rabbit genetics

Rabbit manure as a feedstock for substrate (soil surrogate) production: recent advances and applications

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Abstract. Rabbit manure is an emerging sustainable feedstock for horticultural substrates and soil surrogates due to its high organic matter, lignocellulosic content, and low heavy metal levels. This minireview summarizes recent advances in stabilizing, processing, and formulating rabbit manure-based materials as peat substitutes or components of engineered growing media. Conventional thermophilic composting, vermicomposting, and insect-assisted biodegradation improve substrate maturity, structural stability, nutrient availability, and reduce phytotoxicity. Emerging thermochemical methods, including pyrolysis and hydrothermal carbonization, produce biochar and hydrochar with soil-conditioning and slow-release fertilization properties. Experimental studies show that composted rabbit manure can partially or fully replace peat while maintaining or enhancing seedling emergence, growth, and nutrient uptake in horticultural crops. When applied to degraded soils, manure-derived substrates enhance microbial activity, enzyme function, and nutrient cycling. Integration with liquid organic fertilizers (LOFs) from rabbit excreta supports closed-loop nutrient management. Environmentally, valorizing rabbit manure reduces waste accumulation, lowers greenhouse gas emissions linked to peat extraction, and promotes circular bioeconomy strategies. Further research is needed to standardize processing protocols, optimize peat-free formulations, and assess long-term agronomic and environmental impacts. Overall, rabbit manure represents a versatile, sustainable, and increasingly viable resource for high-quality substrate production and soil restoration.

Key Words: rabbit manure, horticultural substrates, peat substitute, composting, vermicomposting, biochar, hydrochar, soil surrogate, growing media, circular agriculture, waste valorization, soil restoration.

Purpose of the study. This minireview aims to critically evaluate recent scientific advances regarding the use of rabbit manure as a feedstock for the production of horticultural substrates and soil surrogates, with emphasis on processing technologies, substrate formulation, agronomic performance, environmental implications, and future research needs.

Properties of rabbit manure relevant to substrate production. Rabbit manure is characterized by relatively low moisture, high organic matter and lignocellulosic content, and comparatively low heavy metal concentrations, which makes it an attractive raw material for horticultural substrates and soil amendments. Detailed characterization of different types of rabbit manure derived from rabbits at distinct production stages shows hemicellulose contents around 22-24% of dry matter, cellulose about 26-28%, and lignin approximately 16-17%, providing a structurally stable organic matrix after composting (Li et al 2022a). Heavy metals such as Cd, Pb, Cr, and others in raw rabbit manure are far below regulatory thresholds for growing media, indicating a low toxicological risk when used as a substrate component (Li et al 2022a, b). Chemical analyses of rabbit manure compost (RMC) typically reveal moderately acidic to near-neutral pH (around 5.8-7), high organic matter content (> 20%), substantial levels of macronutrients such as nitrogen (N), phosphorus (P), and potassium (K), collectively referred to as NPK, Ca, and Mg, and adequate micronutrients (Cu, Zn, Mn, Fe) for plant growth (da Silva Pereira et al 2020; Bastos et al 2022). These characteristics support both a fertilizing effect and improved physical structure when incorporated into substrates or degraded soils.

Composting and stabilization processes. Producing a safe, agronomically effective substrate from rabbit manure requires appropriate stabilization to reduce phytotoxicity, pathogens, and odors while improving physical properties. Conventional thermophilic composting of rabbit manure, either alone or mixed with bulking agents, can sustain temperatures above 50°C for more than seven days and achieve germination indices over 70%, criteria commonly used to indicate hygienization and maturity suitable for horticultural use (Li et al 2022a, b). Composting reduces readily degradable organic fractions, lowers electrical conductivity, which can otherwise limit seedling growth at high manure incorporation rates, and improves porosity and water-air balance in the final substrate (Li et al 2022a, b). Alternative biological stabilization pathways have been tested. Vermicomposting with *Eisenia fetida* transforms rabbit manure into a fine-grained, microbially active substrate with favorable nutrient availability and improved physical structure; in lettuce seedling production, vermicomposted rabbit manure or manure processed by saprophagous beetle larvae (*Cetoniinae*) produced substrates of sufficient quality to be recommended for commercial use, with adequate pH, porosity, and nutrient availability throughout 28 days of seedling development (da Silva Pereira et al 2020).

Natural composting without macroinvertebrates can also yield usable substrates, but often with less uniform structure and nutrient release, highlighting the advantages of managed biological processing (da Silva Pereira et al 2020). Technological innovations extend beyond conventional composting. Microwave-assisted hydrothermal carbonization of rabbit manure produces a nutrient-enriched hydrochar with increased fixed carbon and total phosphorus content as severity rises, providing a potential slow-release soil conditioner or component of engineered substrates; low application rates of such hydrochar showed phytostimulatory effects in germination assays, although associated process water can remain phytotoxic and requires careful management (Moukazis & Gidarakos 2025). Production of rabbit manure-derived biochar at relatively low pyrolysis temperatures (around 300°C) and its combination with raw manure have also been shown to markedly increase enzyme activity indices and microbial biomass in degraded mining soils, indicating strong potential for use in remediation substrates (Cárdenas-Aguiar et al 2022).

Table 1 summarizes the main rabbit manure processing methods described in this review, along with their stabilization effects and substrate-related benefits.

Table 1

Comparative properties and benefits of rabbit manure processing methods

Processing method	*Main objective / Transformation*	*Effects on substrate*	*Key advantages*	*Limitations / Notes*
Thermophilic composting	Stabilization, hygienization	Reduces phytotoxicity, improves physical structure, lowers EC, increases porosity	Mature, safe compost; supports seedling growth	Needs proper aeration and bulking agents
Vermicomposting (*Eisenia fetida*)	Biological stabilization	Produces fine-grained, microbially active substrate; good nutrient availability	Improved nutrient release and structure; suitable for lettuce seedlings	Requires earthworms, management over 28 days
Insect-assisted composting (saprophagous beetle larvae)	Biological stabilization	Generates uniform substrate with adequate pH, porosity, and nutrients	Can replace part of peat in growing media	Less common; requires insect rearing and management
Hydrothermal carbonization (microwave-assisted)	Thermochemical treatment	Produces hydrochar enriched in nutrients, higher fixed C and P	Slow-release nutrient source, soil conditioner; phytostimulatory at low application	Process water can be phytotoxic; requires careful handling
Biochar production (low-temperature pyrolysis ~300°C)	Thermochemical treatment	Increases enzyme activity, microbial biomass in degraded soils	Soil restoration potential, improves substrate structure	Energy input required; requires blending with soil or manure

Formulation of rabbit manure-based growing media. A major line of recent research addresses how composted rabbit manure can partially or fully substitute peat and commercial substrates in seedling production. In controlled experiments with cabbage, RMCs produced from different diets were mixed with peat, perlite, and vermiculite to create compound growing media. Physical and chemical properties of these mixes, including total porosity, air space, water-holding capacity, bulk density, pH, electrical conductivity, and nutrient content, were characterized and compared with peat-based controls. Seedling emergence above 90%, increased air space (from about 16% up to nearly 29%), and improved root length, shoot height, and chlorophyll content indicated that composted rabbit manure could effectively replace a substantial fraction of peat. The best performance for cabbage seedlings was obtained at a ratio of composted rabbit manure, peat, perlite, and vermiculite of 3:3:2:2 by volume, although further optimization was suggested, particularly regarding salinity for sensitive crops (Li et al 2022a). A follow-up optimization using calendula (salt-tolerant) and cucumber (salt-sensitive) systematically varied the proportion of RMC replacing peat, within mixes that also contained perlite and vermiculite. Across a broad range of total porosity (5-61%) and organic matter (8-40%), rabbit manure compound media supported seedling emergence rates comparable to pure peat (> 90%), while significantly increasing aboveground nutrient content. Phosphorus and magnesium in shoots were raised by 31-141% and 80-108%, respectively for calendula, and by 83-117% and 35-68% for cucumber relative to peat-only media, demonstrating both fertilization and peat-saving potential. Optimal RMC proportions of roughly 30-50% (equivalent to replacing 60-100% of peat) were identified as a practical range for many species (Li et al 2022b). Similar results have been obtained in leafy vegetables such as lettuce, where RMC mixed with a commercial substrate (pine bark, ash, vermiculite, sawdust) at varying rates from 0 to 100% was assessed. Lettuce seedling performance, measured by number of leaves, shoot and root fresh and dry mass, increased with RMC proportion up to about 45-60%, depending on the trait, and then declined at higher proportions, consistent with constraints from salinity and excessive nutrients. Substrate mixtures near 60% RMC generally yielded the best balance among vegetative growth parameters and thus are recommended for substrate formulation in lettuce seedling nurseries (Bastos et al 2022). Rabbit manure substrates processed by vermicomposting or insect-based composting have also been shown to perform well for lettuce seedlings in terms of emergence and root and shoot development, with electrical conductivity and pH remaining within acceptable ranges during 28 days of growth (da Silva Pereira et al 2020). Collectively, these studies indicate that fully or partially peat-free substrates based on stabilized rabbit manure can match or exceed the performance of conventional horticultural media when carefully formulated.

Solid substrates, nursery blocks, and engineered forms. Beyond loose potting mixes, RMC has been incorporated into pressed nursery blocks designed to improve transplanting efficiency and survival. In one study, RMC was combined with vermiculite, rice straw, and peat and subjected to cold pressing under different moisture contents (25-45%), binder (starch) contents (1-5%), molding compression ratios (2.5-4.5:1), and strain maintenance times (0-120 s). The resulting blocks were evaluated for ventilation porosity, relaxed bulk density, compressive resistance, and specific energy consumption. Significant interaction effects between compression ratio and moisture, moisture and binder content, and binder content and strain maintenance time were detected, revealing that the mechanical properties of blocks depend on a finely tuned integration of process parameters. Optimal conditions of a 4:1 compression ratio, 33.5% moisture, 3.1% binder, and 60 s strain maintenance produced blocks with a relaxed density of about 363 kg m^{-3}, ventilation porosity near 19%, and low specific energy consumption (~0.44 J g^{-1}), while still providing satisfactory seedling emergence performance (Li et al 2022c). This line of research demonstrates that rabbit manure-based materials can be engineered into structurally stable, mechanically robust substrates suitable for mechanized transplanting, expanding their application beyond conventional pot culture.

Soil surrogate and soil-quality improvement functions. When used as a component of soil surrogates or as an amendment to degraded soils, rabbit manure-derived materials can substantially improve physical, chemical, and biological properties. Field and mesocosm studies in mining tailings amended with rabbit manure and rabbit manure biochar have shown that these amendments induce large increases in key enzyme activities (dehydrogenase, phosphomonoesterase, β-glucosidase) and in the geometric mean of enzyme activities, used as an integrative soil-quality index, by up to 217-360-fold for rabbit manure alone and 81-270-fold for manure-biochar mixtures. Microbial biomass also increases markedly, reflecting enhanced organic substrate availability and improved habitat conditions (Cárdenas-Aguiar et al 2022). Such improvements are critical for restoring nutrient cycling and supporting vegetation establishment in severely degraded substrates. Historically, rabbit (*Oryctolagus cuniculus*) latrines in semi-arid Spain have been shown to function as natural "fertility hotspots" with elevated concentrations of organic carbon, ammonium, nitrate, potassium, phosphorus, and magnesium relative to surrounding soils, leading to increased biomass and altered root-to-shoot allocation in test plants such as barley (Willott et al 2000). Although not a manufactured substrate, this ecological evidence underscores the capacity of rabbit excreta to generate localized soil surrogates that support plant establishment in nutrient-poor environments. Biochar and hydrochar derived from rabbit manure further expand the range of soil-conditioning options. Low-temperature biochars contribute to improved soil enzyme activity and may support carbon sequestration, while hydrochars from hydrothermal carbonization concentrate phosphorus and fixed carbon, offering slow-release nutrient sources and structural amendments for substrates and degraded soils (Cárdenas-Aguiar et al 2022; Moukazis & Gidarakos 2025). In each case, dilution with mineral soil or inert components and careful control of application rates are essential to avoid salinity and phytotoxic effects.

Liquid organic fertilizers and integrated substrate-fertility systems. Although the primary focus for soil surrogate production is on solid substrates, liquid organic fertilizers (LOFs). Derived from rabbit excreta can complement substrate-based systems. LOFs prepared from rabbit urine and feces have been shown to improve soil pH, available phosphorus, and exchangeable potassium, and to support maize growth and yield comparable to mineral NPK fertilization in field experiments, while enhancing nutrient uptake and overall soil conditions (Azeez et al 2025). Fermented rabbit urine processed with bioactivators over at least 14 days produces a nitrogen-, phosphorus-, and potassium-rich fertilizer that has increased horticultural crop growth by 25-30% relative to untreated controls in on-farm trials, while also generating profitable small-scale enterprises (Moeis et al 2025). Integration of such liquid fertilizers with rabbit manure-based substrates could create closed-loop nutrient management systems that recycle all solid and liquid wastes into agronomically valuable products, especially in smallholder and peri-urban contexts. Furthermore, combining rabbit urine with household organic waste to produce LOF has been proposed as a strategy to buffer farm households against fertilizer price shocks, with economic analyses indicating substantial variable cost savings and attractive benefit-cost ratios for rice cultivation (Ferichani 2024).

Environmental performance and emission considerations. Producing soil surrogates from rabbit manure contributes to waste valorization and can mitigate environmental impacts associated with both intensive rabbit production and peat extraction. Life-cycle-oriented analyses of RMC used to replace peat in horticultural growing media in China estimated greenhouse gas emission reduction potentials on the order of 3.65×10^2 to 4.06×10^2 kg CO_2 equivalent year^{-1} at national scales, primarily by avoiding peat mining and improving waste management (Li et al 2022b). However, raw rabbit manure handling and storage are significant sources of ammonia and greenhouse gases. Controlled experiments have shown that rabbit manure contains around 30% of the feed's organic matter and about 65% of its nitrogen, and that cumulative nitrogen losses during storage and simulated land application can reach 32% of excreted nitrogen as ammonia and 2% as nitrous oxide, while about half of the organic matter can be mineralized to carbon dioxide. Manure incorporation into soil surfaces effectively reduces ammonia emissions but may increase nitrous oxide fluxes, emphasizing the need for optimized management strategies (Dinuccio et al 2019). Composting and conversion into stable substrates, biochar or hydrochar, can reduce readily volatilizable nitrogen forms and labile carbon pools, potentially decreasing gaseous emissions during storage and after application, but this requires site-specific quantification. From a resource-use perspective, substituting rabbit-manure-based substrates for peat and partially replacing synthetic fertilizers with rabbit-derived products contributes to circular agriculture and aligns with sustainable development goals relating to climate action, responsible consumption, and soil health (Li et al 2022b; Wirajaya et al 2023; Mahardika et al 2025; Moeis et al 2025).

Technological and socio-economic aspects of substrate production. The transition from raw manure to marketable substrate products involves technological, organizational, and socio-economic dimensions. Community-based programs in Indonesia and Bali have demonstrated that training rabbit farmers to compost manure into solid organic fertilizer (SOF) and LOF can transform a waste management challenge into a revenue-generating activity. Such initiatives provide knowledge transfer on composting techniques, fermentation, drying, packaging, labeling, and basic quality control, enabling farmer groups to produce standardized products suitable for local horticultural markets (Nurhidayati & Basit 2020; Wirajaya et al 2023). Adoption of simple mechanization and digital control, such as conveyor-based collection systems for rabbit droppings operated via smartphone-linked microcontrollers, can improve efficiency and hygiene in manure collection and compost handling, facilitating upscaling of substrate production in larger enterprises (Sulasmoro & Maulana 2024). These technological and organizational advances are crucial for consistent substrate quality, traceability, and economic viability. At the same time, the composition of the substrate feedstock is influenced by rabbit nutrition; scoping reviews of agroindustrial by-products as alternative feeds for rabbits highlight opportunities to adjust manure nutrient profiles and lignocellulosic content through diet formulation, which in turn may tailor manure properties for specific substrate applications (Jones et al 2024).

Future directions and research needs. Despite substantial progress, several key research needs remain for the optimal use of rabbit manure as a soil surrogate feedstock. First, more standardized protocols are required to link composting and stabilization conditions with final substrate properties across a wider range of crops, including long-term effects on root system architecture, disease suppression, and microbiome assembly (da Silva Pereira et al 2020; Li et al 2022a, b). Second, the environmental trade-offs of different processing routes (simple composting, vermicomposting, biochar production, hydrothermal carbonization, liquid fertilizer fermentation) should be compared through robust life-cycle assessments that consider emissions, energy use, and nutrient recovery (Dinuccio et al 2019; Cárdenas-Aguiar et al 2022; Moukazis & Gidarakos 2025). Third, there is a need to refine formulation strategies for entirely peat-free substrates, particularly for salt-sensitive species, integrating mineral and inert components to balance physical structure and nutrient supply (da Silva Pereira et al 2020; Bastos et al 2022; Li et al 2022b). Finally, socio-economic studies should further examine adoption barriers and incentives for farmers and small enterprises, including market acceptance of manure-derived substrates, regulatory frameworks for organic growing media, and integration into circular bioeconomy models (Nurhidayati & Basit 2020; Wirajaya et al 2023; Ferichani 2024; Moeis et al 2025). Addressing these questions will consolidate rabbit manure's role as a versatile, sustainable resource for producing high-quality substrates and soil surrogates.

Conclusions. Rabbit manure represents a highly suitable raw material for the production of horticultural substrates and soil surrogates due to its balanced nutrient composition, high organic matter content, structural lignocellulosic matrix, and low levels of toxic contaminants. Stabilization processes such as thermophilic composting, vermicomposting, and insect-assisted biodegradation effectively improve substrate maturity, reduce phytotoxicity, and enhance physical and chemical properties essential for plant growth. Advanced thermochemical treatments, including pyrolysis and hydrothermal carbonization, further expand the functional potential of rabbit manure by producing biochar and hydrochar with beneficial effects on soil quality, nutrient retention, and carbon sequestration.

Experimental evidence consistently demonstrates that composted rabbit manure can partially or completely replace peat in growing media, maintaining or improving seedling emergence, growth performance, and nutrient uptake across multiple horticultural species. Proper formulation and dilution with inert components are essential to optimize porosity, water retention, and electrical conductivity, particularly for salt-sensitive crops. Beyond horticultural applications, rabbit manure-derived substrates significantly improve the biological, chemical, and physical properties of degraded soils, supporting microbial activity, enzyme function, and ecosystem recovery.

From an environmental standpoint, the valorization of rabbit manure into substrate products contributes to waste recycling, reduces greenhouse gas emissions associated with peat extraction and manure mismanagement, and supports circular bioeconomy principles. Technological and organizational innovations, including improved composting systems and farmer-level processing initiatives, enhance the feasibility of large-scale implementation.

Future research should focus on standardizing processing protocols, optimizing peat-free substrate formulations for diverse crops, evaluating long-term soil and plant responses, and conducting comprehensive life-cycle assessments of different manure processing pathways. Addressing these aspects will further consolidate rabbit manure's role as a sustainable, economically viable, and environmentally beneficial feedstock for substrate production and soil restoration.

Conflict of interest. The authors declare that there is no conflict of interest.

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