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An Overview on Common Types, Processes of Valorization, and Agriculture Potential Use of Green Farm Waste

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Abstract: The management of organic by-products has become a global issue due to the increase in food consumption. In particular, green waste from farms is of paramount importance in the face of environmental and climate challenges. This waste mainly consists of crop residues, manure, pruning waste, and processing residues. The main processes for converting these by-products for agricultural use include composting, anaerobic digestion, vermicomposting, and fermentation. Various materials or products obtained from the processing of green waste from farms fall into several categories, including agricultural products and fertilizers, energy products and materials, as well as food, pharmaceutical, and industrial products. Among these products, those used for agricultural purposes stimulate soil fertility, generate green energy, and reduce dependence on chemical fertilizers. In addition, recent advances such as nanotechnologies and hydroponic systems are revealing new possibilities. However, their recovery most often contributes to the circular economy and agricultural resilience. Ultimately, this bibliographic study highlights the transformative potential of agricultural green waste for a more sustainable and bioeconomic future.

Keywords: Green farm waste, Valorization processes, Soil amendments, Bioenergy, Sustainable agriculture.

1 Introduction

The management of agricultural by-products has become a global concern due to their increasing impact on the environment and the need to increase agricultural productivity in order to meet human food needs. Understanding the issues related to the management of these agricultural by-products therefore requires an in-depth examination of their nature and importance. Of course, population growth, economic development, and the intensification of agriculture are reflected in the quantity and complexity of agricultural waste generated in many countries. Note that among agricultural by-products, green waste from farms accounts for a significant proportion of the green waste produced on various farms. Global agricultural waste production is estimated at over two billion tons per year [1]. Thus, the average annual

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production of green waste amounts to 47 kg per person. This figure varies over time depending on the agricultural practices of each country [2]. However, certain agricultural practices, such as uncontrolled waste disposal, significantly increase the production of by-products in agricultural production units. This form of inefficient management leads to the deterioration of the planetary health of various components of the environment. Generally, poor disposal of organic waste leads to soil degradation and water quality deterioration, affecting biodiversity and, more specifically, the human species [3]. Furthermore, practices that recover these agricultural by-products often help mitigate negative impacts on the environment, particularly greenhouse gas emissions. These practices also help improve the resilience of farms to climate change [4]. On the other hand, several sustainable practices for converting waste into useful resources can be employed to effectively manage and value green farm waste. These valorization approaches increase agricultural productivity and economic prospects in addition to addressing environmental issues. As with other organic wastes, the most effective methods for managing green farm waste include composting, bioenergy production, and innovative microbial processes [5]. Thus, organic fertilizers are among the main products derived from them that are most usable for agricultural purposes. This approach to integrated organic waste management by producing organic fertilizers through different processes offers numerous economic and environmental benefits [6], both for animal and human health [7]. Despite the many advantages associated with the recovery of by-products,some agricultural production units have not yet implemented initiatives to recover the green by-products they generate and continue to manage them inappropriately. This is why it is necessary to fully understand the origins and types of green waste in order to implement management strategies adapted to modern agriculture. In addition, the conversion of green waste into renewable energy sources and soil amendments requires considerable investigation. This literature review explores the different types and origins of agricultural by-products and the techniques for converting them into resources that can be used for agricultural purposes. It also reviews the various potential uses of the different products derived from them in promoting sustainable agriculture.

2 Common Types of Green Farm Waste

Green waste from farms includes a wide range of by-products generated on agricultural holdings, such as crop residues, livestock manure, and a significant proportion of food processing by-products. This agricultural waste is mainly composed of plant waste, which can be divided into two main categories: non-woody green waste (grass clippings, leaves, flowers) and woody green waste (branches, pruning residues). They are mainly composed of biomass, which is usually degradable by microbial action. These green by-products from farms can be grouped into several categories.

2.1 Crop residues

Crop residues are materials left over from harvesting. They include various parts of abandoned crops, such as stems, leaves, roots, flowers, and the bark of certain tubers, as well as entire plants left in the field. These residues are suitable for a variety of applications due

to their high lignocellulosic biomass content. Among the most common plant residues are cereal straws, such as wheat straw and rice straw, corn cobs and husks, sugarcane bagasse, etc [8].

2.2 Livestock manure

Livestock manure is another category of by-products generated at the farm level due to the livestock activities most commonly carried out on most farms. They can come directly from livestock manure (stables), sometimes mixed with their bedding, or from slaughterhouses, or even from pets. It is a valuable resource for the production of various products,including biogas, due to its richness in organic matter and nutrients. For instance, dairy manure is associated with higher methane yields due to its high protein content [9], [10], [11].

2.3 Fruit and vegetable waste

Fruit and vegetable waste includes materials such as peelings, pomace, seeds, rinds, etc., which are produced in large quantities on farms immediately after harvesting or after processing on site. These by-products can be used as raw material to recover bioactive compounds, including some antioxidants, and to produce organic acids of industrial interest such as citric acid, lactic acid, and acetic acid [12].

2.4 Other agricultural wastes

In addition to the various categories of by-products listed above, there is also plant waste from the maintenance of green spaces and field edges, gardening waste, and household waste consisting of hedge trimmings, branches, dead leaves, grass clippings, etc.

3 Physicochemical and Biological Green Waste Recovery Processes

Various physicochemical and biological processes are currently used to recover agricultural by-products. These different recovery techniques not only enable the recovery of nutrients that can be used as crop fertilizers, but also the production of biogas, biofuels, and other forms of bioenergy [13, 14]. Thus, to improve the biodegradability and digestibility of agricultural waste, physical, chemical, and biological pretreatment techniques have also been developed [15, 16]. As shown in fig:valorization, the various processes for recovering green waste can be grouped into two main categories: biochemical and thermochemical conversion technologies.

Various processes can be used to treat agricultural by-products, each with specific advantages depending on the recovery objectives. These include anaerobic digestion, composting, biochar production, fermentation, extraction of bioactive compounds, etc.

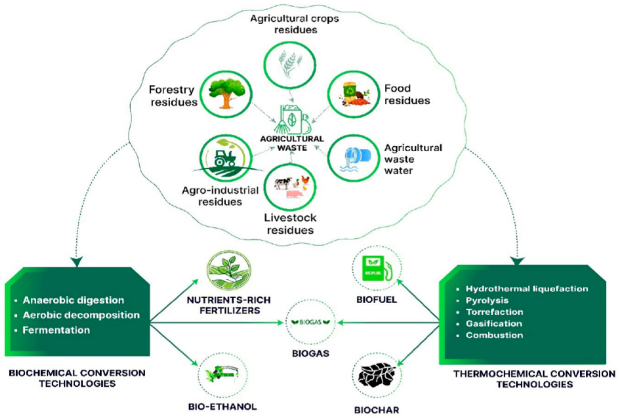


Fig. 1. Biochemical and thermochemical valorization of agricultural waste (Source: [17]).

3.1 Composting

This process involves the aerobic decomposition of organic matter and results in a nutrient-rich organic fertilizer (compost). It involves a population of microorganisms capable of degrading organic matter into bioavailable nutrient sources. Optimization involves reducing particle size, adding co-substrates (e.g., biochar, food waste), and controlling key parameters including temperature and oxygenation [18], [19]. This approach to converting green waste into organic fertilizers has been used in various studies [20], [21], [22], [23].

3.2 Methane production

This is a biological process that takes place in an anaerobic environment and results in two main products, including biogas composed mainly of methane and solid or liquid digestate that can be used to fertilize the soil due to its high content of stabilized organic matter and nutrients [24], [25]. This transformation is suitable for substrates that are particularly rich in easily degradable organic matter, like sorghum stalks [26], [27].

3.3 Pyrolysis

This process is a thermal decomposition of organic matter in the absence of oxygen at high temperatures between 250 and 900 °C [28], [29]. During this process, depolymerization, fragmentation and crosslinking of lignocellulosic material, including hemicellulose, cellulose and lignin, take place at specific temperatures. As reported by [30], this process allows the conversion of residual biomass into value-added products, including biochar, bio-oil and syngas. Thus, the biochar produced by pyrolysis affects the physicochemical properties of the soil, which can then have a rapid influence on plant development [31].

3.4 Fermentation

This biological process (aerobic or anaerobic) uses microorganisms to transform biomass into value-added products such as organic acids, bioplastics, oleochemical compounds, biofuels,

and bioactive compounds [32]. It also enables the production of organic fertilizers that can be used to increase soil fertility, including compost, solid or liquid biofertilizers, etc [33], [34].

3.5 Extraction of bioactive compounds

Use of processes to recover high value-added molecules (antioxidants, phenolics) from plant waste [35], [36]. However, traditional extraction techniques and so-called green methods that are environmentally friendly. Modern and green methods include ultrasound-assisted extraction, microwave-assisted extraction (MAE), and supercritical fluid extraction (SFE) [37]. Compared to conventional techniques, ecological or environmentally friendly extraction is one that minimizes environmental impact and improves sustainability. In addition to the aforementioned uses of green farm waste, it can be utilized in innovative ways to address global challenges, such as climate change and resource scarcity. Among the more recent innovative techniques, nanotechnology allows for the synthesis of nanomaterials that can be used in agriculture,medicine, and environmental remediation [38]. Ultimately, comparing these different processes in terms of profitability and sustainability shows that composting is the simplest and least expensive technique, while metanization, pyrolysis and fermentation require significant energy and technology costs. Similarly, the extraction of bioactive compounds, although this approach offers added value, presents operational complexity due to its advanced technology.

4 Potential Uses of Farm Green Waste

Farm green waste, like other green waste, is a valuable resource. Its potential uses are numerous, depending on the processing sector. Table 1 presents different categories of agricultural by-products and various products resulting from their processing. By analyzing the results presented in Table 1, the main products resulting from the processing of green waste from farms can be grouped according to the recovery processes applied.

Table 1. Common types of green waste and their potential uses.

Type of waste	Examples	Potential uses	References
Crop residues	Wheat straw, rice straw, sugar cane, bagasse	Biofuels, biochar, animal feed, amendments, paper pulp, particle board, cardboard	[2], [39], [40], [41]
Livestock manure	Cow manure and poultry manure	Biogas, organic fertilizers, biochar	[39], [42], [43]
Fruit and vegetable scraps	Bark, pomace, seeds	Nutraceuticals, pharmaceutical products, compost, animal feed	[41], [44], [45]
Agricultural waste fibers	Oil palm fibers, rice husk fibers	Biocomposites, building materials, textiles, decorative products	[45], [46]
Other agricultural waste	Olive residues, coffee waste, etc.	Bioactive compounds, biofuels, environmental remediation	[43], [45], [47], [48]

Three main categories can be identified, namely:

- Agricultural products and fertilizers: compost, digestate, biochar, microbial biofertilizers, vermicompost, and other forms of organic amendments.
- Energy products and materials: biogas, biochar, bio-oils and synthetic gases, and biofuels.
- Food, pharmaceutical, and industrial products: organic acids, bioactive compounds, bioplastics and oleochemicals, and plant fibers.

These various products and materials can be used in a range of fields, mainly in agriculture and horticulture, energy production,eco-construction and bio-based materials, as well as in the chemical, cosmetics and pharmaceutical industries. They can also be used in animal feed and to mitigate environmental pollution.

5 Potential Agricultural Uses of Farm Green Waste

Among the various approaches to waste recovery discussed above, those geared toward agricultural applications include composting, anaerobic digestion, pyrolysis, and fermentation. As indicated in sec:processes, this conversion results in the production of organic fertilizers such as compost, biochar, digestate, and microbial biofertilizers. These materials are currently widely used in agriculture to reducedependence on chemical fertilizers due to their agricultural sustainability. They offer an environmentally friendly alternative that helps maintain or increase agricultural production while preserving soil health. Absolutely, compost is derived from the decomposition of organic matter and is a nutrient-rich organic amendment. As reported by various authors, this amendment improves soil health and optimizes the nutrient cycle thanks to its balanced pH, nutrient composition, and biological activity [49], [50], [51]. Not only do compost, vermicompost, biochar, and digestate from the decomposition of green waste have beneficial impacts on soil health, but their application to crops also increases beneficial microorganisms and their activity, soil organic matter, cation exchange capacity, and soil water retention capacity. In particular, biochar made from certain plants such as cannabis can be used to protect soils thanks to its phytoremediation properties [52], [53], [54]. Like other organic materials, farm by-products can be used to make solid or liquid biofertilizers. Thus, the use of biofertilizers in agriculture is a promising solution for restoring degraded land.These organic fertilizers contain microorganisms that can improve soil fertility by fixing atmospheric nitrogen and solubilizing phosphorus [55], [56]. They also help to limit the spread of crop diseases. The microorganisms contained in biofertilizers have the ability to produce antibiotic compounds or enzymes that inhibit the development of pathogens in the rhizosphere [57]. In addition, various studies have shown that the combined use of organic and inorganic fertilizers results in good yields compared to non-combined treatments [58], [59], [60], [61]. They improve not only soil quality but also the nutritional quality of crops. As indicated by [62], organic fertilizers and biofertilizers contribute to improving the concentration and absorption of nutrients,including N, P, and K, in the grains and straw of crops such as soybeans, corn, and quinoa, compared to mineral fertilizers. Generally, the use of biofertilizers remains an essential approach to sustainable agriculture thanks to the usefulness of these substances in reducing dependence

on agrochemicals, subsequently contributing to the preservation of the environment. The work already carried out highlights that the role of these soil amendments is not only limited to increasing crop productivity, but also that they contribute to reducing production costs for farmers [63], [64]. Therefore, the integration of organic fertilizers and biofertilizers into agricultural systems constitutes a better approach to managing green farm waste with which farmers can benefit from these bioresources. This management approach remains widely important in many countries, especially in developing countries where agricultural inputs from communities are often limited [65], [66]. Thus, adopting these biological products to increase agricultural production could be an effective strategy to improve global food security [67], [68].

6 Conclusions and Future Scope

The valorization of agricultural by-products from farms is an essential solution to the various environmental, economic, and food challenges currently facing the world. As discussed in this literature review, these materials have long been considered useless waste, but today their conversion into valuable products such as compost, biogas, biofertilizers, or bioactive compounds makes them a precious resource. These various products most often contribute to enriching the soil while reducing dependence on inorganic fertilizers, producing renewable energy, and helping to mitigate the impacts of climate change. Beyond the environmental benefits, managing this resource also presents an economic opportunity for farms and facilitates a transition to more sustainable and resilient systems. As for the future, the valorization of green farm waste might be orientated towards the development of more efficient, accessible and economically viable processes. To achieve this, it is necessary to technically optimize valorization approaches, including metanization, pyrolysis or the extraction of bioactive compounds, in order to subsequently minimize the related costs. Thus, certain techniques such as nanotechnologies, microbial bioremediation and the introduction of green waste into hydroponic systems constitute new avenues of further research, allowing for the diversification of their applications. Therefore, the structuring of local valorization sectors is very essential to establish a more resilient agriculture and achieve better global food security. This requires the implementation of adopted public policy and strong public-private partnerships.

Author Contributions

All authors have made equal contributions to the content presented in this paper.

Conflict of Interest

The authors declare no conflict of interest.

Research Involving Human and/or Animals

Not Applicable.

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