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Editorial

Soil Remediation and Improvement Through the Application of By-Product Amendments, 2nd Edition

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Modern society is currently facing two pressing environmental crises: the systemic loss of fertile, healthy soil due to various forms of degradation and the escalating generation of diverse waste streams. These phenomena are intrinsically linked to the intensification of global warming and the acceleration of anthropogenic climate change; however, ongoing research increasingly supports Nature-Based Solutions (NBSs) as an effective framework for addressing these challenges [1,2]. By adopting a circular economy approach [3], by-products that are traditionally viewed as environmental burdens in one sector can be repurposed as valuable resources in another, providing cost-effective strategies that not only restore soil health but also play a critical role in carbon sequestration and the global effort to mitigate climatic instability [4,5].

This second edition of the Special Issue brings together nine contributions that address these challenges from complementary perspectives, including residual nutrient use in crop rotations, vermicompost and vermicompost tea as organic fertilizers, biochar-based soil restoration, organic amendments in vineyards, valorization of sewage sludge and pruning residues, agro-industrial waste-derived circular fertilizers, and soil amendments for improving crop performance under water limitation. Collectively, these studies show that sustainable soil management cannot be based on a single amendment or agronomic practice. Rather, it requires the integration of organic residues, carbon-rich materials, biological processes, crop-specific responses, and rigorous monitoring of soil and plant indicators.

A coherent reading of the contributions included in this Special Issue shows that the value of circular amendments does not lie only in replacing synthetic fertilizers, but in reshaping the soil–plant system through residual fertility, biological activation, carbon stabilization, improved crop quality, and stress mitigation. The two studies by Oyege and Balaji Bhaskar provide an appropriate starting point because they demonstrate that vermicompost-derived nutrients may remain agronomically relevant beyond the crop to which they are initially applied. In a strawberry–corn double cropping system, moderate vermicompost application improved strawberry yield, biomass accumulation, and fruit quality without additional fertilization during the strawberry phase (Contribution 1). In a complementary corn–soybean rotation, residual vermicompost and vermicompost tea inputs enhanced soybean biomass, yield, chlorophyll status, stomatal conductance, and nutrient uptake (Contribution 2). These findings shift the interpretation of organic amendments from short-term nutrient sources to residual fertility tools capable of supporting rotational sustainability.

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However, these same studies also introduce one of the central messages of this Special Issue: circular amendments are not automatically beneficial merely because they are organic. In the strawberry system, excessive vermicompost rates, particularly when associated with elevated sodium content, reduced plant vigor and marketable yield. Similarly, the soybean study showed that positive responses depended on balanced amendment combinations rather than maximal input application. This dose-dependent behavior connects directly with the broader evidence presented throughout the issue: the agronomic performance of waste-derived materials depends on feedstock composition, maturity, salinity, nutrient ratios, crop sensitivity, soil properties, and water availability. Therefore, circularity must be accompanied by characterization, calibration, and agronomic control.

This transition from nutrient supply to plant functional response is further developed by Rehman et al., who investigated the effect of vermicompost tea on the metabolic profile of *Diplotaxis muralis* using NMR spectroscopy (Contribution 3). Their work shows that liquid organic amendments can modify not only growth-related parameters but also the accumulation of amino acids, organic acids, flavonoids, glucosinolates, and phenolic compounds. This is a relevant conceptual advance because sustainable fertilization is frequently evaluated through yield alone, whereas crop nutritional quality and secondary metabolism are often treated as secondary outcomes. In this context, vermicompost tea emerges not only as a nutrient input, but also as a biological modulator of crop quality.

The same need to move beyond a purely fertilizing perspective is evident in the studies focused on carbon-rich amendments. Tang provides a mechanistic framework by reviewing how biochar can influence soil restoration through nutrient retention, reduced leaching, carbon, nitrogen and phosphorus cycling, enzymatic activity, and microbial community dynamics (Contribution 4). Nonetheless, this review also clarifies that biochar is not a uniform product: its behavior depends on feedstock, pyrolysis conditions, pH, surface chemistry, soil mineralogy, and microbial context. This point aligns with the evidence from the vermicompost studies: the effectiveness of a circular amendment is determined not only by its origin but by its physicochemical identity and interaction with the receiving soil.

The field relevance of this principle is illustrated by Pierini et al., who evaluated straw mulch and straw mulch combined with biochar in vineyards of the Alentejo wine region (Contribution 5). Their results show that organic amendments interacted with cultivar and topographic position to influence grape chemical composition, phenolic parameters, and color-related traits. This contribution is particularly valuable because it places soil amendment research in a high-value perennial system, where soil protection, water regulation, topography, and fruit quality are inseparable. In this manner, soil restoration is connected with not only edaphic recovery but also the quality of the final agricultural product.

The circular use of vineyard and agro-industrial residues is further expanded through two complementary technological routes. Nascimento-Gonçalves et al. assessed vermicompost and leachate produced from sewage sludge and vineyard pruning residues using cucumber germination and early seedling growth as bioassays (Contribution 6). Their results showed pathogen-free products, metal concentrations below regulatory limits, and high germination rates under the tested conditions, while also confirming that higher vermicompost doses did not necessarily improve seedling performance. Díaz-Rasero et al., in contrast, transformed vineyard stumps into hydrochars and pyrochars, with and without iron addition, showing that hydrothermal carbonization and pyrolysis generate materials with distinct structural and chemical properties (Contribution 7). Their preliminary grapevine tolerance screening did not reveal evident phytotoxic effects based on chlorophyll index measurements. Together, these studies show two complementary routes for residue valorization: biological stabilization through vermicomposting and thermochemi-

cal conversion into carbonaceous materials. Both routes are promising, but both require safety assessment, phytotoxicity screening, and long-term soil–plant validation.

This functional differentiation among circular products is also central to the study by Maffia et al., who evaluated fertilizers derived from olive pomace, citrus residues, wood sawdust, straw, and sulfur-bentonite enrichment (Contribution 8). Their findings indicate that vermicompost-based formulations enhanced total organic carbon, total nitrogen, microbial biomass carbon, and enzymatic activities, whereas compost-based formulations contributed more strongly to organic matter accumulation and longer-term soil resilience. This distinction is important because it suggests that circular fertilizers should be classified not only by origin but also by function. Vermicompost may be more suitable when rapid biological activation and nutrient cycling are desired, compost may be more appropriate for building persistent organic matter and structural stability, and mineral-enriched formulations may target specific nutrient or soil constraints.

The final contribution, by Kruspe and Koyro, extends the discussion from fertility and soil restoration to climatic stress adaptation. By examining biochar and superabsorbent polymers under contrasting soil water contents in *Chenopodium quinoa*, they showed that amendments can modify plant water-use efficiency, photosynthetic regulation, oxidative stress responses, lipid peroxidation, and proline accumulation (Contribution 9). Their results are particularly relevant because future soil management will have to address not only nutrient depletion and organic matter decline but also drought frequency, irregular rainfall, and reduced irrigation reliability. In this regard, amendment performance must be interpreted through plant physiological responses, not only through soil chemical properties.

Taken together, these studies present a holistic view of circular soil management. Vermicompost and vermicompost tea contribute to residual fertility, microbial activation, nutrient uptake, and crop quality; biochar and related carbonaceous materials offer opportunities for nutrient retention, carbon stabilization, microbial habitat formation, and water regulation; and composted or vermicomposted agro-industrial residues provide practical pathways for recycling organic waste into agronomically useful products. Across these contributions, the same principle emerges repeatedly: circular amendments are most effective when they are selected and applied according to their function, chemical composition, receiving soil, target crop, and environmental constraint.

This integrated perspective also identifies the main knowledge gaps that remain. Long-term field studies are still needed to determine whether short-term improvements in plant performance, microbial activity, nutrient availability, and crop quality translate into durable soil carbon accumulation, stable productivity, and measurable climate mitigation. More attention should also be paid to feedstock variability, salinity, heavy metals, maturity indices, nutrient release kinetics, and potential organic contaminants. The evidence assembled in this Special Issue shows that Nature-Based Solutions and circular economy approaches are scientifically robust and agronomically promising, but their implementation must move from generalized application toward precision management. The future of circular soil restoration will depend not on applying more residues, but on applying better-characterized amendments in the right dose, at the right time, and for the right soil–crop system.

In conclusion, this Special Issue shows that Nature-Based Solutions and circular economy strategies are becoming operational tools for restoring degraded soils, recycling organic residues, reducing dependence on synthetic inputs, improving crop quality, and strengthening plant resilience under climatic stress. Organic residues and carbon-rich amendments can substantially contribute to sustainable agriculture, but their success depends on rigorous characterization, appropriate dosing, site-specific management, and long-term validation. By bringing together field trials, mechanistic review, physiological

analysis, metabolomics, residue valorization, and microbiological assessment, this second edition provides a coherent and timely contribution to the development of circular, climate-resilient, and biologically functional agricultural systems.

Conflicts of Interest: The authors declare no conflicts of interest.

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