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Soil Fertility Improvement Techniques for Newly Reclaimed Cultivated Land

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Abstract

As a fundamental resource and condition for human survival, cultivated land is the most important and irreplaceable intrinsic factor in ensuring comprehensive agricultural productivity. With the accelerating industrialization of society, more and more arable land is being occupied, while the growing population has led to a yearly decline in per capita cultivated land area. To alleviate this situation, new farmland is being reclaimed through various means, including land consolidation. With the continuous development and utilization of newly reclaimed cultivated land, improving soil quality has become a critical issue. This paper reviews the research progress and achievements of different soil fertility enhancement methods in improving the quality of newly reclaimed farmland both domestically and internationally. The aim is to provide theoretical foundations and references for enhancing soil quality in newly reclaimed farmland, which holds significant importance for accelerating the green utilization of cultivated land and promoting sustainable economic development in China.

Keywords

Newly cultivated land; inorganic fertilization; organic fertilization; biological fertilization; integrated fertilization.

1. INTRODUCTION

Against the backdrop of increasingly scarce land resources, newly reclaimed cultivated land has become an important way to expand the space for agricultural production and ensure food security. However, newly reclaimed cultivated land often has problems such as poor texture structure and low nutrient content, failing to meet the growth requirements of crops. In particular, the deficiency of major elements such as nitrogen, phosphorus, and potassium, as well as trace elements, severely restricts the realization of the production potential of the land. Conducting research on soil fertility improvement techniques for newly reclaimed cultivated land plays an irreplaceable role in increasing crop yields, improving the quality of agricultural products, and protecting the ecological environment. In addition, the promotion and application of soil fertility improvement techniques help to promote the green transformation of agriculture, facilitate the sustainable development of agriculture, ensure national food security, and have important practical significance for achieving the strategic goals of rural revitalization.

2. CURRENT STATUS OF SOIL IN NEWLY RECLAIMED CULTIVATED LAND

Currently, China is undergoing rapid urbanization, where the contradiction between land supply and demand as well as the occupation-compensation balance of cultivated land has

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become prominent[1, 2]. To address this situation, China has intensified efforts in land reclamation and cultivation, fully leveraging its potential to supplement arable land. Taking Zhejiang Province as an example, in accordance with the policy principle of "compensation before occupation, replacing superior land with superior land", the province achieved a balance between arable land occupation and compensation. During the 13th Five-Year Plan period (2016-2020), Zhejiang reclaimed cultivated land through multiple approaches, with the total area exceeding 30,000 hectares [3]. With the development and utilization of newly reclaimed cultivated land, soil quality issues have become increasingly apparent. Investigations reveal that the productivity of most newly reclaimed farmland is only 10%-30% of that of the occupied cultivated land, requiring 7-10 years of soil improvement and fertility enhancement to achieve the "occupation-compensation balance" in land quality [4]. The phenomenon of "compensating superior occupied farmland with inferior reclaimed land" is notably prevalent in newly cultivated areas [5]. The majority of newly reclaimed cultivated lands demonstrate significantly inferior quality compared to the occupied farmland, commonly exhibiting prominent issues such as poor soil structure, low nutrient content, and multiple limiting factors [6]. It is difficult to achieve genuine "occupation-compensation balance" in terms of cultivated land quality. The prominent challenges in improving the quality of newly reclaimed farmland are mainly concentrated in the following three aspects:

(1) Poor soil structure and texture

With the ongoing implementation of the "occupation-compensation balance" policy for cultivated land, the development of newly reclaimed farmland has gradually shifted from plains and low-altitude areas to gentle hills and moderate slopes [7]. China possesses abundant land resources in low hills and gentle slopes, with mountainous and hilly areas accounting for 74.8% of the country's total land area [8]. However, mountainous and hilly areas typically feature steeper slopes with relatively thin effective soil layers [9]. A survey study by Wang Daoze et al. of 99 newly reclaimed farmland sites revealed that 85.2% of these lands had a topsoil layer ≤20 cm thick [10], confirming the characteristically "shallow" cultivation layer of newly reclaimed farmland. Additionally, the subsoil in hilly and mountainous areas contains high gravel and sand content, resulting in greater soil bulk density in reclaimed farmland. Land development activities significantly disrupt the original soil structure, causing mixing of upper and lower soil layers and consequently increasing gravel content in the topsoil [11]. The high sand content and elevated proportion of surface debris severely compromise the soil's water and nutrient retention capacity [12].

(2) Low Nutrient Content

Research by Shen et al. [13] on the topsoil organic matter content of 72 newly reclaimed farmland evaluation units in Yuhang revealed that: 28.75% of samples had organic matter content ≤10 g/kg, 41.68% fell within the 10-20 g/kg range. Similarly, data from Fuyang showed an average soil organic matter content of 14.0 g/kg in newly reclaimed farmland, with 42% of samples concentrated in the 10-20 g/kg range [14]. These findings consistently demonstrate suboptimal organic matter levels in reclaimed soils. Furthermore, many newly reclaimed farmlands exhibit deficient available phosphorus and potassium levels, failing to meet standard crop growth requirements.

(3) Multiple Constraint Factors

Newly reclaimed farmland commonly exhibits various soil constraints, including acidification, salinization, and pollution. Soil acidification is particularly prevalent, with Yuhang District's reclaimed farmland showing an average pH value of 5.05 [15], indicating significantly acidic conditions. As a coastal province, Zhejiang has increasingly utilized saline-alkali land for reclamation. However, marine-reclaimed farmland is characterized by: High alkalinity, Elevated salt content, Severe challenges for crop cultivation[16,17].

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3. SOIL FERTILITY IMPROVEMENT TECHNIQUES

Soil fertility refers to the capacity of soil to supply and coordinate nutrients, water, air, and heat for plant growth. It represents a comprehensive manifestation of the soil's physical, chemical, and biological properties, as well as the material foundation of soil as both a natural resource and an agricultural production medium [18]. These techniques involve modifying soil environmental conditions and nutrient composition to improve soil productivity, thereby increasing crop yields and achieving sustainable agricultural development [19]. Soil fertilization is a common agricultural practice and one of the fastest and most effective measures to address existing soil issues. It is also one of the primary methods for maintaining current soil fertility. After large-scale land reclamation for farming, newly cultivated land often faces a series of problems, making post-reclamation management and soil fertilization and improvement essential. To compensate for deficiencies and address the imbalance between crop nutrient demand and supply, a rational soil fertilization plan is formulated based on the current soil conditions [20]. Soil fertilization techniques, as illustrated in Figure 1, primarily include inorganic fertilization, organic fertilization, biological fertilization, and integrated fertilization [21, 22].

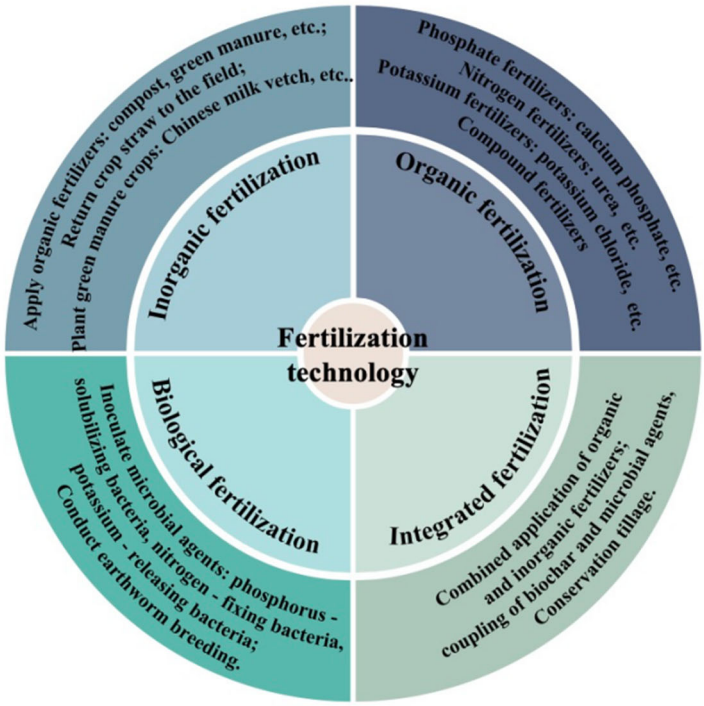


Figure 1. Soil fertility improvement techniques

3.1. Inorganic fertilization technique

Inorganic fertilization primarily involves the application of inorganic substances to supplement the nutrients required for crop growth. In China, inorganic fertilization is characterized by a strong emphasis on the use of chemical fertilizers, particularly those dominated by elements such as nitrogen, phosphorus, and potassium [23]. According to statistics from the United Nations Food and Agriculture Organization (FAO), chemical fertilizers contribute up to 50% of global crop yields [24]. In the early stages of China's development, agricultural production primarily relied on organic fertilizer inputs, yet crop yields showed no significant improvement. Subsequently, as the application of chemical fertilizers increased, agricultural output saw a remarkable rise. Long-term and rational use of inorganic fertilizers can help maintain soil quality and productivity [25]. By the 1980s, the application of chemical

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fertilizers had surpassed that of organic fertilizers. Entering the 21st century, chemical fertilizers accounted for over 70% of nutrient supply, marking China's agricultural production transition into an 'inorganic nutrition' era [26]. Statistics show that over the past decade, the average annual pure nutrient application of chemical fertilizers for China's major grain crops reached 38.5559 million tons [27]. However, the fertilizer utilization rate remains low, and residual fertilizers have caused environmental pollution, affecting soil health and crop safety [28]. The application of chemical fertilizers exhibits a significantly negative correlation with grain yield [29]. Taking nitrogen fertilizer as an example, only 17% of the applied nitrogen is absorbed and utilized by crops as nutrients, while the majority remains in the soil or escapes into the atmosphere [30].

3.2. Organic fertilization technique

China stands as one of the earliest adopters of organic fertilization practices in world agricultural history [31]. Organic fertilization primarily enhances soil structure and fertility through the application of organic materials. Specific approaches include: Application of green manure, compost, and farmyard manure, Straw incorporation, Cultivation of green manure crops. Organic fertilizers, particularly livestock manure, represent a vital nutrient resource. The application of animal waste in agricultural soils serves dual benefits: enhancing key soil fertility indicators while simultaneously addressing the waste management challenges of livestock operations [32]. Straw incorporation demonstrates multifaceted advantages - not only improving soil quality and fertility, but also mitigating environmental pollution caused by open burning. This practice holds significant implications for sustainable agricultural development. Agricultural systems utilize nearly 20 distinct types of straw resources [33]. The decomposition of straw yields various nutrients including carbohydrates, proteins, and cellulose, which provide essential growth substrates for crops. This process stimulates root exudate production and enhances soil enzyme activity in the rhizosphere [34]. Straw incorporation demonstrates significant improvements in critical soil parameters, notably increasing total nitrogen, phosphorus, and available potassium content [35]. From an environmental perspective, this practice effectively mitigates pollution associated with open burning while contributing to sustainable agricultural development. However, excessive straw incorporation may induce nitrogen immobilization, potentially leading to nitrogen deficiency. Furthermore, this practice carries phytosanitary risks, as it may promote pest and disease outbreaks in subsequent growing seasons, ultimately compromising crop productivity [36].

In summary, moderate straw incorporation can effectively enhance soil nutrient content and promote crop growth. The spectrum of organic fertilizers extends to include: Marine-derived amendments (e.g., naturally harvested seaweed), physically processed materials (sun-dried organic products), lignocellulosic byproducts (wood chips, charcoal, and bark containing humic substances), animal-derived amendments (untreated hides, bones, and meat products free from preservatives), fermented industrial and food processing byproducts. In addition, some studies have shown that applying an appropriate amount of green manure can increase the yield of rice and also enhance the accumulation of soil organic matter [37]. These diverse organic amendments serve as valuable nutrient sources for soil fertility enhancement while maintaining ecological safety.

3.3. Biological fertilization technique

Biological fertilization primarily utilizes microorganisms and biological agents to enhance soil fertility. As a vital component of soil ecosystems, soil microorganisms are widely recognized as bioindicators of soil quality [38]. The soil harbors diverse microbial communities, including bacteria, fungi, algae, protists, and viruses. These soil microorganisms play indispensable roles in organic matter decomposition, nutrient transformation, and energy flow within soil

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ecosystems [39, 40, 41]. Microbial fertilizers are specialized biological products containing viable microorganisms that exhibit unique fertilizing effects. These products function by utilizing the active microorganisms or their metabolic byproducts to exert beneficial effects [42]. However, their efficacy is influenced by various factors, including environmental conditions and application methods.

In China, research on microbial fertilizers for soil applications within organic agriculture systems has been progressively expanding among relevant scientific communities. Most microbial fertilizer products demonstrate significant environmental advantages, including: Minimal pollution risk to surrounding soil environments, accelerated decomposition of organic fertilizers in soil, and effective maintenance of stable nitrogen, phosphorus, and potassium levels.

Furthermore, certain beneficial bacteria in microbial fertilizers can convert poorly-available phosphorus and potassium in soil into plant-accessible forms, thereby enhancing nutrient uptake efficiency. Additionally, these microorganisms can: Enrich beneficial microbial populations in soil, modulate soil microbiome composition to promote crop growth [43], improve the nutritional environment during crop development and enhance plant resistance to diseases and pests. Beneficial microorganisms can also enhance soil enzyme activity and indirectly promote normal plant growth, playing a crucial role in facilitating healthy crop development. In microbial fertilizer research, the most significant microorganisms are those capable of phosphorus solubilization, nitrogen fixation, and potassium release (Table 1).

Table 1. Functional mechanisms and typical examples of phosphorus-solubilizing, nitrogen-fixing and potassium-dissolving bacteria

	Mechanism of action	Representing microorganisms	References
P-Solubilizing Bacteria	Phosphorus solubilizing microorganisms utilize their own metabolic products such as phytase, nuclease, and phosphatase, as well as synergistic effects with other organisms, to convert insoluble phosphates in soil into phosphates that can be absorbed and utilized by plants.	*Bacillus, Enterbacter, Alcaligenes, Agrobacterium, Aspergillus, Rhizopus*	[44,45,46]
N-Fixing Bacteria	Nitrogen fixing microorganisms can produce nitrogenase, which converts free N2 into nitrogen-containing substances that are easily absorbed and utilized by plant cells through their life activities.	*Rhizobum, Paenibacillus, Klebsiella*	[47,48]
K-Releasing Bacteria	Potassium solubilizing microorganisms break down aluminosilicates and K-feldspar via acid/enzymatic hydrolysis, EPS secretion, and mineral complex formation, converting insoluble minerals into plant-available K and Mg nutrients.	*Bacillus mucilaginosus, Bacillus edaphicus, Bacillus circulans*	[49,50]

Microbial fertilizers differ from traditional fertilizers mainly in that microbial fertilizers are viable, and the viable bacteria will produce their own metabolites, improving the content of soil organic matter, providing nutrients for plants, and promoting the absorption of effective substances in the soil by plants. From the perspective of the effect of applying microbial fertilizers on the soil, the content of soil organic matter in the soil treated with microbial

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fertilizers is significantly higher than that in the soil with single application of chemical fertilizers or in the control soil, and the content of soil organic matter will increase with the increase of the amount of microbial fertilizers [51]. Applying microbial fertilizers can significantly reduce the pH and total salt content of the soil [52], which is helpful for improving the physical and chemical properties of saline-alkali soil. Jia [53] studied that four different microbial agents can significantly enhance the soil enzyme activity and increase the contents of available phosphorus, rapidly available potassium and alkali-hydrolyzable nitrogen in the soil.

From the perspective of the effects of applying microbial fertilizers on plants, the application of microbial fertilizers has a significant promoting effect on various aspects of crops, including nutrient content, yield, plant height, leaf number, fruit setting rate, and root system condition. Research indicates that microbial fertilizers can significantly increase the accumulation of nitrogen, phosphorus, and potassium in potatoes, enhance starch content during the later stages of potato development, and markedly upregulate tuber gene expression [54]. They also facilitate the transfer of dry matter accumulation from the aboveground parts of soybean plants to the grains, promoting high soybean yields while significantly increasing plant height and pod height at the base [55]. Additionally, microbial fertilizers noticeably improve the net photosynthetic rate, transpiration rate, and chlorophyll content in plant leaves [56]. The microorganisms in these fertilizers enhance root activity and promote nutrient absorption by secreting plant hormones such as auxin (IAA) [57]. Moreover, microbial fertilizers can strengthen plants' resistance to diseases and stress [58, 59, 60]. The secretions of certain soil microorganisms, such as cytokinins and hormones, can alter the plant's growing environment, improving its ability to withstand stress and resist pests and diseases [61].

3.4. Integrated fertilization technique

Integrated fertilization mainly involves the combined use of organic fertilizers, inorganic fertilizers, and microbial fertilizers to achieve more remarkable soil fertilization effects. Research shows that the method of combining chemical fertilizers with organic fertilizers of different dosages and applying them together can better improve soil fertility and crop yields. Compared with long-term application of inorganic fertilizers, the combined application of organic and inorganic fertilizers can better improve the physical and chemical properties of the soil and increase the content of soil organic carbon [62]. Under the same climatic conditions, 30 days after the combined application of chemical fertilizers and organic fertilizers, the content of organic carbon in paddy soil is 98.43% higher than that in dryland soil [63]. The combined application of organic and inorganic fertilizers significantly increases the leaf area and the dry matter accumulation rate [64]. Compared with the single application of nitrogen fertilizers and the single application of manure, the soil treated with the combination of nitrogen and manure has the highest carbon fixation rate, reaching 40.5% [65]. The combined application of inorganic fertilizers and straw decomposing agents can significantly improve the soil structure, enhance soil fertility, promote the absorption and transportation of nitrogen in grains, and increase crop yields [66].

4. SUMMARY AND PROSPECT

It is difficult to ensure the safe production of regional grain without sufficient and fertile cultivated land resources as a support. However, the quality level of most newly reclaimed cultivated land is much lower than that of the occupied cultivated land. There are prominent problems such as poor texture structure, low nutrient content, and numerous obstructive factors, making it difficult to truly achieve the "balance between occupation and compensation" at the level of cultivated land quality. Soil fertilization is one of the fastest and most effective measures to address the current problems of the soil, and it is also one of the main measures to maintain the current soil fertility. By using methods such as inorganic fertilization, organic

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fertilization, biological fertilization, and integrated fertilization to make up for deficiencies according to shortages, and formulating reasonable fertilization plans based on the current situation of the soil, solving the contradiction between the fertilizer demand of crops and fertilizer supply is the key to improving the soil quality of newly reclaimed cultivated land.

The technology for soil fertilization of newly reclaimed cultivated land has broad prospects. By following the concept of sustainable development, green manure, organic waste (such as crop straws, livestock and poultry manure, etc.) can be scientifically processed and applied to newly reclaimed cultivated land. This not only increases the content of soil organic matter and improves the soil structure, but also is environmentally friendly and pollution-free. Moreover, it can realize the recycling of resources, reduce production costs, and promote the sustainable development of agriculture. Technological innovation in soil fertilization is of vital importance. For example, the application of nanotechnology in the field of fertilizer preparation can enable the precise release of nutrient elements in fertilizers, improve the utilization rate of fertilizers, and reduce resource waste and environmental pollution. In addition, by using information technologies (such as satellite remote sensing, geographic information systems, etc.), the nutrient status of the soil can be accurately monitored in real time. Then, through intelligent devices, fertilizers can be applied according to demand, achieving precise fertilization and improving the effectiveness and efficiency of soil fertilization. The deep integration of information technology and intelligence has enabled soil fertilization technology to move from theoretical research to an era of precise implementation and intelligence.

In the future, it is of great significance to develop comprehensive fertilization methods that can both increase soil fertility and promote plant growth, integrate them with modern technologies, explore fertilization plans, and establish a rapid and efficient soil fertilization technology system and a safe production system for newly reclaimed cultivated land. This can enhance the quality of cultivated land, and thus promote the green utilization of cultivated land and the sustainable economic development in China.

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