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Organic boost or health risk? The dual impact of organic amendments in agriculture

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Abstract

The use of organic amendments in agriculture has long been a cornerstone of sustainable farming, providing essential nutrients and improving soil health. Organic amendments, including animal manure, compost, sewage sludge, and other organic wastes, contribute significantly to enhancing soil physical properties such as water retention, aeration. These amendments supply both macro- and micronutrients, which are vital for restoring soil fertility and supporting crop productivity. By increasing soil organic matter, organic amendments improve soil structure, promote microbial activity, and reduce reliance on synthetic fertilizers. However, the continuous application of these amendments also presents potential risks to human and environmental health. These materials often contain pollutants such as heavy metals, persistent organic pollutants, pathogens, and emerging contaminants like antibiotic residues and microplastics. The presence of antibiotic-resistant bacteria and resistance genes in agricultural soils is of particular concern due to their potential to enter the food chain and contribute to the spread of antimicrobial resistance. Furthermore, untreated or improperly managed organic amendments can lead to the accumulation of harmful substances in the soil, posing long-term risks to both human health and the environment. Innovative agronomic practices and effective management strategies are essential to mitigate these risks while harnessing the benefits of organic amendments. Treatment methods, such as composting and anaerobic digestion, can reduce pathogen loads and the concentration of hazardous substances before application to agricultural soils. Additionally, sustainable soil amendment practices, such as the use of green manure, vermicompost, and other organic materials, have been shown to improve soil quality, increase crop yields, and support long-term agricultural productivity. Even though the organic amendments are invaluable for enhancing soil health and agricultural productivity, their use must be carefully managed. A holistic approach that balances the benefits of organic amendments with rigorous safety measures is essential for the future of sustainable agriculture.

Keywords: Organic boost, sustainable agriculture, amendments, agriculture, dual impact

Introduction

The use of organic amendments in agriculture dates back thousands of years, with historical records indicating their widespread use across various ancient civilizations. The Greeks and Romans, for instance, recognized the value of applying human sewage and animal residues to fields to enhance crop growth, adjusting the amounts according to plant and soil types [1]. In medieval times, the importance of animal manure was well understood, as it was used to replenish nutrients removed by crop cultivation. Although materials such as guano and sodium nitrate became commercially available as nitrogen sources, farmyard manure remained the primary source of plant nutrients in Europe and North America until the advent of synthetic fertilizers in the mid-20th century [2]. Despite the rise of synthetic inputs, organic amendments continue to play a crucial role, particularly in resource-poor regions and among animal producers worldwide who rely on these materials to recycle nutrients and improve soil health. The Green Revolution, beginning in the 1960s, marked a significant shift in agricultural practices, introducing new crop varieties, livestock breeds, and extensive use of irrigation, machinery, and synthetic agrochemicals [3].

While these innovations led to unprecedented increases in food production, the intensive use of chemical inputs and the replacement of natural soil processes with external inputs have led to the degradation of soil health over time. The overuse of synthetic fertilizers and pesticides has resulted in soil compaction, reduced biodiversity, and diminished soil organic matter, leading to a decline in the soil's ability to self-regulate and sustain long-term productivity [4]. Soil, a non-renewable resource, is vital for supporting a multitude of ecosystem functions, and its degradation poses a serious threat to agricultural sustainability**.**

Organic amendments, such as animal manure, compost, and sewage biosolids, offer a potential solution to restoring soil health by replenishing soil organic matter, enhancing nutrient cycling, and improving soil structure [5]. These materials contribute to carbon sequestration, water retention, and increased microbial activity, all of which are essential for maintaining soil fertility and supporting sustainable agricultural practices [5]. However, the use of organic amendments is not without risks. They can contain harmful substances, including heavy metals, pathogens, antibiotic residues, and emerging pollutants like microplastics, which pose potential threats to human health and the environment [6]. The challenge for modern agriculture lies in balancing the benefits of organic amendments with the need to mitigate these risks. Innovative practices, such as ecological intensification and precision agriculture, are being developed to enhance crop yields while minimizing environmental impact. Conservation agriculture, which emphasizes minimal soil disturbance, permanent soil cover, and crop diversification, has shown promise in delivering essential ecosystem services, such as carbon sequestration and soil erosion control [7]. Organic farming, which relies on natural processes and excludes synthetic fertilizers, further underscores the importance of organic amendments in long-term agricultural productivity [8]. However, it is essential to address the potential hazards associated with organic amendments to ensure they contribute positively to sustainable agriculture. This review article aims to explore the historical and contemporary use of organic amendments, their impact on soil health, and the potential risks they pose to human health. By examining recent research and emerging technologies, the article seeks to provide a comprehensive overview of how organic amendments can be effectively managed to support agricultural sustainability while safeguarding public health.

Organic Amendments

Modern production systems and transformation processes, designed to generate useful goods and services, often result in the continuous creation and disposal of significant amounts of waste. To achieve a shift toward more ecological and sustainable production systems, it is essential to transition from the current linear production model, where resources are turned into products and waste, to a circular model that emulates the principles and functions of natural ecological cycles [9]. Within the framework of a circular economy, the reuse of organic waste and by-products as soil amendments has gained considerable interest, as it offers a practical, cost-effective, and environmentally sustainable alternative to landfill disposal, which is the least preferred method of waste management.

Soil amendments are materials added to improve soil's physical, chemical, and biological properties. These can be categorized into two types: 1) Organic amendments and 2) Mineral amendments. Organic amendments are typically derived from naturally occurring plant or animal materials, by-products from processing plants or mills, or waste disposal plants. The use of organic amendments in agriculture is a well-established practice due to their ability to boost crop productivity and enhance soil health. Organic amendments, regardless of their origin or composition (e.g., animal slurry, manure, compost, sewage sludge), provide essential nutrients to the soil and increase its organic matter content, leading to significant benefits for soil health.

Types of organic amendments

Crop Residues and Green Manures

Crop residues are defined as the “non-edible part of the plant that is left in the field after harvest”, while the term green manure refers to “specific forage or crop varieties that are incorporated into the soil while green or soon after maturing”. These plant-based amendments are a valuable source of organic matter (OM) and are considered “the greatest source of soil organic matter (SOM)” for agricultural soils. Moreover, they can provide protection against soil erosion, suppress weeds, improve soil physicochemical and biological properties, and enhance soil fertility.

Animal manures

Composed of faeces, urine, and animal bedding, animal manure was long used as soil organic amendment since it can enhance soil fertility through the supply of essential macro- and micronutrients, as well as OM. The application of animal manure can improve soil structure by reducing bulk density and increasing soil porosity, water infiltration/percolation rate, and aggregate stability [10]. Furthermore, manure-based amendments can stimulate soil microbial activity and biomass, as well as alter the composition and diversity of soil microbial communities [11].

Biosolids

Biosolids (also referred to as sewage sludge) are solid organic residues originated in wastewater treatment plants [12]. Given the load of macro- and micronutrients that these organic amendments contain, their application to agricultural soil can be highly beneficial for soil fertility. Indeed, the application of biosolids to soil was shown to enhance its physicochemical and biological properties, and was proposed as a suitable practice for C sequestration in agricultural soil.

Compost

The decomposition of OM under controlled aerobic conditions can lead to a stable, humus-like end product known as compost. Compost can be produced from a wide array of organic materials, including agrarian (crop residues, animal manures) and municipal solid waste and sewage sludge. In fact, compost constitutes the most commonly used organic amendment for agricultural fertilization. Composted amendments incorporate OM into agricultural soil, thereby improving soil porosity, aeration, water holding capacity, aggregate stability, and nutrient availability, as well as stimulating soil microbial activity and biomass [13-14]. Composted amendments contain more recalcitrant organic fractions than the raw components themselves, leading to longer-term positive effects on soil health.

Beneficial Effects of Organic Amendments

The effects of agricultural practices on soil health, whether beneficial or adverse, are typically assessed through a comprehensive set of indicators, which include physical (e.g., soil structure, bulk density, porosity, aggregate stability, water holding capacity), chemical (e.g., levels of plant macro- and micronutrients, organic matter content, pH, cation exchange capacity), and biological (e.g., enzyme activities, respiration, potentially mineralizable nitrogen, microbial biomass carbon and nitrogen, microbial functional and structural diversity, diversity of macro- and mesofauna) properties.

One of the primary advantages of applying exogenous organic matter (OM) to agricultural soils is the restoration and maintenance of soil organic matter (SOM), a crucial factor for sustaining long-term soil fertility and function. SOM is perhaps the most vital soil property, as it underpins the physical, chemical, and biological dimensions of soil fertility and health [15]. Furthermore, SOM enhancement contributes to both soil fertility and carbon sequestration, aiding in climate change mitigation, a goal strongly advocated in international food security and climate forums. Organic amendments are well-documented for their ability to directly stimulate microbial growth by providing essential nutrients and energy or indirectly by promoting plant growth and, consequently, the amount of root exudates in the rhizosphere [16]. In addition to boosting microbial growth and biomass, organic amendments introduce diverse substrates susceptible to enzymatic hydrolysis, thereby stimulating soil microbial activities [17]. Increased nutrient availability and substrate diversity can also influence soil microbial diversity and composition by expanding the number of ecological niches and fostering various ecological interactions, such as competition and antagonism between organisms. Shifts in biodiversity may subsequently lead to functional changes, such as enhanced plant growth and disease suppression [18]. Moreover, enhancing structural and functional soil diversity can bolster the stability of the soil ecosystem, improving its resistance and resilience to both natural and anthropogenic stresses.

The positive impacts of organic amendments on soil organism biomass, activity, and diversity ultimately result in long-term benefits for soil health and the provision of key ecosystem services, such as carbon and nutrient cycling and disease suppression. Numerous studies on organic amendment use have reported increases in soil microbial activity and biomass, changes in microbial community composition with potential effects on soil functioning, and, to a lesser extent, increased microbial diversity. For instance, a 10-year field experiment demonstrated that replacing mineral nitrogen fertilizers with organic amendments (fermented pig manure) at various substitution ratios (0, 25, 50, 75, and 100%) led to increased soil bacterial diversity [19]. Similarly, studies have shown that organic amendments can engineer the soil ecosystem by selectively modifying environmental conditions, thereby enhancing ecosystem sustainability. For example, continuous organic farming over 10 to 20 years, compared to conventional farming practices, has been shown to stimulate soil ecosystem functioning, primarily through alterations in microbial composition rather than changes in species richness [18]. Organic amendments can also affect soil pH and cation exchange capacity, indirectly influencing nutrient availability, microbial activity, and overall soil fertility. The composition and maturity of organic amendments may alter their effects on soil pH, with some containing high levels of calcium or magnesium, leading to a "liming effect" that increases pH in acidic soils [20]. Enhancing the soil cation exchange capacity, largely through increasing the soil carbon pool, can improve nutrient availability and reduce nutrient leaching. The carbon/nitrogen (C/N) ratio of the amendment is particularly important, as it can limit microbial growth and activity, influencing organic matter decomposition rates and nutrient release patterns [21]. Organic amendments can also immobilize heavy metals through the formation of chemically stable metallo-humic complexes or by increasing soil pH, as metal bioavailability typically decreases at higher pH values [22].

Additionally, the physical characteristics of soil can be improved by incorporating exogenous OM, which has been shown to enhance soil structure, porosity, aggregate stability, and water retention capacity, all of which positively affect soil functioning and crop productivity [5]. The stimulation of soil microbial communities by organic amendments may also indirectly improve soil structure, as microbial activity, such as exopolysaccharide secretion and hyphal growth, can significantly influence soil aggregation and stability. Increased soil porosity, in turn, reduces soil crusting and bulk density, facilitating water and air movement through the soil matrix, promoting root development, and enhancing the quality of habitats for soil biological communities [16]. Furthermore, organic amendments can modify particle size distribution and increase the total surface area within the soil, expanding the number and types of available niches for biological colonization.

Adverse Effects of Organic Amendments

Traditional Risks

In spite of all the aforementioned benefits, the application of organic amendments to agricultural soil may also exert some detrimental effects on soil ecosystem health. For instance, organic amendments can harbour potentially harmful constituents such as human pathogens, heavy metal(loid)s, organic pollutants, emerging contaminants (antibiotic-resistance genes, endocrine disruptors, microplastics), etc. Moreover, the inappropriate application and/or overuse of organic amendments may result in other undesired environmental risks, including an excess of nutrients (eutrophication), immobilization of essential nutrients, contamination of underground water, emission of greenhouse gases, and soil acidification or salinization [23]. On the other hand, it is widely accepted that bioavailable contaminant concentrations are more significant for environmental risk assessment than total contaminant concentrations. The potential negative effects exerted by, for instance, toxic heavy metals on soil health are known to depend upon their bioavailable concentrations, which, in many cases, are not correlated with total concentration values. Khanal *et al* [24] conducted a field experiment in Divyapuri, Nawalparasi, Nepal from October to December to evaluate the impact of brewery sludge on heavy metal levels in soils and cauliflower (Brassica oleracea L. var. botrytis). The study involved applying five different rates of brewery sludge (0, 5, 10, 15, and 20 Mg ha^{-1}) along with a recommended dose of fertilizers (100:60:50 NPK/ha). The results showed that the highest concentrations of heavy metals were found in the soil and plant parts when 20 Mg ha^{-1} of brewery sludge was used. Additionally, the accumulation of heavy metals was greater in the leaves compared to the curds of the cauliflower. In spite of this well-known fact, in most countries, the existing legislation on soil contamination still relies on the values of total contaminant concentration. Owing to their lack of biodegradability, heavy metals have an extremely long persistence in the soil environment [25]. Therefore, the regular application of organic amendments may lead to metal accumulation in soil, with concomitant risks of metal bioaccumulation and biomagnification along the trophic chain [26]. Reductions in soil microbial biomass were also observed, following the application of organic amendments. In addition to inorganic contaminants, organic amendments can incorporate organic pollutants into the soil ecosystem which, in some cases, may also show a high level of persistence and recalcitrance [27-28]. Moreover, the breakdown products and secondary metabolites produced during the degradation of these organic pollutants may happen to be even more toxic and persistent than the parent compounds themselves [28]. Some organic amendments, particularly those derived from raw, unstable animal by-products or biosolids, can contain potentially pathogenic organisms [29-30], including enteric bacteria, parasites, viruses, and fungi. In this regard, it was suggested that *Bacillus anthracis* and *Bordetella pertussis* may be dominant human pathogens in animal manure [31], and *Escherichia coli* and *Klebsiella pneumoniae* in biosolids [32]. The possibility of pathogen incorporation to agricultural soil through the application of organic amendments is a risk that must be thoroughly prevented given its serious implications for human health. An exhaustive biological characterization of the organic amendments is, thus, imperative in order to minimize, or better avoid, this potential biohazard. An excessive and inappropriate application of organic amendments may also result in an excess of nutrients (e.g., phosphorus, nitrogen), which can eventually cause negative environmental consequences such as contamination of watercourses and eutrophication [23]. On the other hand, organic amendments with a high C/N ratio can entail the immobilization of mineral nitrogen within the soil microbial biomass, since microorganisms are generally more effective than plants at competing for nutrients. In addition, the application of organic amendments to soil may trigger the release of gases to the atmosphere, including ammonia and greenhouse gases, most relevantly methane and nitrous oxides [33]. The emission of these gases depends upon (i) the type of organic waste, (ii) the applied treatments (composting, anaerobic digestion), (iii) the timing, dose, and method of application, etc. Finally, soil acidification and salinization may occur following the application of organic amendments to agricultural soil which can, in turn, affect soil structure, as well as nutrient availability, and, importantly, the mobility and bioavailability of pollutants, thus threatening agricultural productivity and ecosystem health. Some organic amendments can indeed increase the soil's electrical conductivity (higher salinity and sodicity), with concomitant detrimental effects for crop yield and soil biological activity. Conversely, the use of acid organic amendments or the generation of humic acids (or the activity of some biological processes such as nitrification) may result in soil acidification, often resulting in increased solubility, mobility and bioavailability of soil contaminants [34].

Table 1: Evidence of trace metals in crops harvested from soil treated with organic materials

Crops	Bioaccumulated trace metals	Organic amendment	Authors
Cucumis sativus	Cd, Cu, Pb and Zn	Green manure and compost	[35-36]
Spinach	Cd, Pb and Zn	paper mill sewage, municipal solid waste	[37-38]
Brassica oleracea	Cr, Ni, Cu, Zn, Mo, Cd and Pb	Sewage sludge and poultry manure	[38]
Capsicum annuum	Zn	Treated urban sewage Yard waste, sewage sludge and poultry manure	[39]
Allium cepa	Zn	Home garden	[40]

Table 2: Evidence of Polycyclic aromatic hydrocarbons (PAH), Polychlorinated biphenyls (PCB) and Per-fluorinated compounds (PFC) in crops harvested from soils treated with OM

Crops	PAH, PCB and PFC	Organic amendment	Authors
Tomato	Dimethylphthalate and diethylphthalate	Biosolids	[41]
Onion Lettuce	Perfuoroctanoic acid, perfuorooctane sulfonate and perfuorooctane sulphonamide	Compost	[42]
Cauliflower	Benzofouranthene and benzopyrene	Sewage	[43]
Carrot	Perfuoroctanoic acid, perfuorooctane sulfonate and perfuorooctane sulphonamide	Compost	[44]
Maize	Acenaphthene and fourene	Sewage	[45]

Emerging Contaminants

Microplastics

Microplastics are substances smaller than <5mm in size, arise from weathering and fragmentation of plastics into smaller particles. Microplastics are extremely or completely resistant to biodegradation, and may cause potential detrimental effects on soil ecosystem functioning and, in particular, on soil organisms via their ingestion and accumulation. Furthermore, microplastics can interact with soil contaminants, altering their ecotoxicity and mobility/bioavailability (many contaminants can become adsorbed onto microplastics) [46-47]. Domestic and industrial wastewaters can carry substantial loads of potentially harmful microplastics, which eventually end up in the corresponding wastewater treatment plant. Wastewater treatment plants are very effective at removing microplastics from the treated water, resulting in the accumulation of microplastics in the biosolids themselves. The application of different rates of biosolids, as drivers of microplastic contamination, into agricultural soil was studied, finding detectable levels of these potentially harmful emerging contaminants in the amended soils. A 2019 study by Corradini *et al.* [48] investigated microplastic accumulation in agricultural soils due to sewage sludge disposal, highlighting this growing environmental threat. Although wastewater treatment plants effectively capture microplastics in sludge, which prevents their entry into aquatic environments, the use of this sludge as a fertilizer on soils raises concerns. The study aimed to assess microplastic contamination in soils resulting from repeated sludge applications by counting particles in soil samples. Thirty-one agricultural fields with various sludge application histories and similar conditions were analysed over a ten-year period, with consistent sludge amounts (40 t ha^{-1} dry weight) used. Microplastics were extracted and analysed microscopically, revealing that soils with 1 to 5 sludge applications had median microplastic counts of 1.1 to 3.5 particles g^{-1} dry soil. Sludge microplastic content varied from 18 to 41 particles g^{-1}, with a median of 34 particles g^{-1}. Most microplastics were fibers (90% in sludge, 97% in soil), indicating that microplastic levels increase with successive sludge applications. These findings underscore the role of sludge in soil microplastic contamination.

Antibiotic-resistant bacteria (ARB) and Antibiotic-resistance genes (ARGs)

The antibiotic-resistant bacteria (ARB) and antibiotic-resistance genes (ARGs) in the environment increased substantially due to anthropogenic activities, resulting in their current identification as emerging environmental contaminants [6]. Indeed, the overuse and misuse of antibiotics for human and veterinary applications resulted in a proliferation of clinically relevant ARB and ARGs in the environment. Actually, antibiotic resistance is increasingly being recognized as one of the greatest threats for global health, as evidenced by the high-level policy initiatives that recently arose, e.g., the Transatlantic Taskforce on Antimicrobial Resistance, the Joint Programming Initiative on Antimicrobial Resistance, endorsed by the World Health Organization. Guidelines, actions, restrictions, and objectives are urgently needed, since it was estimated that antibiotic-resistant infections could cause 10 million deaths per year by 2050 [49]. Antibiotics are known to be poorly metabolized in the human and animal body. Hence, a considerable amount of these emerging contaminants is excreted unchanged or as active metabolites of the parent species, resulting in the presence of a high amount of antibiotics in many wastewaters. Not surprisingly, both livestock manure and wastewater treatment plants are acknowledged as important reservoirs for ARB and ARGs [50]. Bhushan *et al.* [51] conducted a study on antibiotic resistance in poultry environment and spread of resistance from poultry farm to agricultural field. The study found that 100% of the *E. coli*, 92% of *K. pneumoniae* and 78% of *S. lentus* isolated from the poultry environment were multi-drug resistant. About 40% of E. coli and 30% of K. pneumoniae isolates were resistant to at least 10 out of 13 antibiotics against which these bacteria were tested for resistance. In this sense, the long-term application of animal manure and biosolids to agricultural soil may lead to the introduction, proliferation, and dissemination of these emerging contaminants in the environment. It was reported that the repeated exposure of the soil environment to amendment-borne ARGs correlates with the emergence and proliferation of ARGs in indigenous soil bacteria. The dissemination of ARGs among bacteria is mainly driven by horizontal gene transfer (HGT). Indeed, HGT is the main mechanism for genetic variation in prokaryotic organisms, allowing their adaptation to changing environmental conditions and disturbances. It facilitates the colonization of ecological niches through the acquisition of genes via mobile genetic elements such as plasmids, integrons, and transposons. Although there are three main mechanisms of intercellular DNA movement (transformation, conjugation, transduction), conjugative plasmid mediated HGT is considered the most relevant mechanism for the dissemination of ARGs among bacteria. In this regard, the rhizosphere was addressed as a major hotspot for HGT [52]. Interestingly, the phyllosphere was also shown to be conducive to conjugative plasmid transfer. Consequently, crops harvested from manure- or biosolid-amended soils can potentially carry ARGs, representing a potential route of exposure to ARB for animals and humans [53]. The abundance and diversity of ARGs in organically versus conventionally produced lettuce was investigated by high-throughput quantitative PCR, detecting 134 ARGs in the phyllosphere and leaf endophytes of lettuce samples, which were significantly enriched in the organically produced lettuces. The same research group conducted an analogous study with lettuce and endive crops in manure-amended soils, obtaining similar results [54]. Dolliver *et al.* [55] demonstrated that sulfamethazine was absorbed by corn, lettuce, and potato plants, with concentrations in plant tissues ranging from 0.1 to 1.2 mg/kg dry weight, as measured by ELISA analysis. The concentration of sulfamethazine in the plants increased with higher levels of the compound in manure-amended soil. These highlighted the importance of pre-treating the raw organic waste and/or establishing offset times between amendment incorporation and crop harvest for safe consumption. Interestingly, antibiotic resistance is frequently associated with metal resistance, as the molecular mechanisms underpinning resistance to both antibiotics and heavy metals are often similar. This phenomenon is due to the evolutionary mechanism of co-selection, which drives the simultaneous resistance to different pollutants (e.g., metals, antibiotics, biocides) through co-resistance (when different genes encoding for metal and antibiotic resistance are allocated in the same genetic determinant) or cross-resistance (when the same gene provides resistance to both antibiotics and metals) mechanisms [56]. Co-selection is a most relevant mechanism for the abovementioned risk of the appearance and dissemination of ARGs associated with the application of organic amendments to agricultural soil, since the presence of heavy metals in the amendments may enhance antibiotic resistance or select for ARB [57].

Table 3: Pharmaceuticals in plants harvested in soil amended with organic materials

Crops	Pharmaceuticals	Organic amendments	Authors
Spinach	Tetracycline	Sludge and municipal waste	[58]
Radish	Sulfamethoxazole, norfloxacin and doxycycline	Animal manure	[59]
Brinjal	Sulfamethazine	Animal manure	[55]
Maize	Sulfamethazine	Animal manure	[55]
Carrot	Triclosan and triclocarban	Biochar	[60]

Pathogens

The number of pathogens released into the environment is an important component of a quantitative risk assessment for the use of organic soil amendments. Animal feces are significant as a source of enteric and other Organic Amendments and Risk to Health 289 organisms, such as bacteria, viruses, protozoa and helminthic worms, some of which can be parasitic or pathogenic in humans [61]. Enteric pathogens can infect both farm animals and humans through contaminated feed, water supplies and faeces [62-63]. Animals can also become infected from contaminated bedding, which when handled can also be a source of diseases for humans. Many of the organisms that are commonly found in animal manure are also found in sewage biosolids [64]. With time in storage the total microbial loading in the manure acts on the organic matter present. Straw provides additional carbon sources that assist survival. Initially, the number of pathogens may increase as manure is put into storage, and then decline. Alter natively, there may be an immediate reduction in numbers, which steadily continues with time [65]. The rate of decline of bacterial populations is much faster in solid manure stores than in liquid manure storage. Zoonotic diseases, such as salmonellosis, enterohaemorrhagic E. coli (EHEC) infections, anthrax, and Newcastle disease, are significant public health concerns related to the improper treatment of organic amendments. Additionally, *Thermoactinomyces vulgaris*, a heat-resistant organism that produces endospores capable of surviving the high temperatures during composting, poses a risk. This bacterium is known to cause "farmer’s lung," an allergic respiratory disease affecting agricultural workers.

Farming practices to minimize risks to human health from organic amendments

4Rs Nutrient stewardship

The 4Rs Nutrient Stewardship framework offers a robust strategy for minimizing the risks associated with the use of organic amendments in agriculture [66]. By applying the principles of the Right Source, Right Rate, Right Time, and Right Place, farmers can enhance nutrient use efficiency, protect environmental quality, and safeguard human health.

1. Right Source

The "Right Source" principle emphasizes selecting the appropriate type of organic amendment based on the nutrient needs of the crop, soil type, and environmental conditions. Organic amendments vary widely in nutrient content and the presence of contaminants such as heavy metals, pathogens, and pharmaceutical residues [67]. By carefully choosing the type of organic amendment, farmers can ensure that they are providing the necessary nutrients without introducing excessive amounts of harmful substances that could pose a risk to human health. For example, while animal manure is rich in nitrogen and phosphorus, it can also contain antibiotic residues and pathogens. Composting manure can reduce these risks, making it a more suitable source.

2. Right Rate

The "Right Rate" refers to applying the correct amount of organic amendments to meet crop nutrient needs without over-application, which could lead to nutrient runoff, leaching, and accumulation of contaminants in the soil. Excessive application of organic amendments, particularly those high in nitrogen and phosphorus, can lead to nutrient imbalances in the soil, water contamination, and increased risk of harmful algal blooms. By carefully calculating the nutrient content of the organic amendment and matching it to the crop's needs, farmers can reduce the risk of nutrient loss to the environment and subsequent impacts on human health, such as nitrate contamination of drinking water.

3. Right Time

The "Right Time" principle involves timing the application of organic amendments to coincide with the crop's nutrient uptake periods. This minimizes nutrient losses due to volatilization, leaching, and runoff, which can be significant if the amendments are applied when the crops are not actively growing [67]. Timing also plays a crucial role in reducing the risks of pathogen transfer from organic amendments to crops. For instance, applying organic amendments well before the harvest allows time for the natural degradation of pathogens, reducing the likelihood of contamination in food products. Additionally, timing applications during periods of low rainfall or when the soil is not saturated can prevent the leaching of contaminants into groundwater. In maize late applications will increase the risk of nitrate contamination of groundwater because the crop has insufficient time to acquire the nutrient from the soil [68].

4. Right Place

The "Right Place" focuses on applying organic amendments in a manner that minimizes the risk of nutrient and contaminant transport to non-target areas. This can involve techniques such as subsurface application, where amendments are incorporated into the soil rather than left on the surface, reducing the risk of runoff and volatilization. Proper placement also involves avoiding the application of organic amendments near water bodies or in areas with a high risk of leaching, which could result in the contamination of water resources and pose a threat to human health. Buffer zones and controlled application methods are essential components of ensuring the safe use of organic amendments.

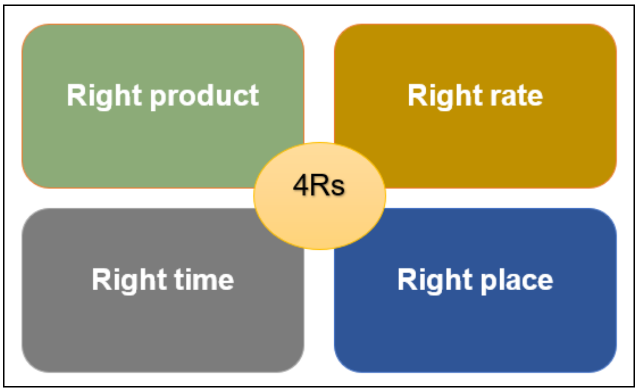

Fig 1: 4Rs Nutrient stewardship

Good agricultural practices (GAP)

Good Agricultural Practices (GAPs) are a set of guidelines designed to ensure that agricultural activities do not pose risks to the environment, food safety, or human health. Implementing GAPs when using organic amendments is essential to minimize potential health risks [22]. Organic amendments, including animal manure, sewage biosolids, and compost, can contain harmful pathogens, heavy metals, and other contaminants. To reduce these risks, farmers and land managers should adhere to the following practices:

Preventing Application of Amendments Near Watercourses and Steep Slopes

To avoid nutrient runoff and contamination of water bodies, organic amendments should not be applied near watercourses or on steep slopes where soil erosion can carry contaminants into streams and rivers [66]. This practice is crucial in preventing the pollution of water resources, which could have serious implications for human health.

Developing Crop Rotations that Restrict Nutrient Leaching

Implementing crop rotations that include cover crops or deep-rooted plants can help minimize nutrient leaching during the drainage season. These rotations improve soil structure, enhance nutrient uptake, and reduce the risk of excess nutrients being washed into water systems, which is vital for maintaining water quality and protecting public health [66].

Specific Limits on Animal Manure Application

The application of animal manure is regulated in many regions to prevent excessive nitrogen loading in soils. For instance, the European Union Nitrates Directive (91/676/EEC) mandates that animal manure applications should not exceed 170 kg of nitrogen per hectare per year in areas vulnerable to nitrate leaching [66]. This regulation helps prevent the contamination of groundwater with nitrates, which is a significant health concern, particularly for infants and pregnant women.

Legislation on trace elements

Many jurisdictions have set legal limits on the amount of trace elements, such as heavy metals, that can be applied through organic amendments. This legislation is designed to prevent the accumulation of toxic elements in soils, which can enter the food chain and pose long-term health risks to consumers [22]. Monitoring and adhering to these limits is essential for safe agricultural practices.

Pathogen Control in Sewage Biosolids

The use of untreated sewage biosolids on vegetable or salad crops is prohibited to prevent the transmission of pathogens to humans. Only conventionally treated biosolids, which have undergone processes to reduce pathogen levels, may be applied to land used for growing certain crops. For example, biosolids can be applied to fields for growing potatoes or other crops that are cooked before consumption [69]. Furthermore, these biosolids must be applied no later than 12 months before the crop is harvested to ensure safety.

Composting: Composting is the process of breaking down organic materials, such as plant matter, food scraps, and yard waste, into a nutrient-rich soil amendment known as compost. This process occurs through the natural action of microorganisms, including bacteria and fungi, which decompose the organic matter [22]. It is an effective method to reduce the risks associated with the use of organic amendments by ensuring the inactivation of harmful pathogens. During the composting process, organic material undergoes a controlled decomposition that generates heat, which is crucial for killing off pathogenic organisms. The efficiency of pathogen inactivation largely depends on maintaining the compost at specific temperatures for a set duration. If the composting process is efficient, it can significantly reduce the load of harmful bacteria and pathogens that might otherwise be transmitted through the soil to the end consumers [70].

Table 4: Lethal time and temperature to inactivate key pathogens in organic amendments

Organisms	Lethal temperature and time
Salmonella spp.	15-20min at 60 °C; 1 h at 55 °C
Escherichia coli	15-20min at 60 °C; 1 h at 55 °C
Mycobacterium tuberculosis	20 min at 70 °C
Corynebacterium diphtheria	45 min at 55 °C; 4 min at 70 °C
Ascaris lumbricoides eggs	60 min at 50°C; 7 min 55 °C
Viruses	25 min at 70 °C

Assessing risks

Table 5: Assessment of risks through various available options

Risk Assessment Questions	Options	Additional Information
What type of soil amendments do you use?	Raw manure Composted manure Sewage sludge Synthetic fertilizers	Raw manure carries a higher risk of pathogen contamination. Composted manure is safer but depends on the efficiency of composting.
What crops receive soil amendments?	Fresh produce Agronomic crops Root vegetables	Fresh produce and root vegetables have a higher risk of direct contamination from soil amendments.
When do you apply them?	Days to harvest Time of year Pre-planting Post-harvest	Timing is critical; applying amendments too close to harvest increases the risk of pathogen survival on crops.
How do you apply them?	Incorporated Injected Surface applied Mulched	Incorporation and injection reduce exposure risk, while surface application increases the likelihood of runoff and exposure.
How much and how often do you apply them?	Low rates Moderate rates High rates Single application Multiple application	Excessive application of amendments increases the risk of nutrient leaching, environmental contamination, and pathogen buildup in the soil.
Do you test your soil or amendments for pathogens?	Regularly Sometimes Rarely Never	Regular testing is crucial to ensure amendments are free from harmful pathogens and contaminants.
What method of composting (if applicable)?	Aerobic Anaerobic Vermicomposting	Aerobic composting is generally more effective at killing pathogens if temperature and time are adequately managed.
What is the proximity of your fields to water sources?	Close proximity Moderate distance Far from source	Fields close to water sources pose a higher risk of nutrient runoff and contamination of water supplies.

Conclusion

In conclusion, while organic amendments offer substantial benefits for enhancing soil health, promoting crop productivity, and supporting sustainable agriculture, they also pose potential risks to human and environmental health. The dual impact of these amendments necessitates a balanced approach that maximizes their advantages while minimizing their hazards. Effective management strategies, such as the 4Rs of nutrient stewardship and the adoption of good agricultural practices, are essential for mitigating the risks associated with contaminants like heavy metals, pathogens, antibiotic-resistant bacteria, and emerging pollutants such as microplastics. Innovative treatment methods, including composting and anaerobic digestion, can significantly reduce the concentration of harmful substances in organic amendments, thereby enhancing their safety and efficacy. Moving forward, a holistic and precautionary approach is vital, integrating rigorous monitoring, improved agronomic practices, and sustainable amendment use to ensure that organic amendments contribute positively to long-term agricultural sustainability. By carefully managing their application, we can harness the full potential of organic amendments to restore and maintain soil health while safeguarding public health and the environment.

References

1. Allison FE. Soil organic matter and its role in crop production. Elsevier; c1973.
2. Pereira L, Bahcevandziev K, Joshi NH. Seaweeds as plant fertilizer, agricultural biostimulants and animal fodder. Boca Raton, FL, USA: CRC Press; c2020.
3. Swaminathan MS. 50 years of green revolution: an anthology of research papers. World Scientific Publishing Company; c2017.
4. Khatri P, Kumar P, Shakya KS, Kirlas MC, Tiwari KK. Understanding the intertwined nature of rising multiple risks in modern agriculture and food system. Environment, Development and Sustainability. 2023;6:1-44.
5. Singh VK, Malhi GS, Kaur M, Singh G, Jatav HS. Use of organic soil amendments for improving soil ecosystem health and crop productivity. Ecosystem Services. 2022;1:20.
6. Urra J, Alkorta I, Garbisu C. Potential benefits and risks for soil health derived from the use of organic amendments in agriculture. Agronomy. 2019;9(9):542.
7. Rehman HU, Nawaz A, Wakeel A, Saharawat YS, Farooq M. Conservation agriculture in south Asia. Conservation agriculture. 2015:249-83.
8. Rehman A, Farooq M, Lee DJ, Siddique KH. Sustainable agricultural practices for food security and ecosystem services. Environmental Science and Pollution Research. 2022;29(56):84076-84095.
9. Adami L, Schiavon M. From circular economy to circular ecology: a review on the solution of environmental problems through circular waste management approaches. Sustainability. 2021;13(2):925.
10. Edmeades DC. The long-term effects of manures and fertilizers on soil productivity and quality: A review. Nutr. Cycl. Agroecosyst. 2003;66:165-180.
11. Liu S, Wang J, Pu S, Blagodatskaya E, Kuzyakov Y, Razavi BS. Impact of manure on soil biochemical properties: A global synthesis. Science of the Total Environment. 2020;745:141003.
12. Singh RP, Agrawal M. Potential benefits and risks of land application of sewage sludge. Waste Manage. 2008; 28:347-358.
13. Das S, Jeong ST, Das S, Kim PJ. Composted cattle manure increases microbial activity and soil fertility more than composted swine manure in a submerged rice paddy. Frontiers in microbiology. 2017;8:1702.
14. Hernández T, Chocano C, Moreno JL, García C. Use of compost as an alternative to conventional inorganic fertilizers in intensive lettuce (*Lactuca sativa* L.) crops-Effects on soil and plant. Soil and tillage research. 2016;160:14-22.
15. Manlay RJ, Feller C, Swift MJ. Historical evolution of soil organic matter concepts and their relationships with the fertility and sustainability of cropping systems. Agriculture, Ecosystems & Environment. 2007;119(3-4):217-33.
16. Ayangbenro AS, Chukwuneme CF, Ayilara MS, Kutu FR, Khantsi M, Adeleke BS, Glick BR, Babalola OO. Harnessing the rhizosphere soil microbiome of organically amended soil for plant productivity. Agronomy. 2022;12(12):3179.
17. Chaudhari S, Upadhyay A, Kulshreshtha S. Influence of organic amendments on soil properties, microflora and plant growth. Sustainable Agriculture Reviews 52. 2021:147-91.
18. Bonanomi G, Lorito M, Vinale F, Woo SL. Organic amendments, beneficial microbes, and soil microbiota: toward a unified framework for disease suppression. Annual Review of Phytopathology. 2018;56(1):1-20.
19. Ji L, Wu Z, You Z, Yi X, Ni K, Guo S, Ruan J. Effects of organic substitution for synthetic N fertilizer on soil bacterial diversity and community composition: A 10-year field trial in a tea plantation. Agriculture, Ecosystems & Environment. 2018;268:124-132.
20. Larney FJ, Angers DA. The role of organic amendments in soil reclamation: A review. Canadian Journal of Soil Science. 2012;92(1):19-38.
21. Mohanty M, Sinha NK, Sammi Reddy K, Chaudhary RS, Subba Rao A, Dalal RC, Menzies NW. How important is the quality of organic amendments in relation to mineral N availability in soils? Agricultural Research. 2013;2:99-110.
22. Urra J, Alkorta I, Garbisu C. Potential benefits and risks for soil health derived from the use of organic amendments in agriculture. Agronomy. 2019;9(9):542.
23. Alvarenga P, Mourinha C, Farto M, Santos T, Palma P, Sengo J, Morais MC, Cunha-Queda C. Sewage sludge, compost and other representative organic wastes as agricultural soil amendments: Benefits versus limiting factors. Waste management. 2015; 40:44-52.
24. Khanal BR, Shah SC, Sah SK, Shriwastav CP, Acharya BS. Heavy metals accumulation in cauliflower (*Brassica oleracea L. var. botrytis*) grown in brewery sludge amended sandy loam soil. International Journal of Agricultural Science and Technology. 2014;2(3):87-92.
25. Zhou X, Qiao M, Wang FH, Zhu YG. Use of commercial organic fertilizer increases the abundance of antibiotic resistance genes and antibiotics in soil. Environmental Science and Pollution Research. 2017;24:701-710.
26. Mann RM, Vijver MG, Peijnenburg WJGM. Metals and metalloids in terrestrial systems: Bioaccumulation, biomagnification and subsequent adverse effects. In Ecological Impacts of Toxic Chemicals; Sánchez-Bayo F, Van Den Brink PJ, Mann R, Eds.; Bentham Science Publishers: Dubai, United Arab Emirates; c2011, p. 43-62.
27. Fijalkowski K, Rorat A, Grobelak A, Kacprzak MJ. The presence of contaminations in sewage sludge-The current situation. Journal of Environmental Management. 2017;203:1126-1136.
28. Semblante GU, Hai FI, Huang X, Ball AS, Price WE, Nghiem LD. Trace organic contaminants in biosolids: impact of conventional wastewater and sludge processing technologies and emerging alternatives. Journal of hazardous materials. 2015;300:1-7.
29. Chen Q, An X, Li H, Su J, Ma Y, Zhu YG. Long-term field application of sewage sludge increases the abundance of

antibiotic resistance genes in soil. Environment International. 2016;92:1-0.
30. Garcia C, Hernandez T, Coll MD, Ondoño S. Organic amendments for soil restoration in arid and semiarid areas: A review. AIMS Environmental Science. 2017;4(5):640-676.
31. Fang H, Wang H, Cai L, Yu Y. Prevalence of antibiotic resistance genes and bacterial pathogens in long-term manured greenhouse soils as revealed by metagenomic survey. Environmental science & technology. 2015;49(2):1095-1104.
32. Ye L, Zhang T. Pathogenic bacteria in sewage treatment plants as revealed by 454 pyrosequencing. Environmental science & technology. 2011;45(17):7173-7179.
33. Thangarajan R, Bolan NS, Tian G, Naidu R, Kunhikrishnan A. Role of organic amendment application on greenhouse gas emission from soil. Science of the Total Environment. 2013;465:72-96.
34. Antolín MC, Pascual I, García C, Polo A, Sánchez-Díaz M. Growth, yield and solute content of barley in soils treated with sewage sludge under semiarid Mediterranean conditions. Field Crops Research. 2005;94(2-3):224-237.
35. Eid EM, Alrumman SA, Farahat EA, El-Bebany AF. Prediction models for evaluating the uptake of heavy metals by cucumbers (*Cucumis sativus L.*) grown in agricultural soils amended with sewage sludge. Environmental Monitoring and Assessment. 2018;190:1-2.
36. Yang Y, Song Y, Scheller HV, Ghosh A, Ban Y, Chen H, *et al*. Commu nity structure of Arbuscular mycorrhizal fungi associated with Robinia pseudoacacia in uncontaminated and heavy metal contaminated soils. Soil Biol Biochem. 2015;86:146-58.
37. Smith RS. A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. Environ Int. 2009;35(1):142-56.
38. Antonious GF, Kochhar TS, Coolong T. Yield, quality, and concentra tion of seven heavy metals in cabbage and broccoli grown in sewage sludge and chicken manure amended soil. J Environ Sci Health; c2012. https://doi.org/10.1080/03601234.2012.676509.
39. Almuktar SA, Abed SNM. Contaminations of soil and two Capsicum annuum generations irrigated by reused urban wastewater treated by different reed beds. Int J Environ Res Public Health. 2018;5(8):1776.
40. Bvenura C, Afolayan JA. Heavy metal contamination of vegeta bles cultivated in home gardens in the Eastern Cape. S Afr J Sci. 2012;108(9-10):1-6.
41. Sablayrolles C, Silverstre J, Lhoutelier C, Vignoles MM. Phthalates uptake by tomatoes after biosolids application: worst case and operational practice in greenhouse conditions. Fresen Environ Bull. 2013;22(4A):1061-1069.
42. Oleszczuk P, Baran S. Polyaromatic hydrocarbons in rhizosphere soil of different plants: effect of soil properties, plant species, and intensity of anthropogenic pressure. Commun Soil Sci Plan. 2007;38(1-2):171-188.
43. Khan S, Cao Q. Human health risk due to consumption of vegetables contaminated with carcinogenic polycyclic aromatic hydrocarbons. J Soil Sediment; c2011. https://doi.org/10.1007/s11368-011-0427-3.
44. Bizkarguenaga E, Zabaleta I, Mijangos L, Iparraguirre A, Fernández LA, Prieto A, *et al*. Uptake of perfluorooctanoic acid, perfluorooctane sulfonate and perfluorooctane sulfonamide by carrot and lettuce from compost amended soil. Sci Total Environ. 2016;571:444-451.
45. Lin H, Shuangcheng TAO, Zuo Q, Coveney R. Uptake of polycyclic aromatic hydrocarbons by maize plants. Environ Pollut. 2007;148:614-619.
46. Rochman CM, Manzano C, Hentschel BT, Simonich SL, Hoh E. Polystyrene plastic: A source and sink for polycyclic aromatic hydrocarbons in the marine environment. Environmental Science Technology. 2013;47(24):13976-13984.
47. Wang J, Peng J, Tan Z, Gao Y, Zhan Z, Chen Q, Cai L. Microplastics in the surface sediments from the Beijiang River littoral zone: Composition, abundance, surface textures and interaction with heavy metals. Chemosphere. 2017;171:248-258.
48. Corradini F, Meza P, Eguiluz R, Casado F, Lwanga HE, Geissen V. Evidence of microplastic accumulation in agricultural soils from sewage sludge disposal. Science of the total environment. 2019; 671:411-420.
49. O'Neill J. Tackling drug-resistant infections globally: final report and recommendations; c2016.
50. Rizzo L, Manaia C, Merlin C, Schwartz T, Dagot C, Ploy MC, *et al*. Urban wastewater treatment plants as hotspots for antibiotic resistant bacteria and genes spread into the environment: A review. Science of the total environment. 2013; 447:345-360.
51. Bhushan C, Khurana A, Sinha R, Nagaraju M. Antibiotic resistance in poultry environment: Spread of resistance from poultry farm to agricultural field. Centre for Science and Environment; c2017, 36.
52. Van Elsas JD, Bailey MJ. The ecology of transfer of mobile genetic elements. FEMS microbiology ecology. 2002;42(2):187-197.
53. Wang FH, Qiao M, Chen Z, Su JQ, Zhu YG. Antibiotic resistance genes in manure-amended soil and vegetables at harvest. Journal of Hazardous Materials. 2015; 299:215-221.
54. Zhu YG, Johnson TA, Su JQ, Qiao M, Guo GX, Stedtfeld RD, *et al*. Diverse and abundant antibiotic resistance genes in Chinese swine farms. Proceedings of the National Academy of Sciences. 2013;110(9):3435-3440.
55. Dolliver H, Kumar K, Gupta S. Sulfamethazine uptake by plants from manure-amended soil. Journal of environmental quality. 2007;36(4):1224-1230.
56. Chapman JS. Disinfectant resistance mechanisms, cross-resistance, and co-resistance. International biodeterioration & biodegradation. 2003;51(4):271-276.
57. Bondarczuk K, Markowicz A, Seget PZ. The urgent need for risk assessment on the antibiotic resistance spread via sewage sludge land application. Environment international. 2016; 87:49-55.
58. Migliore L, Godeas F, Filippis DSP, Mantovi P, Barchi D, Testa C, *et al*. Hormetic effect(s) of tetracyclines as environmental contaminant on Zea mays. Environ Pollut. 2010;158(1):129-134.
59. Wang J, Wang P, Wang X, Zheng Y, Xiao Y. Use and prescription of antibiotics in primary health care settings in China. JAMA Intern Med. 2014;174(12):1914-1920.
60. Fu Q, Wu X, Ye Q, Ernst F, Gan J. Biosolids inhibit bioavailability and plant uptake of triclosan and triclocarban. Water Res. 2016; 102:117-124.
61. Strauch D. Hygiene of animal waste management. In: Strauch, D. (Ed.), Animal Pro duction and Environmental Health, Elsevier Science Publisher B.V., Amsterdam, Neth ERLANDS; c1987, p. 155-202.

62. Herriott DE, Hancock DD, Ebel ED, Carpenter LV, Rice DH, Besser TE. Association of herd management factors with colonization of dairy cattle by shiga toxin positive Escherichia coli O157. J. Food Prot. 1998;61:802-807.
63. Shere JA, Bartlett KJ, Kaspar CW. Longitudinal study of Escherichia coli O157:H7 dissemination on four dairy farms in Wisconsin. Appl. Environ. Microbiol. 1998;64:1390-1399.
64. Gerba CP, Smith JE. Sources of pathogenic microorganisms and their fate during land application of wastes. Journal of environmental quality. 2005;34(1):42-48.
65. Hutchison ML, Walters LD, Avery SM, Moore A. Decline of zoonotic agents in livestock waste and bedding heaps. Journal of Applied Microbiology. 2005;99(2):354-362.
66. Goss MJ, Tubeileh A, Goorahoo D. A review of the use of organic amendments and the risk to human health. Advances in agronomy. 2013;120:275-379.
67. Bruulsema T. 3.1. 14. Managing nutrients to mitigate soil pollution.: 586.
68. Cela S, Berenguer P, Santiveri F, Lloveras J. Potential phosphorus, potassium, and magnesium surpluses in an irrigated maize monoculture fertilized with pig slurry. Agronomy journal. 2010;102(1):96-102.
69. Sabourin L, Duenk P, Gelok BS, Payne M, Lapen DR, Topp E. Uptake of pharmaceuticals, hormones and parabens into vegetables grown in soil fertilized with municipal biosolids. Science of the Total Environment. 2012;431:233-236.
70. Cekmecelioglu D. Fate of pathogenic microorganisms in food waste composting. The Pennsylvania State University; c2004.