Potentiality of Vermicomposting

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Vermicomposting is a biological process of decomposition of degradable residues through the digestive tracts of earthworms. It has been studied since long and still very important and relevant mostly in the viewpoint of organic waste recycling and biofertilizer production. Though wide range of literature are available on the topics, however, there are still unknowns that need to be additionally explored to maximize the potential of vermicompost.

Vermicompost | organic fertilizer | Earthworm | organic waste recycling | biopesticide | Growth regulator

1. Introduction

Vermicompost is an organic fertilizer obtained by the decomposition of degradable residues through the digestive tracts of earthworms. It is regarded both as a sustainable approach to agricultural production and a safe means of waste management [1]. Indeed, it can be produced from waste that is rapid-growing and has a deleterious impact on groundwater resources [2][3][4]. Waste is converted into vermicompost, which has a high-nutrient value that has been shown to contribute to an improvement in soil fertility and plant productivity [5][6][7]. **Figure 1** summarizes the waste conversion to beneficial vermicompost and its influences on soil fertility and crop productivity. Studies have highlighted numerous benefits following its application to many crops, such as cereals and field crops [8][9][10][11], legumes [12], and vegetables [13][14][15], with different amounts of vermicompost applied in each study. It has been shown that vermicompost contains plant hormones that stimulate growth and anticipate the spread or the severity of disease [5][6][1]. Vermicompost provides essential nutrients to the plants in a form they can readily utilize [8][15]. Vermiculture is therefore regarded as a slow and steady application that can be both beneficial for soil health and crop productivity.

Figure 1. Schematic summary of the vermicomposting process and its beneficial effects on soil health and crop productivity (Adapted from Chatterjee et al. (2021) [16]).

2. Use of Vermicompost

Vermicompost has been applied as an organic fertilizer to multiple crops in greenhouses and in open fields. As well as supplying plant nutrients, it has been used as a plant growth regulator, a bio pesticide, and as a soil amendment agent. The vermicomposting process is also a useful method for recycling solid organic wastes. Applications of vermicompost are described below in more detail.

2.1. Plant and Soil Nutrients Supply

Vermicompost has high concentrations of humus, nitrogen (2–3%), phosphorous (1.55–2.25%), potassium (1.85–2.25%), micronutrients, and beneficial soil microbes such as nitrogen-fixing bacteria, mycorrhizal fungi, phosphate solubilizing bacteria, and actinomycetes [4][17]. Bio-oxidation and stabilization of organic matter and biomass occur during the vermicomposting process and increase enzymatic activities such as amylase, lipase, cellulose, chitinase, urease, dehydrogenase and phosphatase, and microbial populations [4][18][19]. For example, vermicomposting stimulates nitrogenase enzyme activity, and therefore nitrogen mineralization and nitrogen availability. Mineralization of nitrogen induces phosphorus availability and uptake. Additionally, vermicomposting also increases the availability of other nutrients such as soluble potassium, nitrates, calcium, and magnesium [20]. Vermicompost application increases the availability of nitrogen in soil mostly in the form of nitrate relative to ammonium due to better soil aeration [16]. Plots treated with vermicompost showed higher levels of total N [21]. In parallel, phosphorus was shown to be more available, and it was released in large amounts due to microorganism activity [4]. Interestingly, reports have shown that when vermicompost is applied in combination with commercial NPK fertilizer, nitrogen availability improved to a greater extent than when only NPK fertilizer was applied [22]. It has also been proposed that, due to the slow mineralization of N with the use of vermicompost, its application leads to improved crop yields and an increase in plant leaf area and number of leaves per plant [22]. Furthermore, with the application of vermicompost, the organic matter releases the nutrients slowly and steadily into the soil and allows the plants to absorb the available nutrients. Hence, the application of vermicompost leads to an increase in cation exchange capacity [23]. High activity of basic cations, e.g., Ca, Mg, K etc., was also reported in the vermicast (earthworms castings) compared to soil [24].

Vermicompost has been included in plant nutrient management programs in large-scale greenhouse production systems. For both fruit and vegetable crops cultivated in greenhouses, when vermicompost is used as a growing medium alone or in combination with soil, it has been shown to improve the release and availability of plant nutrients. Hence, a fertigation practice in greenhouse production systems that includes vermicompost would substitute other plant nutrients within the range of 20–40%. Under large open field conditions, vermicompost is typically applied to soil at a rate of 1–5 tons ha^{-1} yr^{-1} [25]), unless the soil is unfertile where it is applied in larger doses. The application of vermicompost significantly improves the organic carbon content in soil as it is enriched with stable organic matter [20][26]. The application of fully decomposed vermicompost has been shown to reduce the loss of nutrients through leaching [16], due to an increase in total soil organic carbon [27]. In addition, vermicompost helps to remediate the stability of the soil from toxicity [28]. This shows that the application of vermicompost in soil enhances soil physicochemical properties and biological activities, and, thereby, crop production [29]. It has been reported that the population of microbes is more than three times greater where vermicompost is applied compared with a control (only soil) [30].

Nonetheless, there are reasons to approach the use of vermicompost with caution [31]. A few studies have shown negative impacts on plants and soil, typically related to the quantity of vermicompost applied. The application of higher percentages of vermicompost could create an uncomfortable zone for root growth, which directly induces phytotoxicity [32][33]. Furthermore, high concentrations of vermicompost could result in the rapid destruction of the plant due to the accumulation of salt in the soil.

2.2. Growth Regulator

Many studies have reported that improvement in plant growth parameters is achieved rapidly with the addition of vermicompost [34]. Vermicompost application enhances the release of plant hormones, which lead to desirable changes in plant growth parameters [17]. The presence of gibberellic acid (GA) in vermicompost influences Ca and K uptake and leads to better development of shoot elongation [35]. Experiments on the use of vermicompost along with other organic matter substrates show that it leads to relatively more branching than where inorganic fertilizer is used alone, due to phytohormones in the vermicompost [36]. Additionally, the quality of humic and fulvic acids originally obtained from animal manure is improved through the vermicomposting process: vermicompost retains humic and fulvic acids in more active forms, which act as growth promoters similar to hormones and lead to plant nutrients being converted into bioavailable mineral nutrients [37][38]. Consequently, the application of vermicompost improves fruit quality parameters such as firmness, color, and the multiplication of marketable fruits [39]. Improved lettuce weights and plant heights were reported where vermicompost was used due to the presence of the plant growth regulators viz. auxins, IAA, gibberellins, and cytokinins in plots treated with food and paper vermicomposts [40][21][32]. Vermicompost application is reported to have led to improved seed germination in cabbages, radishes, and Swedish turnips [41][42]. Similarly, vermicompost was shown to accelerate the germination of beetroot, bean, and pea seeds [43], as well as tomato and marigold crops [36][21][41]. Results also suggest that leaf chlorophyll, carotenoid content, and the efficiency of plant photosynthesis also improved [44]. Some reports show that the concentration of essential oils in the leaves of mint plants (*Thymus vulgaris*) also increased with the use of vermicompost, as did total concentrations of carbohydrates, fiber, and vitamin C in cabbage heads [45]. Similarly, tomato crops treated with vermicompost were shown to have higher Ca and vitamin C contents compared with control plots. Due to better interactions between microbes and vermicompost, tuber quality (based on N and protein content) in potato crops improved when treated with vermicompost [42].

In some studies, plants grown with pot mix and vermicompost as growing media produced better quality and heavier products than those treated with plant growth regulator Metro-Mix 360 (Sun Gro Horticulture, Agawam, MA 01001, USA) [21]. Similar trends were also observed in the production of different seasonal crops such as okra, cucumber, pepper, eggplant, strawberry, and Amaranthus species [20][46][47][48][49][50][51][52][53][54].

2.3. Bio-Pesticide

The digested organic waste in the form of earthworm casts contains antifungal compounds such as phenolic substances, which contribute to plants' defense mechanisms and help combat the spread of disease and attacks from pests [44]. The synthesized hormones strengthen the plants and create a barrier for pathogen multiplication [44][55][56]. Protection of plant system against diseases is also possible because of the availability of oxidative enzymes in the earthworm casts. These oxidative enzymes facilitate the formation of a lignin (via the phenylalanine ammonia lyase (PAL) enzyme) which, in turn, reinforces the cells of the plant [44]. It has been shown that actinomycetes present in vermicompost help develop resistance within the plants cells and improve their ability to combat pests and diseases [17]. This combating mechanism is mainly due to microbially-mediated synthesis of the enzyme chitinase, which breaks down the chitin in the insect exoskeleton [57]. It can be deduced that the promotion of enzymatic activities through vermicompost application both ameliorates and promotes soil rehabilitation/regeneration and leads to the protection of plant cells and their ability to tolerate biotic and abiotic stress [58][59]. *E. eugeniae* creates a barrier to soil against contamination with glyphosate-based herbicides (GBH) [60].

Field experiments also suggest that the application of vermicompost leads to the suppression of diseases and a reduction in pest attacks. Application of vermicompost to a field site was shown to reduce attacks by jassid (*Empoasca verri*) and aphids (*Aphis cracivora*) [61]. It was also associated with reduced incidences of parasitic fungi such as *Pythium, Rhizoctonia,* and *Verticulum* as well as populations of parasitic nematodes and other types of parasite. The application of vermicompost was also associated with a reduction in the growth of *Fusarium oxysporum f. sp. Lycopersici* in an in vitro trial [62]. Experiments consistently show that plants are more resistant to insect attacks where vermicompost is used and the final plant products are less damaged by sucking or chewing by insects. This was attributed to the presence of organic matter in the vermicompost which, in turn, provides a suitable environment for a balanced nutrient regime required for plant growth and better physiological development [63][64][65]. With a dose of 75% (by volume), vermicompost was applied in the cultivation of balsam *(Impatiens wallerana),* and this was linked to a reduction in the occurrence of *Rhizoctonia* disease [66]. A significant reduction in numbers of mealy bugs was observed in the pots of pepper plants that were treated with varying percentages of vermicompost [63]. It has also been observed that the spray application of aqueous vermicompost is effective in controlling foliar diseases. It was demonstrated that 20% of the aqueous solution could suppress the numbers of aphids on tomato plants for up to 14 days [25].

2.4. Recycling of Solid Waste

Vermicomposting creates a win-win situation by offering a means of recycling organic waste as well as an organic fertilizer [3]. The waste utilized in the process of vermicomposting remains a key parameter for determining the nutrient value of the "end product". A wide range of parent materials can be used in vermicomposting, such as food waste [38], sugarcane trash, sugar industry bi-products, municipal organic waste, bio solids, animal manures [67][68], and paper [69]. It was found that pig manure vermicompost produces a humus-rich odor free vermicast with Zn and Cu as the limiting nutrients [12][70]. Vermicompost produced from sugarcane trash showed the following composition: 24.62% organic carbon, 1.14% nitrogen, 0.46% phosphorus, and 1.61% potassium [37]. However, vermicompost prepared from sugar industry waste bagasse is enriched with nutrients, with 49.53% organic carbon, 0.86% total Kjeldahl nitrogen, a C:N ratio of 57.59, a Zn concentration of 60.63 mg kg^{-1}, and an Mn concentration of 20.67 mg kg^{-1} [71]. Some studies favor a 50:50 mix of bagasse and cattle dung, which gave optimal results in terms of earthworm biomass, cocoon production, and hatchling formation [71][72]. Conversely, vermicompost produced from of a 100:0 mix of bagasse and cattle dung resulted in a maximum increase of total nitrogen, which was attributed to the deterioration of dead earthworm tissue and a subsequent improvement in nitrogen content in the vermicompost [71]. Furthermore, analysis shows that the use of bagasse mixed with cattle dung induces a reduction in total organic carbon, which was more pronounced in the 50:50 mix compared to the 100:0 mix. The total productivity of vermicompost was amplified when sugar cane bagasse was combined with rice straw [72].

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