Regulation Effect of Aerobic Composting on Nutrient Availability in Alkaline Limey Soils

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Abstract. Alkaline Limey Soils are widely distributed around the world. Due to the influence of soil carbonate content and pH, alkali-lime soils lead to crop yield reduction and land use efficiency reduction to a certain extent. However, there is a lack of comprehensive research on the application of compost to improve Alkaline Limey Soils. Through the review of relevant research articles at home and abroad, it is found that there is a lack of specific experiments for compost and Alkaline Limey Soils. Therefore, this study combined environmental and life sciences to comprehensively investigate the relationship between soil and compost from the aspects of plant nutrient uptake and transport, soil physical and chemical properties, and microbial interactions. This paper aims to provide a theoretical basis for interdisciplinary comprehensive research on alkaline limey soil and compost, explore the effects of aerobic compost on Alkaline Limey Soils and their relationship, and review the improvement effects of compost on alkaline limey soil in various aspects.

Keywords: Aerobic composting; Soil nutrients; Rhizosphere microorganisms; alkaline limey soils; Soil structure.

1. Introduction

Composting is a biochemical process that utilizes a variety of microorganisms such as bacteria, actinomycetes, and fungi, microorganisms are widely distributed in nature. Under controlled artificial conditions, it promotes the transformation of biodegradable organic matter into stable humus.

Aerobic composting is a process in which facultative and obligate aerobic bacteria decompose organic matter through biochemical mechanisms. In aerobic composting, microorganisms absorb soluble small molecular organic substances. Simultaneously, macromolecular insoluble matter adheres to the outside of microbial cells, and extracellular enzymes secreted by microorganisms break it down into soluble small molecular organic substances, which are then utilized by microorganisms.

The whole process of aerobic composting can be divided into three stages. The first stage is the heating phase, during which thermophilic microorganisms are more active and decompose some organic substances such as simple sugar structures and starches. The second stage is the high-temperature phase, where thermophilic microorganisms dominate when the temperature exceeds 45 degrees Celsius. They continue to decompose the remaining organic matter from the previous stage, such as hemicellulose and cellulose, which are complex organic compounds. Microorganisms enter a dormant state or die at temperatures above 70 degrees Celsius. The final stage is the cooling phase, where mesophilic microorganisms regain dominance as the temperature decreases. The remaining organic matter from the previous stages continues to decompose, while humus continues to accumulate. Once it enters the maturation stage, the composting process is complete [1-2].

Alkaline limey soil is a type of soil that has high alkalinity or high lime content. The characteristic of alkaline-calcareous soil is that its pH value is higher than 7. Limey soil, on the other hand, refers to a soil that contains a significant amount of carbonate, typically calcium carbonate, due to an increased concentration of carbonates in the soil. These soils typically exhibit alkaline or neutral pH values, thus forming alkaline soil. Alkaline limey soil has a significant impact on plant growth [3-4]. On one hand, the sodium ions and carbonates in highly alkaline soil can hinder the absorption and utilization of water and nutrients by plant roots, leading to restricted plant growth. The acidity and carbonate content of calcareous soil are the main limiting factors. On the other hand, the calcium ions in highly calcareous soil can neutralize aluminum ions in acidic soil, improving soil structure and aeration, thereby promoting plant growth. However, excessively high soil pH values can also impede the uptake of trace elements such as iron and zinc by certain plants, thus affecting their nutritional status. Calcareous soil also has strong fixation capabilities, meaning it strongly binds with trace elements. The more elements present in the soil, the greater the amount that is fixed [5-6].

At present, there is a lack of effective methods for composting alkaline-calcareous soil. However, considering the properties of alkaline-calcareous soil, soil amendment can be achieved through the application of organic materials. Composted manure or organic fertilizers, rich in humus, play an important role in the formation and stability of soil aggregates. They can promote the formation of well-structured soil, thereby improving soil aeration, permeability, and water-holding capacity. Additionally, compost can introduce essential elements required for plant growth and interact with plant roots. The organic acids secreted by plant root growth continue to decompose the remaining nutrients in the soil, thereby improving soil conditions. Simultaneously, the effectiveness of compost in regulating nutrient availability in alkaline-calcareous soil can be assessed through measurements of soil physicochemical properties, plant growth, and rhizosphere microbial composition.

2. Compost is an effective way to regulate soil

2.1. Compost regulates soil nutrients

The role of organic fertilizer is to supply various nutrients required by crops for a longer period during the continuous mineralization process in the soil. It not only provides nutrients to plants and stimulates plant growth but also improves the effectiveness of soil nutrients. The abundant carbon sources in organic fertilizer help promote plant growth and increase yield. At the same time, it can enhance soil fertility, significantly contribute to increasing soil organic matter, improve soil structure, and enhance the effectiveness of soil nutrients [7]. Compared to other fertilizers, organic matter has a lesser impact on the soil and plays a more important role in improving soil, primarily by introducing various nutrients.

Composting, directly and indirectly, improves soil by providing the necessary elements for plant growth. On the one hand, chemical fertilizers, while containing the essential nutrients for plants and providing quick and strong fertilization, lack sustainable soil fertility and can have detrimental effects on the soil [7]. Studies, such as the one conducted by Chang et al., have found that many agricultural practitioners lack knowledge of proper fertilizer application. As a result, there is an increase in the amount of chemical fertilizers used, excessive reliance on fertilization, and neglect of the soil's natural nutrient supply. These improper practices directly limit the growth of crops and can lead to soil quality issues such as soil compaction, acidification, and nutrient loss, ultimately damaging the soil structure [9-10].

Chemical fertilizers may result in uneven infiltration of the necessary nutrients for plants, making it unfavorable for plants to absorb them. On the other hand, composting allows the concentration of nutrients in locations that are more readily available for plant uptake, which promotes better absorption. Choosing compost not only increases crop yield but also directly improves the soil, ensuring that its physical and chemical properties do not lead to soil degradation over time. Additionally, the stability of soil aggregates after compost treatment is significantly higher compared to chemical fertilizer treatment, as the loss of aggregates in the latter is mainly due to the significant loss of large aggregates [11].

2.1.1. Ability to fertilize the soil

The application of compost can enrich the soil and provide the necessary mineral nutrients for plant growth. Organic waste materials in compost contain a variety of essential elements for plant growth, such as N, P, K, Ca, and Mg. When compost is applied, these nutrients are reintroduced into the soil for plant uptake and growth. According to a long-term field experiment on organic fertilizers conducted by Han Bao et al., the organic matter content, total nitrogen, alkaline nitrogen, available phosphorus, and available potassium in the soil showed a positive correlation with the proper application of organic fertilizers for five years [12].

Adding compost can also promote the effective utilization of soil nutrients. In Chinese soils, more than 80% of nitrogen and 20% to 76% of phosphorus exist in organic forms, which are gradually released as soil organic matter mineralizes. Research indicates that applying organic fertilizers for three years led to a 19.5% increase in soil organic carbon and a 12.3% increase in total nitrogen compared to chemical fertilizer application [10]. Soil organic matter refers to organic compounds in the soil mainly composed of C, H, O, and N elements, as well as small amounts of S, P, and metal elements. It is an important indicator for assessing soil fertility. In addition, soil organic matter also contains other mineral elements required for plant growth, and Ca, Mg, as well as trace elements such as S, Fe, Zn, Cu, B, Mn, and Mo, which are indispensable. These mineral elements, along with the diverse organic acids and humic acids abundant in soil humus, can dissolve some mineral components and promote mineral weathering, thereby facilitating the effective utilization of these nutrients. Furthermore, certain metal ions complexed with organic acids and fulvic acids can remain in the soil solution without precipitating, thereby increasing their availability. Organic fertilizers not only provide nutrients for plant uptake but also indirectly promote the effective utilization of certain mineral nutrients, making them more accessible for plant absorption [13].

2.1.2. Improve soil fertility preservation

Compost introduces organic matter into the soil, which is transformed into humus after some time. Humus is a colloidal substance formed by the decomposition and transformation of organic matter by microorganisms. The introduction of colloidal into the soil strengthens its substitution capacity. For different types of soil colloids, the amount of substitution varies greatly; generally, the greater the amount of substitution of soil colloids, the better its fertility retention. Since the cation exchange capacity of humus is 20-30 times that of clay minerals, and the contribution of humus to cation exchange in mineral soils accounts for 20%-90%, increasing soil humus can significantly improve soil fertility preservation and supply [13]. At the same time, combined with the strong fixation of alkaline calcareous soil, it can make the alkaline calcareous soil obtain a more objective soil fertility retaining capacity.

2.1.3. Improve soil physical properties

Humus plays a crucial role in the formation and stability of soil aggregates, facilitating the development of well-structured soil clumps (granules) and thereby improving soil aeration, permeability, and water retention. The introduction of humus through the application of compost enriches the soil with loose, porous, and water-absorbent colloidal materials. These humus colloids combine with the soil to form soil aggregates, creating favorable pore spaces that enhance soil permeability and reduce water evaporation and loss. Increasing the content of humus in the soil enhances its water-holding capacity, thereby improving soil water retention. Humus is generally dark in color, and its incorporation into the soil can enhance the absorption of sunlight, thereby increasing soil temperature. Research has shown that soil treated with compost application has an average mass diameter that is 140% higher than soil treated with chemical fertilizers. The application of compost helps maintain water-stable aggregates, further improving the water-holding capacity of solids [11, 13].

Compost can indirectly improve vegetation establishment, and a direct consequence of this is the mechanical reinforcement of the soil by plant roots. The increase or decrease in plant-available water depends on the soil type. The decrease in plant-available water observed with compost amendment contradicts earlier studies, possibly due to deviations caused by the slight increase in soil bulk density resulting from compost incorporation. Shortly after the addition of compost to the plot, no significant differences in plant-available water were observed, except for a slight increase in individual compost applied on the soil surface. However, over time, the improved plant-available water may demonstrate a combined process involving root growth, compost mineralization, and soil aggregation in enhancing water-holding capacity [13].

2.2. Effects on soil rhizosphere microbial community

Rhizosphere microorganisms were designated microorganisms that were closely attached to the narrow area around plant roots and were directly affected by the root system. The number of microorganisms in rhizosphere soil was greater than that outside the rhizosphere. At the same time, there is a direct or indirect connection between rhizosphere microorganisms and plants, which makes them interact and promote each other. At the same time, the rhizosphere has the function of transporting water between the plant and the interface between soil and microorganisms, and is responsible for controlling the uptake of nutrients and harmful substances by plants [14-15].

Rhizosphere microorganisms play an important role in plant growth. For soybean, the growth of soybean is closely related to its rhizosphere microorganisms. The role of soybean rhizosphere microorganisms is reflected in promoting the circulation of nutrient elements, microbial material circulation, and energy flow. At the same time, the propagation of microorganisms can accelerate the decomposition and transformation of organic matter in soil and promote the development of soil [14]. Therefore, it is important to understand the role of rhizosphere microorganisms in soybean growth promotion. Composting can affect the rhizosphere microbial community to a certain extent. The soil microbial community can be changed by composting to a certain extent, making the soil more conducive to soybean growth and production.

2.2.1. Soil modification indirectly affected rhizosphere microbial communities

Compost can indirectly influence the rhizosphere microbial community by improving the soil. It increases the content of organic matter, nutrients such as NPK, by 1-1.4 times compared to conventional systems. This directly enhances the abundance of bacteria in the soil and provides a more favorable environment for the survival and proliferation of beneficial microbes for soybean growth. Compost can directly or indirectly alter the rhizosphere microbial community by modifying the physical, chemical, and biological properties of the soil [16].

The application of compost provides a large number of carbon sources as raw materials for microbial production of extracellular polymers, enhancing soil aggregation. These substances act as binders for soil aggregates. The increase in fungal biomass can also contribute to the formation of large aggregated structures by binding and entangling soil particles, promoting soil aggregation. It provides a more diverse habitat for microorganisms, leading to an increase in soil microbial diversity. Changes in bacterial communities observed in different aggregate size fractions can be attributed to the unique microenvironments provided by different aggregate habitats, which support the development of different microbial communities. This can further benefit soil properties and ecosystem characteristics [11].

2.2.2. Introduced species in compost directly regulated rhizosphere microbial community

The introduction of microorganisms beneficial to plant growth into compost can directly alter the rhizosphere microbial community. Compost modification introduces a large number of organic substances and a large variety of microorganisms, which can significantly change soil chemistry and structure, and can significantly affect the composition of plant-related microbial communities. The effect of compost application on soil microbiome or dynamic, that is, the succession of microbial communities. The original microbial community through composting has no obvious effect on the rhizosphere microbial community. The main change to the rhizosphere microbial community is the introduction of beneficial microorganisms to change. At the same time, through more indirect effects than soil structure, beneficial microorganisms can survive and form a succession to become the main rhizosphere microbial community [16]. It was mentioned that the strains introduced during compost addition were relatively weak due to competition [14].

It can only cause changes in the rhizosphere microbial community in the short term. In the longer term, the application of compost and the addition of carbon sources, organic matter, and growth elements through the compost itself can make the addition of strains adapt to the compost soil environment and thus exert long-term effects on the plant rhizosphere.

2.3. Interaction between soil and applied compost and plants

The application of compost creates an environment conducive to plant growth by improving soil nutrients and water availability. In addition to improving the soil structure to a certain extent, better soil structure better ventilation, or ion exchangeability also helps plant growth. The effect of compost on plant growth can be visually demonstrated by the determination of root dry weight, plant weight, plant elements, and yield. It improves the soil structure and increases the water-holding capacity of the soil, ensuring the supply of water in the soil and reducing its water loss. The drought stress of plants was reduced. The use of compost increases soil water content at field capacity and permanent wilting points. Maintaining high water content in the root environment can make plants grow better. Composted soil reduces the electrolyte leakage of plants and improves chlorophyll content. The increase in chlorophyll content improves photosynthetic efficiency, enhances plant tolerance to stress, and enables plants to keep growing in a water-deficient environment [17-18]. At the same time, plant growth is of great significance for alkaline calcareous soils. First, plant growth can fix the soil, help the soil form a stable structure, and reduce erosion and weathering to a certain extent. Secondly, plant growth provides a stable environment for soil microorganisms to a certain extent. By improving the soil to help plants grow, the growth of plants will effectively help the soil continue to maintain the improved characteristics, forming a sustainable development of ecological management.

3. Conclusion

The application of aerobic composting is feasible for alkaline limey soils, and its effects are manifested in various aspects. When compost is applied to alkaline and calcareous soils, it improves the soil through the introduction of nutrients, utilizing the inherent advantages of the soil, and supplementing its deficiencies with compost. Subsequently, the indirect interaction between plants and microorganisms continues to help enhance the quality of alkaline and calcareous soils. It is important to consider the specific characteristics of alkaline limey soils when determining suitable approaches for their remediation and improvement. By utilizing the direct multi-faceted improvements that aerobic organic composting has on soils, we can enhance its regulatory efficiency. Furthermore, by introducing nutrients and regulating the microenvironment for plant cultivation, and leveraging the feedback from plant growth to further enhance its effectiveness, a sustainable ecological regulation method is formed. Currently, research on the improvement of alkaline limey soils is relatively scarce. Additionally, soil improvement is a time-consuming process that requires comprehensive consideration of potential influencing factors during experimentation. It is necessary to collect, process, and analyze a large amount of data to obtain conclusive results. Furthermore, a challenge arises from the slight differences in alkaline limey soils across different regions, as well as the influence of external factors. In order to efficiently and effectively regulate these soils, it is important to comprehensively select and propose suitable control methods that best meet the specific circumstances. In the future, the effective regulation of alkaline limey soils should be considered from multiple perspectives. Efforts should be made to identify common patterns and summarize experiences related to compost regulation, while also integrating other control methods to optimize nutrient effectiveness in alkaline and calcareous soils by combining the strengths and weaknesses of different approaches. Additionally, constructing a model that incorporates the influences of different compost components on alkaline and calcareous soils would be beneficial for conducting in-depth research in the field in the future.

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