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Utilizing Waste Materials to Enhance Crop Production: A Review

Purba Mishra [a++] and Gritta Elizabeth Jolly [a#*]

[a] *Department of Agronomy, Lovely Professional University, Jalandhar – 144411, India.*

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This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Waste management is a crucial aspect of modern societies, encompassing various activities to ensure the safe and effective disposal of waste materials. It can be classified as hazardous waste, electronic trash (e-waste), industrial waste, and municipal solid waste (MSW). Sustainable waste management practices aim to reduce environmental impact while protecting public health. Urbanization leads to increased residential water consumption, however reusing wastewater for non-potable applications like agriculture can be cost-effective. The overall costs of delivering wastewater for agricultural reuse, including treatment, storage, and transportation, are less the total costs of safe environmental disposal alternatives. Drainage may also be a source of macronutrients (nitrogen, phosphorus, and potassium), which reduces the cost of wastewater for agricultural reuse. The adoption of these principles could lead to a 48% reduction in global greenhouse gas emissions by 2030. The management of hazardous waste, including toxic, flammable, corrosive, or reactive materials, is also a significant concern. In order to safeguard public health and stop the spread of infectious illnesses, animal manure management is crucial. The global generation of construction and demolition waste is expected to double by 2025, with the majority generated in Asia. Sustainable waste management practices are necessary to ensure public health and the environment.

[++] *Research Scholar;*
[#] *Assistant Professor;*
**Corresponding author: E-mail: elizabethgritta41@gmail.com;*

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1. INTRODUCTION

Management of waste is a crucial task for modern societies, it encompasses a range of activities aimed at ensuring the safe and effective disposal of waste materials. Waste can be broadly classified into several categories, such as municipal solid waste (MSW), and hazardous, electronic, and industrial waste. India has significant environmental problems related to garbage production and insufficient trash transportation, collection, treatment, and disposal. India's current waste management system is unable to deal with the amount of waste generated by the growing urban population of the country, which has damaged the environment and public health[1]. The management of MSW is of particular concern as it comprises a significant portion of the waste generated in both developed and developing countries. According to the World Bank, the global generation of MSW is expected to increase by 70% by 2050, with the majority of this increase occurring in economically poor countries [2]. Another challenge in waste management is the increasing amount of e-waste generated globally. According to a global waste monitoring report, the world produced 53.6 million tons of electronic waste in 2019, of which only 17.4% were recycled [3]. This signifies the improved recycling management practices of electronic waste. The adoption of circular economy principles is becoming increasingly important in waste management. Its aim is to reduce waste and promote the reuse and recycling of materials, thereby reducing the environmental impact of waste. According to a report by the Ellen MacArthur Foundation, this principle leads to a 48% reduction in global greenhouse gas emissions by 2030 [4]. Waste management practices also have a major impact on climate change. According to the Intergovernmental Panel on Climate Change (IPCC), waste management accounts for 5% of global [5]. This highlights the need for sustainable waste management practices that reduce GHG including the adoption of renewable energy sources and the reduction of waste generation. The management of hazardous waste is also of significant concern. Hazardous waste includes toxic, flammable, corrosive, or reactive materials. According to the Economic Cooperation and Development Organization (OECD), the world produces approximately 400 million tonnes of hazardous waste annually, most of which is produced in industrialized areas [6]. To attain high environmental and financial effectiveness, major advances in technology were made in waste recycling, landfilling, and burning facilities; yet, the systems view was restricted to the WM systems alone. Novel concepts were designed with the sole goal of bringing about systemic changes within the WM system and have fallen short of offering a long-term, viable solution to the waste issues[7]. Advance technological improvements were made in waste recycling, incineration, and landfills to achieve high environmental and economic efficiency; however, the system view is limited to WM systems. Innovations have been developed to address system changes in the WM system and have failed to provide long-term sustainable solutions to waste problems [8]. The Food and Agriculture Organization (FAO) estimates that 20-30% of fruits and vegetables are wasted during post-harvest processing. The development of bio-based polymers is critical, given the amount of worldwide environmental contamination caused by the manufacture of synthetic plastics like polypropylene (PP) and polyethylene (PET). Every year, 400 million tons of synthetic plastic are manufactured across the world, with less than 9% recycled. The synthetic approach influences optical, mechanical, and chemical qualities such as ultraviolet (UV) absorption, tensile strength, and water permeability. Bio-based polymer manufacture from renewable sources and microbial synthesis are scalable, simple, and have a low environmental effect when compared to chemical synthesis [9].

Sustainable waste management practices are necessary to ensure the protection of public health and the environment [11]. India confronts significant environmental difficulties related to the creation of garbage and insufficient trash transportation, collection, treatment, and disposal. India's current waste management systems are unable to handle the amounts of garbage produced by the country's growing urban population, which harms the environment and public health [12]. However, the adoption of circular economy principles, investment in waste management infrastructure, education on sustainable waste management practices, and

Fig. 1. Processed waste share of FY2016 - FY2023 in India
(Source: India-waste-management-market)[10]

the adoption of renewable energy sources can help address these challenges and ensure sustainability [13].

2. UTILIZING WASTE MATERIAL FROM DIFFERENT BACKGROUNDS

Co-digesting industrial waste with crops resulted in higher methane output and carbon-to-nitrogen ratio compared to digesting the trash alone. Biogas generation from crops and industrial waste reduces the requirement for micronutrients in crop digestion [14]. Various kinds of waste can be utilized to improve crop yield. One of them is agricultural waste such as agricultural industry waste, fruit and vegetable trash, oil cakes, and crop residue [15]. Agricultural trash in the field often consists of crop remnants such as stovers, seed pods, leaves, and straws. Crop residues are a cheap and abundant source of organic waste that may be converted into value-added goods [16]. De-oiling extraction creates a variety of oil cakes, both edible and non-edible, which can be put into soil or used as livestock feed [17]. Animal waste has been used for centuries as a source of nutrients in agriculture. However, when fertilizer is applied, many other soil properties that contribute to soil health are affected. The density of the granules, aggregate stability, filtration, water storage capacity, soil fertility, and biological properties are affected to different degrees by fertilizer application [18]. Composting is a promising way to recycle domestic garbage, surpassing incineration as a disposal method. Compost is an effective fertilizer that enhances crop yields and soil quality [19].

2.1 Industrial Waste

2.1.1 Paper mill waste

The paper-mill industry generates large quality of sludge from waste paper. In reality, more than 400 million tons of paper were produced worldwide [20] and for each ton of paper, 40–50 kg of dry sludge is created [21]. The paper and pulp industry faces challenges in disposing of this solid by-product since it must be gathered and managed appropriately for proper disposal [22]. The disposal process is expensive and raises environmental concerns that need to be addressed. The source material, production method, chemicals, and additives used, as well as the final product's nature and the wastewater treatment technologies utilized, all affect the composition of sludge [23]. Paper sludge was commonly disposed of in landfills in the past as it was considered garbage. This practice is still in place today. However due to the heavy metals, it may have major negative effects on soil and water quality, this type of disposal is being discouraged more and more, if not outright outlawed. Strict regulatory requirements for landfills are necessary to prevent environmental issues resulting from contaminated soil and watersheds. Therefore, the European Landfill Directive 1999/31/EC must be followed by landfills across Europe [24].

Paper mill sludges include a significant percentage of minerals. The proportion of organic material to mineral matter in primary sludge is 40:60, but in secondary sludge, the ratio is 50:50 [23] The pH level of the Cromic Cambisol soil was elevated from 6.1 to 7.2 by 80 mg ha−1 of secondary paper mill waste [25]. The biological material found in PPMS is abundant in the form of lignin and short cellulose fibers, while the organic matter found in secondary sludge is much richer in the form of dead microbial biomass. It has been consistently demonstrated that using them increases soil C reserves, which is particularly important in the present agricultural and sustainability [26] After that, this pulp can be utilized in an on-site paper mill, dried, and allowed to ship to off-site paper mills, or it can be put to use in other sectors of the economy, like as a binder in food and medicine. This pulp is combined with water, at the paper factory and refined to meet the specifications for the final product before coloring agents and fillers like talc, calcium, and clays are added. After that, this material is treated to conform to the final product's specifications [27].

2.1.2 Slaughter-house industries

Solid slaughterhouse waste (SSW) is often disposed of in open-pit landfills. If this kind of solid waste is released into the environment directly, it may produce an unpleasant smell and pollute the air. Furthermore, as a consequence of the nesting vectors, it may transmit illness, and the leachate that results may contaminate groundwater [28]. The main wastes from slaughterhouses include rumen digesta, blood from cows, and other animal leftovers. All around the world, disposing of slaughterhouse wastes in landfills has been a problem for the environment. Large volumes of waste are produced by rural slaughterhouses, and their open disposal poses risks to the environment and public health. Slaughterhouse wastes are transformed into a non-hazardous organic product by heat treatment, which is an ecologically safe method of managing butcher waste [29] Biologically solid wastes can be recycled into fertilizer, feed, or energy. The primary sources of organic fertilizers are plants, animals, and humans. They are rich in organic matter and benefit microbial communities. The process of turning butcher shop wastes into fertilizer preserves nutrients, gets rid of harmful bacteria, and when used in farming, boosts soil fertility and production. Of all the disposal methods, the slaughterhouse wastes may be turned into fertilizer by drying and composting [30].

Utilization of organic compost derived from solid abattoir wastes in the production of soybeans, corn, and other crops [25].On the other hand, the drying of solid slaughterhouse wastes, primarily rumen digesta and bovine blood, allows nutrients to be recycled back into the soil and is seen as advantageous to the environment and a cost-effective waste management approach. In India, solanaceous vegetable agriculture has made use of bovine blood rumen digesta mixture (BBRDM), which has a high nitrogen content and organic matter, as an organic fertilizer or soil conditioner, particularly for tomato, brinjal, and chili [31,32]. The bones, blood, and leftover meat are fantastic sources of phosphorus, which is essential for root crops like onions, garlic, carrots, and parsnips since it helps young plants form strong roots. It is slow-releasing, so plants can benefit for months at a time, and it is simple for plants to absorb and take up. For most plants, it may be put into the planting hole. It is especially helpful when planting bulbs in the fall since it promotes root development, which improves flowering the following spring. It also includes nitrogen, which supports robust plant growth, and lush, green leaves. Lastly, the organic matter in bone meal naturally promotes the growth of microorganisms that can enhance the fertility and structure of the soil.

2.1.3 Wool industry

The quality of sheep raised for dairy and meat production is poor, their wool is typically viewed as a worthless byproduct of sheep farming, leading to widespread unlawful dumping or landfilling, and their economic value is insufficient to pay for the expenses of shearing. Given the fundamental characteristics of discarded materials, such as waste wool, recycling and reusing waste materials is necessary to develop innovative, sustainable technologies and transformation processes that will lead to sustainable manufacturing, thereby minimizing health and environmental problems [33]. Several research has evaluated the impact of various mulch materials on the retention of soil moisture and how effective water use is in relation to crops [34,35]. Wool mulch is one of the new possible tools that may be used in cultivation in place of artificial mulch products. Alternates, organic, and biological mulch materials are often leftover fibers from textile factories [36,37]. It is rich in nutrients, particularly nitrogen; and also has a strong capacity to hold water; this has proved as an effective soil protection material in various trials [38]. An integrated approach to using organic and inorganic fertilizers might preserve productivity. The hydrolyzed wool application also enhanced plant growth and seed emergence [39]. Wool waste with micronutrient application gave maximum yield in bottle gourd [40].

2.1.4 Sludge and sewage industry

The natural result of operating municipal wastewater treatment plants, sewage sludge is a major problem in many nations because of its growing amount and the effects of disposing of it [41]. Dewatered sewage sludge typically contains 3.4% to 4.0% nitrogen, 50–70% organic matter, 30–50% of minerals (1-4 percent inorganic carbon), and 0.5–2.5% phosphorus (P), along with notable concentrations of other elements, including potentially recoverable micronutrients. For example, it is anticipated that extractable resources like phosphorus (P) may become rare or depleted in the following 50–100 years; as a result, P collection from wastewater is becoming more and more attractive option [42] The disposal process is expensive and raises environmental concerns that need to be addressed. The source material, production method, chemicals, and additives used, as well as the final product's nature and the wastewater treatment technologies utilized, all affect the composition of sludge [23].

Because the nutrients needed to drive microbial activity in secondary treatment, as well as the microbial biomass itself, the N and P content of primary sludge is lower than that of secondary sludge (0.04–0.28 %, 0.01–0.06 %, 1.1–7.7 %, 0.25–2.2 %) [43,44] sewage sludge typically contain 20% fat, 50% carbohydrate (sugar, starch, and fiber), 30% to 40% organic matter, 3% total nitrogen, 1.5% total phosphorus, 0.7% total potassium, a C/N ratio of 10% to 20%, and high levels of heavy metal ions such as Cu and Zn [45]. The decomposition of organic compounds in sludge increases the accessible proportion of nutrients, such as nitrogen and phosphorus. Applying sewage sludge at a rate of 200 t·ha-1 enhanced soil nitrogen by 57% and accessible phosphorus by 64.2% [46]. The use of sewage sludge as mulching has given the best seed yield in experiments [47]. To boost soil fertility and agricultural production, several SS dosages were tested to establish the optimal quantity [48]. Adding biochar to SS has been shown to enhance the development of organisms in the soil [49] and minimize toxicity by speciating trace metals [50]. Increases in soil carbon, accessible phosphorus, sodium, nitrates, and electrical conductivity, as well as an improvement in the C:P ratio, indicate excellent mineralization. This improves plant physiology and leads to higher crop yields [51].

2.2 Agricultural Waste

2.2.1 Residue waste

There are various kinds of agricultural residues such as pulp, stubble, seeds, peel, bagasse,roots, molasses, grain husks, stems, straw, leaves, stalks, shells etc. are some of the remnants received from crops. Around The projected amounts are as follows: 2802×106 mg/year for cereal crops, 3107×106 mg/year for 17 cereals and legumes, and 3758×106 mg/year for 27 crops used for food from where agricultural residue generated worldwide [52]. In the states of Punjab and Haryana alone, almost 25 Mt of straws rice, and wheat are burned. About 31,250,000 million MJ of energy are lost during the burning of the leftovers, and 37 Mt of CO2 are released [53]. Crop residues preserve soil moisture, guard against wind and rain erosion, and enhance aeration and penetration into the soil profile [54]. Many potential crop residue management techniques are being used in various parts of the world under real-world field conditions, including cycling of nutrients, conservation tillage, residual mulching, soil conversation techniques, zero-tillage, application in livestock nutrition, and vermicomposting [55-61]. The adoption of management of residues in rice-maize harvest systems can effectively improve system productivity, efficiency of K-use, and apparent K-balance [62]. The incorporation of residues also contributes up to 15% recycling of available K from the soil, thus generating demand for external K supply [62]. It was also reported that the retention of residues under CA was beneficial in reducing the number of soil nematodes in a wheat and soybean harvesting system [63]. When crops are removed, it is very difficult to determine how much nutrients the crops will be able to absorb, and the crop residues have been established to initially block available soil N due to high C: N ratio, so it is very difficult to determine how many nutrients crops will have available [64]

2.2.2 Oil cakes

The wastes from oil extraction operations include significant Concentrations of soluble solids, particles in suspension, fat, grease, and oil that contaminate the water. There are several varieties of oil cakes, including cakes made with coconut oil, sesame oil, mustard oil, groundnut oil, sunflower seeds, olive oil, rapeseed oil, neem oil, Kanraj oil, and palm kernels [16]. of their high N, P, and K content, edible oil cakes including castor, Karanja, and neem cakes are utilized as organic nitrogenous fertilizers. Certain oil cakes have been seen to enhance plant absorption of nitrogen by delaying soil nitrification. Additionally, they shield the plants from insects, parasites, and soil nematodes, giving them a very high resilience to infection [65]. Using neem cake applied at 6 q/ha was the most effective way to control *M. incognita* on okra, while karanj cake applied at 6 q/ha was the most effective way to increase crop yield (49.18-53.51%) [66]. Adding mustard cake to peanut and chickpea soil resulted in substantial increases in root length, root weight, shoot length, and nodules. Adding mustard cake to the soil dramatically boosted the shoot weight of peanut plants [67]. Certain seeds, like tung nuts and castor beans, have oil-cakes that are utilized as fertilizers rather than feed since they are poisonous to many types of dangerous bacteria. Food and vegetable farmers frequently employ oil-cakes as a source of plant material nutrients as well as to manage nematodes [68].

2.3 Livestock Waste

Agriculture has been using animal dung as a source of fertilizers for generations. Applying manure, however, has an impact on several other soil characteristics that support soil health. Manure incorporation into the field increases the fertility of the soil, density of bulk, infiltration, retention of water, and microbial quantities [18]. FAO database revealed that an estimated 94 million tonnes of N, 21 million tonnes of P, and 67 million tonnes of K were found in all cattle dung in 1996. With 60% of the total, cattle are the biggest contributors; pigs and poultry make up 10% and 9% of the total. It was estimated that 22.9 million tonnes of potassium, 8.8 million tonnes of phosphate, and 34 million tonnes of nitrogen had been recovered as manure. In 2018 125 million tonnes of N were produced worldwide from animal dung, a 23% increase from 1990 [69].

There is strong evidence supporting the utilization of animal dung as a source of fertilizer for crop cultivation with multiple studies reporting significant increases in crop yields and nutrient concentrations. When chicken dung and synthetic fertilizers were applied together, the amount of N in plant parts was greatly enhanced [70]. Best crop growth such as plant height, dry matter accumulation, LAI, and no leaves is obstained by the application of cow urine along with biofertilizer [71]. In addition to increasing crop yields, the application of animal waste as a fertilizer can also significantly increase the concentration of essential nutrients in crops [72]. While the addition of manure at specified rates (30%) can enhance the biomass output of lettuce plants, the addition of manure can have varying effects on the phytochemical composition, based upon the stimulant used [73]. Moreover, applying animal waste as a fertilizer can improve soil health and fertility. In India, it is found that the application of goat manure to induced soil organic carbon, accessible nitrogen, phosphate, and potassium to rise substantially [74]. Overall, the use of animal waste as fertilizer can provide numerous benefits for crop production, including increased yields, improved nutrient concentrations, and improved soil health [75]. By enhancing the soil-surface habitat for predators by promoting decomposer populations, altering soil tilth, adding organic matter, and retaining water that provides non-pest food to soil-dwelling predators, animal waste fertilizers can have a top-down effect on conservation biological control [76].

2.4 Fish Waste

Fish manure is described as a sustainable alternative to chemical fertilizers. The article explains that fish manure is made by decomposing fish waste and is rich in nutrients that plants need to grow, like potassium, phosphorus, and nitrogen[77]. The majority of the world's fish harvest roughly 179 million tonnes is produced for human use; nevertheless, each year,35% of the total harvest is lost or squandered[78]. Fish manure can be used in a variety of ways, including as a liquid fertilizer, a soil amendment, or a compost additive. The primary objective of fish waste hydrolysis is to use the technology for industrial purposes. Less price and simple production results decreasing in material costs, achieving high productivity while minimizing labor and energy consumption are some of the key factors in the industrial application process[79]. As vital nutritional components for growth, fish wastes are a major source of nitrogen, phosphorus, and potassium that crops primarily need for growth[80]. About 60–70% of minerals are found in fish bones, mostly hydroxyapatite, which is composed of calcium and phosphorus [81]. The fish processing sector provides more than 70%

of the fish waste. Fish wastes have negative effects on the environment which can be reduced by utilizing them as beneficial goods like fertilizers because they are abundant in vital macro- and micronutrients[82]. Fish manure can also contain trace elements like iron, magnesium, and sulfur, which are important for plant health. These nutrients can help crops grow strong and healthy, and can also improve the quality of the produce [83].

3. USING DOMESTIC WASTE TO IMPROVE CROP YIELD

Paper towels, plastic, oil, water, peel, veggies, grains, seafood, meat, and bones are all mixed to become kitchen waste. Water, organic materials, oil, and salt are abundant in kitchen waste, and their seasonal composition fluctuates significantly [84]. Perishable kitchen trash contains dangerous chemicals such as mycotoxins, eggs, pathogenic bacteria, and parasites [85,86]. Given the sharp rise in fruit and vegetable waste production and environmental effect, this analysis seeks to investigate the possibilities of traditional and developing fruit and vegetable waste management applications in various industries. Traditional applications such as briquetting, waste to energy conversion (landfilling, composting, anaerobic digestion, and enzyme utilization), and adsorption are highlighted, followed by emerging applications such as nutraceuticals, packaging, flavoring agents, and waste-induced nanoparticles to produced value products, which have a promising potential for a sustainable future [87]. Studies have shown that the use of domestic waste compost may enhance the accessibility of nutrients, structure of the soil, and water-holding ability, leading to increased crop yields [88]. Food waste: Food waste includes uneaten food, spoiled food, and food scraps. Food waste can be composted to create nutrient-rich soil for plants. Composting food waste can reduce greenhouse gas emissions by diverting it from landfills [89]. According to a study by the Food and Agriculture Organization of the United Nations (FAO), domestic waste, also known as organic waste, is the waste material that is generated or found in household areas. It may not be in large quantities, but it can be very useful in improving soil quality. This waste includes eggshells, meat, bones, leftover food, vegetable residues, human excreta, dead animals, and fruit waste [90]. It is noteworthy that organic waste accounts for a substantial proportion, ranging from 60% to 75%, of household waste in India. The value of recyclable waste is significantly enhanced when it is free of organic impurities. The compost generated during the composting process is an invaluable product that can revitalize the nutrient content of gardens and poor soils. Furthermore, the additional compost can improve growth conditions by assisting in the retention of soil moisture. The use of compost with animal manure gave maximum yield in an experiment [91] It has been demonstrated that the enhanced physicochemical qualities attained by the food waste conversion process provide extra advantages for raising soil quality. The yearly ryegrass growth was enhanced by the application of food waste anaerobic digestate because it raised soil organic carbon and offered a steady supply of nutrients [92]. Liquid food waste material might be a feasible alternative to commercially available chemical fertilizers, with no negative impact on soil or vegetable growth [93]. A prior study shown that PGPB inoculation had a good effect on vegetable growth and yield. Furthermore, several studies have shown that local effective microorganisms (LEM) are an efficient inoculant for nitrogen mineralization of organic materials. These findings demonstrate the presence and activity of PGPB in LFM, as well as their effectiveness in promoting eggplant development under the investigated circumstances [94].

4. CONCLUSION

Taking care of the environment is a crucial aspect of sustainability that has become more important than ever before. One of the ways we can ensure a better future for our planet is by implementing effective waste management practices Animal, industrial, and agricultural wastes can significantly pollute the environment. They are also potential nutrient supplies, which are useful in soil development. The soil's microbial activity converts waste into nutrients for plant development. Dumping agricultural waste, particularly coffee pulp in the highlands, into waterways has detrimental impacts on the animals and plants. This study estimates the quantity and value of key using wastes for crop production. This method not only reduces the need for chemical fertilizers but also enriches the soil with essential nutrients, thereby improving its chemical and physical properties. It's an effective way to protect both our planet and humankind. Overall, sustainable waste management is key to promoting a healthier and more sustainable future for our world.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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