Bio-Organic Mineral Fertilizer

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This entry discusses about Bio-Organic Mineral Fertilizer for Sustainable Agriculture.

Keywords: mineral fertilizer ; organic fertilizers ; soil microbes ; sustainable agriculture

1. Background

Minerals are also an important component of the soil; they are the skeleton of the soil and the source of mineral elements. Minerals play an important role in the improvement of soil's physical and chemical properties and the growth and metabolism of microorganisms. However, the beneficial effects of the use of appropriate minerals in the soil have long been neglected. In addition, our research has found that forms of mineral weathering, such as silicate weathering, are often accompanied by the formation of secondary carbonate minerals in the process of biological weathering, which undoubtedly increases the potential of cultivated soil carbon sinks [1][2][3][4]. Further studies have shown that secondary minerals formed with mineral weathering have a good remediation effect on heavy metal pollution [5][6]. In addition to the formation of secondary minerals, the cations released by mineral weathering can also combine with the soil's organic complexes through co-precipitation, which in turn mediates the formation of soil aggregates, preserving soil organic carbon, thereby reducing the potential of soil carbon depletion. Therefore, bio-organic mineral fertilizers (BOMFs) have a positive impact on agriculture, soil health and the ecological environment [7][8][9][10][11][12].

2. BOMFs: A Current Need

By the end of 2020, the total global amount of fertilizer (N, P and K) reached more than 200 million tons per year [13]. This is alarming as fertilizers have severe adverse effects on soils as well as on surrounding ecosystems. In addition to this, the use of pesticides to prevent and control plant diseases is accelerating at a much more perilous rate. China (1,773,676 t), the United states of America (407,779 t), and Brazil (377,176 t) occupy the top three places in the world for pesticide utilization as of 2019, according to FAO. However, concerning the consumption rate (kg/hectare), Maldives (52.6), Trinidad and Tobago (24.9) and Costa Rica (22.5) are the top three consumers of pesticides despite their smaller areas of agriculture [14]. Long-term conventional farming has far reaching consequences for human health and the environment [15][16][17][18].

As a response to the many hurdles, contemporary and very recent research has demonstrated that soil quality can be improved by applying organic matter, organic fertilizer (OF), dust, and mineral powder (MP), and/or by growing pasture legumes as green manure [19][20][21]. The natural breakdown of many minerals due to microbial metabolic activities, combined with abiotic factors innate to a given ecosystem, provide sustenance to plant growth [5][22]. It is a widely acknowledged fact that organic matter is a crucial component for improving the physical properties of soil, and that returning organic matter to soil can increase the content of soils' active organic carbon (AOC) and improve soil vitality. However, organic matter alone, which lacks adequate accessible nutrients (for plants), exerts slow and variable effects on crop growth [23]. Although applying chemical fertilizers (CFs) can promote rapid crop growth, extensive CF use has reduced soil quality worldwide [24]. Utilizing and/or enhancing the mineral weathering potential of many microbial groups (bacteria and fungi) coupled with mineral ore (rock phosphate, feldspar, etc.) application has been reported to exert extremely positive effects on soil health and fertility, an approach devoid of environmental concerns [11][22][25][26]. Hence, compound fertilizers composed of suitable microbes, organic matter, and raw mineral powders, along with low quantities of CF, offer the potential to achieve sustainability goals under the prevailing environmental scenario [8][27][28].

Contemporary research shows that potassium-containing minerals transformed by microorganisms in soil can promote crop growth [29][30][31][32]. For example, *Paenibacillus mucilaginosus* (also known as silicate bacterial in China) is an important species, widely used in microbial fertilizers in China [32][33][34][35]. Lian et al. (2002 and 2020) explored the potassium-releasing effect and mechanism of bacteria, and proposed the comprehensive effect of the potassium-releasing mechanism by bacteria. The potassium release effect of silicate bacteria on aluminosilicate-containing potassium minerals is based on the formation of a bacteria–mineral complex through the combined effects of acidolysis, chelation, dissolution, and active absorption, which promote each other and together lead to the gradual release of potassium ions in minerals. Further, the micro-environment formed by microbial extracellular secretions and microbial–mineral interactions (bacteria–mineral complex) is closely related to the release of potassium ions from mineral weathering [7][8][9]. These findings helped to further the understanding of the mechanism of weathering potassium-bearing minerals to improve soil potassium utilization rates through silicate bacteria.

In some areas, Chinese farmers have used potassium-containing mineral powder, phosphate rock powder, agricultural by-products, and organic wastes to make compost [3][36][37]. This method of fertilizing fields by supplementing potassium and phosphorus is simple but varies greatly in its effect on crops. In recent years, some scholars have also begun to try similar methods to obtain organic potassium phosphate fertilizers using different organic materials and minerals, supplemented with microbial agents [6][12][38][39][40]. The results indicate that fermentation with a microbial agent greatly increase the soluble content of nutrients (K and P), suggesting that microbial fermentation can efficiently transform low-grade mineral rocks. Furthermore, potassium-containing rocks and auxiliary materials can be converted into multifunctional compound organic mineral fertilizers, which can not only supplement the nutrients needed for crop growth and improve its quality, but also repair inferior soil that has been severely degraded due to the excessive application of chemical fertilizers [3][11][27].

In summary, BOMFs are fertilizers prepared with minimally processed components (chemical agents such as urea, phosphates, etc.). BOMFs mostly comprise mineral sources and animal excreta (cow dung, chicken feces, etc.) as bio-organic components and differ significantly from conventional organic fertilizers or bio-fertilizers in their composition and resultant effects. The components and basic differences with conventional chemical fertilizers are presented in **Table 1**.

Table 1. Differences in compositional and functional attributes between BOMFs and conventional synthetic fertilizers.

Different Distinguishing Components	BOMFs	Conventional Fertilizer
Mineral source (P, K, Ca, B, Mg, etc.)	Natural	Chemical
Mineral (dust or powder)	✓	x
Microbial agents	✓	x
Plant growth-promoting microbes	✓	x
Plant protecting microbes	✓	x
Organic carbon	Natural (agri. waste)	x
Nitrogen source	Natural (animal waste)	Chemical (urea)
Inorganic additives	xx	Chemical additives (P, K, etc.)
Negative impact environment	x	✓
Known CO_2 sequestration potential	✓	x
Positively influences soil parameters	✓	x

Note: ✓ means contained, x means excluded, xx means excluded unless otherwise noted (adding a small amount of chemical fertilizer).

Additionally, the organic component serves two functions: as a carrier for the microflora and as an active soil carbon source, further improving soil fertility. The most noticeable feature of BOMFs is the presence of a natural, unprocessed mineral source instead of chemical agents for supplementing macro-elements (phosphate, potassium, calcium, magnesium, sulfur, boron, etc.). Phosphate (P), the most widely applied non-nitrogen fertilizer, features limited bioavailability in its raw form (rock phosphate or phosphorite), needing further chemical processing before its application to soil. This can be managed with BOMFs, where rock phosphate itself is used as P source that is gradually weathered by the action of innate/or added microflora in BOMFs. Besides P, many other macro-elements can be supplemented as their raw sources (feldspar, muscovite-potassium; dolomite-magnesium; calcite-calcium; gypsum-sulfur) before high-temperature fermentation. Furthermore, BOMFs can be prepared with widely available materials, reducing the manufacturing process as well as the financial pressure on the farmer to obtain healthy produce from the fields. BOMFs could also be much more effective in soils lacking pedogenic parent minerals (such as karst soils in Southwest China, sodic soils in south Asian countries, and sandy soils in Africa) as the mineral component can be gradually weathered by microbial community-enhancing soil agricultural attributes. Thus, the organic mineral fertilizer obtained by comprehensively using organic waste and cheap low-grade mineral powders (such as potash mineral powder and phosphate rock powder, etc.) and adopting microbial engineering fermentation technology can partially replace chemical fertilizers to promote crop growth, improve low-quality soil, and exert a positive ecological effect (**Figure 1**).

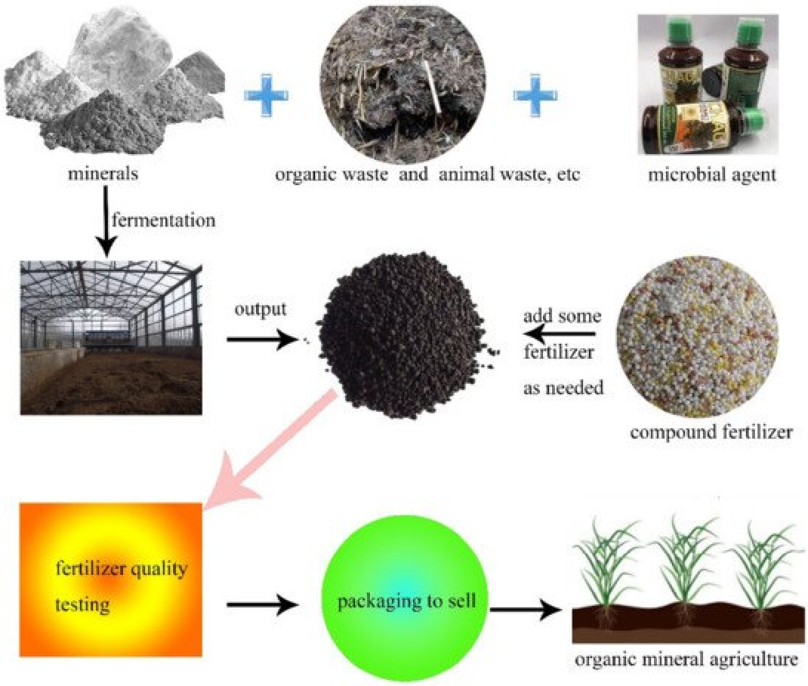

Figure 1. Simplified production process of BOMFs.

3. Ecological Effects of BOMFs

The application of BOMFs in agriculture can improve soil's physical and chemical properties, regulate soil ecological communities, and reduce environmental pollution. Beneficial rhizosphere bacteria play a critical role in the agricultural ecosystem i.e., by preserving soil quality and maintaining soil fertility and crop productivity [41]. An appropriate community structure, rich diversity, and high microbial activity are significant factors in maintaining soil ecosystems and productivity [42].

3.1. Impacted Microbial Functions and Plant Growth Promotion

Years of different types of fertilizer application (including NPK, manure, and cattle slurry) demonstrated statistically significant differences in the content and quality of humic substances, soil reaction and available nutrient content. Based on principal component analysis, fertilizers are divided into two categories: (1) NPK treatment—higher acidity, lower soil organic carbon and humic substances content, higher content of available nutrients; and (2) organic manure treatments—lower acidity, higher soil organic carbon and humic substances content, lower content of available nutrients. Organic manures are known to improve microbial community stability and enhance associated functions [43]. Furthermore, long-term NPK application without organic input can accelerate humus mineralization and soil degradation due to soil acidification, with several negative consequences, such as low nutrient availability, nitrogen leaching, high toxic element availability, fewer sources and energy for microorganisms' activity etc. [44][45][46]. Amendment through the use of organic fertilizers (manure and cattle slurry) and BOMFs can help to achieve stable yields in the long term while maintaining optimal soil properties. The total microbial diversity and density significantly increase along with the microbial community-associated functions (soil enzyme activity, organic carbon and total available nutrients such as N, P, and K) [47][48][49][50]. BOMFs also enhance the disease suppression potential of soils by maintaining stable rhizosphere microbial communities [51].

3.2. Restoration of Soil Fertility and Organic Carbon

The loss of fertility due to intense agricultural practices in the current scenario is of immense significance. Enhancing fertility in intense farms or in non-arable lands is a possible approach to increasing productivity, thus increasing food production without further burdening natural resources. The unique combination of BOMFs with the supplementation of natural organic matter, raw natural ores instead of synthetic fertilizers, and microbial assemblages capable of weathering, metabolizing and nourishing, could create a stable agricultural microenvironment. Sun et al. (2019) reported an increase in the soil water holding capacity and agronomic characteristics along with an increase in the biomass of Chinese *cabbage* when fertilized with BOMFs (in this case, potassic rock and organic waste) [3]. Additionally, the concentration of inorganic carbon (largely in the form of HCO_3^-) in surface run-off water treated by BOMFs was higher than in the other treatments, establishing carbon sequestration's potential. The combined addition of dolomite and K-feldspar mineral powder to soil has been shown to be effective at improving the plant growth parameters as well as carbon capturing. Plants and microorganisms weather minerals by secreting organic acids, which release cat ions, such as Ca^{2+} and Mg^{2+}. The released cat ions manage atmospheric CO_2 by forming carbonates under a series of biological actions [1][2][3][22]. In addition, the cat ions released by mineral weathering are often combined with organic matter, which is sequestered in secondary carbonate minerals when carbonate minerals are formed. These sequestered organic carbons are difficult to decompose and utilize for organisms, thereby increasing soil organic carbon. In one study, the carbon content of the soil was enhanced as mineral weathering accelerated fixation of organic and inorganic carbon. Moreover, the available potassium content was also increased when K-feldspar was added [2]. Facing the global greenhouse effect and cultivated soil degradation, adding moderate amounts of carbonate, phosphorus, and silicate minerals into soil is a sustainable approach through which to accelerate atmospheric CO_2 fixation and improve the nutrient content of soil.

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