing reports. Soil testing is made more open, trustworthy, and accountable with the use of blockchain technology. Figure 5 is a graphical depiction that is intended to assist farmers in dealing with erroneous soil testing findings.

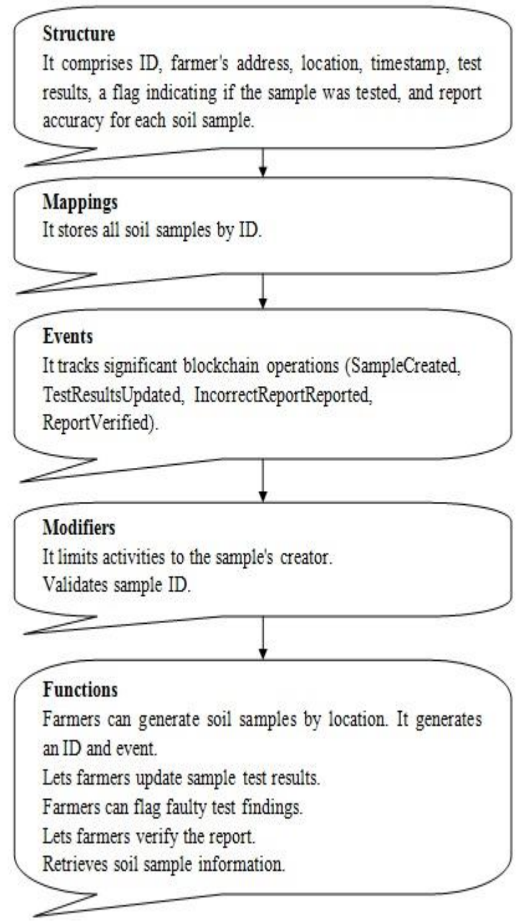

Figure 5.Graphical depiction to help farmers deal with inaccurate soil testing reports.

Pseudo code to help farmers deal with inaccurate Soil testing reports

START

FUNCTION GetSoilTestReport (cultivatorID):
soilReport = FetchSoilTestReport (cultivatorID)
RETURN soilReport
FUNCTION ValidateSoilTestReport (soilReport):
IF soilReport is missing or incomplete THEN

```
RETURN "Invalid report: Missing data"
ENDIF
IF soilReport.values OUTSIDE acceptable range
THEN
RETURN "Warning: Values outside acceptable
range"
ENDIF
RETURN "Report valid"
FUNCTION SuggestCorrections (soilReport):
IF soilReport.ph < 6.0 THEN
RECOMMEND "Add lime to increase pH"
ELSE IF soilReport.ph > 7.5 THEN
RECOMMEND "Add sulfur to decrease pH"
ENDIF
IF soilReport.nutrients DEFICIENT THEN
RECOMMEND "Apply fertilizers according to
nutrient deficiency"
ENDIF
RETURN "Recommendations provided"
FUNCTION Main ( ):
cultivatorID = GetCultivatorID ( )
soilReport = GetSoilTestReport (cultivatorID)
validationMessage = ValidateSoilTestReport
(soilReport)
PRINT validationMessage
IF validationMessage is "Report valid" THEN
suggestions = SuggestCorrections (soilReport)
PRINT suggestions
ENDIF
END FUNCTION Main ( )
```

Algorithm 2.For farmers deal with inaccurate Soil testing reports.

RESULTS AND DISCUSSION

Data security, traceability, and stakeholder participation are all greatly enhanced when blockchain technology is used to soil sampling and testing. The main takeaways from the studies and research on blockchain technology in this area are as follows:

Improved Data Integrity and Security

One of the main results of using blockchain for soil sampling and testing is the enhanced integrity and security of data. Blockchain's immutable ledger ensures that once soil health data (such as pH levels, nutrient content, and moisture levels) is recorded on the blockchain, it cannot be altered. This prevents tampering with records, ensuring that data shared among stakeholders remains authentic and verifiable.

Result: Since the data has not been altered since its original recording, researchers and farmers may have faith in its authenticity.

Supporting Evidence: Blockchain solutions offer immutable records for agricultural data, including soil sample, which significantly decreases the likelihood of fraud and mistakes in soil health monitoring, according to studies like (Tian, 2016).

Enhanced Transparency and Traceability

Due to blockchain's decentralized structure, all stakeholders, including government agencies, research institutions, testing facilities, and farmers, have real-time access to the same data, which promotes transparency. Every soil sample and its associated test results are documented as an individual transaction that can be traced back to the specific field, the farmer who collected them, the testing facility, and the date of collection.

Result: Full transparency is maintained throughout the whole process thanks to this traceability, which allows for the tracing of every soil sample from its collection to its testing and analysis.

Supporting Evidence: By linking data points like GPS locations, field numbers, and soil test results, blockchain technology improves agricultural traceability, as shown by (Lin et al., 2020). This makes it much easier to verify where information on soil health is coming from.

Reduction in Human Error and Data Manipulation

Manual data input is prone to mistakes and manipulation in traditional soil sampling and testing. Smart contracts and IoT devices can automatically record soil parameters like moisture and nutrient content, reducing these risks using blockchain.

Result: Human mistakes and soil test manipulation are greatly reduced by minimizing manual input.

Supporting Evidence: Blockchain and IoT devices might automate soil data collecting in real time, generating a safe, accurate, and trustworthy dataset for precision agricultural decision-making, according to (Aliyu & Liu, 2023).

Greater Collaboration among Stakeholders

Secure data exchange throughout the agricultural value chain is made possible by blockchain technology. Without centralized data management systems, academics, agronomists, and farmers can obtain soil data in real-time. Local, regional, and even national soil health monitoring is made easier with this common access, which also enhances collaboration.

Result: Farmers, academic institutions, and government organizations are working together more closely to monitor soil health, which improves agricultural decision-making.

Supporting Evidence: (Kouhizadeh & Sarkis, 2018) state that blockchain technology has several potential uses in agriculture, including the facilitation of real-time data exchange between various stakeholders, the promotion of cooperation, and the assurance of adherence to agricultural and environmental regulations.

Cost Savings in Soil Testing and Monitoring

Soil testing and monitoring organizations and farmers can save money by using blockchain technology. Blockchain technology eliminates the need for costly and time-consuming middlemen (such as data certifiers) and streamlines the data reconciliation process. Smart contracts can also reduce administrative burden by automatically ordering additional tests or applying fertilizers based on recorded data.

Result: Saving money on data administration, certification, and compliance while increasing the efficiency of soil health monitoring is a win-win for farmers and agricultural organizations.

Supporting Evidence: By automating procedures and reducing the need for centralized data reconciliation in agricultural supply chains, including soil health monitoring, blockchain applications might save operating costs, according to (Zheng et al., 2018).

Scalability and Future-Proofing Challenges

Although there have been several benefits to using blockchain technology for soil testing and sampling, there are still scaling issues to address. As the usage of Internet of Things (IoT) devices in agriculture grows, public blockchain networks in particular may not be able to manage the massive amounts of data produced by all the sensors and soil samples.

Result: To properly process huge information, the system requires more development. This is particularly important for small-scale farmers, who may encounter financial obstacles when trying to use blockchain technologies.

Supporting Evidence: (Kshetri, 2017) brought attention to the scalability problems with blockchain technology, pointing out that bigger farms could require tailored blockchain solutions to handle the massive amounts of data produced by soil health monitoring systems over time.

Positive Environmental and Regulatory Impact

The immutability and transparency of blockchain data can assist governments and farmers in ensuring adherence to environmental standards. Responsible application of fertilizers, herbicides, and irrigation may be guided by accurate data on soil health, which in turn promotes sustainable agriculture practices. In addition, regulatory organizations can utilize this data to confirm that farms are adhering to soil conservation regulations.

Result: Blockchain technology has the potential to improve agricultural sustainability by providing regulators with verifiable data and encouraging more responsible farming methods.

Supporting Evidence: (Tripoli & Schmidhuber, 2020) state that in order to guarantee that environmental standards are satisfied in agriculture, it is essential to be able to audit and trace farming techniques that impact soil health. Blockchain's immutability makes this possible.

CONCLUSION

The use of blockchain technology in soil testing and sampling offers a revolutionary strategy for protecting soil health, to conclude. Stakeholders may reap the benefits of improved data accuracy, transparency, and security by incorporating blockchain technology into soil sampling and testing at both the basic and advanced levels. By creating permanent records, basic soil sampling may increase confidence and dependability, making sure that basic evaluations are correct and easy to retrieve.

Improvements in decision-making and resource management may be achieved via the use of blockchain technology, which enables thorough assessments for enhanced soil testing through the careful recording of complicated data. While there may be some up-front expenses associated with using blockchain technology, the potential savings from fewer mistakes, more efficient procedures, and better teamwork more than make up for it. More informed agricultural decisions are made possible by combining trustworthy data with cost-effective procedures. This leads to sustainable soil health management and overall agricultural resilience. Farmers and land managers may optimize their operations and create a more sustainable future for agriculture by embracing this revolutionary technology.

A novel strategy to improving the dependability of soil data has emerged at the junction of blockchain technology and soil health monitoring. Stakeholders may strive for more sustainable farming methods by fixing the problems with soil testing and using blockchain technology. To fully utilize the promise of this integration, future research should concentrate on actual implementations, stakeholder participation, and resolving regulatory hurdles.

FUTURE SCOPE

It plans to use smart contracts to guarantee regulatory compliance, create decentralized testing networks to make testing easier, and improve data integrity and transparency through immutable records. Secure data logging for actionable insights is made possible by connecting blockchain with IoT sensors, allowing for real-time monitoring of soil conditions. In addition to enhancing soil health and food security, this technology may promote consumer engagement in sustainable agriculture practices, inform policy choices, and encourage collaborative research and development. These findings strongly support the use of blockchain technology to improve the safety and efficiency of soil health monitoring. The technical and economical hurdles of deploying blockchain in agriculture necessitate more study.

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REFERENCES

Albaaji, G. F., & Chandra, S. S. V. (2024). Blockchain technology in agriculture: Digitizing the Iraqi agricultural environment | Environment, Development and Sustainability. https://link.springer.com/article/10.1007/s10668-024-04623-4

Ali, Md. A., Balamurugan, B., Dhanaraj, R. K., & Sharma, V. (2022). IoT and Blockchain based Smart Agriculture Monitoring and Intelligence Security System. 2022 3rd International Conference on Computation, Automation and Knowledge Management (ICCAKM), 1–7. https://doi.org/10.1109/ICCAKM54721.2022.9990243

Aliyu, A. A., & Liu, J. (2023). Blockchain-Based Smart Farm Security Framework for the Internet of Things. Sensors, 23(18), Article 18. https://doi.org/10.3390/s23187992

Dey, K., & Shekhawat, U. (2021). Blockchain for sustainable e-agriculture: Literature review, architecture for data management, and implications. Journal of Cleaner Production, 316, 128254. https://doi.org/10.1016/j.jclepro.2021.128254

Hassan, M. U., Rehmani, M. H., & Chen, J. (2020). Differential privacy in blockchain technology: A futuristic approach. Journal of Parallel and Distributed Computing, 145, 50–74. https://doi.org/10.1016/j.jpdc.2020.06.003

Karlen, D. L., Mausbach, M. J., Doran, J. W., Cline, R. G., Harris, R. F., & Schuman, G. E. (1997). Soil Quality: A Concept, Definition, and Framework for Evaluation (A Guest Editorial). Soil Science Society of America Journal, 61(1), 4–10. https://doi.org/10.2136/sssaj1997.03615995006100010001x

Kaur, J., & Sran, E. S. S. (2012). SBPGP Security based Model in Large Scale Manets. 4(1), 1–10.

Kouhizadeh, M., & Sarkis, J. (2018). Blockchain Practices, Potentials, and Perspectives in Greening Supply Chains. Sustainability, 10(10), Article 10. https://doi.org/10.3390/su10103652

Kshetri, N. (2017). Blockchain's roles in strengthening cybersecurity and protecting privacy. Telecommunications Policy, 41(10), 1027–1038.

Lal, R. (2015). Restoring Soil Quality to Mitigate Soil Degradation. Sustainability, 7(5), Article 5. https://doi.org/10.3390/su7055875

Lawrence, P. G., Roper, W., Morris, T. F., & Guillard, K. (2020). Guiding soil sampling strategies using classical and spatial statistics: A review. Agronomy Journal, 112(1), 493–510. https://doi.org/10.1002/agj2.20048

Lin, W., Huang, X., Fang, H., Wang, V., Hua, Y., Wang, J., Yin, H., Yi, D., & Yau, L. (2020). Blockchain Technology in Current Agricultural Systems: From Techniques to Applications. IEEE Access, 8, 143920–143937. IEEE Access. https://doi.org/10.1109/ACCESS.2020.3014522

Liu, W., Shao, X.-F., Wu, C.-H., & Qiao, P. (2021). A systematic literature review on applications of information and communication technologies and blockchain technologies for precision agriculture development. Journal of Cleaner Production, 298, 126763. https://doi.org/10.1016/j.jclepro.2021.126763

McBratney, A., Field, D. J., & Koch, A. (2014). The dimensions of soil security. Geoderma, 213, 203–213. https://doi.org/10.1016/j.geoderma.2013.08.013

Nakasumi, M. (2017). Information Sharing for Supply Chain Management Based on Block Chain Technology. 2017 IEEE 19th Conference on Business Informatics (CBI), 01, 140–149. https://doi.org/10.1109/CBI.2017.56

Podder, A., Paul, S., Sen, A., Roy, K., & Chakraborty, A. (2024). Revolutionizing the Agriculture and Food Industry through Blockchain Technology: Challenges and Opportunities. Educational Administration: Theory and Practice, 30(6), Article 6. https://doi.org/10.53555/kuey.v30i6.5148

Singh, R., & Singh, S. (2011), Detection of Rogue Base Station using MATLAB.International Journal of Soft Computing and Engineering, 1(5), 190–201.

Tang, A., Tchao, E. T., Agbemenu, A. S., Keelson, E., Klogo, G. S., & Kponyo, J. J. (2024). Assessing blockchain and IoT technologies for agricultural food supply chains in Africa: A feasibility analysis. Heliyon, 10(15). https://doi.org/10.1016/j.heliyon.2024.e34584

Tian, F. (2016). An agri-food supply chain traceability system for China based on RFID & blockchain technology. 2016 13th International Conference on Service Systems and Service Management (ICSSSM), 1–6. https://doi.org/10.1109/ICSSSM.2016.7538424

Tripoli, M., & Schmidhuber, J. (2020). Emerging opportunities for the application of blockchain in the agri-food industry. https://policycommons.net/artifacts/1422549/emerging-opportunities-for-the-application-of-blockchain-in-the-agri-food-industry/2036638/

Vangala, A., Sutrala, A. K., Das, A. K., & Jo, M. (2021). Smart Contract-Based Blockchain-Envisioned Authentication Scheme for Smart Farming. IEEE Internet of Things Journal, 8(13), 10792–10806. IEEE Internet of Things Journal. https://doi.org/10.1109/JIOT.2021.3050676

Xiong, H., Dalhaus, T., Wang, P., & Huang, J. (2020). Blockchain Technology for Agriculture: Applications and Rationale. Frontiers in Blockchain, 3. https://doi.org/10.3389/fbloc.2020.00007

Zheng, Z., Xie, S., Dai, H.-N., Chen, X., & Wang, H. (2018). Blockchain challenges and opportunities: A survey. International Journal of Web and Grid Services, 14(4), 352–375.

Zhong, B., Guo, J., Zhang, L., Wu, H., Li, H., & Wang, Y. (2022). A blockchain-based framework for on-site construction environmental monitoring: Proof of concept. Building and Environment, 217, 109064. https://doi.org/10.1016/j.buildenv.2022.109064

Zhu, L., & Li, F. (2021). Agricultural data sharing and sustainable development of ecosystem based on block chain. Journal of Cleaner Production, 315, 127869. https://doi.org/10.1016/j.jclepro.2021.127869