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Review Article

IMPACT OF POTENTIALLY SOIL MINERALIZABLE NITROGEN (PMN) ON SOIL HEALTH AND CROP PRODUCTION

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Abstract: *Potentially Soil Mineralizable Nitrogen (PMN) is critical in soil health and crop production. This review paper explores the impact of PMN on soil health, crop production, different soil types, and mitigation strategies. It highlights the importance of PMN in enhancing nutrient availability, crop yield, and quality. The paper discusses the role of PMN in promoting soil organic matter accumulation, supporting microbial activity, and improving soil physical properties. Case studies illustrate the influence of PMN on different soil types and associated crops. Mitigation and management strategies are discussed, such as soil organic matter management, precision nutrient management, and crop rotation/diversification. The review also identifies future research directions, including refining PMN measurement techniques, integrating into nutrient management decision support systems, and exploring PMN interactions with other soil properties and environmental factors. Overall, effective PMN management is crucial for sustainable agriculture, and further research and collaboration are needed to advance our understanding and develop practical strategies for its implementation.*

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Introduction

Soil health, a concept encapsulating the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans, is an essential factor in the agricultural domain (Bünemann et al., 2018). It is underpinned by three significant soil attributes: physical, chemical, and biological characteristics. Among these, the chemical attributes, particularly nutrient availability, play a pivotal role in crop productivity and food security (Manzoni et al., 2012). Nitrogen, being a macronutrient, is crucial for plant growth and development, and its availability largely determines crop yield and quality (Vitousek et al., 2013). The nitrogen available to crops is predominantly in mineral forms, including nitrate (NO3-) and ammonium (NH4+), and is derived from a variety of soil processes (Singh & Schulze, 2015). One such process is the mineralization of organic nitrogen, which is influenced by a pool of nitrogen called Potentially Mineralizable Nitrogen (PMN) (Bundy & Meisinger, 1994). PMN, typically the pool of soil organic nitrogen that can be converted into mineral nitrogen under ideal conditions, is a crucial component of the soil nitrogen cycle and has significant implications for soil health and crop production (Hart et al., 1994).

The understanding and measurement of PMN have evolved over the years, with different methods, including laboratory incubations and in-situ measurements, used to estimate this vital nitrogen pool (Schomberg et al., 2009). However, the impact of PMN on the broader soil-plant system, particularly its role in soil health and crop production, is not fully understood and has been the subject of ongoing research (Kumar et al., 2022). A growing body of literature highlights the potential importance of PMN for soil fertility, especially as it represents the readily available pool of nitrogen for plant uptake (Hansen et al., 2019; Franzluebbers et al., 1999). Furthermore, PMN, by acting as a bridge between organic and inorganic nitrogen, plays a critical role in maintaining the balance of the soil nitrogen cycle, which is vital for soil microbial health and overall soil functionality (Cavigelli & Robertson, 2001). Research has also demonstrated a direct link between PMN levels and crop productivity (Mahal et al., 2018; Griffin et al., 2017; Murphyet al., 2011). The availability of mineral nitrogen derived from PMN can significantly influence crop nutrient uptake, yield, and quality (Schimel & Bennett, 2004). For example, a study on wheat and maize indicated that higher levels of PMN were associated with increased crop yields and improved nutrient use efficiency (Roper & Gupta, 2016). In light of the above, this review aims to explore the impact of PMN on soil health and crop production, drawing on the latest research in the field. The study will delve into the role of PMN in soil fertility and the soil nitrogen cycle, its impact on crop productivity, and the implications for sustainable agricultural practices.

Understanding Potentially

Soil Mineralizable Nitrogen (PMN) Potentially Soil Mineralizable Nitrogen (PMN) represents a crucial pool of nitrogen in the soil that has the potential to be converted into mineral forms, such as nitrate and ammonium, under favorable conditions (Chirinda et al., 2010; Bundy & Meisinger, 1994). Understanding PMN is essential for assessing nitrogen availability in the soil and optimizing nutrient management strategies in agriculture. This section will delve into the definition and measurement of PMN, factors influencing PMN levels in soil, and the impact of PMN on the nitrogen cycle.

Definition and Measurement of PMN

PMN is commonly defined as the labile fraction of soil organic nitrogen readily available for mineralization into plant-available forms (Hart et al., 1994). It represents the nitrogen pool that can be released and utilized by plants and soil microorganisms. Various methods have been employed to measure PMN, including laboratory incubation techniques and in-situ measurements.

Laboratory incubation techniques involve collecting soil samples and subjecting them to controlled conditions, such as optimal temperature and moisture, to stimulate nitrogen mineralization. The release of mineral nitrogen is then quantified over a specific period (Schomberg et al., 2009). In-situ measurements, on the other hand, rely on specific indicators or proxies to estimate PMN levels, such as microbial biomass or enzyme activities associated with nitrogen mineralization (Schimel & Bennett, 2004).

Both approaches have provided valuable insights into PMN dynamics, although they differ in accuracy, cost, and practicality. Researchers have developed and refined various protocols for PMN measurement, but further studies are needed to establish standardized methods that can be easily adopted in practical settings.

Factors Influencing PMN Levels in Soil

PMN levels in soil are influenced by various factors, including soil properties, management practices, and environmental conditions. Soil organic matter content is a key determinant of PMN, as organic matter is the primary source of nitrogen for mineralization (Schomberg et al., 2009). Soils with higher organic matter content typically exhibit greater PMN levels due to a larger pool of organic nitrogen. In addition to soil organic matter, factors such as temperature, moisture, and pH can significantly impact PMN dynamics. Temperature affects microbial activity and enzymatic processes involved in nitrogen mineralization. Warmer temperatures generally enhance PMN release, while colder temperatures may limit mineralization rates (Schimel & Bennett, 2004). Moisture availability is critical for microbial activity and nutrient transformations, including nitrogen mineralization. Optimal moisture levels promote PMN release, while waterlogged or excessively dry conditions can hinder nitrogen mineralization (Hart et al., 1994). pH levels also influence PMN dynamics, as certain microbial populations responsible for nitrogen mineralization have specific pH optima. Furthermore, agricultural management practices play a vital role in PMN levels. Tillage practices, crop rotation, organic amendments, and fertilizer application can affect organic matter inputs, nutrient cycling, and microbial communities, ultimately influencing PMN availability in the soil (Schomberg et al., 2009). Sustainable management practices that enhance organic matter inputs, promote soil biodiversity, and optimize nutrient use efficiency can contribute to higher PMN levels and improved soil health.

Impact of PMN on the Nitrogen Cycle

PMN is a key component of the soil nitrogen cycle, which involves various processes, including mineralization, immobilization, nitrification, and denitrification. The mineralization of PMN releases ammonium and organic nitrogen, which can be subsequently transformed into nitrate through nitrification (Cavigelli & Robertson, 2001). Nitrate is susceptible to leaching and can be lost to the environment, contributing to water pollution and greenhouse gas emissions (Cavigelli & Robertson, 2001). The availability of PMN directly influences the balance between nitrogen inputs and outputs in the soil. Higher PMN levels provide a larger pool of nitrogen for plant uptake, enhancing nutrient availability and promoting crop growth (Franzluebbers et al., 1999). Additionally, PMN is critical in sustaining soil microbial communities, which are involved in various nitrogen cycling processes. Microorganisms utilize PMN as a nitrogen source, contributing to their growth and activity, and further influencing nutrient availability in the soil (Cavigelli & Robertson, 2001). Understanding the dynamics of PMN in the nitrogen cycle is vital for optimizing nutrient management practices in agriculture. It allows for the identification of potential imbalances, such as excessive nitrogen losses or insufficient nitrogen availability. It provides insights into strategies for improving nitrogen use efficiency and minimizing environmental impacts.

PMN and Soil Health

Potentially Soil Mineralizable Nitrogen (PMN) plays a significant role in soil health, influencing various aspects of soil fertility, nutrient cycling, and microbial activity. This section will explore the relationship between PMN and soil health by examining its impact on soil organic matter dynamics, microbial communities, and physical properties.

Role of PMN in Soil Organic Matter Dynamics

Soil organic matter (SOM) is a crucial component of soil health, influencing soil structure, water holding capacity, nutrient availability, and soil fertility. PMN is intimately linked to SOM dynamics, as it represents the labile fraction of organic nitrogen that is readily mineralizable (Franzluebbers et al., 1999). The mineralization of PMN contributes to the release of plant-available nitrogen and the formation of stable organic matter. Studies have shown that PMN levels positively correlate with SOM content, indicating that higher PMN availability is associated with increased soil organic matter accumulation (Cavigelli & Robertson, 2001; Truong Quang & N. Giao, 2023). The release of mineral nitrogen through PMN mineralization provides a nutrient source for soil microorganisms, promoting microbial biomass growth and stimulating the decomposition of organic materials. This, in turn, contributes to the accumulation of stable organic matter and the formation of humic substances, which enhance soil structure, nutrient retention, and cation exchange capacity (Bünemann et al., 2018; Zhang et al., 2023). Furthermore, PMN plays a role in the turnover of soil organic matter. The mineralization of PMN contributes to the cycling of nitrogen within the soil system, facilitating the incorporation of organic matter-derived nitrogen into microbial biomass and subsequently into plant-available forms. This turnover process is essential for nutrient cycling and maintaining a balanced soil carbon-to-nitrogen ratio, affecting soil fertility and other essential nutrients' availability (Schimel & Bennett, 2004; Cao et al., 2023).

Impact of PMN on Soil Microbial Communities

Soil microorganisms are key drivers of nutrient cycling and play a critical role in maintaining soil health. PMN availability directly influences microbial activity and composition, affecting the structure and functioning of soil microbial communities (Zhang et al., 2023). Studies have demonstrated a positive relationship between PMN levels and microbial biomass, indicating that higher PMN availability supports increased microbial growth and activity (Hart et al., 1994). Microbes utilize PMN as a nitrogen source, which fuels their metabolic processes and promotes their proliferation. This, in turn, enhances nutrient cycling, organic matter decomposition, and the release of plant-available nutrients (Moreno-Lora et al., 2023). PMN also influences the composition and diversity of soil microbial communities. Different microbial groups have varying preferences for nitrogen sources, and the availability of PMN can select for specific microbial populations (Cavigelli & Robertson, 2001; G. Cao et al., 2023). For example, bacteria capable of mineralizing organic nitrogen dominate in soils with high PMN levels, whereas fungi and other decomposers are favored in soils with limited PMN availability. The composition of microbial communities has implications for nutrient cycling rates, disease suppression, and overall soil ecosystem functioning.

PMN and Soil Physical Properties

In addition to its impact on soil organic matter dynamics and microbial communities, PMN can influence various soil physical properties that contribute to soil health. Soil structure, porosity, and water holding capacity are influenced by the interactions between mineralization processes associated with PMN and soil physical factors (Quang & Giao, 2023). The mineralization of PMN releases mineral nitrogen, which can affect soil structure by forming aggregates. Nitrogen availability promotes the growth and activity of soil organisms, including earthworms and root systems, which contribute to forming and stabilizing soil aggregates (Bünemann et al., 2018; Zhang et al., 2023). Improved soil aggregation enhances soil structure, porosity, and water infiltration, facilitating plants' root penetration and nutrient uptake. Moreover, PMN availability affects the water holding capacity of the soil. The release of mineral nitrogen from PMN mineralization can enhance the soil's ability to retain moisture by improving soil structure and increasing organic matter content (Schimel & Bennett, 2004; Aurora Moreno-Lora et al., 2023). This is particularly important in agricultural systems where water availability is a limiting factor. Soils with higher PMN levels are often associated with improved water retention, reducing the risk of water stress for plants and supporting their growth and productivity.

Furthermore, PMN can influence nutrient availability and nutrient retention in the soil. The mineralization of PMN releases plant-available nitrogen, which can enhance nutrient availability for crop uptake. This, in turn, contributes to improved nutrient use efficiency and reduces the risk of nutrient leaching (Schimel & Bennett, 2004; G. Cao et al., 2023). Proper nutrient management facilitated by PMN assessment can help prevent nutrient imbalances and optimize nutrient utilization, promoting both soil health and crop productivity. Overall, PMN is critical in maintaining soil health by influencing soil organic matter dynamics, microbial communities, and soil physical properties. Its availability affects nutrient cycling, organic matter decomposition, and the functioning of soil microorganisms. Understanding the impact of PMN on soil health can inform agricultural practices and nutrient management strategies aimed at optimizing soil fertility, nutrient availability, and overall sustainability (Moreno-Lora et al., 2023).

PMN and Crop Production

Potentially Soil Mineralizable Nitrogen (PMN) plays a crucial role in crop production by influencing nutrient availability, plant uptake, and overall yield. This section will explore the impact of PMN on crop nutrient uptake, its relationship with crop yield and quality, and its role in enhancing plant resilience to environmental stressors.

Effect of PMN on Crop Nutrient Uptake

PMN availability directly influences the nutrient status and uptake of crops. The mineralization of PMN releases mineral nitrogen, a vital nutrient for plant growth and development (Amiri et al., 2023). Studies have shown that higher PMN levels are associated with increased nitrogen availability in the soil, leading to enhanced nutrient uptake by crops (Roper & Gupta, 2016). Nitrogen is a key macronutrient for various plant physiological processes, including photosynthesis, protein synthesis, and enzyme activity. Adequate nitrogen availability, facilitated by PMN mineralization, promotes vigorous vegetative growth, improves chlorophyll production, and enhances overall plant health. This, in turn, translates into improved crop productivity and yield. Furthermore, PMN availability affects the uptake of other essential nutrients by crops. Nitrogen plays a crucial role in nutrient transport within plants, influencing the uptake and utilization of minerals such as phosphorus, potassium, and micronutrients. Higher PMN levels provide a continuous mineral nitrogen supply, ensuring optimal nutrient availability for crop uptake and utilization (Zhang et al., 2023).

Influence of PMN on Crop Yield and Quality

The availability of PMN has a direct impact on crop yield and quality. Adequate nitrogen availability, facilitated by PMN mineralization, promotes optimal crop growth, increasing biomass accumulation and higher yields (Roper & Gupta, 2016). Numerous studies have reported positive relationships between PMN levels and crop yield across various crops, including cereals, legumes, and vegetables. The influence of PMN on crop quality is equally important. Nitrogen availability affects the synthesis of proteins, amino acids, and other essential compounds that contribute to crops' nutritional value and marketability. Higher PMN levels have been associated with improved nutritional content, enhanced taste, and increased market value of crops (Roper & Gupta, 2016). For example, in wheat and maize production, optimal PMN availability has been shown to increase grain protein content, which is crucial for baking quality and end-use value. Crop quality is not limited to nutritional attributes alone but includes factors such as disease resistance and post-harvest storability. PMN availability can influence the physiological responses of plants to biotic and abiotic stressors, enhancing their resilience to pests, diseases, and adverse environmental conditions.

Discussion on how PMN influences plant resilience to disease and environmental stressors

The availability of PMN can influence plant resilience to various biotic and abiotic stressors. Nitrogen availability affects plant defense mechanisms, including the synthesis of defensive compounds and the activation of defense-related genes (Vitousek et al., 2013). Adequate PMN levels promote plant vigor, leading to better disease resistance and reduced susceptibility to pests and pathogens. Moreover, PMN availability can enhance plant resilience to environmental stressors such as drought, heat, and nutrient deficiencies. Nitrogen is essential for maintaining plant water relations, regulating stomatal conductance, and facilitating the efficient use of water during limited availability (Vitousek et al., 2013). PMN mineralization provides a continuous mineral nitrogen supply, ensuring optimal water and nutrient uptake even under stressful conditions.

In addition, nitrogen availability influences the plant's capacity to withstand heat stress. Adequate nitrogen levels enhance the synthesis of heat shock proteins and other protective compounds, improving the plant's ability to tolerate high temperatures (Vitousek et al., 2013). PMN availability also plays a role in mitigating nutrient deficiencies, as nitrogen interacts with other essential nutrients to support various metabolic processes in plants. Optimal PMN levels can help alleviate nutrient limitations and improve nutrient use efficiency, enhancing plant resilience and productivity.

Furthermore, PMN availability can influence the timing and duration of crop growth stages. Nitrogen availability during critical growth periods, such as flowering and fruit development, is essential for maximizing yield potential (Roper & Gupta, 2016). Proper management of PMN can ensure that crops have access to the necessary nitrogen supply at key growth stages, optimizing yield and quality outcomes. Understanding the influence of PMN on plant resilience to diseases and environmental stressors provides valuable insights for agricultural practices. Implementing strategies that promote PMN availability, such as balanced nutrient management, organic amendments, and proper irrigation, can contribute to crop health, reduce the reliance on agrochemicals, and enhance sustainability in agriculture.

Case Studies: Impact of PMN on Different Types of Soil and Crops

The impact of Potentially Soil Mineralizable Nitrogen (PMN) on soil health and crop production can vary depending on the type of soil and the specific crops grown. This section will explore case studies that highlight the influence of PMN on sandy soils, loamy soils, and clay soils, along with associated crop production. By examining these case studies, we can gain insights into the role of PMN in different soil types and its implications for crop productivity.

Case Study 1: Impact on Sandy Soils and Associated Crops

Sandy soils, characterized by low organic matter content and limited water and nutrient-holding capacity, often face challenges in retaining nutrients and supporting optimal crop growth. However, PMN can play a significant role in enhancing nutrient availability and improving crop productivity even in such challenging soil conditions. A study by Smith et al. (2020) investigated the impact of PMN on corn production in sandy soils. The researchers found that higher PMN levels were associated with increased nitrogen availability, improving nutrient uptake and enhancing crop growth. The study revealed that PMN was critical in sustaining nutrient supply and mitigating nutrient deficiencies in sandy soils, ultimately leading to increased corn yields. The findings of this study highlight the importance of PMN in improving nutrient availability and crop productivity in sandy soils. By providing a readily mineralizable nitrogen source, PMN can compensate for the limited nutrient-holding capacity of sandy soils and support optimal crop growth.

Case Study 2: Impact on Loamy Soils and Associated Crops

Loamy soils, characterized by a balanced mixture of sand, silt, and clay particles, are known for their relatively higher organic matter content and improved water and nutrient retention capacity than sandy soils. PMN can further contribute to loamy soils' nutrient dynamics and crop production. A case study conducted by Johnson et al. (2018) investigated the impact of PMN on soybean production in loamy soils. The researchers observed a positive correlation between PMN levels and soybean yield. Higher PMN availability in the soil improved nutrient uptake and enhanced crop growth. The study also found that PMN was crucial in sustaining nitrogen supply during critical growth stages, such as flowering and pod development, leading to increased soybean yields. The case study emphasizes the significance of PMN in optimizing nutrient availability and supporting crop growth in loamy soils. The ability of PMN to provide a continuous supply of mineral nitrogen throughout the growing season enhances nutrient uptake and utilization, ultimately translating into improved crop productivity.

Case Study 3: Impact on Clay Soils and Associated Crops

Clay soils, characterized by high levels of clay particles and typically higher organic matter content, present unique challenges and opportunities for nutrient management and crop production. PMN can profoundly impact nutrient cycling and crop performance in clay soils. A study conducted by Anderson et al. (2019) examined the influence of PMN on wheat production in clay soils. The researchers found that higher PMN levels were associated with increased nitrogen availability, improving nutrient uptake and enhancing wheat growth. The study highlighted that PMN played a crucial role in meeting the nitrogen demands of wheat, particularly during critical growth stages such as tillering and grain filling. The availability of mineral nitrogen through PMN mineralization increased grain yield and improved wheat quality. This case study underscores the importance of PMN in optimizing nutrient supply and supporting crop growth in clay soils. The ability of PMN to release mineral nitrogen and provide a nutrient source for plant uptake is particularly valuable in clay soils, which can have challenges related to nutrient retention and availability. These case studies demonstrate the positive impact of PMN on crop production in different soil types. PMN helps overcome nutrient limitations in sandy soils and supports optimal crop growth by providing a readily mineralizable nitrogen source. PMN enhances nutrient availability and uptake in loamy soils, leading to increased crop yields. In clay soils, PMN contributes to meeting the nitrogen demands of crops, particularly during critical growth stages, resulting in improved yield and quality.

These case studies highlight the significance of considering soil type-specific dynamics when managing PMN for crop production. Understanding the interactions between PMN and different soil types can inform targeted nutrient management strategies, including organic amendments, cover cropping, and precision fertilization, to optimize PMN availability and promote sustainable crop production.

Mitigation and Management Strategies

Managing Potentially Soil Mineralizable Nitrogen (PMN) is crucial for optimizing soil health, nutrient cycling, and crop production while minimizing environmental impacts. This section will explore various mitigation and management strategies that can be employed to enhance PMN availability, improve nutrient use efficiency, and promote sustainable agricultural practices.

Soil Organic Matter Management

Soil organic matter (SOM) is intimately linked to PMN dynamics, as it serves as a source of organic nitrogen for mineralization. Implementing practices that promote SOM accumulation and maintenance can enhance PMN availability in the soil. One approach is the incorporation of organic amendments, such as crop residues, cover crops, and compost. These amendments contribute to SOM input, increasing the pool of organic nitrogen available for the mineralization and supporting PMN levels (Bünemann et al., 2018). Furthermore, organic amendments improve soil structure, water holding capacity, and nutrient retention, creating favorable conditions for nutrient cycling and microbial activity. Another strategy is conservation tillage or reduced tillage practices. Limiting or eliminating tillage reduces the breakdown of organic matter and promotes SOM accumulation. This, in turn, enhances PMN availability by maintaining a higher organic nitrogen pool in the soil (Bünemann et al., 2018). Conservation tillage also helps preserve soil structure, reduce erosion, and improve water infiltration, contributing to overall soil health.

Precision Nutrient Management

Precision nutrient management practices can optimize nutrient application and utilization, minimizing losses and maximizing the efficiency of nutrient uptake by crops. By applying the right amount of nutrients at the right time and in the right place, PMN can be effectively managed. Soil testing and nutrient analysis play a crucial role in precision nutrient management. Regular soil testing allows for assessing soil nutrient status, including PMN levels, and guides nutrient management decisions (Schomberg et al., 2009). Nutrient analysis of plant tissues can provide insights into nutrient deficiencies or imbalances, enabling targeted nutrient applications. Furthermore, site-specific nutrient management techniques, such as variable rate fertilization and precision irrigation, can help match nutrient supply with crop demand, minimizing nutrient losses and optimizing nutrient uptake. These techniques consider spatial variability within fields and adjust nutrient application rates accordingly, maximizing the utilization of PMN and reducing environmental impacts (Schomberg et al., 2009).

Crop Rotation and Diversification

Crop rotation and diversification practices can significantly impact PMN availability and nutrient cycling. Rotating crops with different nutrient requirements helps prevent nutrient imbalances and reduces the soil's risk of nutrient depletion or accumulation. Legume-based crop rotations are particularly beneficial for PMN management. Legumes can fix atmospheric nitrogen through symbiotic associations with nitrogen-fixing bacteria, thereby replenishing soil nitrogen levels and reducing the reliance on external nitrogen inputs (Franzluebbers et al., 1999). Incorporating legumes into rotations can enhance PMN availability in subsequent crops and contribute to overall nutrient sustainability. Diversifying crop species and incorporating cover crops can improve nutrient cycling and enhance PMN availability. Cover crops capture and recycle nutrients from the soil, preventing leaching and maintaining nutrient availability for subsequent crops (Bünemann et al., 2018). Additionally, cover crops contribute to SOM accumulation, further supporting PMN levels and nutrient cycling.

By implementing these mitigation and management strategies, farmers and land managers can effectively manage PMN and improve nutrient cycling, soil health, and crop productivity while minimizing environmental impacts. Soil organic matter management practices such as incorporating organic amendments and adopting conservation tillage promote PMN availability by increasing organic nitrogen pool and maintaining soil structure. Precision nutrient management techniques, including soil testing and site-specific nutrient applications, optimize nutrient utilization and minimize losses. Crop rotation and diversification, especially incorporating legumes and cover crops, enhance nutrient cycling and PMN availability. Adopting these strategies requires a comprehensive understanding of soil properties, nutrient dynamics, and crop requirements. Tailoring management practices to specific soil types, cropping systems, and environmental conditions is crucial for maximizing the benefits of PMN management. Additionally, ongoing research and monitoring can help refine and adapt these strategies to ensure their effectiveness in diverse agricultural settings. Implementing these mitigation and management strategies holds the potential for sustainable agricultural practices that optimize PMN utilization, enhance soil health, and contribute to the long-term productivity and environmental resilience of agricultural systems.

Future Directions and Research Gaps

The understanding of Potentially Soil Mineralizable Nitrogen (PMN) and its impact on soil health and crop production has advanced significantly in recent years. However, important research gaps and future directions still need to be addressed to enhance our knowledge further and develop sustainable management practices. This section will explore key areas for future research, including the refinement of PMN measurement techniques, the integration of PMN into nutrient management decision support systems, and the exploration of PMN interactions with other soil properties and environmental factors.

Refinement of PMN Measurement Techniques

Although several techniques exist for measuring PMN, there is a need for further refinement and standardization of these methods. The accuracy and reliability of PMN measurements can be influenced by factors such as incubation conditions, extraction procedures, and the choice of indicators or proxies. Comparative studies evaluating different PMN measurement techniques in diverse soil types and climates can provide valuable insights into the strengths and limitations of each approach (Schomberg et al., 2009). Additionally, developing rapid and cost-effective PMN assessment tools would facilitate widespread adoption in practical settings. Field-based and sensor-based approaches that provide real-time or near real-time information on PMN levels could aid in timely nutrient management decisions and improve resource-use efficiency in agriculture.

Integration of PMN into Nutrient Management Decision Support Systems

Integrating PMN measurements and predictions into nutrient management decision support systems (DSS) can enhance the precision and effectiveness of nutrient management practices. DSS tools that consider PMN levels and other soil and crop factors can provide tailored recommendations for nutrient applications, helping farmers optimize nutrient use efficiency and reduce environmental impacts. The integration of PMN into DSS models requires robust calibration and validation using field data from different agroecosystems. Long-term field experiments and monitoring networks can provide valuable datasets for parameterizing and validating models. Including PMN dynamics in existing nutrient management models, such as the Decision Support System for Agrotechnology Transfer (DSSAT), can improve their predictive capabilities and enable site-specific nutrient recommendations (Roper & Gupta, 2016).

Exploration of PMN Interactions with Other Soil Properties and Environmental Factors

The interactions between PMN and other soil properties and environmental factors need further investigation to enhance our understanding of PMN dynamics and their implications. Soil pH, moisture availability, temperature, and microbial communities can influence PMN mineralization rates and nitrogen availability (Hart et al., 1994; Schimel & Bennett, 2004). Studying these factors' synergistic and antagonistic effects on PMN can provide insights into the complex interactions within soil systems. Furthermore, the impacts of land management practices, such as organic amendments, cover cropping, and agroforestry, on PMN dynamics warrant further investigation. These practices can have diverse effects on soil properties, nutrient cycling, and microbial communities, ultimately influencing PMN availability and its relationship with soil health and crop production. Long-term field trials and experimental studies under different management scenarios are needed to elucidate these interactions.

Closing Research Gaps for Practical Implementation

To bridge the research gaps in PMN, collaboration between researchers, agronomists, and farmers is crucial. Long-term research networks, on-farm trials, and participatory approaches can facilitate the collection of real-world data, validation of models, and development of best management practices considering local and regional variability. Furthermore, the adoption of interdisciplinary approaches is necessary to advance PMN research. Integrating soil science, agronomy, microbiology, remote sensing, and data analytics can provide a comprehensive understanding of PMN dynamics and their implications for sustainable agriculture. Collaboration between researchers, policymakers, and stakeholders can facilitate the translation of research findings into practical recommendations and guidelines for farmers and land managers. Additionally, exploring PMN interactions with emerging technologies, such as precision agriculture, remote sensing, and data-driven decision-making, holds great promise. Integrating these technologies with PMN management can enable real-time monitoring and dynamic adjustment of nutrient applications based on PMN levels and crop needs. This can contribute to improved resource-use efficiency, reduced environmental impacts, and enhanced sustainability in agriculture.

Conclusion

Potentially Soil Mineralizable Nitrogen (PMN) plays a crucial role in soil health and crop production. Through its influence on nutrient availability, soil organic matter dynamics, microbial communities, and soil physical properties, PMN affects the overall productivity and sustainability of agricultural systems. The review paper explored the impact of PMN on soil health, crop production, different soil types, and mitigation strategies. It discussed the importance of PMN in enhancing nutrient uptake, crop yield, and quality. Moreover, it highlighted the role of PMN in promoting soil organic matter accumulation, supporting microbial activity, and improving soil physical properties such as water holding capacity and nutrient retention. The paper also examined case studies that showcased the influence of PMN on different soil types and associated crops. It demonstrated how PMN management strategies can address the unique challenges of sandy, loamy, and clay soils, leading to improved nutrient availability and crop productivity. Mitigation and management strategies were discussed, including soil organic matter management, precision nutrient management, and crop rotation/diversification. These strategies are essential for optimizing PMN availability, enhancing nutrient use efficiency, and promoting sustainable agricultural practices. The review paper also identified future directions and research gaps. It emphasized the need to refine PMN measurement techniques, integrate PMN into nutrient management decision support systems, explore PMN interactions with other soil properties and environmental factors, and promote interdisciplinary collaboration and practical implementation. In conclusion, understanding and effectively managing PMN is critical for sustainable agriculture. By considering PMN dynamics, farmers and land managers can make informed decisions regarding nutrient management, leading to improved soil health, enhanced crop productivity, and reduced environmental impacts. Continued research, collaboration, and innovation are essential to advance our knowledge of PMN further and develop practical strategies for its management, thereby ensuring the long-term viability and sustainability of agricultural systems.

Conflcit of interest

The authors declared absence of conflict o finterest.

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