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Review

Assessment of Manure Compost Used as Soil Amendment—A Review

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Abstract: Organic waste management is an important concern for both industries and communities. Proper management is crucial for various reasons, such as reducing greenhouse gas emissions, promoting sustainability, and improving public health. Composted manure is a valuable source of nutrients and organic matter that can be used as a soil amendment in agriculture. Some important benefits of using composted manure in agriculture include: improves soil fertility, enhances soil structure, reduces soil erosion, suppresses plant diseases, and reduces reliance on synthetic fertilizers. Composted manure represents one of the most effective methods of organic waste valorization. Its macronutrients and micronutrients content can increase plant yield, without any reported negative or toxic effects on the soil and plants at various application rates. However, improper use of farmyard manure can have negative effects on the environment, such as air pollution from greenhouse gas emissions, soil acidification, and contamination of surface water and groundwater by nitrates and phosphates. The properties of the soil, including aeration, density, porosity, pH, water retention capacity, etc., can be improved by the structure and composition of manure. The slow-release source of nutrients provided by the nutrient content of compost can determine proper plants growth. However, it is crucial to use compost in moderation and regularly test soil to prevent excessive nutrient application, which can have adverse effects on plants and the environment.

Keywords: waste management; manure compost; soil amendment

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Citation: Goldan, E.; Nedeff, V.; Barsan, N.; Culea, M.; Panainte-Lehadus, M.; Mosnegutu, E.; Tomozei, C.; Chitimus, D.; Irimia, O. Assessment of Manure Compost Used as Soil Amendment—A Review. *Processes* **2023**, *11*, 1167. https://doi.org/10.3390/pr11041167

Academic Editors: Gang Luo, Shicheng Zhang, Abdul-Sattar Nizami, Andrzej Bialowiec and Yan Shi

Received: 24 February 2023
Revised: 6 April 2023
Accepted: 7 April 2023
Published: 11 April 2023

1. Introduction

Waste management is a global concern, which uses valuable resources and determines the implementation of restrictive policies regarding waste valorization/recovery/reuse, etc. [1]. Organic waste results in large quantities and can cause significant pollution levels and environmental problems in the absence of rapid control [2]. More than 50% of this waste could be recycled or reused to turn waste into a usable resource [1,3].

Livestock production in the European Union generates an annual output of around 1400 million tons of manure [4]. Livestock farming in Europe remains responsible for a wide range of environmental problems, and public pressure for improvement is unlikely to disappear in the future [5]. The livestock sector is an important user of natural resources and has a significant influence on air quality, global climate, soil quality, biodiversity, and water quality by modifying the biogeochemical cycles of nitrogen, phosphorus, and carbon. The size of global livestock production is the result of human food development, which is based on products of animal origin [6].

The livestock sector must respond to the global demand for food, but under certain conditions, it can generate environmental problems and climate change [2]. Worldwide, about 65 billion chickens, 1.5 billion pigs, 1 billion goats and sheep, and about 330 million cattle and buffaloes are bred for meat production. The number of cattle used for milk production reaches almost 234 million, while the egg production sector has 7.6 billion specimens [6].

Organic wastes intended for use on agricultural land can be processed by different methods so as to retain as many nutrients as possible (e.g., nitrogen N, or phosphorus P) and to increase their capacity for agricultural use while minimizing their impact on the environment. Depending on the technology used, the processing of organic waste can add agronomic, economic, and ecological value to the final product [7].

Proper management of organic waste as a soil amendment can improve essential services provided by the soil, such as water filtration, food production, and climate regulation. The use of waste as a soil amendment can produce positive effects on the organic matter content and trace elements, reducing the need for inorganic fertilizers. In addition to this, it can help with forming soil macroaggregates and improving soil structure, water infiltration, and water retention capacity in the soil [1,8].

Organic fertilizers (amendments) are important sources of nutrients for sustainable agricultural production and, in combination with soil microorganisms and fauna, can bring a significant contribution to improving soil structure and favorable plant-growing conditions [9–11].

From the literature analysis, some knowledge gaps related to manure composting can be identified. Optimal composting conditions for manure depend on factors such as: type of manure, climate, and other variables. Ongoing research is being conducted to determine the ideal conditions for manure composting, including temperature, moisture content, aeration, and carbon–nitrogen ratio. While composting can reduce pathogen levels in manure, there is still uncertainty about the effectiveness of different composting methods in reducing pathogen contamination, particularly for emerging antibiotic-resistant bacteria. Although the literature generally mentions that composting can reduce greenhouse gas emissions from manure, there is limited knowledge about the overall impact of composting on emissions and the potential for composting to mitigate climate change [2–12].

This article aims to present the main aspects specific to the use of manure in agriculture, while also highlighting the main benefits of composting. Some important parameters were also discussed by considering the main objective of the manure compost used as a soil amendment to ensure an environmentally friendly product, which is beneficial for the growth and development of plants, with a low production cost compared to other methods.

2. Some Perspectives of Manure Used as Soil Amendment

The livestock production results in large amounts of waste, which can become a barrier to development if not disposed of properly [12]. In Europe, the livestock sector is currently responsible for around 80% of total ammonia emissions, 10–17% of greenhouse gas (GHG) emissions, 40–50% of diffuse nitrogen, and 70% of inorganic phosphorus. Several government policies have been implemented by the European Union, contributing to the development of manure treatment technologies, while some Member States have increased the use of manure in agriculture and have, therefore, reduced the impact on the environment [13].

2.1. Manure Management

The management of animal waste (manure) includes primarily composting for agricultural applications, combustion used for the production of heat and electricity, and the conversion of livestock waste into bioenergy through biological or thermochemical processes [12].

Manure disposal becomes a problem due to the increase in its volume and the risk of potential contamination of the soil, air, surface water, and groundwater caused by the draining of this organic waste from storage sites and by the odors released [14]. There are many problems with the storage and use of untreated manure, such as odor, emissions, leaching of hazardous substances and the appearance of health risks, the loss of nutrients, and the difficulty of handling this waste [15].

The use of improper disposal practices could cause serious environmental problems, which could include the addition of potentially harmful metals, inorganic salts, and pathogens to the soil, and would lead to increased soil nutrient loss through leaching and to increased emissions of hydrogen sulfide, ammonia, and other toxic gases into the air [16].

Alternative environmentally friendly disposal methods with potential financial benefits are manure processing technologies, which provide energy and products from manure [17]. Although manure is a resource for preserving soil fertility, its management has become one of the main environmental problems [4]. Even though the main objective of manure processing is to reduce the impact on the environment, not all technologies achieve the reduction of pollution, and most technologies are considered too costly [17]. In order, to assess the economic and environmental sustainability of manure management methods and to support decision making, different types of methods are used, based on mathematical programming or simulation methods [17].

Since the early 1990s, the European Union legislation has regulated animal production and, indirectly, the use of manure [18]. This legislation requires that management criteria, such as the best application rates and timing, be adapted to specific local conditions (soil, climate, culture, type of manure) [18].

Overall, effective manure management is important for both environmental and agricultural sustainability. By implementing best practices for manure management, we can reduce the negative impacts of manure while maximizing its potential benefits as a nutrient-rich fertilizer. Additionally, if we refer to the manure management, we can mention the practices used to handle and process manure related to the current concepts on manure management such as: nutrient management, which is a critical component of manure management. Nutrients in manure, such as nitrogen, phosphorus, and potassium, can be valuable fertilizers for crops, but if not managed properly, they can also contribute to environmental problems such as nutrient pollution. Anaerobic digestion is a process that breaks down organic matter in manure in the absence of oxygen, producing biogas (a mixture of methane and carbon dioxide) and a nutrient-rich digestate that can be used as a fertilizer. This process can help reduce greenhouse gas emissions and odors from manure. Composting is another way to process manure that can help reduce odors and pathogens. The process involves allowing manure to decompose naturally with the help of microorganisms, turning it periodically to ensure adequate aeration. Manure storage and handling can help to reduce environmental and health risks associated with manure. This can involve using covered storage structures, proper ventilation, and appropriate equipment for handling and spreading manure. Water management can also be mentioned and involves managing water excess, a consequence that can lead to nutrient runoff and contamination of surface and groundwater. Proper management of water can help minimize these risks [12–18].

2.2. The Principal Techniques Used as Manure Treatment for Use in Agriculture

2.2.1. Anaerobic Digestion

Anaerobic digestion is the process of organic material degradation by microorganisms in the absence of oxygen, producing a biogas composed mainly of methane and carbon dioxide (CH_4 and CO_2) [4]. Manure used for anaerobic digestion becomes a compound rich in nutrients, called digestate, which makes it a potential substitute for chemical fertilizers [4]. Anaerobic digestion is a widely used process for stabilizing waste, controlling pollution, improving manure quality, and biogas production [17]. Biogas plants come with many significant benefits, including the reduction of methane emissions, the production of electricity, and renewable heat, resulting in reduced odor and CO_2 [19].

2.2.2. Mechanical/Physical Separation of Manure

Manure separation produces two fractions: a liquid fraction, which contains a small amount of dry matter, and a solid fraction [17]. The purpose of separation is to reduce the volume of manure and to obtain a solid fraction that can be used for the fertilization of crops [17]. The performance of this process can be determined by the degree of clarification of the supernatant produced, which is then used for irrigation. If activities around the farm are considered, such as washing manure channels, a high degree of clarification is necessary, but without producing large volumes of diluted sludge. Usually, mechanical/physical separation processes succeed one another. A single separation process rarely removes suspended matter and produces a solid phase rich in dry matter [20].

2.2.3. Aerobic Treatment

The purpose of aerobic treatment is to remove nitrogen by nitrification and denitrification, which is achieved by alternating the anoxic and aerobic phase, or by low levels of aeration [4]. Aerobic treatment was initially used to reduce nitrogen excess and was then supplemented with a mechanical separation to manage phosphorus excess [4]. This process results in nitrogen emissions and, sometimes, under adverse conditions, nitrogen oxide can form, and the resulting sediment can be mechanically separated and used for the fertilization of crops or for composting [4]. For example, biological nitrogen removal can only be obtained by combining anaerobic and aerobic treatments. Therefore, effective integrated anaerobic/aerobic treatments can only be achieved through a better management of electron flows. Several authors have reported experimental and full-scale applications of the combined anaerobic–aerobic process configuration [21].

2.2.4. Pyrolysis

During pyrolysis, manure is decomposed in an oxygen-deficient environment to produce gas, liquid, and coal [22]. The resulting coal is a solid residue, composed mainly of carbonic and inorganic materials (ash), and can be applied as a soil amendment and for the production of activated carbon [22]. In many situations, pyrolysis is applied in several stages for a better evolution of the product regarding its properties and temperature [23].

With regard to the use of the resulting compound after using pyrolysis as a soil amendment, it can be stated that if the pyrolysis is carried out at temperatures between 400–550 °C, there is no major impact on the pH [24].

2.2.5. Composting

An alternative approach to manure management is composting, which involves stabilizing organic matter, suppressing weeds and pathogens, deodorizing, improving the handling of the finished product, and the possibility of safe storage and transport [15].

Composting is an ecological and economical alternative for organic waste treatment, which turns manure into fertilizer/organic amendment [25]. Composting is not considered a new technology, but among the waste management strategies this method is considered a suitable option for manure management due to the economic and environmental benefits [26]. The composting process, if carried out correctly, converts wet and odorous organic waste into a dry, odorless, decomposed, and reusable product [27].

There are four stages in the composting process: the initial mesophilic phase, where mesophilic bacteria and fungi degrade simple organic compounds, such as sugars, amino acids, proteins, etc., by rapidly increasing the temperature; the thermophilic phase, when the composting material reaches its maximum temperature (>40 °C), this being the fastest stage of the decomposition process; the cooling phase, which is a decrease in temperature due to the reduction of microbial activity; the maturation phase, representing a long stabilization period of time meant to help obtaining high-quality stabilized, matured, and humified compost [28].

Composting is a method that can be used to reduce the amount of organic waste through recycling, because during the composting process up to 30% of the volume of waste can be reduced, resulting in a product that can have beneficial effects on the soil [27,29]. Composting significantly reduces the volume of manure through biochemical mineralization and partial humification of organic compounds, also reducing the mass, water content, and many of the undesirable elements present in manure, such as pathogens, parasites, and weed seeds [30–32]. The composting process can be influenced by many factors, including: oxygen content/level, humidity, biochemical composition of manure, pH, and temperature, which ultimately affect the quality of the final product and the efficiency of composting [28].

Both pathogens and weed seeds in the raw material are suppressed by: high temperatures, microbial antagonism and/or competition for nutrients, toxicity produced by by-products through organic matter degradation (e.g., ammonia, sulfides, organic acids, and phenolic compounds), and enzymatic degradation [32].

As a result of this process, the risk of spreading pathogens, parasites, or weed seeds is eliminated or reduced, and a stabilized final product is obtained, which can be used to improve and maintain the quality and fertility of the soil [26]. All these present environmental and economic advantages, such as more efficient transport and storage compared to the original raw material [32]. Composting reduces the environmental risks that can occur if untreated manure is stored (degradation of water, soil, and air quality) and improves soil quality in nutrient-deficient areas [30].

The advantages of using compost compared to the use of untreated manure are: pathogens and weeds elimination/reduction, microbial stabilization, volume and humidity reduction, odors elimination and control, ease of storage, transport and use, the production of organic fertilizers, or good-quality substrates [26]. Another advantage is the homogeneous and fragmented structure of the compost, which leads to easier scattering on the soil surface compared to uncomposted manure [32].

3. Manure and Compost as Soil Amendment

3.1. Some Positive Aspects Related to the Use of Manure and Compost as Soil Amendment

Manure has been used on farmland for many centuries, not only for the disposal of this waste, but also as a fertilizer/amendment [33]. Before the advent of inorganic fertilizers, manure was the main source of nutrients added to the soil for plant growth [33]. Manure from cattle was used centuries ago to improve soil fertility due to an increase in the content of organic matter in the soil and the improvement of its physical, chemical, and biological properties [34].

The application of manure to the soil has been shown to improve soil structure and adsorption properties by reducing volumetric density while increasing porosity, infiltration rate, hydraulic conductivity, and stability of the aggregate [9]. Used as a soil amendment, manure adds nutrients to soils (e.g., organic nitrogen or ammonia) and also improves soil structure, thereby increasing nutrient retention, the amount of organic matter, and the water retention capacity [9,35].

The beneficial effects of the use of manure on agricultural land are generally based on the ability to favorably alter soil properties, such as the availability of nutrients for plants, soil pH, cation-exchange capacity, water retention capacity [36,37]. Manure generally contains bicarbonates, organic anions, and basic cations such as Ca^{2+} or Mg^{2+}, which can buffer and neutralize soil acidity [9]. The increase of the soil cation-exchange capacity (CEC) after the application of manure is attributed to the increase in organic matter and carbon in the soil [9]. Since manure has a high content of organic matter, its application to the soil often contributes to the restoration of organic matter in degraded areas, and most of the nutrients are in organic form, which causes a gradual release of nutrients over time [35]. This waste added to the soil can contribute to the development of soil biodiversity in terms of species number, abundance, and diversity [9]. Soil biodiversity can contribute to the suppression of diseases through a variety of mechanisms, including the reduction of the abundance of certain pathogens and pests, releasing allochemics, increasing pH, and increasing the presence of soil microbial antagonists, such as *Actinobacteria* [9].

In general, the manure compost can improve the physical, chemical, and biological properties of soil as the other types of compost. So, we refer to the three types of properties that can be mentioned [33–38]:

- Physical properties of manure compost can vary depending on the specific mixture of organic materials used in the composting process. However, there are several physical properties for manure compost such as: texture, color, odor, and moisture.
- The chemical properties of manure compost are an important factor in determining its effectiveness as a fertilizer. Some key chemical properties of manure compost are nutrient content, organic matter, pH, salinity, and heavy metals.
- Biological properties of manure compost refer in general to microorganisms, a variety of microorganisms, including bacteria, fungi, and protozoa, which can help to break down organic matter and release nutrients. These microorganisms can also help to suppress plant pathogens and improve soil structure. Additionally, at the biological properties of manure, beneficial insects can be mentioned because manure compost can attract beneficial insects, such as earthworms, which can help to improve soil structure and promote healthy plant growth.

Properly used manure is a valuable source of plant nutrients and improves the soils' quality and productivity [38]. The increase in plant yield following the application of manure is due to the nutrients supplied to the soil, to the organic matter, to increased water retention in the soil, and due to the general improvement in the physico-chemical properties of the soil [16,39,40]. The use of an organic source of nutrients, such as manure from cattle, has become an alternative used to prevent a reduction in crop productivity, improving soil quality at the same time [37]. Soils modified with manure tend to have a higher pH and improved productivity resulting from increasing the availability of N, P, K, Ca, and Mg for plants [9]. This organic waste contains numerous essential elements necessary for plant growth, and its long-term use can have beneficial effects on plants, even at low application rates [9,41].

Compost contributes to the formation of soil structure, can improve soil physical properties by improving soil structure, water retention capacity, and aeration, while improving soil chemical properties by providing nutrients and adjusting soil pH. Compost also improves soil biological properties by promoting beneficial microorganisms and enhancing soil fertility [30,42].

Compost used in the soil can improve soil properties such as organic matter, water and nutrient retention capacity, infiltration, aeration, resistance to compaction and erosion, and resistance to soil-borne diseases [43]. Compost obtained from manure provides significant benefits when incorporated into the soil, since the organic matter in manure acts as a nutrient reservoir, improves the nutrient cycle, increases the cation-exchange capacity (CEC), pH, and also improves the physical properties of the soil, such as aggregation, friability, density, porosity, root infiltration, water retention capacity, and water infiltration [9,44,45].

Compost is favorable for the development of soil macrofauna, which plays an important role in improving soil quality. Furthermore, compost slowly releases nutrients that can be taken up by plants and thus contributes to improving crop productivity [43]. Compost contains both macroelements (mainly nitrogen, phosphorus, and potassium) and microelements, which are essential for plant growth; therefore, its use contributes to improving soil fertility [42]. Compost stimulates the activity of microorganisms, thus increasing the availability of nutrients for plants and produces hormone-like substances that can contribute to the growth of crops [42].

Finished compost contains highly active microbial communities that can stimulate soil biota and microbial community structure (this can alter the function of microorganisms involved in the biogeochemical cycle), suppress diseases, help plant development, increase nutrient availability, and increase fertilizer use efficiency and plant production [9]. Compared to the chemical ones, animal waste-based fertilizers (manure) can limit pest growth by increasing the content of micronutrients in the vegetal tissue and/or by increasing the production of defensive secondary metabolites [45].

It is very important to establish the cattle manure application rates, so as to ensure the necessary nutrients to the plants and to have beneficial effects on the properties of the soil [40].

3.2. Some Risks Related to the Use of Manure as Soil Amendment

Manure collection, storage, processing, and application on agricultural fields causes losses of nitrogen, phosphorus, and carbon [46]. These losses have an impact on the environment and human health, including climate change, soil acidification, water eutrophication, and the formation of particles in the air [46]. The use of manure as fertilizer also has several disadvantages for the environment, which are mainly related to the contamination of water sources with nitrates and phosphates [47]. For example, a part of the N and P supplied in excess of the plant requirements can leak out of the root area and thus contaminate the soil and affect both surface and ground waters [15,40,48].

The direct use of untreated manure in the soil at high application rates diminishes its role as soil amendment, and it is often seen as a problem of waste disposal rather than as a valuable source of nutrients [30]. It is very important to properly manage and use the manure application rates in order to avoid massive leaching of contaminants in groundwater [47]. Very large amounts of manure can cause water pollution and eutrophication by leaching and/or nitrate/phosphate leakage/and air pollution by greenhouse gas emissions and ammonia [4].

Following cattle manure overapplication, a possible decrease in crop yield and a negative impact on the environment may occur [40]. Manure in an untreated form, used as a soil amendment, can cause certain environmental and food safety problems [49]. This untreated organic waste is an important source of ammonia, which may lead to negative effects on crop growth and is, at the same time, an important source of pathogens and nitrates that can be transferred to surface and groundwater [49].

The levels of pathogens in manure depend on the type of animal, on its state of health and on how the manure was stored before use [50]. Pathogens can persist in manure for a long time depending on the storage conditions, type of manure mixture, storage temperature, and type of pathogen [50].

Some of the risks related to the use of manure as a soil amendment are presented in Table 1.

The inadequate use and inefficient recycling of manure from animals, especially in regions with high animal density, have exerted several negative effects on the environment [13]. This can contribute to increased climate change through emissions of methane and nitrogen dioxide, while ammonia emitted by manure can affect air, soil, and water quality [48]. Ammonia has undesirable direct and indirect effects on natural ecosystems, on greenhouse gas emissions, and on human health. For example, NH_3 contributes to the formation of small particles less than 2.5 μm in the atmosphere, and when inhaled, these particles, which are less than 2.5 μm, reach the deepest areas of the lungs, causing serious health problems. The nitrogen is mainly emitted as ammonia, nitrogen dioxide, nitrogen monoxide, harmless inhaler gas (N_2), and nitrate (NO_3^-), which drain and accumulate in soils, surface water, and groundwater [46]. Phosphorus, which is not absorbed by the crops, is retained in the soil and is susceptible to the leaching process [46]. Carbon, which contributes to climate change, is mainly emitted as methane and carbon dioxide. Emissions of N and P cause low efficiency in nutrient use. Reducing N emissions and increasing the efficiency of nitrogen use leads to a low environmental impact [46].

Table 1. Some of the risks related to the use of manure as a soil amendment.

Risks	Risks Description	Ref.
Nutrient balance	Manure contains a variety of nutrients such as nitrogen, phosphorus, and potassium, but the nutrient content can vary depending on the animal type, diet, and storage practices. Over-application of manure can lead to an imbalance in soil nutrients, resulting in excessive growth of plants, soil acidity, and soil nutrient pollution. For example, pig manure is typically high in nitrogen. So, if too much nitrogen is applied to the soil in the form of pig manure, it can lead to excessive vegetative growth, reduced fruit and seed production, and increased susceptibility to pests and diseases.	[46]
Pathogens	Manure can contain harmful pathogens such as bacteria, viruses, and parasites that can cause human and animal illnesses. If manure is not properly handled or stored, these pathogens can spread to crops, soil, water, and air, posing a health risk to humans and animals. For example, the main pathogen risks associated with bovine manure are *E. coli*, *Salmonella*, and *Cryptosporidium*.	[32,50]
Contamination	Manure can contain heavy metals, antibiotics, and hormones, which can contaminate the soil and water. These contaminants can accumulate in the soil over time and pose a risk to human and animal health if they enter the food chain. One significant example of contamination refers to antibiotic residues from chicken manure that can reduce its effectiveness as a fertilizer, as the residues can inhibit the growth of beneficial microorganisms in the soil that are important for nutrient cycling and soil health.	[40,48]
Odors	Manure can emit a strong odor that can cause discomfort and annoyance to nearby residents and nature in general. This can lead to complaints and even legal action against farmers who use manure as a soil amendment.	[51]
Environmental Impact	The improper use of manure can have negative environmental impacts, such as eutrophication, soil erosion, and greenhouse gas emissions. Excessive use of manure can lead to the runoff of nutrients and pathogens into water bodies, leading to algae blooms and fish kills.	[13,48]

Manure treatment is recommended so as to reduce greenhouse gas and ammonia emissions [4]. The volatilization of certain organic compounds from manure that cause unpleasant odors can represent yet another problem [51].

Figure 1 presents some aspects related to the use of manure and manure compost uses.

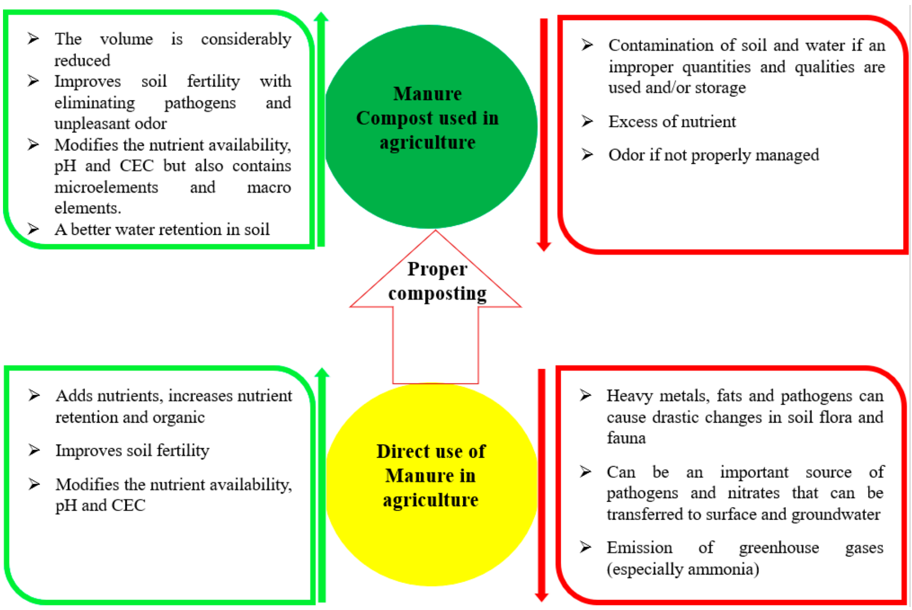

Figure 1. Some aspects related to the use of manure and manure compost used as soil amendment.

3.3. The Influence of Manure Compost on the Soil and Plants

Compost has high organic content (90–95%), but compared to chemical fertilizers, it generally includes low concentrations of nitrogen, phosphorus, potassium, and macro- and micronutrients [27].

Among the organic amendments, manure has been widely used on agricultural fields, and the composted form of this organic waste is preferred to eliminate the risk of nitrogen loss through leaching and surface leakage, as well as for suppressing pathogens, mitigating greenhouse gas emissions, and increasing organic matter in the soil. The use of compost to increase crop productivity is associated with minimizing the risk of spreading pathogens and weeds and improving soil quality and fertility [31].

Table 2 presents experiments from specialized literature, carried out under different experimental conditions, in which the fertilizing potential of manure was tested.

Table 2. Some examples of cattle manure compost.

Experimental Conditions	Raw Materials/Application Rate	Effect on the Soil	Effect on Plants	Ref.
The experiments were conducted in plastic containers, in outdoor conditions, for a time span of 300 days. Two experiments were conducted, each with 3 types of soil collected from different agricultural land plots. Experiment 1: 50% humidity. Experiment 2: 95% humidity.	vineyard soil vineyard soil + CMC compost (cattle manure compost) potato crops soil potato crops soil + CMC compost orchard soil orchard soil + CMC compost Application rate: 9 t/ha	Compost increased pH, EC, organic matter content, cation-exchange capacity, and nutrients. In the case of soil–compost mixtures maintained at 95% WHC moisture content, the EC, CEC, N, K, and Na values were lower than in the mixtures from the experiment with 50% moisture content.	No data.	[52]
The experiment was conducted in field conditions. Rice seedlings (*Oryza sativa Japonica*) were transplanted to the flooded field.	control soil cattle manure compost CMC, 5 t/ha swine manure compost, 6.35 t/ha.	Both types of compost increased pH, nutrient availability (C, N, and P), microbial biomass and enzymatic activities. The increase of these parameters was more significant in the case of cattle manure compost.	Plant growth parameters recorded significant values in the case of both types of compost. The yield of rice plants recorded maximum values in the case of cattle manure compost.	[53]
An experiment was conducted in field conditions for 210 days. Study plant: onions.	control soil soil + cattle manure compost and (chaff) rice husk Application rate: 20, 40, 60, and 80 t/ha.	Organic matter and soil pH increased in accordance with the increase of application rates. Compared to soil control, compost increased the amount of nutrients.	Growth parameters of onion plants recorded high values in the case of all application rates.	[54]
The experiment was conducted in greenhouse conditions, in a time span of 3 months. Study plant: French marigolds. Compost was produced from cattle manure and wood splinters.	commercial peat (control variant) 100% synthetic aggregate 20% CMC compost (cattle manure compost) + 80% synthetic aggregate 40% CMC compost +60% synthetic aggregate 60% CMC compost +40% synthetic aggregate 100% CMC compost.	pH and EC increased depending on the increase in the concentration of compost. Compost significantly increased N, K, P, C, Mg, and Ca. High concentrations of compost increased the values of Cu, Zn, Cr, Mn, and Pb, but these were lower than the limits imposed by the law.	A maximum yield of French marigolds was recorded in the case of the substrate with 40% compost. K, Mg, Ca, and P had the highest values in the substrate with 100% compost. Cu, Mn, Zn, Cd, Cr, and Pb were much lower than the phytotoxic levels in specialized literature.	[55]
The experiment lasted 8 weeks in greenhouse conditions and two types of soil were used. Study plant: spinach. Cattle manure was composted in poplar leaves mixture, ratios: 1:0; 1:1; 1:2, and 1:3 (manure: leaves).	sandy soil + compost (1:0, manure: leaves) sandy soil + compost (1:1) sandy soil + compost (1:2) sandy soil + compost (1:3) clay soil + compost (1:0) clay soil + compost (1:1) clay soil + compost (1:2) clay soil + compost (1:3) Application rate: 20 t/ha.	Compost increased the content of K and P. Cu, Zn, Fe, and Cd decreased in proportion to the increase in the amount of poplar leaves in the compost. An increase in the quantity of poplar leaves fom the compost caused increases in pH and EC of the soil.	Spinach biomass increased in the case of compost with a large quantity of leaves. Plant biomass was higher in the sandy soil. Increasing the ratio of leaves in the compost reduced N, Zn, Fe, Cu, and Cd and increased the content of P and K in spinach.	[29]

Table 2. *Cont.*

Experimental Conditions	Raw Materials/Application Rate	Effect on the Soil	Effect on Plants	Ref.
The study was conducted between 2006/2007 and 2007/2008, in field conditions. Study plant: maize.	control soil soil+ poultry manure compost soil+ cattle manure compost soil + urea soil + chemical fertilizer (Calcium Ammonium Nitrate—CAN) soil+ ammonia sulphate (AS) Application rate: 60 and 90 kg N ha^{-1}	Organic matter, organic carbon, total nitrogen, phosphorus, pH, EC and Ca, Mg, K, Na, recorded high values in the case of the two compost types compared to the soil modified with inorganic fertilizer.	The number of gray leaves decreased in the case of composts. The yield of plants reached the highest values in the case of cattle manure compost samples.	[56]
The experiment was conducted between 2010 and 2014 on a cultivated land rotating wheat (*Triticum aestivium* L.) with maize (*Zea mays* L.) crops.	control soil soil + 100% inorganic fertilizer (IF) soil + 25% CMC + 75% (IF) soil + 50% CMC + 50% (IF) soil + 75% CMC +25% (IF) soil + 100% CMC.	The inorganic fertilizer produced a decrease in the water content and the total N content, but instead these parameters increased in accordance with the increase in the amount of compost from cattle manure.	The average annual yield of wheat and maize plants increased in all treatments. The highest yield was obtained in the treatment with 25% CMC + 75% IF compost.	[57]
The experiment was conducted between April 2002 and May 2003, in field conditions. Study plant: maize.	control soil soil+ CMC compost +IF soil + IF.	Compost treatment resulted in more significant increases of pH, EC, organic matter, and nutrient content. Cr, Ni, Pb, and Cd were similar in both treatments and were not significantly higher than the values in the control soil.	The yield of maize grain production did not vary significantly. Ca, Mg, Mn, Fe, Cu, Zn, and B did not vary significantly. Cr, Ni, Pb, Cd, and Hg in maize grain were lower than the detection limit.	[15]
Experiment conducted in a vineyard in a time span of 5 years. Study plant: grapevine.	control soil, soil+ CMC compost applied between rows soil + grapevine compost applied between rows/to the inter-rows areas soil + grapevine applied under rows Application rate: 4 t/ha.	The use of compost resulted in an increase of soil pH, organic matter, total nitrogen, and microbial biomass compared to the control variant.	The vegetative growth of the vine was best stimulated by the compost from cattle manure. The number of grapes and their weight were similar in the case of both types of compost.	[58,59]
Experiment in greenhouse conditions for 35 days. Study plant: spinach.	control soil, soil + 5% cotton compost soil + 10% cotton compost soil + 5% CMC compost soIl + 10% CMC compost	Compared to cotton compost, cattle manure compost significantly increased the amount of nutrients and organic matter.	Both types of compost had a positive effect on spinach plants. The productivity of spinach plants was significantly improved by the use of cattle manure compost.	[43]
Experiment conducted in greenhouse conditions, for a period of 90 days. Study plant: autumn barley	control soil soil + 0% CMC compost, 100% sewage sludge biochar soil + 10% compost, 90% biochar soil + 20% compost, 80% biochar soil + 30% compost, 70% biochar soil + 40% compost, 60% biochar soil + 50% compost, 50% biochar soil + 60% compost, 40% biochar; soil + 70% compost, 30% biochar soil + 80% compost, 20% biochar soil + 90% compost, 10% biochar soil + 100% compost, 0% biochar Application rate: 5 and 30 t/ha.	Organic matter, organic carbon, and soil organic content increased due to the application of compost mixed with biochar for both application rates, but a more significant increase was recorded in the case of the application rate of 30 t/ha. ATR-FTIR spectra showed that the chemical composition of the soil did not change as a result of applying compost–biochar mixtures to the soil	No data.	[11]

Table 2. *Cont.*

Experimental Conditions	Raw Materials/Application Rate	Effect on the Soil	Effect on Plants	Ref.
Experiment conducted between August–November 2016, for a period of 90 days. Study plant: autumn barley	control soil soil + 0% cattle manure compost, 100% sewage sludge biochar soil + 10% compost, 90% biochar soil+ 20% compost, 80% biochar soil + 30% compost, 70% biochar sol + 40% compost, 60% biochar soil + 50% compost, 50% biochar soil + 60% compost, 40% biochar; soil + 70% compost, 30%biochar soil + 80% compost, 20% biochar soil + 90% compost, 10% biochar; soil + 100% compost, 0% biochar Application rates: 5 and 30 t/ha.	Compost–biochar mixtures used at an application rate of 30 t/ha significantly increased the pH, soil respiration, and electrical conductivity in the soil.	A more significant increase in plant height, number of shoots, and dry biomass was determined at application rates of 30 t/ha of compost–biochar mixtures, especially in the case of mixtures with a high concentration of compost.	[60]
Experiment conducted in greenhouse conditions, for a period of 90 days, having as study plant autumn barley.	control soil soil +0% cattle manure compost, 100% sewage sludge biochar. soil + 10% compost, 90% biochar; soil+ 20% compost, 80% biochar; soil + 30% compost, 70% biochar; soil + 40% compost, 60% biochar; soil + 50% compost, 50% biochar; soil + 60% compost, 40% biochar; soil + 70% compost, 30% biochar; soil + 80% compost, 20% biochar; soil + 90% compost, 10% biochar; soil + 100% compost, 0% biochar Application rates: 5 and 30 t/ha.	Pb and Cd concentrations recorded an increase in the case of mixtures with 100% sewage sludge biochar. Cu concentration increased at application rates of both 5 t/ha and 30 t/ha in accordance with the increase in cattle manure compost concentration in the mixtures.	No data.	[3]

As it is presented in Table 2, composting can indeed increase pH, electrical conductivity (EC), and organic matter content of the composted material. During the composting process, microorganisms break down organic matter, releasing carbon dioxide as a byproduct. This can lead to a decrease in acidity (lowering of pH) in the composted material. Additionally, the decomposition of organic matter can release nutrients and minerals, which can contribute to an increase in EC [52]. Additionally, the extent of the increase in organic matter and soil pH will depend on the amount and quality of the compost applied, as well as the starting properties of the soil. Generally, the higher the application rate of compost, the greater the increase in organic matter and soil pH, up to a certain point where additional compost may not result in further increases. It is important to note that the effects of adding compost to soil may take some time to fully manifest, as the organic matter must decompose and integrate into the soil ecosystem [54,58,59].

Biotests are usually used to estimate ecotoxicity and include a leachate analysis as well as direct tests using organisms of different taxonomic and trophic levels [61]. For ecotoxicological analysis, different methods (contacts and elutriates/leachates) are recommended, using terrestrial and aquatic organisms from different trophic levels [61].

The use of compost on the soil surface depends on its maturity and stability, which can be assessed by measuring physico-chemical characteristics and phytotoxicity [25]. Phytotoxicity is one of the most important criteria for assessing the quality of compost used for agricultural purposes [62]. Phytotoxicity is mainly caused by increased solubility of heavy metals, or by the production of phytotoxic substances such as ammonia, ethylene oxide, and organic acids [62]. The germination index (GI) is widely used to assess the phytotoxicity of compost, given that a high germination index indicates a decrease in phytotoxicity, and the obtained results should be carefully interpreted, as they are affected by the type of seeds used and the source of the compost [62].

Earthworms and other animal species such as enchytraeids, collembola, soil mites, isopods, nematodes, and protozoa also indicate the possibility to assess soil ecotoxicity [62].

Table 3 presents toxicity experiments in specialized literature, regarding toxicity testing of cattle manure. From the literature data, it can be observed that the toxicity testing of cattle manure is an important step in assessing its safety as a soil amendment. Manure can contain various contaminants, including pathogens, antibiotics, heavy metals, and hormones, which can potentially harm human health and the environment if not properly managed. For example, one common method of toxicity testing for manure is a bioassay. Additionally, plant germination and growth tests can be used to assess the chronic toxicity of manure, as plants are sensitive to long-term exposure to contaminants. Chemical analyses can also be conducted to assess the concentration of various contaminants in the manure.

Table 3. Experiments using sewage sludge biochar/sewage sludge.

Experimental Conditions	Raw Materials/Application Rate	Effects on Plants/Test Organisms	Ref.
The experiment was conducted on a field cultivated with wheat and corn by rotation. At two temporal intervals (June and October 2014) from each plot, a cube of soil was sampled, and earthworms of *Eisenia foetida* and *Pheretima guillelmi* species were sorted manually.	control soil, soil + 100% inorganic fertilizer, soil + 25% CMC compost + 75% inorganic fertilizer, soil + 50% CMC compost + 50% inorganic fertilizer; soil + 75% CMC compost + 25% inorganic fertilizer, soil + 100% CMC compost.	Treatment with 100% inorganic fertilizer had a negative effect on earthworms. The total density and biomass of earthworms of *Eisenia foetida* species increased in proportion to the increase of the compost concentration. Treatment with 75% compost +25% inorganic fertilizer had a positive effect on *P. guillelmi* earthworms.	[57]
Folsomia candida species was used in the first test conducted in a time span of 28 days, under laboratory conditions, at a temperature of 20–22 °C, in the dark. In the second test, *Eisenia Andrei* was used as the test organism. The containers were kept at a temperature of 20 °C for 14 days.	artificial soil soil + 0% CMC compost, 100% sewage sludge biochar soil + 10% compost, 90% biochar soil + 20% compost, 80% biochar soil + 30% compost, 70% biochar soil + 40% compost, 60% biochar soil + 50% compost, 50% biochar soil + 60% compost, 40% biochar soil + 70% compost, 30%biochar soil + 80% compost, 20% biochar soil + 90% compost, 10% biochar soil + 100% compost, 0% biochar Application rates: 5 and 30 t/ha	The number of juveniles of *Folsomia candida* determined at a 30 t/ha application rate of compost–biochar mixtures, did not exceed the number detected at application rates of 5 t/ha. In the case of the test in which the *Eisenia Andrei* was used, the compost from cattle manure, used at a concentration of 100% in the mixture, produced a significant increase in the biomass of the earthworms.	[10]
The *Tetrahymena pyriformis* species was chosen as an indicator of toxicity. The samples were incubated for 36 days.	0 Compost: control soil soil + 12.5 g leachate soil + 25 g leachate soil + 37.5 g leachate soil + 50 g leachate 25 g Compost: control soil, soil+ 12.5 g leachate + compost soil+ 25 g leachate + compost soil + 37.5 g leachate + compost soil+ 50 g leachate + compost. 50 g Compost: control soil soil + 12.5 g leachate + compost soil+ 25 g leachate + compost soil + 37.5 g leachate + compost soil+ 50 g leachate + compost.	Increases in compost rates had the effect of increasing pH and enzymatic activities. Increases in the amounts of leachate in the soil produced an increase in the toxicity of the samples. A remarkable decrease in toxicity was observed following the addition of cattle manure compost.	[63]

3.4. Future Research Directions

After a literature evaluation and interpretation, some future research directions can include:

- Conducting comparative studies regarding the effects of chemical fertilizers and the effects of treated organic waste on the soil and plants.
- Analyzing the use of other treated organic waste, generated by animal husbandry (poultry, horses, pigs, sheep, etc.), to reduce the amount of organic waste, including their use in a way that is beneficial to the environment, and to reduce the use of chemical fertilizers.
- Analyzing long-term studies to identify the efficiency of treated organic waste and its persistent effects in the soil.
- Comparative studies that examine the production costs of chemical and organic fertilizers and determine the effects that may occur during the production and long-term use of organic and chemical fertilizers.

4. Conclusions

The use of manure in agriculture is considered an optimal method for valorizing this waste, because the nutrients in this waste are recycled and reused in a beneficial way for degraded soils. The improvement of the physical, chemical, and biological properties of the soil due to the use of manure as a fertilizer is widely known. Similarly, this organic waste increases crop productivity due to the high content of organic matter and nutrients necessary for plant growth and development.

Manure, if used improperly, can cause disadvantages for the environment, for example, air pollution by greenhouse gas emissions, soil acidification, contamination of surface and groundwater by nitrates and phosphates.

Composting of manure allows obtaining a humified product, which contains organic matter and has the capacity to favorably modify the properties of the soil, thus contributing to the recovery of degraded agricultural soils following intensive agriculture.

The structure and composition of manure improve the properties of the soil, such as: aeration, density, porosity, pH, electrical conductivity, water retention capacity, etc. Additionally, the nutrient content of compost can ensure the growth and development of plants by providing a slow-release source of nutrients that can be taken up by plants as they need them. However, it is important to use compost in moderation and to test soil regularly to avoid over-application of nutrients, which can be harmful to plants and the environment.

The content of nutrients in the compost ensures the growth and development of plants over long periods of time, without the need to apply another type of fertilizer for a period of 2–3 years, thus reducing the number of chemical fertilizers. Additionally, by creating a healthy, balanced soil ecosystem, compost can reduce the need for chemical pesticides and herbicides.

Compost from cattle manure, used in various studies, under different experimental conditions, had a positive impact on the soil due to improving soil quality and productivity.

In general, the use of manure compost as a soil amendment can provide some benefits such as: improving soil fertility, waste reducing, improving soil health, slow-release source of nutrients for plants grows, and reducing environmental impacts.

Author Contributions: Conceptualization, E.G. and V.N.; methodology, E.G.; validation, C.T. and M.P.-L.; formal analysis, M.C.; investigation, E.G.; writing—original draft preparation, E.G.; writing—review and editing, N.B.; visualization, E.M., D.C. and O.I.; supervision, V.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

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

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