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Impact of Maize Cultivation on Soil Health

Wei Wang, Jinhua Cheng
Institute of Life Science, Jiyang College of Zhejiang A&F University, Zhuji, 311800, China
Corresponding email: tina.wei.wang@jicat.org
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Abstract Corn (*Zea mays* L.) is one of the most important food crops in the world, not only related to food supply, but also closely related to economic development. Long term monoculture and high-intensity cultivation have brought significant pressure to the soil. This study mainly focuses on the effects of corn planting on soil physicochemical properties, biological communities, and enzyme activity, and analyzes the relationships between different tillage methods, fertilization patterns, climatic conditions, and soil types. Practices such as crop rotation, straw returning, organic fertilizer application, and conservation tillage can improve soil structure, increase organic matter content, and promote microbial diversity. Long term continuous cropping or excessive use of fertilizers often cause soil acidification, structural degradation, and ecological problems. The results of this study provide reference for corn production management and also contribute to better protecting and utilizing soil resources while increasing yield.
Keywords Corn cultivation; Soil health; Bio-diversity; Nutrient cycling; Conservation tillage

1 Introduction

Maize (*Zea mays* L.) is grown across the Americas, Asia, Africa, and Europe. Its high yield, broad adaptation, and many uses—food, feed, and industry—make it central to food supply. In many developing regions it also supports household income and national food security (Sobiech et al., 2025). At the same time, intensive and monoculture production puts pressure on soils and nearby ecosystems (Fujisao et al., 2020; Dawar et al., 2022; Mukhametov et al., 2024).

Soil health is the base of sustainable farming. Soils with stable structure, enough organic matter and nutrients, and diverse microbes support plant growth, regulate water and nutrient flows, and buffer stress (Ablimit et al., 2022; Dawar et al., 2022; Yang et al., 2024). When soils lose organic matter, nutrients, or structure—and when biodiversity declines—yields fall and greenhouse gas emissions may rise (Fujisao et al., 2020; Yang et al., 2022). Protecting soil health is therefore a core goal for agriculture worldwide (Luo et al., 2024; Mukhametov et al., 2024).

Maize management strongly shapes soil outcomes. Long-term monocropping can reduce soil organic carbon and key nutrients (N, P, K), weaken structure, and lower microbial diversity, which harms yield stability (Fujisao et al., 2020; Dawar et al., 2022; Wang et al., 2022; Mukhametov et al., 2024). High yields often rely on heavy fertilizer and pesticide inputs, which can add further stress (Zhang et al., 2022a; Afata et al., 2024). In contrast, crop rotation, intercropping, organic amendments, and biostimulants have improved soil properties, microbial activity, and nutrient cycling in many trials (Moreira et al., 2019; Ablimit et al., 2022; Dawar et al., 2022; Luo et al., 2024; Mukhametov et al., 2024; Wu et al., 2024; Yang et al., 2024).

This study reviews long-term experiments and recent literature to assess how different maize systems—monoculture, rotations, intercropping, and fertilizer regimes—affect soil physical, chemical, and biological traits and yield. It also compares results across climates, terrains, and management styles to identify key drivers of soil health and to provide practical guidance for sustainable maize production in major growing regions.

2 Overview of Maize Cultivation Practices

2.1 History and regional trends of corn production

Maize was domesticated in Central America about 9 000 years ago and is now one of the world's leading cereal crops. Advances in technology and rising population have expanded its area and boosted yields, making it the most productive cereal globally. The United States, China, and Brazil produce the largest shares (Ranum et al., 2014; Erenstein et al., 2022). In Africa and Latin America, maize remains both a staple food and a key crop for small farmers.

2.2 Common cultivation methods (conventional tillage, conservation agriculture, intercropping, monoculture)

Conventional tillage often involves deep plowing and land preparation, which can improve soil permeability. Long-term high-intensity operations often lead to a reduction in organic matter, damage to soil structure, and exacerbation of erosion problems (Ramadhan, 2021). Conservation tillage reduces soil disturbance through no till or reduced tillage, retention of crop residue cover, and implementation of crop rotation (Ramadhan, 2021; Flynn et al., 2024).

Intercropping corn with leguminous, potato, and forage crops reduces pest and weed pressure (Khongdee et al., 2022). In Southeast Asia and other regions, it plays a role in preventing soil erosion and maintaining soil fertility. Although long-term monoculture of corn is beneficial for mechanization and high yield, it can easily lead to soil degradation and accumulation of pests and diseases (Erenstein et al., 2022; Wang et al., 2022).

2.3 Fertilization and irrigation management

Corn cultivation relies heavily on chemical fertilizers (especially nitrogen fertilizers) to meet the high nutrient requirements of crops, but excessive fertilization increases costs and can also lead to soil acidification, nutrient leaching, and environmental pollution (Wang et al., 2022; Feng et al., 2023; Sivamurugan et al., 2025). Optimize fertilization strategies, such as deep application of nitrogen fertilizer, staged fertilization, organic-inorganic combination, and precision fertilization based on crop growth status (Zheng et al., 2023; Marbun, 2024; Patel et al., 2024). Global corn cultivation is mainly rain fed, but irrigation is important in arid or semi-arid regions (Sah et al., 2020). Drip irrigation, sprinkler irrigation and other efficient irrigation technologies are gradually being promoted to improve water use efficiency and crop stress resistance (Sivamurugan et al., 2025).

2.4 Pesticide and herbicide use in corn system

Common management measures include seed coating, field spraying of insecticides, fungicides, and various herbicides to control major pests and diseases such as corn borer, aphid, leaf spot disease, rust disease, etc. (Erenstein et al., 2022; Terefe et al., 2023). Long term dependence on chemical control can lead to increased drug resistance, damage to non target organisms, and environmental pollution. In some regions, the excessive use of pesticides and herbicides has also led to a decline in soil microbial diversity and weakened ecosystem service functions (Norris et al., 2016).

Integrated pest management (IPM) and biological control are gradually receiving attention. By implementing measures such as reasonable crop rotation, intercropping, selection of disease resistant and insect resistant varieties, optimization of field management, and precise pesticide application, pesticide usage can be effectively reduced and the development of drug resistance can be slowed down (Erenstein et al., 2022; Terefe et al., 2023).

3 Key Indicators of Soil Health

3.1 Physical properties (texture, structure, bulk density, porosity, water holding capacity)

The soil texture (proportion of sand, powder, and clay particles) affects the soil's water retention, aeration, and ease of cultivation. Soil with intact aggregate structure can improve erosion resistance and promote water infiltration; Once the structure is damaged, it is prone to compaction, increased surface runoff, and restricted root growth. Bulk density reflects the compactness of soil, and a high value often indicates that the soil is compacted, which is not conducive to root extension and water vapor flow. Porosity is closely related to aeration and water retention capacity, and higher porosity contributes to microbial activity and root respiration (Es and Karlen, 2019; Lu et al., 2020; Bagnall et al., 2023).

Conservation tillage, planting cover crops, and increasing organic matter input can enhance soil aggregate stability and improve water retention performance (Es and Karlen, 2019; Liptzin et al., 2022; Bagnall et al., 2023). Some soil physical indicators, such as available water capacity (AWC) and water stable aggregates (Agstab), are often used for soil health assessment (Es and Karlen, 2019; Bagnall et al., 2023).

3.2 Chemical properties (pH, organic matter, nutrient content, cation exchange capacity)

The pH value affects the availability of nutrients and microbial activity in soil, and an appropriate pH range is beneficial for crop growth and nutrient absorption. Soil organic matter (SOM) and organic carbon (SOC) provide energy and nutrients for microorganisms and plants, promote aggregate formation, enhance water holding capacity and buffering capacity (Es and Karlen, 2019; Bhaduri et al., 2022; Liptzin et al., 2022; Bagnall et al., 2023). The accumulation of organic matter is closely related to soil management measures, such as reducing tillage, increasing organic inputs, and crop rotation, all of which can enhance SOC levels (Liptzin et al., 2022; Bagnall et al., 2023; Liptzin et al., 2023).

The nutrient content (such as nitrogen, phosphorus, potassium, etc.) and cation exchange capacity (CEC) reflect the fertility and buffering capacity of soil. The higher the CEC, the stronger the soil's ability to retain and supply nutrients (Sanderman et al., 2020; Bagnall et al., 2023). New chemical indicators such as soil protein, activated carbon, and mineralizable nitrogen can reflect soil nutrient cycling and organic matter dynamics (Bagnall et al., 2023; Liptzin et al., 2023; Naasko et al., 2023).

3.3 Biological properties (microbial biomass, diversity, enzyme activity, earthworm population)

Microbial biomass carbon (MBC), basal respiration rate, and decomposition rate are the most reliable and interpretable biological indicators that can quickly respond to management measures and environmental changes (Doran and Zeiss, 2000; Bhaduri et al., 2022; Liptzin et al., 2022; Semenov et al., 2025). Microbial diversity and community structure reveal the stability and stress resistance of soil ecosystems, although their interpretability and standardization still face challenges (Hermans et al., 2016; Schloter et al., 2017; Semenov et al., 2025).

Enzyme activity (such as β - glucosidase, urease, etc.) reflects the ability of soil organic matter decomposition and nutrient cycling (Bhaduri et al., 2022; Liptzin et al., 2022; Semenov et al., 2025). Large soil animals such as earthworms play an important role as "ecological engineers" in improving soil structure, decomposing organic matter, and redistributing nutrients. Their quantity and diversity are used as intuitive biological indicators of soil health (Doran and Zeiss, 2000; Lu et al., 2020).

3.4 Indicators related to long-term sustainability of soil

SOC and organic matter content are core indicators for measuring soil long-term carbon pool and ecosystem stability, directly affecting soil erosion resistance and greenhouse gas emissions (Bagnall et al., 2023; Bhaduri et al., 2022; Liptzin et al., 2022). The physical and chemical indicators such as aggregate stability, water holding capacity, and CEC reflect the buffering capacity and resilience of soil to external disturbances (such as extreme climate and tillage disturbances) (Es and Karlen, 2019; Bagnall et al., 2023). Microbial diversity, enzyme activity, and stability of soil animal communities are key to the long-term health and functional maintenance of soil ecosystems (Doran and Zeiss, 2000; Bhaduri et al., 2022; Semenov et al., 2025).

4 Impact of Maize Cultivation on Soil Physical Properties

4.1 Changes in soil structure caused by cultivation intensity

Traditional deep tillage and frequent plowing can help improve soil looseness and aeration in the short term, but long-term high-intensity tillage often leads to soil aggregate destruction, loose structure, and susceptibility to surface erosion. In special soil types such as soda saline alkali land, the use of deep tillage combined with rotary tillage and no tillage (SRT) can significantly improve the penetration resistance and bulk density of the 0~40 cm soil layer, promote soil structure optimization, and facilitate the development of maize roots and yield increase (Jiang et al., 2025) (Figure 1). Compared with single no tillage or rotary tillage, compound tillage can better balance the stability of soil structure and crop growth needs.

Conservation tillage (such as no tillage and straw mulching) has been widely used in corn producing areas in recent years. Long term no tillage and straw returning not only increase the content and stability of soil aggregates, but also improve the physical structure of soil, which helps to enhance soil erosion resistance and water retention capacity (Wang et al., 2024). Measures such as intercropping and organic mulching can also promote the restoration of soil structure and reduce structural degradation caused by monoculture cultivation.

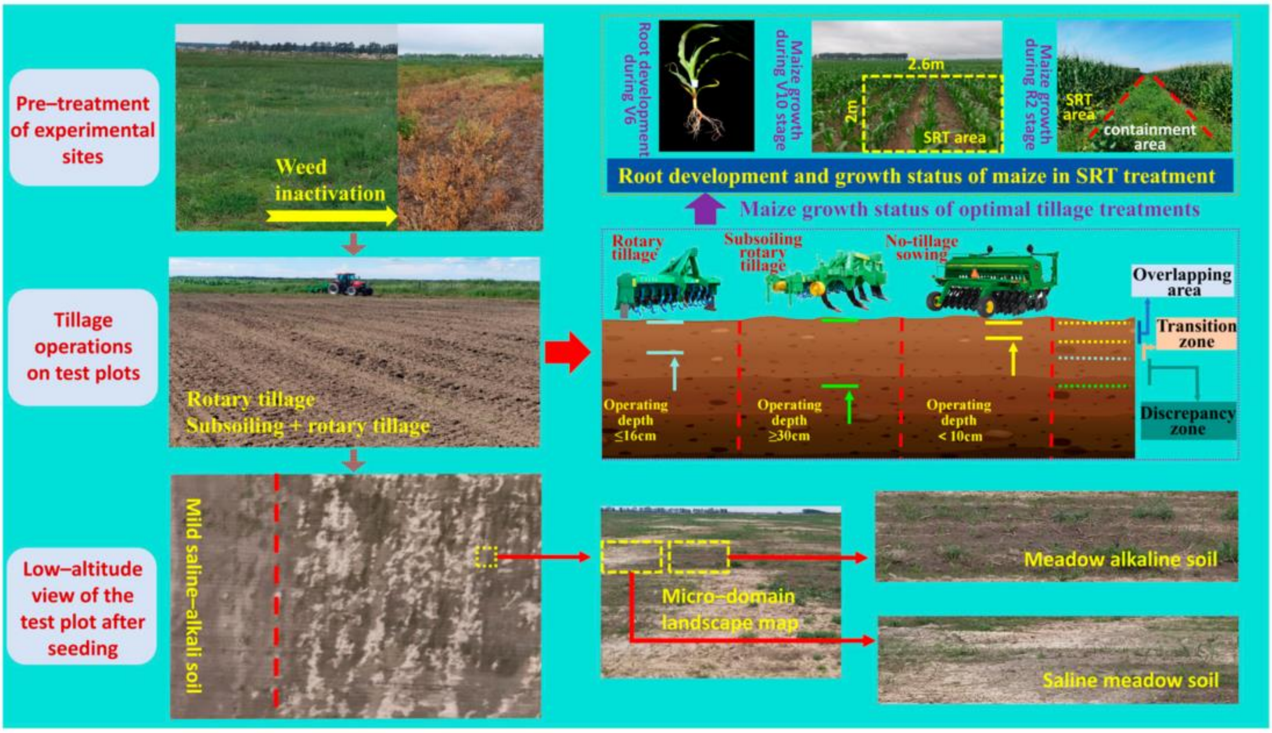

Figure 1 Experimental field preparation, tillage measures, and implementation effects (Adopted from Jiang et al., 2025)

4.2 Effects on soil bulk density and compaction

Soil bulk density and compactness directly affect root growth and water vapor circulation. High intensity cultivation or long-term monoculture of corn can easily lead to soil compaction, increased bulk density, and thus limit root rooting and water infiltration. Measures such as deep loosening and tillage can effectively reduce soil bulk density, alleviate soil compaction, improve root distribution and crop growth environment (Ramadhan, 2021; Jiang et al., 2025). Under different cultivation methods, the soil bulk density of deep tillage and conventional tillage is significantly lower than that of no tillage and shallow tillage, and deep tillage helps to break the plow layer and improve the overall permeability of the soil (Ramadhan, 2021).

Intercropping and cover crops can help reduce compaction. In subtropical Brazil, maize–ruzigrass intercropping lowered bulk density in the 10~20 cm layer by 10% and increased macroporosity (Secco et al., 2023). Returning straw to the field and applying organic mulch also add organic matter, help form aggregates, and further reduce compaction (Negiş, 2023; Wang et al., 2024).

4.3 Impact on water infiltration and retention capacity

The ability of soil moisture infiltration and retention is an important indicator for measuring its physical health. High intensity cultivation and long-term monoculture of corn often lead to soil structure damage, reduced porosity, and thus affect water infiltration and storage. Research has found that protective tillage measures such as deep tillage combined with rotary tillage and no tillage can significantly improve soil water holding capacity and water use efficiency (Ramadhan, 2021; Wang et al., 2024; Jiang et al., 2025). Under straw mulching and organic mulching conditions, the evaporation of soil surface water decreases and the water retention capacity increases, which is beneficial for crop growth under drought stress (Ramadhan, 2021).

A comparative study between long-term corn planting and grass rotation shows that corn monoculture can reduce soil available water capacity and near saturated hydraulic conductivity, especially in soil types that are susceptible to structural damage (Hu et al., 2022). Adding organic substances such as corn stover or biochar can significantly enhance soil aggregate stability and available water capacity, improve water distribution and drought resistance (Kim et al., 2016; Negiş, 2023).

5 Impact on Soil Chemical Properties

5.1 Nutrient consumption and enrichment (N, P, K, and trace elements)

As a high-yield crop, corn has a great demand for major nutrients such as nitrogen (N), phosphorus (P), and potassium (K). Long term monoculture of corn can easily lead to soil nutrient consumption and imbalance. Continuous planting of corn can lead to a significant decrease in soil nutrient content such as total carbon, total nitrogen, available phosphorus, exchangeable potassium, and calcium with increasing planting years, especially in sloping areas and areas lacking fertilization management, where nutrient loss is more severe. Within 30 years, relevant nutrients can drop to about half of their initial values (Fujisao et al., 2020). The planting density and sowing date of corn also affect the distribution and residue of nutrients. An increase in density usually leads to a decrease in grain N, P, and K content, while soil residual N and K fluctuate with planting management (Djaman et al., 2024). Trace elements such as zinc and iron may also be deficient under high-intensity fertilizer and herbicide management, affecting crop quality and soil health (Afata et al., 2024).

To alleviate nutrient consumption, scientific fertilization and crop rotation management have become key. Organic fertilizers, chemical fertilizers, and their combined application can significantly increase soil N, P, K content and crop yield, and the addition of organic fertilizers helps to slow down nutrient release and enhance soil buffering capacity (Mahmood et al., 2017; Adekiya et al., 2024; Jiang et al., 2024). Crop rotation and mulching (such as alfalfa maize rotation) can increase soil organic matter and available nutrient content, promote crop absorption of N, P, and K, enhance nutrient cycling and sustainability of the system (Zhang et al., 2022b; Mukhametov et al., 2024).

5.2 Soil acidification and alkalization trends

In the corn planting system, long-term and large-scale application of chemical nitrogen fertilizers, especially ammonium nitrogen fertilizers, can lead to soil acidification and a decrease in pH value (Neelima et al., 2022; Khavkhun, 2024). The different types and amounts of mineral fertilizers can lead to soil acidification or alkalization. The application of certain fertilizers (such as diammonium phosphate and potassium sulfate) can lower pH, while calcareous fertilizers may increase pH (Khavkhun, 2024). Under the combined application of organic fertilizer and biochar, soil pH usually tends towards neutrality or slightly increases (Wu et al., 2023; Jiang et al., 2024).

Acidified organic fertilizers like treated cattle slurry reduce nitrogen loss by lowering ammonia release, though their short-term effect on pH is limited and microbial diversity remains stable (Wierzchowski et al., 2021). In some cases, irrigation water or soil parent material may push the system toward alkalinization during long-term maize production.

5.3 Organic matter changes under different corn management systems

Long term monoculture of corn, especially in the absence of organic inputs and sloping environments, leads to a significant decrease in soil organic matter (SOM) content, resulting in soil structure degradation and weakened nutrient supply capacity (Fujisao et al., 2020; Feng et al., 2022). In long-term positioning experiments in Northeast China, Laos and other places, continuous corn planting for 30 years resulted in a decrease of up to 50% in soil total carbon and total nitrogen content, which is closely related to yield decline (Fujisao et al., 2020; Feng et al., 2022). In flat land or fields with good organic management, the decline trend of organic matter is relatively slow, and it can even maintain stability.

Management measures such as organic fertilizer, straw returning, biochar, and crop cover can increase soil organic matter and organic carbon content (Mahmood et al., 2017; Zhang et al., 2022b; Wu et al., 2023; Jiang et al., 2024; Xing et al., 2024). The combined application of fertilizers and biochar can increase soil organic carbon and total nitrogen content by more than 20%, and enhance microbial activity (Wu et al., 2023; Xing et al., 2024). The introduction of crop rotation and mulching can accumulate organic matter and cycling nutrients (Zhang et al., 2022b; Mukhametov et al., 2024).

6 Impact on Soil Biological Properties

6.1 Changes in microbial diversity and community structure

Diversified management measures such as intercropping corn and green manure can enhance soil microbial diversity and community complexity, promote the enrichment of beneficial microbial communities (such as root promoting bacteria and arbuscular mycorrhizal fungi), and inhibit the spread of pathogens (Tao et al., 2017; Ablimit et al., 2022). Physical and chemical factors such as soil pH, nutrient status, and organic matter content can indirectly affect maize yield and soil health by regulating microbial community structure (Tao et al., 2017; Chukwuneme et al., 2021).

The soil microbial diversity and metabolic function of corn fields, which were originally grasslands, were significantly higher than those of corn fields under long-term intensive cultivation, and soil pH was the main factor determining microbial distribution (Chukwuneme et al., 2021). The application of biofertilizers, crop cover, and organic matter during corn cultivation can promote microbial diversity and enrichment of functional groups (Ascari et al., 2019; Ablimit et al., 2022).

6.2 Changes in soil animal abundance (such as nematodes and earthworms)

Corn cultivation also has a significant impact on the abundance and diversity of soil animal communities, especially nematodes and earthworms. Long term monoculture corn cultivation and high-intensity tillage often lead to soil structure damage and organic matter decline, thereby inhibiting the survival and reproduction of large soil animals such as earthworms, reducing soil animal diversity and ecological functions (Furtak et al., 2017; Ablimit et al., 2022). Adopting measures such as conservation tillage, straw returning, and organic fertilizer management can help improve the soil environment, promote the reproduction of earthworms and beneficial nematodes, enhance soil biological activity and nutrient cycling capacity.

The abundance of soil animals is closely related to soil microbial communities and enzyme activity. Large soil animals such as earthworms enhance the physical structure and biological functions of soil by decomposing organic residues, promoting aggregate formation, and microbial reproduction. Under diversified planting and organic management systems, the number and diversity of soil animals have significantly increased, and the stability and stress resistance of soil ecosystems have been enhanced.

6.3 Enzyme activity changes related to nutrient cycling

In the corn planting system, enzyme activity is jointly influenced by management measures, soil physicochemical properties, and microbial community structure. Measures such as intercropping corn with green manure, applying biological fertilizers, and organic matter can significantly enhance the activity of key enzymes such as soil dehydrogenase and alkaline phosphatase, promote organic matter decomposition and nutrient release, and enhance soil nutrient supply capacity (Furtak et al., 2017; Hafez et al., 2021; Ablimit et al., 2022). Under water stress and salinization conditions, measures such as inoculation with root promoting bacteria (PGPR) and application of nano silicon can also enhance soil enzyme activity and alleviate the negative effects of adversity on soil and crops (Hafez et al., 2021).

6.4 Effects of genetically modified (GM) maize on soil microorganisms

The planting of genetically modified corn has limited impact on soil microbial community structure, and changes in microbial diversity and major functional groups are mainly influenced by soil type, management measures, and environmental factors, rather than the genetically modified traits themselves (Afandor Barajas et al., 2021). In greenhouse and field experiments, there was no significant difference in the impact of genetically modified maize on soil bacterial communities compared to non genetically modified maize. The main changes in microbial diversity and community structure were still dominated by management measures such as tillage, fertilization, and crop rotation.

Applying bio fertilizers and covering crops can significantly enhance soil microbial diversity and functional group richness, improve soil health and crop yield (Ascari et al., 2019; Ablimit et al., 2022). The direct impact of genetically modified corn on soil microorganisms is limited, and the improvement of soil health relies more on scientific management measures and diversified planting systems.

7 Environmental and Management Factors Influencing Impact

7.1 The role of crop rotation and monoculture

Crop rotation, especially with leguminous crops such as velvet beans and soybeans or green manure crops, can effectively improve soil fertility and nutrient content. *Mucuna pruriens*-*Zea mays* and *Glycine max*-*Zea mays* rotation can increase soil fertility by 10% to 15%, while monoculture maize exhibits lower soil nutrient levels and higher risk of nitrate leaching (Ablimit et al., 2022; Mukhametov et al., 2024). Crop rotation improves soil microbial community structure, promotes the enrichment of beneficial microorganisms, and inhibits the spread of pathogens (Ablimit et al., 2022; Araújo et al., 2023).

Crop rotation also enhances soil organic carbon and enzyme activity by increasing crop residue and organic matter input, promoting nutrient cycling and soil structure recovery. Compared with monoculture, soil pH, total nitrogen, and organic matter content were significantly increased under crop rotation system, and soil enzyme activity and microbial biomass were also higher (Ablimit et al., 2022; Mukhametov et al., 2024).

7.2 Effects of fertilizer types (synthetic and organic) and application rates

The widespread use of synthetic nitrogen fertilizers has greatly increased maize yields, but long-term intensive application often causes soil acidification, nutrient imbalance, and environmental problems such as nitrate leaching and ammonia volatilization (Bacenetti et al., 2016; Kumar et al., 2022; Mukhametov et al., 2024). Organic fertilizers, including pig manure, biogas residues, and green manure, add organic matter and stimulate microbial activity, which improve soil structure and buffering capacity while reducing environmental stress. Balanced use of organic and inorganic fertilizers, together with straw return, can raise soil organic carbon, total nitrogen, and enzyme activity, improve soil pH, and reduce the risk of nitrate loss (Bacenetti et al., 2016; Ablimit et al., 2022; Mukhametov et al., 2024).

Although excessive application of nitrogen fertilizer can increase yield in the short term, it can lead to a decrease in soil microbial diversity and enzyme activity inhibition, increasing environmental burden (Kumar et al., 2022; 2024). Adopting recommended fertilizer application rates (such as 100% or 150% recommended nitrogen fertilizer) combined with no tillage and crop residue cover can improve soil organic carbon, microbial biomass, and enzyme activity while increasing yield (Kumar et al., 2024). The application of biostimulants and microbial fertilizers can enhance crop stress resistance and soil health (Singh et al., 2025; Sobiech et al., 2025).

7.3 Interaction between climate and soil types

There are significant differences in the response of management measures among different climate zones (such as arid, semi-arid, humid) and soil types (such as sandy, loam, clay). The extreme temperature and precipitation fluctuations brought about by climate change directly affect soil moisture, microbial activity, and nutrient cycling (Zhang et al., 2022b; Yang et al., 2023; Singh et al., 2025). Under high temperature or drought conditions, soil organic matter decomposition accelerates, microbial diversity decreases, and soil structure is easily damaged. Measures such as organic coverage, drip irrigation, and stress tolerant varieties need to be taken to alleviate this (Zhang et al., 2022b; Singh et al., 2025).

Sandy soil is more prone to water loss and nutrient loss under drought and high temperatures, while clay is more prone to water accumulation and compaction. Conservation tillage and organic management measures are effective for soil organic carbon and yield in sandy and acidic soils (Baier et al., 2023). The soil organic carbon content is positively correlated with maize yield, but the marginal effect of SOC increase on yield varies under different climates and soil types (Oldfield et al., 2018).

8 Case Study Analysis

8.1 Case 1: high input conventional corn system - impact and lessons learned

The high input conventional corn system is characterized by deep plowing, monoculture, high-dose fertilizers and pesticides, and is widely distributed on large farms in Europe, America, Southeast Asia and other regions. This type of system can achieve high yields in the short term, but it puts multiple pressures on soil health. Long term monoculture and high-intensity tillage lead to a decrease in soil organic matter, destruction of aggregates, increase in bulk density, and decrease in porosity, which in turn affect water retention and root growth (Bruun et al., 2017; Nyéki et al., 2022; Smith and Boardman, 2025). The excessive use of fertilizers and pesticides can also lead to soil acidification, imbalance of trace elements, and decreased microbial diversity, increasing the risk of pests and diseases (Bruun et al., 2017; Afata et al., 2024; Mukhametov et al., 2024). In cases such as Thailand and Hungary, intensive corn cultivation led to a significant decrease in quality indicators such as soil oxidizable carbon (Pox-C), and soil quality was negatively correlated with planting intensity (Bruun et al., 2017; Nyéki et al., 2022).

High input systems are also prone to soil erosion and sediment loss, especially in slopes and areas with concentrated rainfall. The case of East Devon, England, shows that soil compaction and bare land exposure during corn harvesting and planting are very likely to cause muddy water flooding and serious erosion after rainstorm, threatening farmland and surrounding environment (Ruf et al., 2021; Smith and Boardman, 2025) (Figure 2). These issues suggest that relying solely on high input and mechanized conventional corn systems can increase yields in the short term, but in the long run, it will incur the cost of soil degradation and ecological risks, and there is an urgent need for management optimization and sustainable transformation.

8.2 Case 2: conservation tillage maize system - impacts and outcomes

Long term field trials in China, the United States, Brazil, and other regions have shown that conservation tillage can significantly enhance soil organic carbon, aggregate stability, and microbial diversity, improve soil structure and water retention capacity (Ablimit et al., 2022; Da Silva et al., 2022; Li et al., 2023; Flynn et al., 2024). In the intercropping system of green manure maize in northwest China, ten years of conservation tillage increased soil pH, nutrient content, and enzyme activity, reduced pathogen abundance, promoted the enrichment of beneficial microorganisms, and resulted in better soil health and yield than monoculture systems (Ablimit et al., 2022).

Intercropping and covering crops can increase the diversity of soil animals (such as nematodes and earthworms) and microorganisms, enhance the complexity of food webs and nutrient cycling efficiency (Da Silva et al., 2022; Liang et al., 2024). In the tropical regions of Brazil, maize grass rotation and no till management significantly improved soil organic matter and aggregate stability, as well as soil structure and erosion resistance (Da Silva et al., 2022).

8.3 Comparative analysis of cases: soil health indicators

There are significant differences in soil health indicators between high input conventional systems and conservation tillage systems. Under high input conventional systems, soil organic matter, aggregate stability, microbial diversity, and enzyme activity all show a decreasing trend. Soil structure deteriorates, bulk density increases, porosity decreases, water retention capacity weakens, and erosion and nutrient loss are prone to occur (Bruun et al., 2017; Nyéki et al., 2022; Mukhametov et al., 2024; Smith and Boardman, 2025). Conservation tillage systems can significantly enhance organic carbon, aggregate stability, and microbial diversity, improve soil structure and water regulation capacity, and reduce erosion risk (Ablimit et al., 2022; Da Silva et al., 2022; Li et al., 2023; Flynn et al., 2024; Liang et al., 2024).

In terms of biological indicators, soil microorganisms and animal communities under conservation tillage systems are more abundant, food web complexity and ecological functions are stronger, enzyme activity and nutrient cycling efficiency are higher (Ablimit et al., 2022; Da Silva et al., 2022; Liang et al., 2024). Chemical indicators such as pH, nutrient content, and organic matter levels are also superior to high input systems.

Figure 2 Ottery St Mary hailstorm event, 2008 image Thorne Farm Way. (a) Aerial view of Ottery St Mary and surrounding land showing soil erosion and runoff. (b) Muddy runoff from compacted soil in maize stubble. (c) Soil erosion in a winter cereal crop seedbed with compacted soil following maize. (Adopted from Smith and Boardman, 2025)

9 Synthesis of Findings

9.1 Common trends in different corn planting systems

There are some significant common trends in the impact of corn cultivation on soil health worldwide. The changes in soil health are closely related to management measures, whether in high input conventional systems, crop rotation systems, or conservation tillage systems. Research has generally found that reasonable crop rotation, straw returning, and organic fertilizer input can significantly improve soil organic matter, aggregate stability, microbial diversity, and enzyme activity, thereby improving soil structure, enhancing nutrient supply, and strengthening ecological functions (Zhang et al., 2021; Ablimit et al., 2022; Dawar et al., 2022; Li et al., 2023; Sankhyan et al., 2023; Liang et al., 2024; Mukhametov et al., 2024). However, long-term monoculture corn cultivation and high-intensity fertilizer application can easily lead to a decrease in soil organic matter, loss of microbial diversity, soil acidification, and structural degradation, increasing the risk of erosion and nutrient loss (Ruf et al., 2021; Wolińska et al., 2022; Mukhametov et al., 2024).

Examples include maize intercropped with green manure in Northwest China and with soybean in Northeast China, where beneficial microbes increased and soil aggregates became stronger (Zhang et al., 2021; Ablimit et al., 2022). In general, more diverse systems show better soil conditions, while single high-input models carry higher risks of decline.

9.2 Key driving factors for soil health changes in corn cultivation

Crop rotation and intercropping improve soil fertility and structure by increasing organic matter input, promoting microbial diversity and nutrient cycling (Zhang et al., 2021; Ablimit et al., 2022; Liang et al., 2024; Mukhametov et al., 2024). Organic inputs such as organic fertilizers, straw returning, and biochar can increase soil organic carbon and nutrient content, promote microbial and enzyme activity, and improve soil physicochemical properties (Dawar et al., 2022; Sankhyan et al., 2023; Yang et al., 2024).

Although long-term high-intensity fertilizer application can increase yield in the short term, it can easily lead to soil acidification, trace element imbalance, and decreased microbial diversity (Wolińska et al., 2022; Sankhyan et al., 2023; Afata et al., 2024; Mukhametov et al., 2024). The combination of organic-inorganic fertilizers and scientific regulation of fertilizer application can balance yield and soil health (Dawar et al., 2022; Sankhyan et al., 2023; Afata et al., 2024). The regulation of soil microbial community structure, such as the application of rhizosphere bacteria, green manure, and crop cover, can enhance soil health and crop stress resistance (Hafez et al., 2021; Zhang et al., 2021; Ablimit et al., 2022; Yang et al., 2024; Singh et al., 2025).

9.3 Balance between yield optimization and soil protection

In corn production practice, there is a clear trade-off between maximizing yield and soil protection. High input conventional systems achieve short-term high yields through deep cultivation, high-dose fertilizers, and pesticides, but often at the cost of decreased soil organic matter, structural degradation, and loss of microbial diversity, which may lead to long-term yield decline and land degradation (Ruf et al., 2021; Wolińska et al., 2022; Sankhyan et al., 2023; Mukhametov et al., 2024). Although conservation tillage, crop rotation, and organic management systems have limited initial yield increases, they can significantly improve soil health, enhance long-term productivity and stress resistance of the system (Zhang et al., 2021; Ablimit et al., 2022; Dawar et al., 2022; Li et al., 2023; Sankhyan et al., 2023).

Scientific management measures, such as the combination of organic-inorganic fertilizers, crop coverage, and rational rotation, can to some extent balance yield and soil protection, achieving a win-win situation of "high yield and health" (Zhang et al., 2021; Ablimit et al., 2022; Dawar et al., 2022; Li et al., 2023; Sankhyan et al., 2023; Mukhametov et al., 2024; Yang et al., 2024). But in areas with limited resources and high land pressure, farmers often tend to pursue short-term yields and neglect long-term soil health.

9.4 Long term impacts on agricultural sustainability

Long term single high input systems lead to soil organic matter depletion, structural degradation, loss of microbial diversity, and ecological function decline, posing a threat to food security and the ecological environment (Ruf et al., 2021; Woli ń ska et al., 2022; Sankhyan et al., 2023; Mukhametov et al., 2024). Diversified and eco-friendly management measures, such as crop rotation, intercropping, crop cover, organic inputs, and microbial regulation, can significantly improve soil health, enhance system resilience and ecological service functions (Zhang et al., 2021; Ablimit et al., 2022; Dawar et al., 2022; Sankhyan et al., 2023; Li et al., 2023; Liang et al., 2024; Yang et al., 2024).

Long term positioning experiments and multi-point studies have found that soil health indicators (such as organic carbon, aggregate stability, microbial diversity, enzyme activity, etc.) are closely related to crop yield and system sustainability (Zhang et al., 2021; Ablimit et al., 2022; Dawar et al., 2022; Li et al., 2023; Sankhyan et al., 2023; Liang et al., 2024; Yang et al., 2024). Continuous monitoring and scientific management can not only increase current production, but also ensure the long-term productivity and ecological security of land resources.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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