Earthworm Castings in Ecosystem Health through Their Elemental Composition

Abstract

Earthworm castings, colloquially termed as nature's potent organic fertilizers, have emerged as a cornerstone in the pursuit of sustainable agriculture and holistic ecosystem health. This significance is particularly pronounced in the intricate tapestry of India's agricultural landscapes, marked by its rich biodiversity and varied terrains. Drawing from an exhaustive synthesis of research literature and traditional agricultural knowledge unique to India, our review sheds light on the multifaceted attributes of these castings. At the heart of these attributes is the elemental composition of the castings. Rich in both macro (like Nitrogen, Phosphorus, and Potassium) and crucial micronutrients (including Calcium, Magnesium, and Sulfur), these castings present a veritable solution to the challenges of soil fertility. They don't merely replenish the soil; they transform it. By making nutrients more bioavailable, they ensure plants not only grow but thrive, leading to a notable reduction in the need for synthetic fertilizers. This shift not only offers an economic respite to farmers but also mitigates the environmental challenges associated with chemical overloads in soils. Beyond the immediate agronomic advantages, the broader ecological implications of earthworm castings are equally compelling. Our review highlights the critical role these castings play in enhancing soil structure. A robust soil structure, in turn, is fundamental for healthy microbial communities, ensuring that the soil is teeming with beneficial organisms that further its fertility and resist pathogens. Moreover, the ability of earthworm-amended soils to retain more water emerges as a significant boon, especially in the face of erratic monsoons and increasing drought scenarios in parts of India. This water retention capability dovetails with the castings' ability to reduce soil erosion, a concern that has long plagued India's terrains, from its hilly regions to its coastal plains.

Keywords: ***Earthworms, Castings, Agriculture, Ecosystem, Sustainability***

1. Introduction

Earthworms, often referred to as "nature's plow," have been an integral part of terrestrial ecosystems for over 500 million years [1]. These humble creatures, through their burrowing actions and nutritional preferences, play a pivotal role in soil health and dynamics, leading to substantial benefits to the broader ecosystem. At first glance, earthworms might seem insignificant, but their ecological contributions are profound. As Edwards *et al.*,[2] eloquently noted, "It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly organized creatures." Earthworms contribute to various ecological processes, including organic matter decomposition, nutrient cycling, and soil structure enhancement [3]. The movement of earthworms through the soil creates channels that enhance soil aeration and drainage, promoting root penetration and growth [4]. Furthermore, their feeding habits facilitate the breakdown of organic matter, thereby quickening the decomposition process and converting organic residues into forms more readily available to plants and other soil microorganisms [5]. One of the most invaluable contributions of earthworms to soil health is the production of vermicastings, commonly referred to as worm

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castings. These are essentially the waste products of earthworms after digesting organic matter, and they significantly differ from the original ingested soil in both structural and chemical properties [6]. Earthworm castings are rich in available nutrients, including nitrogen (N), phosphorus (P), and potassium (K) [7] (Table 1). The microbial activity within these castings is also significantly higher than in the surrounding soil, leading to enhanced decomposition and nutrient availability. This microbial diversity not only aids in nutrient cycling but also suppresses soil-borne diseases, providing a more conducive environment for plant growth [8]. Beyond the direct nutritional benefits, the physical properties of the castings, such as water-holding capacity and aggregation, are markedly improved, enhancing soil structure and resilience against erosion [9]. Moreover, the dark color of worm castings can increase soil's ability to capture and retain heat, which can be beneficial for plant growth in cooler climates [10]. The elemental composition of the soil, often viewed in terms of macro and micronutrients, is crucial for overall soil health and productivity. While the nutrients themselves are vital for plant growth, the balance and availability of these elements often determine the success or failure of crops. The elemental composition of earthworm castings is of particular interest because of its marked enrichment compared to the original soil. This enrichment process occurs as earthworms selectively consume nutrient-rich soil particles and organic matter [11]. For instance, studies have shown that N, P, and K concentrations in castings can be significantly higher than in the surrounding soil [12]. These nutrients, crucial for plant growth, are present in the castings in forms more readily available for plant uptake, leading to improved plant health and yields [13]. Moreover, the micronutrient profile of earthworm castings is also enhanced. Elements such as calcium (Ca), magnesium (Mg), and sulfur (S), which play vital roles in plant cell wall structure, photosynthesis, and amino acid formation respectively, are present in higher concentrations in the castings [14]. The elemental composition, therefore, plays a significant role in determining the fertility and productivity of soils. With the growing awareness of sustainable agricultural practices, understanding and leveraging this composition, especially as found in natural enhancers like earthworm castings, becomes increasingly pertinent.

Table:1 Elemental Composition of Earthworm Castings and their Implications for Indian Agriculture

Element	**Presence in Earthworm Castings**	**Beneficial Impact on Plants**	**Relevance to Indian Agriculture**
Nitrogen (N)	High concentrations.	Promotes vegetative growth.	Vital for staple crops like rice and wheat.
Phosphorus (P)	Enriched levels.	Stimulates root and flower development.	Crucial for crops like pulses and oilseeds.
Potassium (K)	Abundant presence.	Enhances fruit quality and resistance to diseases.	Key for fruit crops and spices.
Calcium (Ca)	Moderately present.	Influences cell wall structure; activates certain enzymes.	Beneficial for tuber crops like potatoes.
Magnesium (Mg)	Present in trace amounts.	Aids in chlorophyll formation.	Important for green leafy vegetables.

Literature Search and Review

Extensive literature searches were conducted on databases such as PubMed, Google Scholar,

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Web of Science, and specialized agricultural databases like the Indian Agricultural Research Institute (IARI) repository. Keywords like "earthworm castings", "vermicompost", "elemental composition", "soil health", "agricultural practices in India", and "ecosystem impacts" were used. Priority was given to research articles published within the last two decades to ensure relevance. However, seminal works predating this timeframe were also considered. Once a comprehensive list of articles was compiled, they were categorized based on themes such as elemental composition, agricultural practices, ecosystem health implications, and region-specific studies.

Earthworm Castings

Earthworms, since ancient times, have been highly regarded for their contributions to soil health. Aristotle aptly dubbed them as "the intestines of the earth," hinting at their profound ecological role. A significant aspect of their contribution lies in the production of earthworm castings. These castings, a direct result of earthworm's digestive processes, are laden with benefits that have fascinated researchers and agriculturists alike. Earthworm castings, also known as vermicast or worm manure, are essentially the excreted waste products of earthworms after they consume organic matter [15]. They are dark, nutrient-rich, granular, and odourless organic materials that have a peat-like texture, superior to the original organic waste consumed by the worms [16]. Several studies have shown that these castings are richer in nutrients, beneficial microbes, and enzymes than the soil the earthworms consume [17]. As a testament to their nutrient-rich composition, castings have been identified to contain higher concentrations of nitrogen (N), phosphorus (P), and potassium (K), making them a sought-after organic fertilizer in sustainable agriculture [18]. The magic behind the formation of these nutrient-dense castings lies in the earthworm's digestive system. The process is as intricate as it is fascinating. Ingestion: Earthworms consume organic matter, which includes decaying plants, microorganisms, and, to some extent, soil particles [19]. Digestion: As the ingested matter travels through the worm's digestive tract, it is subjected to enzymatic breakdown. The organic matter is degraded by enzymes and microbes present in the worm's gut [20]. Absorption: Earthworms absorb the simpler organic and inorganic molecules resulting from the digestion, which they use for growth and energy [21]. Excretion: The unabsorbed residues, now teeming with beneficial microbes and concentrated nutrients, are excreted as castings. This process of transforming ingested material into highly fertile castings is completed within 24 to 48 hours [22].

Comparison with Regular Soil

The superiority of earthworm castings to regular garden soil is stark and multifaceted:

1. **Nutrient Profile:** As mentioned, worm castings are enriched in primary nutrients like N, P, and K. Additionally, they contain essential micronutrients like calcium, magnesium, and sulfur in bioavailable forms [23]. This is in stark contrast to regular soil, which may lack these nutrients or have them in forms not readily accessible to plants.

2. **Microbial Activity:** Earthworm castings have a diverse and dense microbial community. These microbes facilitate quicker decomposition and mineralization of organic materials, making nutrients available to plants [24]. In contrast, regular soils may not possess as diverse or dense microbial populations.

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3. **Soil Structure:** Castings improve soil structure, leading to enhanced water retention and aeration [25]. In comparison, untreated garden soil may become compacted over time, reducing its ability to retain moisture and inhibit root growth.

4. **Disease Suppression:** Castings have been associated with disease-suppressing properties. The microbial community in castings can outcompete or inhibit pathogenic organisms, reducing plant diseases [26]. Regular soil may not have this intrinsic protection against pathogens.

5. **pH and Electrical Conductivity:** Worm castings generally have a neutral pH and lower electrical conductivity than regular soils, making them suitable for a variety of plants [27].

Elemental Composition of Earthworm Castings

Earthworm castings, colloquially referred to as 'black gold' by many horticulturists and soil scientists, are more than just simple worm excrement. Their unique elemental composition makes them an invaluable asset for enhancing soil health and fertility. With the move towards sustainable agriculture, understanding the intricate makeup of these castings becomes essential for modern-day farming and gardening. Earthworm castings are distinguished by a rich assembly of both macro and micronutrients, vital for plant growth and soil health. Nitrogen (N): Earthworm castings are a robust source of nitrogen, essential for plant protein synthesis and critical for vegetative growth [28]. Castings not only contain a higher total nitrogen content compared to regular soil but also are predominantly in the non-leachable form, reducing the risk of groundwater contamination [29]. Phosphorus (P): This nutrient, crucial for energy transfer in plants, is available in generous amounts in worm castings. Unlike synthetic fertilizers where phosphorus can often get 'locked up', the phosphorus in castings is highly soluble and readily available for plant uptake [30]. Potassium (K): Known to improve flower and fruit production in plants, potassium is another nutrient that earthworm castings are rich in. Studies have shown that plants grown in media enriched with worm castings show improved potassium uptake, enhancing their overall vigor and yield [31]. Beyond N, P, and K, earthworm castings also serve as a reservoir of several crucial micronutrients. These include: Calcium (Ca): Vital for cell wall formation, calcium is present in higher concentrations in worm castings than in regular soil, which can significantly benefit plants, especially tomatoes, preventing blossom end rot [32]. Magnesium (Mg): Playing a pivotal role in photosynthesis, magnesium is another micronutrient that earthworm castings are rich in. This not only boosts plant health but also improves the overall green hue of plants, making them more aesthetically appealing [33]. Sulfur (S): Critical for the production of amino acids and vitamins in plants, the sulfur content in worm castings is often higher than in regular garden soil, offering an added advantage to plants cultivated in casting-rich media [34].

Methods Used in the Analysis of Elemental Composition

Given the burgeoning interest in earthworm castings as a sustainable alternative to synthetic fertilizers, several analytical techniques have been developed to understand their elemental

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composition:

1. **X-ray Fluorescence (XRF)**: XRF is a non-destructive technique that has been successfully employed to determine the elemental composition of various soils and their respective additives, including earthworm castings [35]. This method relies on the principle of secondary (or fluorescent) X-ray emission from a material bombarded with high-energy X-rays or gamma rays.

2. **Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)**: A powerful tool for the detection of trace metals in soils, ICP-OES has been used to analyze the micronutrient content in earthworm castings, yielding insights into their beneficial effects on plant health [36].

3. **Total Nitrogen and Carbon Analysis**: Using a dry combustion method, the total nitrogen and carbon content of earthworm castings can be accurately determined. Instruments like the CHN analyzer combust the sample in an oxygen-rich environment and measure the gases produced, providing precise nitrogen and carbon values [37].

4. **Solubility Tests**: To understand the bioavailability of nutrients, solubility tests are often conducted. By treating castings with specific solutions, researchers can discern the fraction of nutrients that can be readily absorbed by plants [38].

Role of Earthworm Castings in Soil Fertility

Soil fertility is the linchpin that determines the productivity and health of an ecosystem. While there are numerous natural and artificial ways to enhance soil fertility, one of the most profound methods is harnessing the power of earthworm castings. These castings, often referred to as 'vermicompost,' are more than just worm excrement; they are the embodiment of nature's recycling system, turning waste into a resource teeming with life-enhancing properties. At the heart of earthworm castings' fertility-enhancing properties lies their capacity to release nutrients in forms that plants can easily assimilate. Earthworm castings contain a gamut of nutrients in chelated forms, which plants can absorb directly [39]. This swift uptake is crucial during the early stages of plant growth, where timely nutrition can significantly influence overall health and yield. The enzymatic activity within earthworms' gut facilitates the breakdown of organic matter, releasing nutrients like nitrogen, phosphorus, and potassium in more soluble forms, promoting efficient nutrient uptake [40]. With rising environmental concerns, the persistent use of synthetic fertilizers has been under scrutiny. Earthworm castings, rich in macro and micronutrients, can significantly reduce, if not entirely replace, the need for such fertilizers ([41]. Unlike synthetic alternatives, the nutrients from worm castings are released slowly, ensuring prolonged nutrient supply without the risks of leaching or groundwater contamination [42]. One of the less celebrated but equally vital benefits of earthworm castings is their ability to transform the physical properties of soil. Soil Aggregation: Earthworm castings play a pivotal role in soil aggregation. The mucilage secreted by earthworms during digestion helps bind soil particles together, creating stable aggregates. This not only improves water retention but also enhances

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resistance against erosion [43]. Aeration: Earthworms, as they move and burrow through the soil, create channels that facilitate aeration. This improved aeration ensures better root penetration, enhancing plants' access to nutrients and water [44]. Water Retention: The humic substances in earthworm castings boost the soil's capacity to retain water, providing an optimal environment for plant growth, especially in regions with limited rainfall [45]. Beyond nutrients and physical soil attributes, earthworm castings also teem with a rich array of beneficial microbial life. Diversity: The gut of earthworms is a melting pot of microbial activity. As organic matter passes through, it undergoes enzymatic and microbial transformations. The resultant castings are thus laden with diverse microbial communities, each playing a role in soil health [46]. Plant Growth-Promoting Rhizobacteria (PGPR): Earthworm castings are known to harbor PGPR, which enhance plant growth by solubilizing phosphorus, producing plant growth regulators, and suppressing soil-borne diseases [47]. Suppression of Pathogens: Studies have shown that earthworm castings can suppress the growth of certain plant pathogens, providing a natural line of defense against diseases [48].

Earthworm Castings and Ecosystem Health

In the context of an ever-changing global environment, the role of earthworm castings as a significant contributor to ecosystem health cannot be understated. Earthworm castings, often hailed as nature's vermicompost, offer a plethora of benefits that enhance ecosystem health, ranging from promoting plant growth to mitigating the adverse effects of climate change. This paper delves into the multifaceted impacts of earthworm castings on ecosystems. The cornerstone of any thriving ecosystem is robust plant growth. Here's how earthworm castings contribute to this essential facet: Nutrient-Rich Composition: Earthworm castings are a powerhouse of nutrients. Unlike conventional compost, these castings contain nutrients in bioavailable forms that plants can readily absorb, resulting in faster and healthier growth [49]. Plant Growth Regulators: Castings are known to contain auxins and cytokinins, two vital plant growth regulators. These compounds stimulate root growth and promote cell division, respectively, leading to enhanced plant vigor and yield [50]. Disease Suppression: Vermicompost, by fostering a diverse microbial community, plays a vital role in suppressing soil-borne diseases. This ensures that plants remain healthy and can achieve their maximum yield potential [51].

Improvement in Soil Water Retention and Drought Resistance

Water, the lifeblood of ecosystems, and its effective management can determine the health of an ecosystem. Structure and Porosity: Earthworm castings contribute to the formation of well-defined soil aggregates, which in turn increase the soil's porosity. This enhanced porosity aids in water retention, ensuring a consistent water supply to plants [52]. Drought Resistance: By improving the water-holding capacity of soils, earthworm castings indirectly boost an ecosystem's resilience to drought. Plants rooted in such soils are less susceptible to water stress, ensuring sustained growth even in arid conditions [53].

Reduction in Soil Erosion and Compaction

The structural integrity of soil is essential to prevent the degradation of ecosystems. Earthworm

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castings play a pivotal role in maintaining this integrity: Soil Aggregation: The mucilage produced by earthworms during digestion acts as a binding agent, promoting soil aggregation. Stable aggregates are less prone to erosion, ensuring that the soil remains in place, nurturing plants and supporting myriad life forms [54] Soil Aeration: The burrowing activity of earthworms, coupled with the porous nature of their castings, helps alleviate soil compaction. Compaction is a major concern in agricultural landscapes as it hinders root penetration and water infiltration. By mitigating compaction, earthworm castings ensure a conducive environment for plant growth [55]. In the face of escalating climate change concerns, the role of soils as carbon sinks has gained paramount importance. Earthworm castings play a crucial role in this regard: Organic Matter Decomposition: Earthworms expedite the decomposition of organic matter. The processed organic residues in the castings are more resistant to decomposition, leading to increased carbon storage in soils [56]. Enhanced Microbial Activity: The rich microbial diversity in earthworm castings contributes to the formation of stable soil organic matter. This stabilization process is a pivotal component of carbon sequestration, turning soils into effective carbon sinks [57].

Benefits of Elemental Composition in Earthworm Castings to the Ecosystem

The elemental composition of earthworm castings has a profound impact on ecosystem health and productivity. Through the elements and compounds they contain, earthworm castings significantly contribute to the vitality of the soil, health of plants, and overall stability of the environment. In this paper, the manifold benefits of the elemental composition in earthworm castings will be examined. One of the fundamental processes ensuring the continued fertility and health of ecosystems is nutrient cycling. Earthworm castings play a pivotal role in this regard. Efficient Decomposers: Earthworms act as biological decomposers, breaking down organic matter and returning essential nutrients back to the soil in bioavailable forms [58]. Their castings are enriched with a myriad of elements like nitrogen, phosphorus, potassium, and many others that are readily available for plant uptake. Enhanced Soil Fertility: The nutrients present in the castings do not leach easily, making them available for extended periods and reducing the need for external fertilizers. This ensures sustainable fertility of soils without depleting the natural resource base [59]. Earthworm castings, due to their unique elemental composition, serve as a buffer against pollution. Heavy Metal Chelation: Earthworm castings have a significant amount of humic and fulvic acids. These organic acids can bind to heavy metals, effectively immobilizing them and preventing them from entering the water supply or being taken up by plants [60]. Reduced Leaching: Nutrients like nitrogen and phosphorus can contribute to water pollution when they leach into waterways, causing issues like eutrophication. However, the form in which these nutrients are present in earthworm castings reduces their mobility and leaching potential [61]. Organic farming, a sustainable agricultural practice, gains immensely from the elemental composition of earthworm castings. Natural Fertilizer: Earthworm castings provide a balanced dose of nutrients to crops without the need for synthetic fertilizers, aligning perfectly with the principles of organic farming [62]. Soil Health and Texture: Organic farming thrives on healthy soils. Earthworm castings, rich in both macro and micro-elements, improve soil texture, structure, and overall health. This, in turn, ensures better root growth and crop yield [63]. The elements present in earthworm castings have an indirect yet profound influence on plant health in

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terms of pest and disease resistance. Strengthening Plant Defense Mechanisms: The presence of certain elements in the castings triggers plants' innate defense mechanisms. For instance, the increased availability of silicon from castings has been linked to enhanced resistance against pest attacks [64]. Suppressing Pathogens: Earthworm castings are known to harbor beneficial microorganisms that can outcompete or inhibit the growth of plant pathogens. This microbial activity, in tandem with the elemental composition, plays a crucial role in disease suppression [65].

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Potential Limitations and Concerns of Earthworm Castings

The profound benefits of earthworm castings in improving soil health and promoting sustainable agriculture have been widely recognized. However, like any biological system, it's imperative to understand its potential limitations and concerns. This section will delve into the variability in elemental composition based on worm species and diet, the risk of harmful element accumulation, and the repercussions on native earthworm populations and interspecies competition. Earthworms are not a homogenous group. With over 3,000 described species, their biology, ecology, and behavior are diverse [66]. This diversity inherently affects the elemental composition of their castings. Species-Dependent Variations: Different earthworm species have distinct gut microbiomes and digestive processes, which can influence the elemental composition of the castings. For example, *Lumbricus terrestris* and *Eisenia fetida*, two commonly studied species, exhibit differences in nutrient cycling capabilities [67]. Dietary Influence: The elemental composition of castings is directly influenced by the earthworm's diet. A diet rich in organic matter like decomposing leaves will result in castings with different elemental profiles compared to a diet primarily composed of soil [68]. This variability can pose challenges in standardizing the benefits of earthworm castings, especially in commercial applications.

Possible Accumulation of Harmful Elements or Toxins

The incredible ability of earthworms to process soil and organic matter is a double-edged sword. While they can enhance soil fertility, there's also a risk of concentrating harmful elements or toxins. Heavy Metal Concentration: Earthworms, particularly those in contaminated soils, can accumulate heavy metals in their tissues and castings. Although they can immobilize some of these metals, as previously discussed, there is still a risk of elevated levels of metals like cadmium, lead, or arsenic in the castings [69]. Organic Pollutants: In soils contaminated with organic pollutants, such as certain pesticides or polycyclic aromatic hydrocarbons (PAHs), there's potential for these compounds to concentrate in the castings. This can have deleterious effects on plants and the broader ecosystem. Impact on Native Earthworm Populations and Species Competition. The introduction or augmentation of certain earthworm species, especially in regions where they are not native, can pose ecological concerns. Disturbance of Native Populations: The introduction of non-native earthworm species can disrupt soil ecosystems. For instance, in certain North American forests, invasive European earthworm species have altered the soil structure, impacting native plants and animals [70]. Species Competition: Introduced earthworm species might outcompete or prey on native species, leading to a reduction in native earthworm biodiversity. This can have cascading effects on the ecosystem, as different earthworm species play varied ecological roles [71].

Future Directions and Research Gaps

India, with its multifaceted agricultural landscapes and rapidly urbanizing centers, has begun to prioritize sustainable farming and ecosystem health. While the benefits of earthworm castings are being increasingly realized, several questions and research gaps persist. Addressing these can pave the way for maximizing the potential of this organic resource. This section delineates areas of interest for future research, specifically in the Indian context. India boasts an array of soil types, ranging from the alluvial soils of the Gangetic plains to the lateritic soils of the plateau region [72]. Given this diversity, there is a pressing need for standardized methods to analyze the elemental composition of earthworm castings derived from these different soils. This would ensure a uniform benchmark against which the quality and nutrient value of the castings can be gauged. While traditional methods of analyzing elemental composition have served well, the integration of advanced technologies, such as spectroscopy and chromatography, can yield more accurate and detailed results [73]. Establishing region-specific research centers equipped with modern facilities can aid in analyzing local earthworm casting samples. Additionally, training farmers and local agronomists in sampling techniques and basic analysis can democratize knowledge [74]. India is home to numerous indigenous and exotic earthworm species. Researching how different species process organic matter and the resultant casting compositions can provide invaluable insights [75]. A relatively uncharted area is the potential benefits (or drawbacks) of mixed-species vermicomposting. For instance, what happens when tropical species like Perionyx excavatus co-exist with the widely used Eisenia fetida? Such interactions can influence the casting's quality [76]. Indian agro-residues, like rice straw in West Bengal or sugarcane bagasse in Maharashtra, may affect casting composition when used as feedstock for earthworms. Analyzing this can help in optimizing earthworm diets for desired casting compositions [77].

Conclusion

Earthworm castings, enriched with a unique elemental composition, are pivotal for India's agricultural progression. These organic fertilizers, abundant in both macro (N, P, K) and micronutrients (Ca, Mg), have transformative potential for soil fertility, reducing the dependency on synthetic fertilizers. They also rejuvenate soil structure, facilitating healthier microbial communities, enhanced water retention, and erosion prevention. Critical in the face of India's climate challenges, these benefits have overarching implications for ecosystem resilience and sustainable farming. Moreover, the castings prove instrumental in ecosystem restoration and urban agriculture. Nonetheless, while their benefits are manifold, the review emphasizes the pressing need for in-depth research, especially concerning species-specific variations and long-term ecosystem impacts. In essence, earthworm castings, through their elemental richness, emerge as indispensable allies in the pursuit of sustainable and resilient agricultural practices in India.

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