Waste as a Resource

Jaya Arora
Abhishek Joshi
Ramesh C. Ray *Editors*

Transforming Agriculture Residues for Sustainable Development

From Waste to Wealth

Springer

Waste as a Resource

Series Editor

Cristina Trois, Engineering, University of KwaZulu-Natal, Durban, South Africa

The Waste as a Resource series explores state-of-the-art knowledge and innovation in waste management strategies focused on approaches and technologies that ensure maximum value recovery from waste through materials recycling and energy production. The series aims to navigate the transition toward a circular economy by presenting techniques and strategies for waste minimization, effective waste diversion from landfills, and, most importantly, exploring the possible pathways for treating waste as a resource. The series has a global scope, focusing on developing countries and emerging economies. This will assist in filling the gap in current publications that need to adequately explore valorization technologies that are appropriate for and adaptable in low-income countries or informal contexts.

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Editors
Jaya Arora
Laboratory of Biomolecular Technology
Department of Botany
University College of Science
Mohanlal Sukhadia University
Udaipur, Rajasthan, India

Abhishek Joshi
Laboratory of Biomolecular Technology
Department of Botany
University College of Science
Mohanlal Sukhadia University
Udaipur, Rajasthan, India

Ramesh C. Ray
Center for Industrial Biotechnology Research
Siksha 'O' Anusandhan (SOA)
deemed to be University
Khandagiri, Bhubaneswar, India

Formerly, ICAR-Central Tuber Crops
Research Institute (Regional Center)
Bhubaneswar, Odisha, India

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Preface

Agricultural residues are a significant waste product of various agriculture practices. These residues mainly include crop residues, industrial processing wastes, livestock wastes, and fruit and vegetable wastes. Global trends in agricultural waste production reveal a complex landscape influenced by various factors. Rapid population growth, urbanization, and changing dietary preferences contribute to increased demand for food, amplifying agricultural activities. This in turn leads to higher waste production, encompassing crop residues, post-harvest losses, and livestock waste. Farmers in the countryside burn agricultural waste on their fields after each harvest season. As a result, it has polluted the country's rural areas, water, and air. Efforts to address food security may inadvertently escalate waste volumes. Moreover, as countries modernize, the shift toward intensive farming practices and agro-industrial activities intensifies waste generation. These residues are usually left to decompose, or dumped in landfills, leading to environmental degradation and health hazards. However, with the growing demand for sustainable agriculture practices, there is a need to find innovative ways to utilize these residues. This book aims to provide a comprehensive exploration of the potential of agriculture waste valorization, showcasing innovative technologies and applications for transforming waste materials into valuable resources such as value-added metabolites, bioenergy, etc. Addressing various aspects of the agricultural waste-to-wealth paradigm, it will serve as a valuable resource for researchers, policymakers, and industry professionals seeking sustainable solutions for agricultural residue management and the transition to a more circular economy.

There are 17 chapters in this book, divided into 4 parts. Part I is the *Introduction* consisting of two chapters. Chapter 1 provides an overview of the impacts of agricultural waste on the environment, and Chap. 2 provides a glimpse of various valorization strategies in agricultural residue management. Part II (*Routes for Valorization to Agricultural Wastes*) consists of four chapters describing the biochemical and thermochemical conversion strategies, emerging technologies for the extraction of value-added compounds from agriculture wastes along with the integration of cross-industry technology to increase precision agriculture output and efficiency, including the Internet of Things, artificial intelligence, blockchain, machine learning, unmanned aerial vehicles, and artificial neural networks for the transformation of agricultural activities on digital platforms. One of the chapters in this section has explored the possibility of biodegradable trash as a feasible substitute for developing a maintainable economy that aids society by providing safer and less hazardous greenways for the manufacture of nanoparticles. Part III (*Recent Trends in the Valorization of Agricultural Wastes*) consists of nine chapters covering a wide range of aspects on agro-waste valorization, such as the production of single-cell protein, biofertilizers, and application in soil amendment, high-value animal feed, sustainable packaging materials, i.e., bioplastics, biopolymers, and biocomposites, sustainable building materials, and production of bioenergy. A chapter is dedicated to dealing with agricultural waste applications in water and wastewater treatment. Part IV (*Public Policy and Circular Economy*) has two chapters discussing the challenges and perspectives in agri-waste valorization, taking sugarcane trash as a case study, and the last chapter on economic viability and policy implications of agriculture waste valorization: social, economic impacts, policy frameworks, and regulations, with a case study in Veracruz, Mexico.

The book provides up-to-date information on research and development in the field of agricultural residue transformation into the production of high-value products and biocommodities, from waste to wealth. The book will be useful for all those involved in the environment, disposal of agricultural waste, rural economy, production of useful metabolites, and energy. Editors wish to thank all the international contributors who have put their time at our disposal and made serious efforts to put all the latest information in one place for this book. We are thankful to Prof. Cristina Trois, Director of the Centre for Renewable and Sustainable Energy Studies, South African Research Chair in Waste and Climate Change (SARCHI), School of Engineering, University of KwaZulu-Natal, for accepting the book proposal in the "Waste as a Resource" Book Series. We are also thankful to the staff at Springer editorial and production house for their professional support.

Udaipur, Rajasthan, India Jaya Arora
Udaipur, Rajasthan, India Abhishek Joshi
Bhubaneswar, Odisha, India Ramesh C. Ray
March 2024

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About the Editors

Jaya Arora, Assistant Professor, Department of Botany, Mohanlal Sukhadia University, Udaipur, India has been teaching Botany since 2012. She did her MSc and PhD in Botany with a specialization in plant tissue culture and secondary metabolite production from Mohanlal Sukhadia University. She was awarded the Maharana Fateh Singh Award in 2000 for meritorious performance during her matriculation and the Gargi Award and Scholarship for matriculation by Govt. of Rajasthan, India, 2000. She has 14 years of research experience with one UGC start-up completed project (2013–2015) and mentored one Women Scientists Scheme-A project (2016–2019) funded by the Ministry of Science and Technology, Dept. Science and Technology, Govt. of India. Currently, she is Co-PI in two different projects funded by MHRD RUSA 2.0, India. The research group of Dr. Arora has published research papers in various international and national repute journals with high impact factors, such as *Acta Physiologiae Plantarum*, *In Vitro Cell Dev Biol – Plant*, *Bioengineered*, *Frontiers in Plant Science*, *Nanomaterials*, *Biofuels*, *Biologia Futura*, *Horticulturae*, *Plants*, dealing with plant biotechnology, proteomics (bioactive peptides), natural products, secondary metabolite production, seed biology studies, and conservation of medicinal plants. Dr. Arora has edited and authored five books, including publications with prestigious publishing houses mainly Springer, Cham. This work was funded by various funding agencies like UGC, CSIR, and DST. Currently, she is supervising two PhD students and two students have been awarded PhD degree .

Abhishek Joshi, is currently associated with research and teaching at the Department of Botany, Mohanlal Sukhadia University, Udaipur, India. He holds a Master's degree in Botany with a specialization in Plant tissue culture and halophyte biology. His doctoral research was focused on unraveling the biochemical and molecular mechanisms that enable halophytes to thrive in saline conditions. He had 8 years of research experience of halophytes occurring in Southern Rajasthan of Indian subcontinent with 1 e-book and 26 publications in the international repute journals and books.

Ramesh C. Ray FNAAS, FNABS is currently working as Adjunct Professor, Center for Industrial Biotechnology Research, Siksha 'O' Anusandhan (SOA) deemed to be University, Khandagiri, Bhubaneswar, India, former principal scientist (Microbiology) and head of the ICAR-Central Tuber Crops Research Institute (Regional Centre), Bhubaneswar, India. He has 40 years of research experience in agriculture, food, and industrial microbiology; published 145 research and review papers in national and international journals; 75 books chapters, edited/co-edited 24 books published by Springer, CRC, and Elsevier; and co-authored three books and received more than 8250 citations. He was a guest faculty to Department of Botany and Microbiology, Utkal University, Orissa (India), and visiting professor/scientist at several universities and research institutes in India and abroad and consultant to International Potato Centre, Lima, Peru, on sweet potato. He is a distinguished fellow of the prestigious National Academy of Agricultural Sciences, New Delhi, and the National Academy of Biological Sciences, Chennai, India.

Part I
Introduction

Chapter 1
Agricultural Waste and Its Impact on the Environment

Chitra Yadav, Pooja Yadav, Abhishek Joshi, Mukesh Meena, Harish, and Jaya Arora

Abbreviations

BT	Billion tons
CH4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
EEA	European Environment Agency
Eq	equivalence
FAOSTAT	Food and Agriculture Organization of The United Nations Statistics
GDP	Gross domestic product
GHGs	Greenhouse gases
KT	Kilotons
MT	Million tons
N	Nitrogen
NO2	Nitrous oxides
P	Phosphorus
PAHs	Polycyclic aromatic hydrocarbons
PM	Particulate matter
SDGs	Sustainable development goals

C. Yadav · P. Yadav · A. Joshi · J. Arora (✉)
Laboratory of Biomolecular Technology, Department of Botany, University College of Science, Mohanlal Sukhadia University, Udaipur, India
e-mail: jayaarora@mlsu.ac.in

M. Meena
Laboratory of Phytopathology and Microbial Biotechnology, Department of Botany, Mohanlal Sukhadia University, Udaipur, Rajasthan, India

Harish
Plant Biotechnology Laboratory, Department of Botany, Mohanlal Sukhadia University, Udaipur, Rajasthan, India

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SO2	Sulfur dioxides
UNEP	United Nations Environment Programme
VOCs	Volatile organic compounds

1.1 Introduction

The world's population marked 8 billion people on November 15, 2022, and with this milestone of growing population, it is expected to increase to 9.7 billion by 2050 and 11.2 billion by 2100, respectively (United Nations Department of Economic and Social Affairs, Population Division, 2022). The world population is increasing daily, and fulfilling the food requirements of this growing human population is a major challenge worldwide (Arora et al., 2023; Koul et al., 2022; Riseh et al., 2024). To combat this food insecurity, global food production has increased significantly as a result of the use of modern agricultural techniques. Particularly in developing nations like India and Mexico, the development of dwarf varieties of rice and wheat has a major positive impact on food grain production (Duque-Acevedo et al., 2020). For farm scientists, achieving SDG 2 (Sustainable Development Goal 2) with this growing population is a difficult task. Another important factor is to achieve a balance between the production of nutritious food production and farmer income. To feed this population, agroecological and organic agricultural concepts are integrated (Giller et al., 2021). It is imperative to control population growth while managing agro-industry waste efficiently. Therefore, it is necessary to use all resources sustainably (Ramawat et al., 2023). China, India, and Africa have seen incredible population and economic growth over the past century, along with an increase in the production of agricultural waste, with China holding the top position and India being the second-largest country in agricultural waste generation (Kaul et al., 2022). The agricultural wastes which are the by-products of producing and processing agricultural products mainly staple food crops, fruits, vegetables, and livestock manure produce 998 million tons every year at the global level (Joshi & Arora, 2023; Raut et al., 2023; Tripathi et al., 2019, Fig. 1.1). These waste products came from arable land and horticulture practices. Stems, branches, and leaves make up the majority of crop residue (Mohite et al., 2022; Ray, 2022). Unfortunately, only a small proportion of this waste is utilized in the form of fodder for cattle, used as manure, shed building, low-quality paper, and matchsticks making, while most of it is being disposed of through random burning or landfilling activities (Maji et al., 2020; Patel et al., 2022; Phiri et al., 2023). Burning agricultural waste has traditionally been used to prepare land for the next crop cycle (Arora et al., 2023; Choochuay et al., 2022). They may contain materials useful beings, but their economic value is less than the cost of collection (Obi et al., 2016).

The disposal of agricultural waste through open burning, landfilling, and direct dumping significantly contributes to the emission of various gaseous and solid pollutants including carbon dioxide (CO_2), carbon monoxide (CO), methane

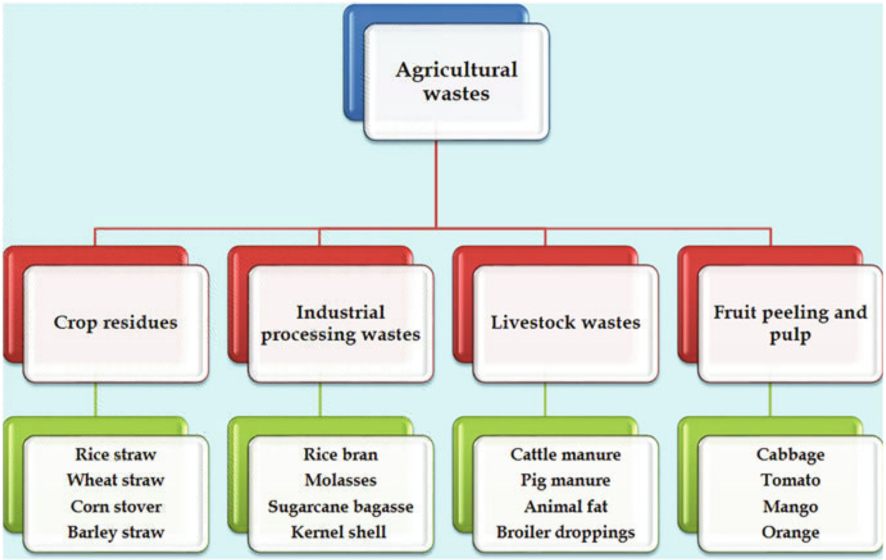

Fig. 1.1 Classification and major examples of agricultural wastes

(CH_4), nitrogen oxides (NOx), sulfur oxides (SOx), particulate matter (PM_{10} and $PM_{2.5}$), and polycyclic aromatic hydrocarbons (PAHs). These pollutants can cause serious environmental damage and pose a risk to human health and safety (Kaab et al., 2019; Koul et al., 2022). Besides, disposal of agrochemicals (fertilizer, pesticides, herbicides veterinary antibiotics) rich residue could result in the deterioration of natural resources, particularly soil and water at a regional scale, and may threaten people's health (He et al., 2019).

Another important issue related to agricultural waste is related to the economy of a country. Despite agricultural food loss, the food waste generated in the food chain comprised 42% from domestic activities, 38% from food dispensation, and 20% from other procedures (Capanoglu et al., 2022; Bancal & Ray, 2022). Such food waste has been estimated at around 57 million tons costing EUR 130 billion in the European Union (EAA, 2024). Thus, food waste reduction can be used to feed the starving deprived people of the growing population. It is a critical issue in terms of the economy, environment, and society. To combat the situation of increasing agro-waste, many countries started working on 5R strategies (Refuse, Reduce, Reuse, Repurpose, and Recycle). The agriculture waste is now being reused as the substrate for producing various value-added compounds (Arora et al., 2023; Bala et al., 2023, see Chap. 2 for details). Agricultural waste can be valorized through various strategies to produce the desired compound and achieve the goals of sustainable development (see Chap. 2). Besides this reduction in food loss is also a big measure being taken up by many countries to fill the food gap, generated by 2050 for feeding approximately 9 billion population (Capanoglu et al., 2022). This chapter deals with the current status of agro-waste generation throughout the world and its impact on the environment along with regulatory framework and policies being implemented by governments of various countries.

1.1.1 Trends in Agriculture Waste Production

Global trends in agricultural waste production reveal a complex landscape influenced by various factors. Rapid population growth, urbanization, and changing dietary preferences contribute to increased demand for food, amplifying agricultural activities. This in turn leads to higher waste production, encompassing crop residues, post-harvest losses, and livestock waste. Farmers in the countryside burned agricultural waste on their fields after each harvest season. As a result, it has polluted the country's rural areas' water and air (Tran et al., 2024). Efforts to address food security are directly correlated with an increase in waste volumes.

On the international scale, agriculture waste varies widely by country and region. In the Food Waste Index Report (United Nations Environment Programme, 2021), studies were carried out with 152 food waste data points identified in 54 countries representing 75% of the world population. The three main sectors were identified for food waste calculation, comprising household, food service, and retail. The contribution of high-income, upper-middle income, and lower-middle-income countries in household waste generation is 79, 76, and 91 kg/capita/year, respectively, while for low-income group, data is insufficient. The high-income countries' contribution to food service and retail is 26 kg/capita/year and 13 kg/capita/year, while for the rest groups, the data is insufficient. Overall, the per capita per year food waste generation is similar in high, upper, and lower-middle-income countries (United Nations Environment Programme, 2021). The estimated waste, arising from food supply chains mainly produced in special geographical conditions, are vegetable oil in the UK approx. 50,000–100,000 tons per year, tomato pomaces in Europe approx. 4,000,000 tons per year, wheat straw in the USA approx. 57,000 tons per year, cereal waste in Europe approx. 40,000–45,000 tons per year, orange peel in the USA approx. 700 tons per year, grape pomace in France approx. 700 tons per year, olive waste worldwide 2,881,500 tons per year, 3,000,000–4,200,000 tons per year apple pomace worldwide, and 70–140 tons per year potato peel worldwide (Capanoglu et al., 2022).

China being the most populous country is occupying the top position in agriculture waste generation. Recently China has generated 870 million tons of straw comprising 230 million tons (MT) of rice straw and 1.06 billion tons (BT) of poultry manure, livestock along 160 MT of household waste as agriculture waste. China is making policies, generating funds to reuse these agricultural wastes, and diverting towards bioenergy generation to fulfill the ever-increasing demand for energy (Liu et al., 2022; Cong et al., 2023). India is the second-largest country in terms of agricultural output, with 70% of rural households still depending on agriculture for their livelihood.

India produces 350–990 MT/year of agricultural waste comprising 130 MT/year of paddy straw (Koul et al., 2022). In a study done by Jain et al. (2014), the major agricultural waste residue comprised of cereals including millet husk, rice husk and oilseeds including groundnut cake and rapeseed mustard cake, fibers with jute, cotton stalk, coconut husk, and sugarcane bagasse. The edible part of crop, the residue-to-crop ratio, and the dry matter fraction in the crop biomass were used to estimate the amount of crop residue generated. For cereal crops, the residue-to-crop ratio ranged from 1.5 to 1.7, for fiber crops from 2.15 to 3.0, for oilseed crops from 2.0 to 3.0, and for sugarcane, it is 0.4. Nine major crops produced 620.4 MT of dry crop residue in total. Uttar Pradesh made the largest contribution followed by Punjab, West Bengal, Haryana, Maharashtra, and Andhra Pradesh in crop residue generation and further burning (Jain et al., 2014).

Malaysia, having good agricultural practices, alone produces almost 1.2 MT of agricultural waste with pineapple leaves as one of the major agricultural waste (Sarangi et al., 2023). Nowadays to achieve zero agriculture waste target, Malaysia has taken the initiative to derive commercial products from pineapple leaves including high-quality fibers, bioethanol, biofertilizer, and hydrogels (Sarangi et al., 2023). Iran produced approximately 3.1 MT of rice (paddy) in 2019, according to FAO statistics. Thus, the production of rice husk and straw will be approximately 620 thousand tons and 4.65 MT, respectively, in the coming years (Pashaki et al., 2024).

In EU countries, agricultural waste, including food waste and related unused products, was estimated at around 2.6 BT/year, from the year 2010 to 2016, which was greater than the waste generated in all other sectors (i.e., industrial solid waste and municipal solid wastes) (Bedoić et al., 2019). Eurostat estimated that 0.088 BT of agriculture waste was generated in the year 2018. EU is contributing approximately 1.3 BT/year to global food waste generation according to the United Nations' Food and Agriculture Organization (FAO) (Duquennoi & Martinez, 2022). Europe including the former Russian Federation contributed 14% to global food wastage and hold the third position worldwide in this sector comparable to North America and Oceania (also 14%). In the same year, Industrialized Asia and South and Southeast Asia contributed to 28% and 23% of food waste generation (Lipinski et al., 2013).

Agriculture waste generation is an indispensable part of countries where either agriculture plays a major role in its gross domestic product (GDP) or has the burden to feed the ever-increasing population. Worldwide various organizations are keeping an eye on that sector to make it more sustainable in terms of the generation of valuable by-products and safe disposal of such agricultural waste. This is not the point in debating which country is producing which waste more as the data points are random and not comparable; the time is to take action to achieve SDG 12.3, SDG 12.4, and SDG 12.5 of Agenda 2023 by ensuring sustainable consumption and production of food.

1.2 Impact of Agriculture Waste on the Environment

Various agricultural activities are correlated with an increase in waste biomass generation at different levels. The improper disposal results in various hazardous environmental impacts (Fig. 1.2). The following sections deal with some of them in detail.

1.2.1 Emissions of Greenhouse Gases (GHGs)

Open burning is the primary cause of air pollution, climate change, and the melting of ice and snow in regions such as the cryosphere (Estrellan & Iino, 2010). Worldwide, farmers frequently burn cultivated fields to remove stalks, weeds, and leftovers before planting new crops. Stubble burning is a substantial contributor to air pollution, particularly in South Asia (Abdurrahman et al., 2020). Several recent studies have reported that open burning of crop residues releases substantial amounts of PM, black carbon, PAHs, volatile organic compounds (VOCs), and other toxic pollutants into the atmosphere, which adversely affect air quality, produce photochemical smog, and reduce visibility (Mehmood et al., 2020; Jaffe et al., 2020; Bahşi et al., 2023). In a recent study, Phuong et al. (2021) investigated the impact of open rice straw burning on the air quality in the Mekong Delta of Vietnam. This study reported a substantial increase in the concentrations of PM, PAHs, VOCs, and

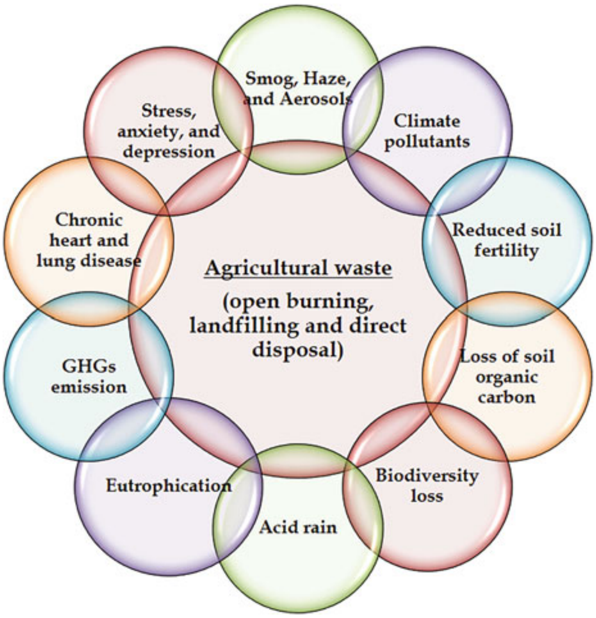

Fig. 1.2 Impacts of agricultural waste on Ecosystems and human health

Table 1.1 Estimated region-wise GHGs emissions by the crop residue-burning practices in the year 2021

Region	Estimated emission (KT)		
	CH_4	N_2O	CO_2 eq (AR5)
Africa	151.3226	3.923	5276.6278
America	275.3083	7.1374	9600.0434
Asia	522.663	13.5506	18,225.473
Europe	121.9359	3.1608	4251.8172
Oceania	14.6803	0.3807	511.9339
World (total)	1085.9101	28.1525	37,865.8953

Data generated from agri-food systems disseminated in the FAOSTAT Climate Change Emissions domains

primary gaseous pollutants. Furthermore, a 1000-fold increase in PAH concentration was reported during this study. The latest gridded emission inventory of $PM_{2.5}$ emissions from residue burning in India reported 990.68 kilotons (KT or Gg) of $PM_{2.5}$ emissions (Sahu et al., 2021), with rice contributing 41% followed by wheat (27%) sugarcane (14%), maize (8%), and coarse cereal (7%).

Also, open burning practices lead to the release of gaseous pollutants, including CO_2, CH_4, and N_2O, which are potent GHGs. These GHGs have detrimental impacts on global warming and climate change (Jogdand, 2020; Mar et al., 2022). Both CO_2 and CH_4 emissions from burning can be attributed to combustion processes, whereas N_2O emissions can be attributed to the decomposition of nitrogen-containing compounds in soil after a burning event (Jiménez et al., 2015). As reported in a recent study by Abdurrahman et al. (2020), burning 63 MT of crop stubble releases 3.4 metric tons of CO, 0.1 metric tons of NOx, 91 metric tons of CO_2, and 0.6 metric tons of CH_4 into the atmosphere.

The most recent data from FAOSTAT indicate that the global emissions of CH_4, N_2O, and CO_2 (eq) resulting from crop residue burning in 2021 are estimated to be 1085.91, 445.17, and 396,983 KT, respectively (Anonymous, 2024). Furthermore, Asia is the largest emitter, accounting for over 48% of total CH_4, N_2O, and CO_2(eq) emissions, followed by Africa, America, Europe, and Oceania (Table 1.1). A recent study that used a novel satellite-based approach to track crop residue burning reported that GHG emissions from agricultural residue burning across India have increased by 75% (1.3 ton CO_2e per hectare) since 2011 (Deshpande et al., 2023).

Other major agri-food system practices such as agri-food waste disposal systems, food processing, and manure management have also produced organic waste, which is commonly disposed of in landfills and composted. A variety of pollutants are released during these processes, including GHGs, phenols, heavy metals, and acid-sensitive compounds (Gaur et al., 2020). When GHGs react with water, they create acidulous compounds such as nitric acid, sulfuric acid, and ammonium nitrate, which later disperse as acid rain that harms every component of both terrestrial and aquatic ecosystems (Debnath et al., 2021; Bhardwaj & Saxena, 2023).

Based on the most recent data from FAOSTAT, it is estimated that the global emissions of CH_4 in 2021 accounted for 42,283.84 KT from agri-food waste disposal, 159.30 KT from food processing, and 9964.68 KT from manure

Table 1.2 Estimated region-wise GHGs emissions by the different practices of agri-food systems in the year 2021

Agri-food system practices	Region	Estimated emission (KT)		
		CH_4	N_2O	CO_2 eq (AR5)
Agri-food waste disposal	Africa	5824.572	29.4668	170,896.7215
	Americas	9395.6797	37.9916	276,465.4041
	Asia	22,565.3707	137.1134	689,840.3073
	Europe	4268.7354	38.7371	137,033.9414
	Oceania	229.4889	1.6641	7023.7549
	World (total)	42,283.8467	244.973	1281,260.1293
Food processing	Africa	1.5101	0.1409	10,164.5488
	Americas	15.8731	0.8762	145,437.1035
	Asia	121.0629	4.0253	295,689.5149
	Europe	19.3422	1.2858	198,386.6935
	Oceania	1.5093	0.0848	9326.5353
	World (total)	159.2977	6.413	659,004.396
Manure management	Africa	769.3245	28.8953	10,164.5488
	Americas	2356.2583	88.1227	145,437.1035
	Asia	4061.8643	224.2352	295,689.5149
	Europe	2463.3302	96.601	198,386.6935
	Oceania	313.9044	7.3231	9326.5353
	World (total)	9964.6817	445.1773	659,004.396

Data generated from agri-food systems disseminated in the FAOSTAT Climate Change Emissions domains

management practices (Anonymous, 2024). Similarly, global N_2O emissions were estimated to be 244.97 KT from agri-food waste disposal, 6.413 KT from food processing, and 445.18 KT from manure management practices. Meanwhile, global CO_2(eq) emissions were estimated to be 1,281,260.13 KT from agri-food waste disposal, 659,004.39 KT from food processing, and 659,004.39 KT from manure management practices (Table 1.2). In the current report published by the European Environment Agency (EEA), in 2024, agriculture in the European Union contributed to 11% of GHGs, with a significant contribution of harmful air pollutants such as ammonia.

1.2.2 Pollution of Land and Water Resources

Agricultural activities generate a significant amount of organic waste, which can have significant impacts on terrestrial as well as aquatic ecosystems if improper landfilling and dumping are not managed (Siddiqua et al., 2022).

Undoubtedly, the agriculture sector consumes 70% of the global surface water supply and is the primary cause of the deprivation of both surface and groundwater resources (Jury & Vaux, 2007). Over the past decades, there has been a significant increase in the use of fertilizers, pesticides, herbicides, and other synthetic agri-chemicals to meet the growing food demand in moving dietary preferences and population growth (Verma et al., 2023). When these chemicals are applied beyond the capabilities of the soil to retain, agrochemical runoff during the production of crops, vegetables, and fruits can lead to water pollution (Pericherla et al., 2020; Verma et al., 2022; Zahoor & Mushtaq, 2023).

Although, nitrogen (N) and phosphorus (P) are crucial macronutrients for plant growth, an excess amount of these nutrients in water can have severe ecological consequences. The presence of excessive amounts of nitrate (NO_3^-) and phosphate (PO_4^{3-}) in surface waters can result in eutrophication, which is caused by excess nutrients stimulating the growth of plants and algae (Liu et al., 2021; Akinnawo, 2023).

It has been shown that the groundwater can be contaminated by synthetic pesticides and herbicides through a process called leaching, which implicates the downward crusade of chemicals from the soil surface by rainfall, infiltration, and irrigation (Sadegh-Zadeh et al., 2017). As a result of the intensive use of pesticides in agriculture for high yields, water bodies have been polluted by runoff from terrestrial environments, as well as the direct disposal of chemical waste. Besides deteriorating water quality, these chemicals also pose a threat to non-target organisms, including fish, shrimp, phytoplankton, and zooplankton (Kumar et al., 2023).

Similarly, veterinary antibiotics are widely used in livestock farming, and their utilization is anticipated to increase by over 60% shortly (Spielmeyer, 2018). A substantial portion of such antibiotics added to animal feed is excreted in the urine or feces. Studies have indicated that many antibiotics are strongly adsorbed in soils and are not easily degraded. Upon excretion, antibiotics can pollute the surface or groundwater via nonpoint source pollution from manure-applied land (Peña et al., 2020; Kokotović et al., 2024). Despite the low concentrations, manure-applied antibiotics could lead to a decline in microbial population by shrinking food sources and affecting decomposition and mineralization processes (Zaller et al., 2021; Kaur et al., 2021).

The pollutants generated from agri-food and livestock production practices have detrimental effects on aquatic ecosystems, resulting in a decline in fish populations and alterations to the composition of aquatic plants and animals (Akinbile et al., 2016; Zhao et al., 2020). Furthermore, these pollutants can disrupt biodiversity by eliminating weeds and insects, which can have cascading effects on the ecological food chain (Mahmood et al., 2016; Naz et al., 2023).

Food processing industries, such as oil mills and paper and pulp industries, have detrimental effects on both land and water resources. The waste produced by these industries contains a mixture of organic and inorganic contaminants, primarily arising from utensils and floor cleaning rather than food waste (Singh & Chandra, 2019). This wastewater, commonly referred to as effluent, ultimately flows into rivers and lakes, leading to pollution of aquatic ecosystems (Asgharnejad et al., 2021). Furthermore, the waste generated from the lye peeling of vegetables and fruits, which utilizes high salt concentrations for pickling and food processing, has been shown to adversely affect soil fertility. Several recent studies have demonstrated that residual waste and effluents produced by food processing industries adversely impact aquatic and terrestrial ecosystems, leading to changes in water and soil quality as well as a decline in aquatic and terrestrial creature populations (Nguyen et al., 2020; Read et al., 2020; Shabir et al., 2023).

1.2.3 Impact on Human Health and Well-Being

The burning of crop residues releases a mixture of hazardous pollutants that can exacerbate respiratory diseases, including asthma, chronic obstructive pulmonary disease, and bronchitis (Parikh et al., 2021). Recent studies have also linked exposure to chronic pollutants to adverse cardiovascular outcomes, such as an increased risk of heart attack, stroke, and cardiovascular mortality (Adetona et al., 2020; Chukwuemeka et al., 2021).

The abundant release of pollutants like black carbon, $PM_{2.5}$, and some gaseous pollutants (SO_2, CO, N_2O, etc.,) during stubble burning can induce systemic inflammation, oxidative stress, and endothelial dysfunction, contributing to the development and progression of cardiovascular and neurodegenerative disorders (Jadhav et al., 2022; Kusumawardani et al., 2023). Long-term exposure to these pollutants can also increase stress, anxiety, and depression as well as decrease cognitive function and productivity (Lai et al., 2022; Ramadan et al., 2023). It has been shown that psychologically vulnerable populations, such as children, the elderly, and individuals with preexisting health conditions, are disproportionately affected by these pollutants, further contributing to social disparities in health outcomes (Ajay et al., 2022; Khurana et al., 2023).

Landfilling and disposal practices for agro-industrial waste pose significant risks to human populations. Residents living near landfills may experience respiratory issues and infections owing to chronic exposure to landfill emissions, particularly VOCs and PM (Ogbuehi et al., 2022). Agro-industrial waste contains organic pollutants, pathogens, and heavy metals, which can be leached into water bodies, causing waterborne diseases such as diarrhea and drowsiness, especially in populations that rely on untreated or inadequately treated water sources (Kumari et al., 2017; Asomaku, 2023).

During the cultivation practices, agricultural workers are frequently exposed to synthetic agrochemicals, which can negatively impact both workers and surrounding communities. Through skin contact, exposure to these chemicals may cause serious health problems, such as diabetes, reproductive disorders, neurological dysfunction, cancer, and respiratory illness (Rani et al., 2021).

1.3 Regulatory Framework and Policies

Regulatory frameworks and policies are crucial for managing the environmental impact of agricultural waste and promoting sustainable waste management practices. International agreements, conventions, and policies provide a global cooperative framework for environmental issues, while national legislation and regulations establish standards and requirements for waste management (Joshi et al., 2019; Zorpas, 2020).

The Basel Convention, established in 1989, aims to control the transboundary movement of hazardous wastes and ensure environmentally sound management. It provides guidelines for waste classification, minimization, and disposal, emphasizing the prevention of pollution and the protection of human health and the environment. Regulating the international trade of hazardous waste helps to prevent dumping and improper disposal practices (Krueger, 2001).

The Stockholm Convention, adopted in 2001, targets persistent organic pollutants (POPs) related to agriculture, such as pesticides and agrochemicals. Essentially, this convention aims to eliminate or restrict the production, use, and release of POPs (Rayfuse, 2016). It contributes to protecting biodiversity and public health by minimizing the release of POPs into the environment (Wang et al., 2022).

International cooperation and coordination regarding environmental issues, including agricultural waste management, is greatly facilitated by the UN Environment Programme (UNEP). The UNEP promotes integrated approaches to addressing agricultural runoff and waste disposal pollution (Ijaiya, 2017). By raising awareness, providing technical assistance, and supporting capacity-building efforts, UNEP helps countries develop and implement policies and strategies for sustainable agricultural waste management, thus reducing environmental degradation and promoting ecosystem resilience (Citaristi, 2022). Further, see Chap. 17 of this book for details on policy frameworks and regulations related to agricultural waste management.

1.4 Conclusion

The impact of agricultural waste on soil, water, air, biodiversity, and climate poses significant challenges to both environmental sustainability and human well-being, highlighting the importance of waste management in agriculture. Policy instruments and incentives encouraging farmers to adopt environmentally friendly practices coupled with RandD initiatives supporting innovation and technological advancement in waste management can help mitigate these challenges. For instance, the implementation of “no burn” and 5R (Refuse, Reduce, Reuse, Repurpose, and Recycle) strategies has the potential to reduce GHGs and black carbon emissions by half, while also providing economic and social benefits not only to farmers but to the entire population. By implementing comprehensive regulatory frameworks and policies, policymakers can protect the environment, promote public health, and ensure the sustainability of agricultural production systems.

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