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Value-Added Dolomite Products as Soil Ameliorants for Enhanced Soil Fertility: A Review

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Soil fertility constraints associated with acidity, nutrient imbalance, and declining base saturation continue to pose serious challenges to agricultural productivity, particularly in tropical and subtropical regions. Dolomite ($CaMg(CO_3)_2$) is widely used as a liming material to correct soil acidity while simultaneously supplying calcium and magnesium; however, its effectiveness is often limited by slow dissolution, low reactivity, and inefficient nutrient release under field conditions. To address these limitations, various value-added dolomite formulations have been developed through physical, chemical, biological, and nano-scale modifications. This review synthesizes recent research on advanced dolomite-based products, including chemically activated, organo-mineral, nano-engineered, and bio-enhanced formulations, with emphasis on their mechanisms of action, effects on soil chemical and biological properties, crop performance, and environmental implications. The analysis highlights the potential of value-added dolomite products as multifunctional soil amendments capable of supporting sustainable and climate-resilient agricultural systems, while also identifying key research gaps requiring further investigation.

Keywords: Dolomite; soil acidity; value-added fertilizers; calcium and magnesium nutrition; soil amelioration; sustainable agriculture; nano-fertilizers; organo-mineral amendments

Introduction

Soil degradation and the progressive decline in soil fertility represent major constraints to sustainable agricultural production worldwide, particularly in developing regions characterized by intensive land use, unbalanced fertilizer application, and limited organic matter inputs. Among the various forms of soil degradation, soil acidity is especially problematic in tropical and subtropical agroecosystems, where it restricts nutrient availability, suppresses microbial activity, and impairs root growth. Acidic soils are commonly associated with aluminum and iron toxicity, phosphorus fixation, and deficiencies of essential base cations such as calcium and magnesium, collectively resulting in reduced crop productivity. The application of liming materials remains one of the most effective approaches for mitigating soil acidity. Dolomite ($CaMg(CO_3)_2$) is frequently preferred over calcitic lime because it not only neutralizes soil acidity but also supplies magnesium, an essential nutrient often deficient in acidic soils. Despite these advantages, the agronomic performance of conventional dolomite is frequently constrained by its low solubility, slow reaction rate, and coarse particle size, which delay pH correction and limit nutrient availability, particularly in short-season cropping systems. In response to these constraints, considerable research attention has been directed toward the development of value-added dolomite products designed to enhance reactivity, nutrient-use efficiency, and interactions with soil biological systems. Value addition involves modifying dolomite through physical processing, chemical activation, integration with organic materials, nano-scale engineering, or microbial inoculation. These innovations have transformed dolomite from a traditional liming agent into a multifunctional soil amendment with the potential to improve soil health, nutrient cycling, and crop performance. The expanding interest in value-added dolomite products aligns with broader objectives of sustainable agriculture, including integrated nutrient management, resource recycling, and climate-smart soil practices. By combining dolomite with organic amendments, industrial by-products, or advanced materials, these formulations offer opportunities to enhance agronomic efficiency while minimizing environmental risks. Therefore, a critical synthesis of recent research on value-added dolomite products is essential to evaluate their potential role in improving soil fertility and supporting sustainable agricultural systems.

Mechanisms of Dolomite Action in Acidic Soils

The effectiveness of dolomite as a soil ameliorant in acidic environments is primarily associated with its role in neutralizing soil acidity and improving base cation balance. Following application, dolomite undergoes gradual dissolution in the soil solution, releasing calcium and magnesium carbonates that react with hydrogen ions, thereby increasing soil pH. The released Ca^{2+} and Mg^{2+} ions subsequently replace exchangeable H^{+} and Al^{3+} ions on soil colloids, leading to increased base saturation and reduced acidity (Parmar, 2025; Salgado et al., 2025). Raising soil pH through dolomite application significantly reduces aluminum toxicity, a major growth-limiting factor in acidic soils. As pH increases, soluble Al^{3+} ions are converted into less reactive aluminum hydroxides, minimizing root damage and improving root proliferation. This detoxification enhances nutrient uptake efficiency and overall plant growth. Calcium contributes to improved soil structure by promoting aggregation and stabilizing cell membranes, while magnesium plays a vital role in chlorophyll formation and enzyme activation, directly influencing photosynthesis and metabolic processes (Gupta et al., 2025).

Recent research indicates that value-added and nano-modified dolomite formulations can accelerate these ameliorative processes compared with conventional dolomite. Increased surface area, improved dispersion, and enhanced interactions with soil particles allow faster dissolution and more efficient nutrient release. In addition to pH regulation, advanced dolomite-based composites have been reported to influence phosphorus dynamics and immobilize potentially toxic metals in acidic soils, thereby expanding the functional role of dolomite beyond simple liming (Kamali et al., 2020). These findings highlight the potential of modified dolomite formulations to simultaneously address soil acidity, nutrient availability, and environmental quality.

Types and Characteristics of Value-Added Dolomite Products

Value-added dolomite products are formulated to overcome the inherent limitations of raw dolomite by improving its chemical reactivity, physical properties, and biological interactions in soil. Based on the nature of modification, these products can be broadly classified into physically modified, chemically enriched, organically integrated, nano-engineered, and bio-enhanced dolomite formulations. Each category differs in mode of action, agronomic effectiveness, and suitability for specific soil–crop systems.

Physically Modified Dolomite

Physical modification primarily involves reducing particle size through fine grinding or micronization to increase surface area and accelerate dissolution in acidic soils. Finely ground dolomite reacts more rapidly with soil acidity, leading to faster pH correction and earlier alleviation of aluminum toxicity. Granulation and pelletization techniques further improve application efficiency by reducing dust formation, enhancing uniform field distribution, and allowing compatibility with conventional fertilizer spreaders. Although physically modified dolomite improves reaction kinetics, its effectiveness remains dependent on soil moisture, buffering capacity, and incorporation depth.

Chemically Enriched Dolomite

Chemical value addition involves altering the chemical composition or surface properties of dolomite to enhance solubility and nutrient availability. Acid-activated dolomite, phosphate-enriched dolomite, and chemically converted dolomite fertilizers represent important advances in this category. Parmar (2025) reported that chemically transformed dolomite powder, when integrated with vermicompost, significantly improved calcium and magnesium availability, biomass accumulation, and yield of tomato plants under pot culture conditions. Similarly, dolomite-supported micronutrient formulations have been developed to improve micronutrient delivery and nutrient-use efficiency. Gupta et al. (2025) demonstrated that dolomite-supported and cellulose nanofiber-translocated micronutrients enhanced nutrient uptake and growth performance in ryegrass, highlighting the potential of dolomite as a nutrient carrier matrix. Despite these advantages, the complexity of chemical processing and potential cost implications necessitate further evaluation under field conditions.

Organically Integrated Dolomite

Organic integration involves combining dolomite with organic materials such as compost, farmyard manure, vermicompost, crop residues, or biochar. Organic matter enhances soil aggregation, microbial activity, and nutrient retention, while dolomite corrects soil acidity and supplies base cations. The synergistic interaction between organic and inorganic components often results in improved nutrient cycling and sustained soil fertility. Nevertheless, variability in organic material quality and decomposition rates can influence the consistency of agronomic outcomes.

Nano-Engineered and Composite Dolomite

Nano-engineered dolomite formulations represent a recent innovation aimed at maximizing nutrient-use efficiency through particle-size reduction and composite formation. Nano-dolomite and dolomite-based nanocomposites exhibit high reactivity, enhanced nutrient adsorption, and controlled release characteristics. When combined with materials such as biochar or cellulose nanofibers, dolomite-based composites can function as nutrient carriers and soil conditioners. Despite promising laboratory and greenhouse results, the field-scale applicability, environmental safety, and economic feasibility of nano-dolomite products require further investigation.

Bio-Enhanced Dolomite Products

Bio-enhanced dolomite formulations incorporate beneficial microorganisms, including phosphate-solubilizing bacteria, nitrogen-fixing bacteria, and mycorrhizal fungi. These microorganisms enhance nutrient solubilization, improve root–soil interactions, and promote plant growth. Dolomite provides a favorable pH environment that supports microbial survival and activity, making it a suitable carrier for biofertilizers. However, the stability and persistence of microbial populations under varying soil conditions remain key challenges.

Agronomic and Environmental Impacts of Value-Added Dolomite

Evidence from recent case studies suggests that value-added dolomite products generally outperform conventional dolomite in improving soil chemical properties and crop productivity, although outcomes vary depending on formulation and soil conditions. Parmar (2025) observed significant improvements in tomato biomass and yield following application of chemically converted dolomite integrated with vermicompost, emphasizing the importance of nutrient transformation for improving plant availability.

Nano-engineered dolomite formulations and dolomite-based nanocomposites have attracted increasing attention due to their enhanced reactivity and multifunctionality. Kamali et al. (2020) demonstrated that vinasse–dolomite nanocomposite biochar improved phosphorus recovery and immobilized toxic metals in acidic soils, thereby contributing to both soil fertility enhancement and environmental remediation. Similarly, Gupta et al. (2025) reported improved nutrient-use efficiency and plant growth in systems using dolomite-supported micronutrient nano fertilizers.

From an environmental perspective, the valorisation of dolomite by-products has shown promise for the rehabilitation of degraded and contaminated soils. Salgado et al. (2025) reported significant improvements in soil pH and stabilization of trace metals following the application of dolomite-based by-product composites. However, many of these studies are short-term or conducted under controlled conditions, highlighting the need for long-term, multi-location field trials to validate agronomic and environmental sustainability.

Limitations and Research Gaps

Despite their promising benefits, value-added dolomite products are not without limitations. Excessive application may result in over-liming, micronutrient deficiencies, and reduced phosphorus availability. The production costs associated with nano-scale and chemically activated formulations may also restrict their adoption, particularly among smallholder farmers. Moreover, many existing studies are short-term in nature, underscoring the need for long-term field experiments to evaluate residual effects, economic feasibility, and environmental impacts under diverse agroecological conditions.

Future Research Prospects

Future research should prioritize the development of site-specific dolomite formulations tailored to different soil types and cropping systems. Long-term field studies are required to assess the sustainability of value-added dolomite applications, including their effects on soil carbon dynamics and microbial communities. Integration with biofertilizers, precision nutrient management, and digital agriculture technologies offers additional opportunities to enhance the efficiency and adoption of dolomite-based soil amendments.

Conclusion

Value-added dolomite products represent a progressive advancement in soil amelioration and sustainable nutrient management. Through physical, chemical, and biological modifications, dolomite can be transformed into a multifunctional soil conditioner that addresses the limitations of conventional liming materials. Evidence from recent case studies demonstrates improvements in soil chemical and biological properties, enhanced nutrient-use efficiency, and increased crop productivity. However, variability in formulation methods, experimental scale, and soil conditions highlights the need for long-term, field-based validation. Overall, value-added dolomite formulations show strong potential for inclusion in integrated soil fertility management strategies aimed at sustainable and resilient agricultural systems.

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