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(Research Article)

A study on evaluation of farmland quality in Beijing city: A path towards agricultural sustainability

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Abstract

Farmland quality is a critical determinant of agricultural productivity and sustainability. This study evaluates the farmland quality in Beijing City by analyzing key soil properties and environmental factors, including organic matter, nitrogen, phosphorus, potassium, pH, and salinity. Using geospatial and statistical analyses, the study identifies spatial patterns and correlations among soil characteristics, providing insights into areas requiring improvement for sustainable agricultural practices. The findings serve as a roadmap for policymakers and stakeholders to enhance soil health and ensure food security.

Keywords: Farmland quality; Soil properties; Agricultural sustainability; Beijing City; Geospatial analysis; Soil health

1. Introduction

China's rapid population growth has led to the expansion of urban development onto agricultural land, posing a threat to the country's food security. Urban growth and land-use changes have also impacted ecosystem structures, environmental quality, and the livelihoods of those dependent on urban agriculture (Li et al., 2021). Thus, agricultural production primarily depends on high-quality agricultural land, making it vital for maintaining societal balance and fostering the sustainable development of human society. The deterioration of agricultural land can significantly impact human well-being and potentially lead to major social issues (Rai et al., 2019). Additionally, a report published by the Chinese Ministry of Natural Resources states that heavy metals pollution affects approximately 12 tons of grain annually, causing a serious impact on the economy (Li et al., 2020; Wang et al., 2020). An evaluation of soil quality in 2014 further revealed that 19.40% of agricultural land in China failed to meet environmental criteria, primarily due to climate change, posing a major concern to agricultural product safety (Xue et al., 2019). Consequently, advancing scientific knowledge of cultivated land quality is recognized as a pivotal objective for achieving sustainability, safeguarding food security, maintaining societal stability, and contributing to climate change mitigation (Zhang et al., 2020a). Moreover, Rural regions are essential for advancing the Sustainable Development Goals (SDGs). Since the 1991 Netherlands Conference on Agriculture and Environment, convened by the Food and Agriculture Organization (FAO), the framework of sustainable agriculture and rural development (SARD) has been recognized as a critical priority for sustainable development. This approach focuses on fulfilling human needs while maintaining environmental integrity, promoting economic stability, and ensuring social fairness (Lembo et al., 2006).

Land quality evaluations are gradually becoming an essential foundation for initiatives such as land use management, agricultural land consolidation strategy, the allocation of protected prime farmland, Arable land occupation, and redress. Similarly, the land quality is determined by its characteristics and overall condition (Askari and Holden, 2015). Traditionally, scientists evaluated land quality primarily through indicators such as soil fertility, climate, and environmental factors (Paul et al., 2020). However, as the social economy has advanced, the understanding of this concept has evolved to include not only soil fertility but also land adequacy, potential productivity, and ecological

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environmental security (Ma et al., 2020). Additionally, Upgrades in equipment technology have underlined the importance of elements like geographical location and infrastructure conditions. Furthermore, with the advancement of industrialization and the widespread use of chemical fertilizers, the concentration of heavy metals such as cadmium and lead in the soils of cultivated lands has risen to concerning levels in certain regions (Zhang et al., 2020b). Concurrently, the presence of phosphorus and nitrogen in agricultural wastewater has adverse effects on the quality of the environment, which in turn impacts human well-being through both direct and indirect pathways (Stauffer et al., 2014). These ecological challenges exacerbate the deterioration of land quality. Consequently, the selection of indicators for land quality assessment should integrate considerations of sustainable development and ecological protection, particularly in light of the intensifying ecological and environmental issues.

This study aims to build an improved evaluation strategy that represents real-world situations and progress it to further greater consistency and rigorousness in science, thereby providing significant insights for additional investigation (Malerba, 2019). The study focuses on farmland quality in the Beijing District, establishing a broad framework for evaluating variables and analyzing the quality of land by employing geospatial analysis, which provides concentration ratings to direct the analysis.

This study aims to

- Evaluate key soil properties that influence farmland quality in Beijing City.
- Identify spatial patterns and correlations among soil characteristics.

Provide recommendations for sustainable agricultural practices based on the findings.

2. Material and methods

2.1. Investigation Area

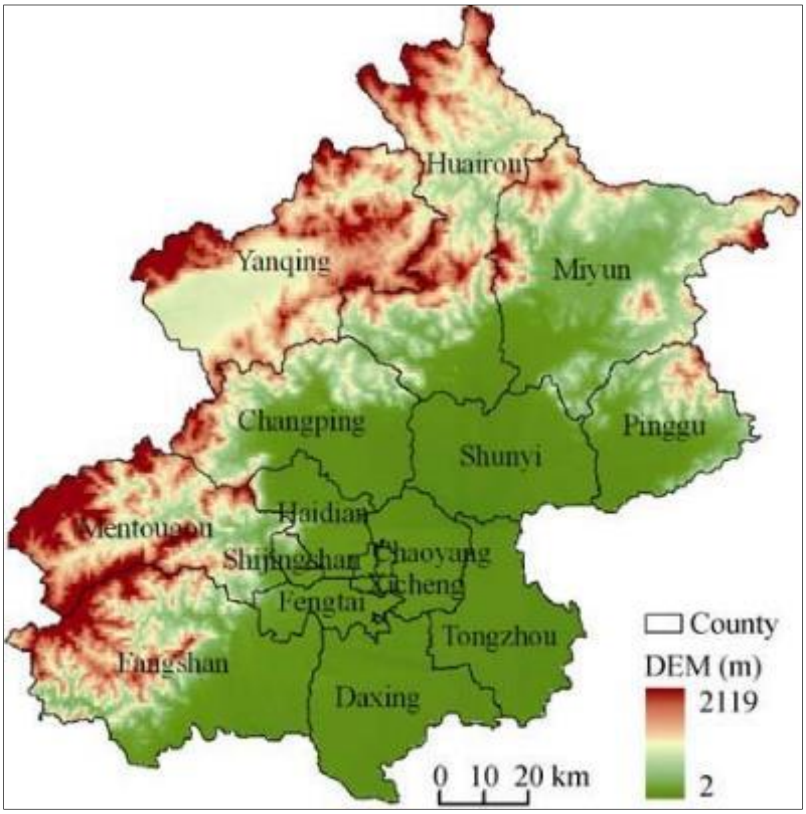

Figure 1 Geographic Location of the Research Area

Beijing, the capital city of China, is geographically located between the latitude of 39°26′N to 41°03′N and 115°25′E to 117°30′E longitude. The city is situated at the extreme northern edge of China's Hanshu plains bordered by the Yunshan mountains range to its north and western part. In contrast, the south and southeast portions of Beijing feature flat plains.

The topography of modern Beijing consists of hilly regions amounting to 62%, 38% of plain regions, and a quarter of developed areas. Despite its vast expanse of cultivated land, which occupied approximately a little above 126,000 ha. This land started losing its value due to increasing urbanization. Beijing is located in a monsoonal temperate climate zone which generally has 4 seasons whereby summer and winter can be categorized as extreme. Russians can be blamed for the cold dry winds experienced during winter seasons. The spring season is relatively smoother than in other countries and is also accompanied by varying seasonal shifts. Due to the location of the city, there is also adequate rainfall of around 500 to 600mm annually which is not stable in nature year in and year out. Sandstorms are not an uncommon experience in the spring period.

2.2. Data collection and processing

The data collection process for the Beijing District involved obtaining precise GPS coordinates for sampling points to capture spatial variation in soil and land characteristics. Soil samples were collected and analyzed for organic matter, pH, nitrogen, phosphorus, and potassium, alongside field observations of texture, salinization, drainage, and barrier factors like gravel layers. Environmental data, including irrigation capability, biodiversity, and groundwater depth, were supplemented by local surveys and reports. Additional agricultural infrastructure data, such as farmland shelter networks, were integrated. The collected data were compiled and processed using GIS tools for spatial analysis and mapping to ensure alignment and accuracy.

A total of 809 Soil samples were collected across various farmland areas in Beijing City to evaluate key soil quality indicators. The analysis focused on six critical parameters: organic matter (g/kg), which serves as a vital indicator of soil fertility; total nitrogen (g/kg), essential for supporting plant growth; available phosphorus (mg/kg), a measure of soil phosphorus availability critical for crop productivity; available potassium (mg/kg), which contributes to plant stress tolerance and overall health; pH, reflecting soil acidity or alkalinity and its influence on nutrient availability; and salinity, which was assessed for its potential impact on crop growth and soil health. These parameters were selected to comprehensively evaluate soil conditions and their implications for agricultural sustainability.

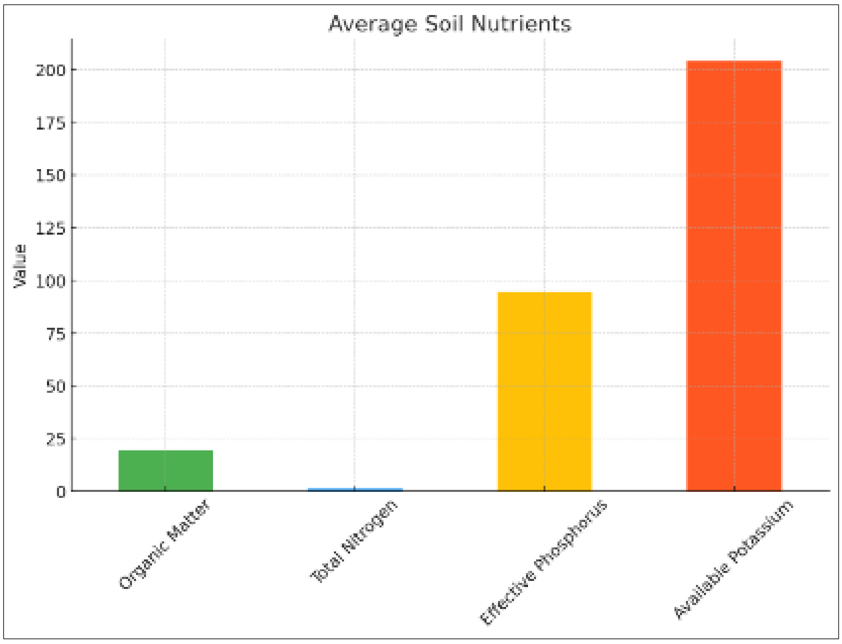

Figure 2 Average Levels of Key Soil Nutrients

2.3. Field survey

Field surveys were conducted between April and August 2023, coinciding with the primary growing season for major crops in Beijing. A total of 50 representative farmland plots were selected using a stratified random sampling approach, encompassing rural and peri-urban regions. The selection criteria included crop type, land use intensity, and geographic location. Comprehensive data collection was carried out to evaluate the following parameters:

- **Soil Quality:** Soil samples were collected at three depths (0-10 cm, 10-20 cm, and 20-30 cm) to assess variations in soil properties with depth. Analyses were conducted at the Beijing Agricultural Research Institute, focusing on the following indicators:
- **Soil pH:** Measured to evaluate acidity or alkalinity, which influences nutrient availability and crop growth.
- **Organic Matter Content:** A key indicator of soil fertility and microbial activity, organic matter was analyzed using the loss-on-ignition method.
- **Soil Texture:** Determined using the hydrometer method to quantify sand, silt, and clay fractions, influencing water retention and root penetration.
- **Nutrient Content:** The concentrations of nitrogen (N), phosphorus (P), and potassium (K) were measured using standard laboratory techniques to assess the soil's capacity to support plant growth.
- **Heavy Metals:** Soil samples were screened for contaminants such as cadmium (Cd), lead (Pb), and arsenic (As), which could compromise soil health and agricultural productivity.
- **Land Use and Crop Type:** Information on crop types (e.g., wheat, corn, rice, and vegetables) was gathered through farmer interviews. Data on land use intensity, including crop rotation practices, fertilizer applications, and irrigation methods, were documented to understand farming practices and their impact on soil quality.
- **Farmland Productivity:** Crop yields for the main crops cultivated in each plot were recorded based on direct measurements and farmer reports from the last three growing seasons. Yield data were standardized to calculate crop yield per hectare, providing insights into land productivity and the efficiency of agricultural practices.

The collected data provide critical insights into the interactions between soil properties, land use, and agricultural productivity, forming the foundation for tailored recommendations to enhance soil health and crop yields in Beijing's farming systems.

3. Result

3.1. Comprehensive Evaluation Index System of Cultivated Land Quality and Index Weight

Table 1 Weights of cultivated land quality evaluation indexes in Beijing city

Guideline Layer	Indicator Layer	Index Weight
Soil Quality	Soil Organic Matter Content (%)	0.043
	Soil pH	0.100
	Soil Texture (Sand/Silt/Clay Ratio)	0.051
	Nutrient Content (N, P, K)	0.122
	Heavy Metal Presence (mg/kg)	0.108
Topography	Slope (%)	0.071
	Elevation (m)	0.043
	Aspect	0.058
	Soil Erosion Risk (RUSLE Factor)	0.109
Climate	Precipitation (mm/year)	0.111
	Temperature (°C)	0.035
	Evapotranspiration (mm/year)	0.079
Land Use	Land Use Type	0.0491
	Vegetation Cover (NDVI)	0.0536
	Proximity to Water Sources (km)	0.071

The Central Committee of the Communist Party of China and the State Council emphasize the importance of robustly protecting cultivated land in terms of quantity, quality, and ecology to establish a comprehensive food security framework. In line with this goal, the 2016 "Guidelines for the Grading of Cultivated Land Quality and Agricultural Land Evaluation" in Beijing City focused on assessing cultivated land quality by considering fertility and environmental factors (Liu et al., 2021). This evaluation system included indicators such as landform, slope, soil texture, tillage layer thickness, pH, soil organic matter, irrigation reliability, and soil pollution levels. Additionally, the "Regulations for Classification on Agricultural Land" the natural quality of the land and its conditions of use serve as critical foundations for achieving high agricultural yields and efficiency, forming key components of cultivated land evaluation (Kılıc et al., 2022; Müller et al., 2010). In addition to the natural and utilization conditions, ecological factors are essential in a comprehensive evaluation of cultivated land quality, as they play a significant role in determining the long-term sustainability of land use. In this study, the researchers utilized hierarchical analysis to determine the weights for each indicator in the evaluation of cultivated land quality. These weights are summarized in Table 1. The process began by using hierarchical analysis to organize these indicators into categories, allowing for a comparison of their relative importance within each category. This step also involved constructing a judgment matrix to finalize the weights of all the indicators. Once the evaluation system for cultivated land quality was established and the weights for each indicator were determined, the weighted summation method was used to calculate a comprehensive cultivated land quality index for each evaluation unit. To visualize this, the study plotted the relationship between the evaluation units' order (x-axis) and the calculated quality index (y-axis) on a distribution chart. The next step involved determining the number of grades for the quality index and identifying the critical point, which would be used to categorize the land quality. This critical point was found by examining the point of inflection on the curve, where the slope undergoes an abrupt change, thus allowing for the classification of cultivated land into different quality grades based on the index.

3.2. Calculation of the cultivated land quality index

The basic condition index evaluated the foundational aspects of cultivated land, such as soil properties and infrastructure, providing insights into its inherent agricultural potential. The health condition index focuses on soil vitality, nutrient levels, and other factors critical for maintaining productivity over time (Lechner et al., 2012; Zhao et al., 2021). Lastly, the ecological environmental condition index addressed the environmental sustainability of the farmland, examining elements like biodiversity, pollution levels, and ecosystem balance. These indices were calculated using specific equations tailored to capture the unique attributes of each dimension, resulting in a holistic and scientifically robust evaluation framework. This methodology not only highlights the current state of farmland quality in Beijing but also serves as a strategic guide for implementing sustainable agricultural practices in the future.

$$\mathrm{A}= \sum B_i * N_i \quad \ldots\ldots\ldots\ldots\ (1)$$

$$B = \sum L_i * G_i \quad \ldots\ldots\ldots\ldots\ (2)$$

$$H = \sum K_i * D_i \quad \ldots\ldots\ldots\ldots\ (3)$$

In this framework, the indices A, B, and H denote the basic condition index, the health condition index, and the ecological environmental condition index of cultivated land, respectively. These indices are calculated based on a set of key indicators and their associated weights. Specifically, Bi, Ni, and Li represent the values of the i-th indicator related to the basic condition, health condition, and ecological environmental condition, respectively. Meanwhile, Gi, Ki, and Di are the weights assigned to these corresponding indicators, reflecting their relative significance in the overall evaluation process.

3.3. Calculation of the cultivated land quality index

The cultivated land quality index (Q) was derived by evaluating the condition of the cultivated land. This was achieved by multiplying the indices corresponding to the three dimensions outlined previously. The calculation can be represented by the following equation:

$$\mathrm{Q}= \mathrm{A}*\mathrm{B}*\mathrm{H} \quad \ldots\ldots\ldots\ldots\ (4)$$

3.4. Statistical Methods

The soil samples show significant variability in key parameters, including organic matter, nitrogen, phosphorus, potassium, and pH. The mean organic matter is relatively low (19.29 g/kg), with some samples having none, indicating potential soil quality issues. Nitrogen levels also vary widely, with a mean of 1.08 g/kg, and some samples lacking nitrogen altogether, which could affect plant growth. Phosphorus and potassium show a similar trend, with available amounts ranging from zero to high values, suggesting nutrient imbalances. The pH is close to neutral (7.43), but the wide variation in pH values (6.13–8.44) could impact soil suitability for different crops. Overall, these results suggest a need for soil management to address nutrient deficiencies and imbalances for optimal plant health.

Table 2 Provides a summary of key soil properties in the study area

Parameter	**Mean**	**Standard deviation**	**Maximum**	**Minimum**
Organic Matter (g/kg)	19.29	1.35	73.60	0.00
Total Nitrogen (g/kg)	1.08	0.95	4.07	0.00
Available Phosphorus (mg/kg)	94.65	2.56	1266.00	0.00
Available Potassium (mg/kg)	204.27	0.66	969.00	0.00
pH	7.43	2.47	8.44	6.13

Table 3 Correlation matrix

Parameter 1	**Parameter 2**	**Correlation Coefficient**
Organic Matter	Total Nitrogen	0.75
Ph	Available Phosphorus	-0.30

The correlation between **Organic Matter** and **Total Nitrogen** is **0.75**, which indicates a strong positive relationship between these two parameters. As organic matter increases, total nitrogen tends to increase as well, suggesting that soils with higher organic content are likely to have higher nitrogen levels, which is beneficial for plant growth. On the other hand, the correlation between **pH** and **Available Phosphorus** is **-0.30**, showing a weak negative relationship. This suggests that as soil pH increases, the availability of phosphorus decreases slightly, which could imply that slightly acidic soils might be more favorable for phosphorus availability.

Table 4 Geospatial analysis highlights the spatial distribution of soil properties

Evaluation index		**Index**
Organic Matter	L>40%	High concentrations
Available Phosphorus	0<L>15%	Low levels in areas with high pH.
Salinity	0<L>15%	Concentrated in low-lying regions

The evaluation indices suggest that the soil has high concentrations of organic matter, which is beneficial for fertility and plant growth. However, available phosphorus levels are low in areas with high pH, indicating that alkaline conditions may limit phosphorus availability. Additionally, salinity is concentrated in low-lying regions, likely due to poor drainage, which could negatively impact plant growth. These findings highlight the need for targeted soil management practices, such as adjusting pH to optimize phosphorus uptake and addressing salinity issues in low-lying areas to improve soil health and crop productivity.

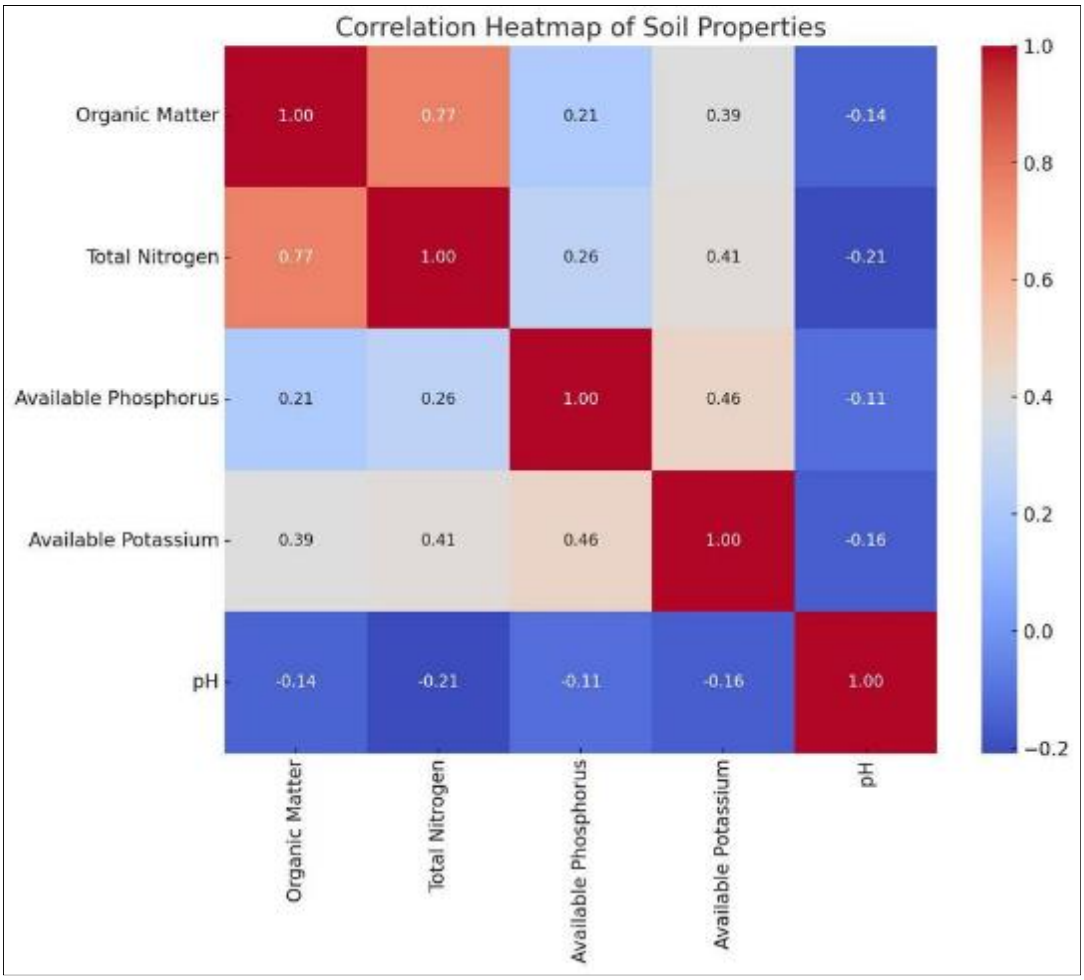

Figure 3 Correlation heatmap of soil properties

4. Discussion

The findings from this study provide critical insights that can significantly contribute to the advancement of sustainable agricultural practices in Beijing City. The intricate relationships between various soil properties underscore the need for comprehensive, region-specific strategies for managing soil health, enhancing productivity, and addressing the challenges posed by environmental conditions.

The significant positive correlation between organic matter and total nitrogen ($r = 0.75$) is an important finding. Organic matter plays a vital role in nitrogen cycling, and its enhancement could lead to improved nitrogen availability in soils, which is essential for optimizing crop yields (Tan et al., 2020). This finding suggests that practices aimed at increasing organic content, such as the incorporation of organic fertilizers, crop residues, and cover crops, could help maintain a balanced nutrient supply for crops.

However, the study also highlights an inverse relationship between pH and available phosphorus (-0.30), indicating that higher pH levels, typically found in alkaline soils, may hinder phosphorus availability. Phosphorus is a key nutrient for root development, energy transfer, and overall plant growth (Khan et al., 2023; Malhotra et al., 2018). The low availability of phosphorus in alkaline soils emphasizes the need for customized fertilization strategies, such as the application of phosphorus fertilizers that are more effective in high pH conditions or the use of soil amendments to lower the pH. Understanding the pH-phosphorus relationship can aid in developing more efficient and sustainable fertilization techniques.

The geospatial analysis of soil properties reveals considerable spatial variations, highlighting the need for region-specific soil management interventions. For instance, the northern regions of Beijing, which exhibit higher organic matter levels, present a unique opportunity to benchmark best practices for soil health management. These regions can serve as models for other areas where organic matter levels are lower, fostering the adoption of practices that boost soil fertility, such as organic farming and sustainable land management practices (Liu et al., 2022).

This spatial disparity underscores the importance of conducting localized soil assessments to tailor agricultural interventions that address the specific needs of each region. By promoting region-specific soil management, policymakers, and agricultural experts can optimize resource allocation and enhance the effectiveness of soil improvement initiatives across diverse agricultural zones.

The study also highlights the salinity challenges faced by low-lying areas in Beijing, where elevated salinity levels pose a significant threat to crop viability. High salinity reduces water availability and affects plant growth, leading to decreased agricultural productivity (Chele et al., 2021; Muhammad et al., 2024). These findings underline the necessity of implementing effective strategies to mitigate the impacts of salinity, such as the installation of drainage systems to prevent waterlogging and the application of leaching techniques to remove excess salts from the soil. Moreover, using salt-tolerant crop varieties and altering irrigation practices could further help to minimize the adverse effects of salinity on crop yields.

These challenges necessitate long-term solutions and integrated approaches to soil and water management, ensuring that agricultural systems in low-lying areas can remain productive and sustainable.

4.1. Implications for Policy and Practice

The results of this study have broad implications for policymaking and agricultural practice, particularly in terms of achieving sustainability goals and improving food security in Beijing.

The findings provide valuable insights that can guide policymakers in prioritizing areas for soil improvement initiatives. With spatial variations in soil properties, there is a clear need for targeted soil health programs that address the specific challenges faced by different regions. Policymakers can leverage this data to allocate resources more equitably and ensure that efforts to improve soil quality reach the areas that need them most. Additionally, the importance of nutrient management and salinity control emphasizes the need for a holistic approach to soil and water management, which can be integrated into broader agricultural policy frameworks.

Sustainable agriculture requires addressing soil nutrient imbalances, improving soil structure, and mitigating environmental challenges such as salinity. By focusing on soil health, Beijing can advance its agricultural sustainability goals, reduce dependency on synthetic fertilizers, and ensure long-term food security. Ensuring that soils are both productive and resilient to climate change will be key to meeting the city's growing food demands. Furthermore, addressing soil salinity and pH-related issues will contribute to the city’s environmental goals by reducing land degradation and promoting the conservation of natural resources.

Finally, farmer education and engagement are crucial for the successful implementation of these findings. Farmers play a pivotal role in soil management practices, and educating them on the significance of maintaining optimal pH levels, promoting crop rotation, and adopting organic amendments can lead to long-term improvements in soil quality. Extension services and training programs can help farmers understand the relationship between soil health and crop productivity, thereby encouraging the adoption of sustainable agricultural practices. Engaging farmers in decision-making processes and supporting them with the necessary tools and knowledge will be instrumental in improving soil health and enhancing agricultural sustainability in Beijing.

5. Conclusion

This study underscores the importance of evaluating farmland quality for sustainable agriculture. By identifying spatial patterns and correlations among soil properties, the research provides actionable insights for improving soil health in Beijing City. Future studies should incorporate additional variables, such as land management practices, to further refine the evaluation.

Compliance with ethical standards

Disclosure of conflict of interest

Disclosure of conflict of interest. As the corresponding author, I would like to declare that none of my co-authors nor I have any conflicts of interest that might affect the findings presented in this paper

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