IntechOpen

Agricultural Waste and Residues

Edited by Anna Aladjadjiyan

AGRICULTURAL WASTE AND RESIDUES

Edited by **Anna Aladjadjiyan**

Agricultural Waste and Residues
http://dx.doi.org/10.5772/intechopen.74361
Edited by Anna Aladjadjiyan

Contributors

George Fouad Antonious, Mutala Mohammed, Rosa María Fuentes-Rivas, Francisco Martin-Romero, Reyna Maria Guadalupe Fonseca-Montes De Oca, Jose Ramos, Ignacio Gómez, Jose Navarro-Pedreño, Mª Belén Almendro-Candel, Antonis Zorpas, Nurudeen Ishola Mohammed, Nassereldeen Ahmed Kabbashi, Abass Alade, Gabriel Malomo, Aliyu Madugu, Stephen Bolu, Zainab Usman, Umar Bunjah, Hamidatu Darimani, Ryusei Ito, Anna Aladjadjiyan

© The Editor(s) and the Author(s) 2018
The rights of the editor(s) and the author(s) have been asserted in accordance with the Copyright, Designs and Patents Act 1988. All rights to the book as a whole are reserved by INTECHOPEN LIMITED. The book as a whole (compilation) cannot be reproduced, distributed or used for commercial or non-commercial purposes without INTECHOPEN LIMITED's written permission. Enquiries concerning the use of the book should be directed to INTECHOPEN LIMITED rights and permissions department (permissions@intechopen.com).
Violations are liable to prosecution under the governing Copyright Law.

Individual chapters of this publication are distributed under the terms of the Creative Commons Attribution 3.0 Unported License which permits commercial use, distribution and reproduction of the individual chapters, provided the original author(s) and source publication are appropriately acknowledged. If so indicated, certain images may not be included under the Creative Commons license. In such cases users will need to obtain permission from the license holder to reproduce the material. More details and guidelines concerning content reuse and adaptation can be foundat http://www.intechopen.com/copyright-policy.html.

Notice

Statements and opinions expressed in the chapters are these of the individual contributors and not necessarily those of the editors or publisher. No responsibility is accepted for the accuracy of information contained in the published chapters. The publisher assumes no responsibility for any damage or injury to persons or property arising out of the use of any materials, instructions, methods or ideas contained in the book.

First published in London, United Kingdom, 2018 by IntechOpen
eBook (PDF) Published by IntechOpen, 2019
IntechOpen is the global imprint of INTECHOPEN LIMITED, registered in England and Wales, registration number: 11086078, The Shard, 25th floor, 32 London Bridge Street
London, SE19SG – United Kingdom
Printed in Croatia

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Additional hard and PDF copies can be obtained from orders@intechopen.com

Agricultural Waste and Residues
Edited by Anna Aladjadjiyan

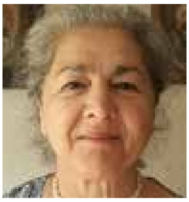
p. cm.

Print ISBN 978-1-78923-572-2

Online ISBN 978-1-78923-573-9

eBook (PDF) ISBN 978-1-83881-793-0

Meet the editor



Anna Aladjadjiyan has worked for 40 years in the Agricultural University (AU), Plovdiv, Bulgaria. She holds an MSc degree in physics of semiconductors, a PhD degree in physics of condensed matter and a DSc degree in agriculture. She was the former head of Department (Physics and Mathematics) and vice-rector (International and Public Relations) of AU. She has previously been a professor of physics and was a member of the editorial board of the Journal of Central European Agriculture (2001–2007) and the editorial board of the Journal of Environmental Protection and Ecology (2002–2009). She has coordinated 15 international projects for Bulgaria: Altener, Thermie, PECO, Bulgarian Research Fund, Socrates-Erasmus Institutional Co-ordinator (2000-2007), Quality Culture (2003-2005), ISEKI-FOOD (Erasmus Network; 2005 –2012), FP7, Horizon2020. She was an expert in the evaluation of ALTENER proposals in 2002 and ERASMUS proposals in 2006–2009. Presently, she is the president of the National Biomass Association (BGBIOM).

Contents

Preface XI

Section 1 Introduction 1

Chapter 1 Introductory Chapter: Agricultural Waste as a Source of Raw Materials 3
Anna Aladjadjiyan

Section 2 Fertilisers from Agricultural Waste 7

Chapter 2 Physical Properties of Soils Affected by the Use of Agricultural Waste 9
María Belén Almendro-Candel, Ignacio Gómez Lucas, Jose Navarro-Pedreño and Antonis A. Zorpas

Chapter 3 Chromium Species and 3D-Fluorescence Spectroscopy in a Soil Irrigated with Industrial Wastewater 29
Rosa María Fuentes-Rivas, Francisco Martin-Romero, Daury García Pulido, Reyna Maria Guadalupe Fonseca-Montes de Oca, Janete Moran Ramírez and Jose Alfredo Ramos Leal

Chapter 4 Biochar and Animal Manure Impact on Soil, Crop Yield and Quality 45
George F. Antonious

Section 3 Biofuels from Agricultural Waste 69

Chapter 5 Significance of Agricultural Residues in Sustainable Biofuel Development 71
Nurudeen Ishola Mohammed, Nassereldeen Kabbashi and Abass Alade

Chapter 6 **Bio-Drying of Biodegradable Waste for Use as Solid Fuel: A Sustainable Approach for Green Waste Management 89**
Mutala Mohammed, Augustine Donkor and Ismail Ozbay

Section 4 Sustainability and Risk Assessment 105

Chapter 7 **Post-Treatment and Microbial Risk Assessment of Compost for Food Production 107**
Hamidatu S. Darimani and Ryusei Ito

Chapter 8 **Sustainable Animal Manure Management Strategies and Practices 119**
Gabriel Adebayo Malomo, Aliyu Shuaibu Madugu and Stephen Abiodun Bolu

Preface

This book is dedicated to the reuse of waste and residues from the agricultural sector. Plant residues, as well as animal manure and residues from animal breeding, contain useful elements that can be processed for production of fertilizers, compost for soil recultivation and biofuels. The emerging energy and resources crisis calls for development of sustainable use of resources, namely reuse of waste and residues. The reuse of waste is an important part of the cycle or green economy, which is the subject of present development. This book contains eight chapters and is divided into four sections. The first section contains the introductory chapter from the editor. The second section is related to the preparation of fertilizers and compost for soil amelioration from agricultural residues and waste water. The third section considers the use of agricultural waste for biofuels - solid and biogas. The fourth section contains chapters discussing sustainability and risk assessment related to the use of agricultural waste and residues. Some of the chapters are with high scientific value and hence are oriented to more narrow auditory; some are popular and can be applied for dissemination of useful practices.

With the publication of this book, the editor (as well as the authors) hopes to increase the interest and information about the development of recycle economy especially in the rural regions.

Anna Aladjadjiyan
National Biomass Association (BGBiom)
Plovdiv, Bulgaria

Section 1

Introduction

Chapter 1

Introductory Chapter: Agricultural Waste as a Source of Raw Materials

Anna Aladjadjiyan

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79621

1. Introduction

The intensive development of industrial technologies in the last century led to considerable exhaustion of natural resources. The growing human population needs more and more food and energy and creates higher and deeper pollution of the environment. Without taking measures for prevention of these harmful tendencies, the planet soon would face an ecological catastrophe. To avoid the problem, politicians and scientists from all over the world are looking for different solutions. Considerable importance has the reuse of waste and residues because it offers new resources of raw materials and decreasing of pollution. Most attractive possibilities at the moment represent the processing of waste and residues for bioenergy, and for soil additives and bio-fertilizers as well.

The reuse of waste and residues from the agricultural sector is an actual task in our time. Plant residues and animal residues (manure and bedding) contain useful elements and can be processed for production of bio-fertilizers, compost for soil re-cultivation and biofuels.

Unfortunately, six authors of the chapters included in this book represent non-European societies. Only one chapter is authored by representatives of EU countries. This fact creates the impression for less interest to the reuse of waste and residues in the EU countries. Our experience in this field shows the opposite.

2. Use of agricultural waste and residues as a source for biofuels production

In recent years, Bulgarian National Biomass Association took part in different projects, related to the reuse of agricultural waste and residues. In the frames of the project Improved Nutrient and Energy Management through Anaerobic Digestion (INEMAD), new flows of energy and materials within the agricultural sector (or linked to the agricultural sector) have been analyzed for creating opportunities for rethinking the relation between crop and livestock production. The possibilities for biogas production from animal manure and plant residues in partner countries have been studied [1, 2]. Composting of waste residues and using the compost for soil re-cultivation [3] have been explored as well. A comparison of nutrient content in composted solid residues from anaerobic digestion and bio-fertilizers has been performed [4]. The economic efficiency of different installations for bioenergy production and composting has been compared, too [5].

The new EU programme H2020 also gives possibilities for developing bioenergy investigations. The project B4B (Bioenergy for Business “Uptake of Solid Bioenergy in European Commercial Sectors”, Horizon 2020, Coordination and Support Action [6]) explores the possibilities to increase the usage of bioenergy. This task should be realized through a fuel-switch from coal, oil or natural gas, used in “in-house” boilers in commercial sectors for heat purposes or in district heating, to solid biomass sources—wood pellets and chips.

The project BioRES (Sustainable Regional Supply Chains for Woody Bioenergy, Horizon 2020 [7]) aimed to increase the local production and consumption of wood biomass via the development of Biomass Logistics and Trade Centres (BLTCs). The project gave a thorough and

useful insight into all important aspects of the BLTC concept—from the wood logging process to the delivery of quality solid biofuels to the end users, through presentation of practical guidance and best practices from European technology leaders.

As a result of both projects, B4B and BioRES, the interest to wood pellet production from wood and plant residues and its use for heating in Bulgaria raised. The use of pellets for heating is expected to decrease air pollution.

3. Agricultural waste and residues as a source for BioBased products

The last project, ENABLING (Enhance New Approaches in BioBased Local Innovation Networks for Growth [8]) is related to cycle economy. It intends to respond to the need, felt by practitioners across Europe, of improving and systematizing collaboration among the different stakeholders, and in particular between the source of biomass streams, and the processing and transformation industry, or Bio-Based Industry (BBI). The main goal of the project is to support the spreading of best practices and innovation in the provision, production, and pre-processing of biomass for the BBI. In particular, ENABLING aims at creating appropriate conditions for the development of efficient biomass to Bio-Based Products and Processes (BBPs) value chains. The agricultural waste and residues are considered as important source of biomass for BBPs as well.

4. Conclusion

Development of technologies for reuse of agricultural waste and residues makes significant contribution to sustainable society by decreasing the depletion of natural resources and the pollution of the planet. Additionally, in social aspect it creates new jobs and provides cleaner living environment.

Author details

Anna Aladjadjiyan

Address all correspondence to: anna.garo@gmail.com

National Biomass Association (BGBiom), Plovdiv, Bulgaria

References

[1] Zahariev A, Penkov D, Aladjadjiyan A. Biogas from animal manure—Perspectives and barriers in Bulgaria. Annual Research & Review in Biology. 2014;**4**(5):709-719

[2] Aladjadjiyan A, Kakanakov N, Zahariev A. Improvement of agricultural waste and residues use through biogas production. Forestry Ideas. 2014;**20**(2):151-155

[3] Zahariev A, Kostadinova S, Aladjadjiyan A. Composting municipal waste for soil recultivation in Bulgaria. International Journal of Plant & Soil Science. 2014;**3**(2):178-185

[4] Aladjadjiyan A, Penkov D, Verspecht A, Zahariev A, Kakanakov N. Biobased fertilizers—Comparison of nutrient content of digestate/compost. Journal of Agriculture and Ecology Research International. 2016;**8**(1):1-7

[5] Atanasov D, Aladjadjiyan A, Penkov D. Economic efficiency comparison of different installations for bio-energy and compost production. BAOJ Nutrition. 2017;**3**(3):045

[6] www.bioenergy4business.eu/

[7] http://bioresproject.eu/

[8] www.enabling-project.com

Section 2

Fertilisers from Agricultural Waste

Physical Properties of Soils Affected by the Use of Agricultural Waste

María Belén Almendro-Candel,
Ignacio Gómez Lucas, Jose Navarro-Pedreño and
Antonis A. Zorpas

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.77993

Abstract

This chapter provided an overview of the physical properties of soils and their importance on the mobility of water and nutrients and the development of a vegetation cover. It also gives some examples of why the use of agricultural residues can affect positively soil physical properties. The incorporation of agricultural wastes can be a sustainable practice to improve soil characteristics, favoring a model of zero waste in agricultural production and allowing better management of soils. We review and analyze the effect of the use as amendments of different agricultural residues, on physical properties of the soil (e.g., bulk density, porosity, and saturated hydraulic conductivity), especially related to the movement of water in the soil.

Keywords: saturated hydraulic conductivity, bulk density, porosity, agricultural wastes

1. Introduction

The major environmental problems all over the world are the production and accumulation of wastes. Many considerations should be taken into account but, especially, those from the targets given by the European Union (EU). These problems related to wastes, together with the exhaustion of many resources, direct the European Union (EU) toward a strategy of zero waste through the circular economy. The transition to a more circular economy, where the value of products, materials, and resources is maintained in the economy for as long as possible, and the generation of waste minimized is an essential contribution to the EU's efforts to develop a sustainable, low-carbon, resource-efficient, and competitive economy [1].

IntechOpen

In the EU plan action for the circular economy, we can find targeted actions for various types of waste. Agricultural wastes can be reflected in two aspects of this plan: recycling of nutrients and biomaterials.

Recycled nutrients are a distinct and important category of secondary raw materials, for which the development of quality standards is necessary. They are present in organic waste and can be returned to soils as fertilizers. Their sustainable use in agriculture reduces the need for mineral-based fertilizers, the production of which has negative environmental impacts, and depends on imports, e.g., phosphate rock, a limited resource [1].

Bio-based materials, e.g., those based on biological resources (such as wood, crops, or fibers), can be used for a wide range of products (construction, furniture, paper, food, textile, chemicals, etc.) and energy uses (e.g., biofuels). The bioeconomy hence provides alternatives to fossil-based products and energy and can contribute to the circular economy. Bio-based materials can also present advantages linked to their renewability, biodegradability, or compostability. On the other hand, using biological resources requires attention to their life cycle environmental impacts and sustainable sourcing. The multiple possibilities for their use can also generate competition for them and create pressure on land use [1].

Agriculture is one of the major activities that produces wastes and consumes space, the agricultural soils. It is important to find a synergy between this activity and the soil. In this sense and following the considerations of the EU, crop residues are an important source of plant nutrients and organic matter [2]. Reuse of organic materials is desirable in order to reduce waste streams and to take advantage of the soil benefits associated with added organic matter and associated plant nutrients [3].

Nowadays, it is well known that the application to the soil of organic amendments derived from urban, agricultural, industrial, or municipal activity has several agronomic and environmental effects [4]. This addition can be a good strategy to maintain or even increase the levels of organic carbon in the soil [5]; to improve physical properties such as stability of aggregates and soil porosity [6–8]; to incorporate nutrients such as N, P, and K, thus avoiding the high fossil energy costs and therefore the impact on global warming due to the production and the use of synthetic fertilizers [9]; and to help cushion climate change through the sequestration of atmospheric CO_2 by the organic compounds of the soil [10].

Considering the physical properties and the soil organic carbon (SOC), organic matter amendments can increase water holding capacity, soil porosity, water infiltration, and percolation while decreasing soil crusting and bulk density [11–13]. One of the main measurable effects of the repeated application in the soil of organic wastes is the increase of soil porosity and, therefore, the decrease in the bulk density of the soil [8, 14]. It is also expected to be beneficial for the work of tilling the soil, thus reducing the draft force and, consequently, a possible decrease in tractor fuel [15]. The energy saved due to the lower resistance that the soil offers when being worked if we apply waste is being ignored from the waste treatments that imply the application to the soil of this in the environmental evaluations. However, reducing greenhouse gas emissions can be important [15].

This chapter pays attention to the physical properties of the soil due to their importance in plant growth and soil stability and the possibilities associated to the use of agricultural wastes. Moreover, it is centered in applying the circular economy concept and zero waste in agricultural systems that can be able to reuse their own wastes.

Agricultural wastes can be used as a source of organic matter and nutrients for soils and influence the physical properties of soils. They can also be easily applied as mulching, providing numerous advantages [16]. So, this chapter gives an overview of the positive effects of recycling vegetable wastes and soil physical properties.

2. Importance of the physical properties of the soil

The physical properties of the soil are very important for agricultural production and the sustainable use of soil. The amount and rate of water, oxygen, and nutrient absorption by plants depend on the ability of the roots to absorb the soil solution as well as the ability of the soil to supply it to the roots. Some soil properties, such as low hydraulic conductivity, can limit the free supply of water and oxygen to the roots and affect negatively to the agricultural yield.

2.1. Soil structure

Soil structure is one of the most important soil's physical factors controlling or modulating the flow and retention of water, solutes, gases, and biota in agricultural and natural ecosystems [17, 18]. Soil structure is very important in soil productivity and is a limiting factor of crop yield [19, 20]. Soil structure controls many processes in soils. It regulates water retention and infiltration, gaseous exchanges, soil organic matter (SOM) and nutrient dynamics, root penetration, and susceptibility to erosion [21]. For these reasons, soil structure stands out among the physical properties of the soil, since it exerts an important influence on the edaphic conditions and the environment.

The term "structure" of a granular medium refers to the spatial arrangement of solid particles (texture) and void spaces. Most soils tend to exhibit a hierarchical structure. That is, primary mineral particles, usually in association with organic materials, form small clusters or "first-order aggregates." These form larger clusters or "second-order aggregates" [22]. Aggregate hierarchy in soils is reflected in increasing aggregate size with each successive level. However, the term "structure" in soil cience generally carries a connotation of bonding mechanisms in addition to geometrical configuration of particles [22]. Organic matter acts as a cement that can help the formation of aggregates and, therefore, the soil structure.

Without hierarchical structure, medium- and fine-textured soils such as loams and clays would be nearly impermeable to fluids and gases [22]. Moreover, the soil organic carbon has a greater effect on aggregation especially in coarse-textured soils [23]. Thus, structure plays a crucial role in the transport of water, gases, and solutes in the environment and in transforming soil into a suitable growth medium for plants and other biological organisms [22].

Aggregation is an indicator of soil structure and results from the rearrangement of particles, flocculation, and cementation [24–26]. Organic matter has been clearly identified as one of the key components of soil structural stability. However, in agricultural soils, it is progressively being depleted by intensive cultivation, without adequate yield of plant biomass. The loss of soil structure is increasingly seen as a form of soil degradation [27] and is related to the activities that are carried out in the soil and by the crop. Maintenance of optimum soil physical conditions is important for sustaining plant growth and other living organisms in soils. Poor soil structure results in poor water and aeration conditions that restrict root growth, thus limiting efficient utilization of nutrients and water by plants [28]. Soil structure also determines the depth that roots can penetrate into the soil [29].

2.2. Aggregate stability

Soils with high organic matter content tend to have larger, stronger, and more stable aggregates that resist compaction, whereas the opposite is true for soils with less organic matter. An improvement in soil aggregate stability has several consequences for an agroecosystem, including reduced risk of soil compaction and erosion [30]. The quality of soil structure greatly depends on the soil organic carbon (SOC) content [31], especially on the fraction of labile SOC (also called the "particulate organic matter" because of this fraction cycles relatively quickly in the soil). Labile organic matter also plays an important role in maintaining soil structure and providing soil nutrients [32].

Aggregate stability is a keystone factor in questions of soil physical fertility and can be enhanced by means of an appropriate management of organic amendments, which can maintain an appropriate soil structure. This agronomic procedure could improve pore space suitable for gas exchange, water retention, root growth, and microbial activity [9]. Aggregate stability at the soil surface is affected mainly by exposure to rainfall (drop impact and runoff). A bare soil (e.g., a soil from which crop residues have been exported or incorporated into the soil by plowing) is in direct contact with raindrops, which facilitates a breakdown of soil aggregates, increasing soil erodibility. Aggregate degradation can lead to surface sealing and crust formation, which reduces the water infiltration rate and increases the risk of soil erosion and the loss of valuable topsoil [33]. High silt content, together with low organic matter content, results in soils that are more prone to aggregate breakdown and surface crusting [29, 34]. Organic matter applied on the topsoil protects to the erosion and favors the aggregation of mineral particles.

2.3. Soil compaction

Soil compaction is a form of physical degradation in which soil biological activity and soil productivity for agricultural and forest cropping are reduced, resulting in environmental consequences. Compaction is a process of densification and distortion in which total and air-filled porosity and permeability are reduced, strength is increased, soil structure are partly destroyed, and many changes are induced in the soil fabric and in various characteristics [35].

Generally, four indicators quantify soil compaction: total porosity, pore size distribution, bulk density, and penetration resistance. Given that root growth is impeded by soil compaction, these indicators are probably negatively correlated with root growth and rooting depth [29]. Even more, these properties are closely related to water movement, water availability for plants, and soil gas exchange.

2.4. Porosity

Porosity is a main indicator of soil structural quality. Therefore, its characterization is essential for assessing the impact of adding organic matter to a soil system. Reduced porosity results from the loss of larger pores and the increase of finer pores [36].

A soil's porosity and pore size distribution characterize the pore space of the portion of the soil's volume that is not occupied by solid material. The basic character of the pore space governs critical aspects of almost everything that occurs in the soil: the movement of water, air, and other fluids; the transport and the reaction of chemicals; and the residence of roots and other biotas. By convention, the definition of pore space excludes fluid pockets that are totally enclosed within solid material. Thus, porous space is considered a single and a continuous space within the body of soil. In general, it has fluid pathways that are tortuous, variably constricted, and usually highly connected among themselves [37].

The relationship between the storage capacity and the movement of water in soils with porosity is evident and fundamental. However, not only the total number of pores defines the water behavior of the soil but also and in many cases predominantly the shape, size, and distribution of the pores. From the agronomic point of view, the size distribution not only affects the amount of water that can hold the soil but also regulates the energy with which it is retained, the movement toward the plant, toward the atmosphere, and toward other zones of soil.

The use of agricultural wastes as soil amendments facilitates the maintenance of the porosity in two forms: directly, if the agricultural wastes are ligneous matters with high resistance to biodegradation and, indirectly, after the transformation of the initial organic matter into humic substances and forming aggregates and enhancing the soil structure.

2.5. Bulk density

One of the most prominent indicators of soil structure is soil bulk density (dry bulk density (BD)), its determination does not require any specific expertise or expensive equipment, and it is based on sampling undisturbed soil. Bulk density (BD) is calculated as the ratio of the dry mass of solids to soil volume. The values of both bulk and particle density are necessary to calculate soil porosity [38]. Porosity can then be derived from BD, knowing or approximating the particle density value [21].

This physical property is dynamic and varies depending on the edaphic structural conditions. It can also be modified by soil biota, vegetation, and mechanical practices, trampling by livestock, agricultural machinery, weather and season of the year, etc. [39, 40].

Bulk density is an important indicator of soil quality, productivity, compaction, and porosity. BD is mainly considered to be useful to estimate soil compaction. Root length density, root diameter, and root mass were observed to decrease after an increase in BD [41]. However, the interpretation of BD with respect to soil functions depends on soil type, especially soil texture and soil organic matter (SOM) content [21].

2.6. Hydraulic conductivity

One of the properties most directly related to the structure and movement of water in the soil is hydraulic conductivity. It is known that water movement in soils occurs both vertically and horizontally, depending on the humidity conditions. In saturated conditions, which occur below the groundwater level, the movement is predominantly horizontal and in a lesser proportion in a vertical direction. In conditions of non-saturation, when the large pores are filled with air, the flow is preferably vertical. The ability of soil to transmit water depends on the presence of interlinked pores and their size and geometry [42].

The saturated hydraulic conductivity (Ksat) of soil is a function of soil texture, soil particle packing, clay content, organic matter content, soil aggregation, bioturbation, shrink-swelling, and overall soil structure [43–46]. The Ksat is one of the main physical properties that aids in predicting complex water movement and retention pathways through the soil profile [47, 48], and it is also widely used as a metric of soil physical quality [49].

2.7. Water holding capacity

Water holding capacity is the ability of a soil to storage water. Thus, the importance of this storage is that water can be available for plants. Environmental conditions such rain, temperature, and isolation join to the soil properties of soil organic matter, texture, and structure and determine the capacity of a soil to retain water.

In rainfed agriculture of arid and semiarid environments, the capacity of the soil to store water plays an important role in the success of crops. Infiltration and evaporation are the most important processes that determine the storage of water in the soil. Surface conditions play an important role in determining the infiltration and evaporation rates of water in the soil. Tillage is the most effective way to modify the characteristics of the soil surface due to its effect on the porous space (shape, volume, and continuity of the pores).

The roughness of the soil surface is another property of the soil that influences the balance of water, since it increases the storage capacity in soil depressions [50, 51]. In agricultural soils, the roughness of the surface is influenced by tillage, vegetation, soil type, and rainfall intensity [51].

The use of waste as surface cover has been shown to be effective in reducing the evaporation of water from bare soil, which translates into a greater potential availability of water for plants [16]. This reduction is due to the isolation of the soil from the sun’s rays and the temperature of the air and the increase in the resistance to the flow of water vapor by reducing the wind speed [52, 53].

However, it is also necessary to determine the influence on the movement of water in the soil profile. In the arable layer, it is determinant for the proper functioning of agricultural soils. Therefore, the determination of hydraulic conductivity becomes very relevant information to predict the proper behavior of water against infiltration and storage capacity or loss by the soil.

3. The use of agricultural wastes in soils

Agricultural residues used as soil amendments or fertilizers may represent an excellent recycling strategy [54]. They are important to improve soil physical (e.g., structure, infiltration rate, plant available water capacity), chemical (e.g., nutrient cycling, cation exchange capacity, soil reaction), and biological (e.g., SOC sequestration, microbial biomass C, activity, and species diversity of soil biota) properties as organic soil conditioners [55–58]. Cultivating crops that produce substantial amounts of residues can increase SOC in the soil profile, depending on the tillage practices used [29]. Incorporated residue can beneficially influence soil chemical and physical properties, especially in non-flooded soils [57].

Organic residues can contribute to the development of soil structure with a binding agent in the formation of aggregates. The application of organic wastes to soils reduces bulk density; increases total pore space, mineralization, available nutrient elements, and electrical conductivity of soils; and increase microbial activity [26, 59, 60].

Crop residue application offers several environmental and ecological benefits for the soil-water-plant system, including improved soil structural quality, which ensures optimum soil functions. Generally, the incorporation of crop residues increases soil porosity (especially the large pores) and reduces soil bulk density, regardless of tillage operations. Large pores are particularly favored because organic matter is much less dense than mineral particles. The application rate can affect the extent of compaction. The effect of crop residues in a given tillage practice also depends on soil type and depth. When they are mechanically incorporated, crop residues can reduce the bulk density at depth. Conservation tillage with the incorporation of crop residues increases SOC content near the soil surface, whereas in conventional tillage, soil C is distributed throughout the plowed area. Soils with higher organic matter content tend to have higher aggregate stability and therefore less risk of compaction and soil erosion [29].

With regard to soil hydraulic properties, the presence of crop residues on the soil surface tends to increase hydraulic conductivity at the surface, whereas tillage affects soil hydraulic properties both at the soil surface and below it because of the destabilization of soil aggregates [61]. The influence of residue management on crop production is complex and variable and results from direct and indirect effects and interactions. A direct effect is, for example, the presence of residues on the soil surface, which constitutes a direct obstacle to crop emergence. Indirect effects include residue mineralization, which leads to more nutrients available for the plants or the presence of organic matter from residues modifying the soil structure and therefore modifying the root system development [29].

Incorporation of vegetable crop residues affects soil quality not only in terms of nutrient supply but also by influencing soil food web organisms and improving soil physicochemical properties, resulting in a better environment for crop growth and improved productivity [62–69]. The application of organic residues on carbon and nitrogen mineralization and biochemical properties in an agricultural soil led to a significant increase in soil microbial biomass size and activity [54].

Poppy waste, a suitable seed-free, inexpensive source of non-animal-based organic carbon, was used to evaluate its effect on soil organic carbon content and production of Bocane spinach

(*Spinacia oleracea*) [70]. Application of poppy waste at 200 m^3/ha increased soil organic carbon content, soil pH, and soil salinity.

Wheat stalk, cotton stalk, millet stalk, and soybean stalk were used as the main material, and oven-dried lentil straw was used as an additive material in 100:10, 100:15, and 100:20 w:w ratios for 100 g of main material (70% moisture content) to cultivate *Pleurotus ostreatus* and try to improve the total harvest amount [71].

3.1. Composted agricultural wastes

Agricultural wastes can be composted before their application to soil. The composting process, with other residues or alone, facilitates the transformation into a stable organic matter, more complex and more resistant to the biodegradation. However, the control of the process should be undertaken in order to obtain a mature compost [72]. Green tea waste and rice bran were composted, while various parameters such as compost pile temperature, pH, electrical conductivity, nitrate content, and carbon to nitrogen ratio were measured regularly. There was no further change in the state of the compost pile after 90 days indicating that it could be used for agricultural applications [73]. The possible bioconversion of wet olive cake by low-cost biostabilization (vermicomposting process) has been evaluated [74]. Wet olive cake fresh (WOC), pre-composted (WOCP), or mixed with biosolids (WOCB) were vermicomposted for 6 months to obtain organic amendments for agricultural and remediation purposes.

The application of composted organic amendments derived from different crop residues, generally, has a positive impact on the physical, chemical, and biological properties of soils [75].

Crop residues are composed of lignin, cellulose, hemicellulose, micro-, and macronutrients. The degradation of these residues varies depending not only on their lignin and cellulose content and their C/N ratio, which is crop dependent, but also on the environment and soil conditions. Residues with a high C/N level (e.g., wheat straw) decompose slowly, sometimes resulting in the immobilization of soil N. This can be positive in no-tillage systems, creating a mulch that protects the soil from erosion and evaporation, but it also means that there are fewer nutrients available for the next crop. Residues with a low C/N level mineralize quickly, releasing more N and nutrients for the next crop. Only specialized fungi and some microorganisms can degrade lignin. Residues with high lignin content will take longer to decompose than those with low lignin content [29, 76].

4. Examples of the use of agricultural wastes and the effects on some physical properties

The physical properties of soils condition their quality and, in particular, the porosity which affects different processes related to the transformations of organic matter, gas exchange, the growth of plant roots, and movement of water in the soil, as before it was indicated.

Soil porosity is the property that, due to the effect of compaction, is being altered largely in the European Union (and developing countries), together with the loss of organic matter from soils [77], and, for this reason, our management of the soils should allow maintaining this property at adequate levels.

The use of plant residues as soil amendments is a sustainable alternative to improve the physical properties [28], although we must take into account the characteristics of the waste to ensure its efficiency. Once incorporated into the soil, the waste can be mineralized more or less rapidly, depending on characteristics such as its degree of lignification, its C/N ratio, and environmental conditions [78]. Fresh vegetable residues, such as tomato (C/N = 12) and onion (C/N = 15) residues [79], with high water content, decompose quickly [80] modifying the composition of soil organic matter [9]. However, there are residues with high C/N ratios, such as wheat or rice wastes (C/N = 105), more lignified, which degrade more slowly [81], lasting for more time the modifications they produce on certain physical properties of the soil.

In this second type of waste, we can consider the cereal straw and the palm tree leaves (**Figure 1**). Both, with high lignin composition and after a conditioning process (drying and crushing), can be used to modify the physical properties of the soil such as bulk density, porosity, and hydraulic conductivity.

These agricultural wastes have a similar total organic matter (determined by loss on ignition) content but a different density, bulk, and particle density (**Table 1**).

Figure 1. Palm tree leaves.

	Palm tree leaves	Hay straw
Bulk density (kg/m^3)	84	29
Particle density (kg/m^3)	870	405
Organic matter (%)	93.2	94.8

Table 1. Density and total organic matter in the wastes.

Laboratory experiments were performed on cylinders similar to those used for the determination of densities of organic materials, according to UNE-EN13040:2008 and the methods of soil analysis of SSSA-ASA [82–84]. These experiments showed that the agricultural residues applied (hay straw and palm tree leaves, air dry and cut with a size of approximately 4 cm in length) modified the density of soils and improved their porosity.

Figures 2 and **3** show the changes of the particle (PD) and bulk (BD) densities in two soils (soil 1: sandy clay loam; soil 2: clay loam), when these wastes were added in a proportion (waste/dry soil): 0, 3, and 6% (w/w).

The agricultural residues reduced the densities of the two soils, depending on the dose applied. The apparent densities were clearly affected, which indicates that the addition of the amendments favors that the soils were less compacted. Depending on the physical characteristics of

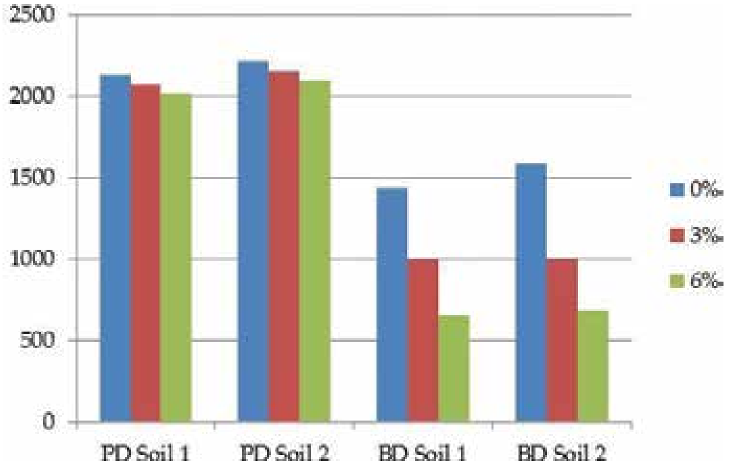


Figure 2. Evolution of particle density (PD) and bulk density (BD) (in kg/m^3) in soils amended with hay straw.

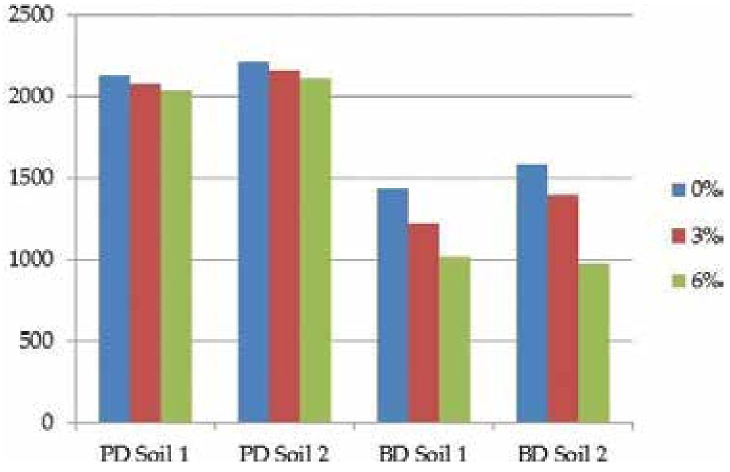


Figure 3. Particle density (PD) and bulk density (BD) (in kg/m^3) in soils amended with palm tree leaves.

the agricultural waste, it will be more or less efficient. In this sense, straw residues reduce the bulk density more than that of palm tree leaves.

Bulk density decreases in the soils, which means that the porosity, spaces that can be filled with air and water, increases. This is observed in **Figure 4**, where the changes in the porosity of the two soils were showed. Porosity increased when the amount of agricultural wastes applied was greater. Hay straw residue increased the porosity more than palm tree residue.

Obviously, the types of waste that improve the porosity of soils also favor the movement of water. This fact is very important because it allows a better root growth.

One of the parameters that gives information on the movement of water in soils is the saturated hydraulic conductivity (Khs), based on Darcy's law, and calculated by using a constant-head permeameter. The texture of the soils determines the quantity and size of the pore, and, therefore, we should expect that more clay soils have lower Khs values than those with a sandy texture.

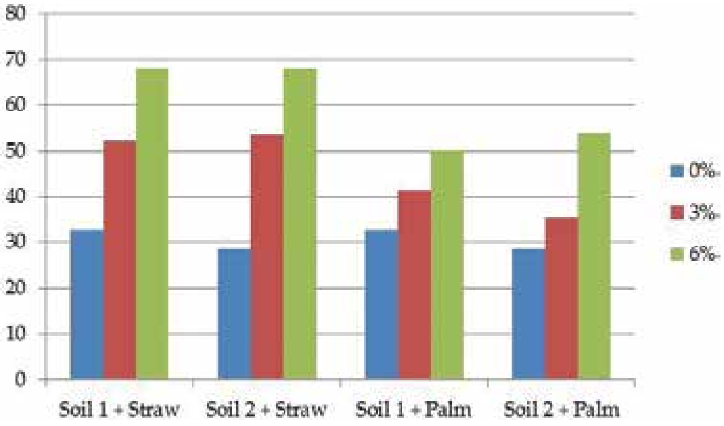


Figure 4. Porosity (%) in soils amended with vegetable wastes.

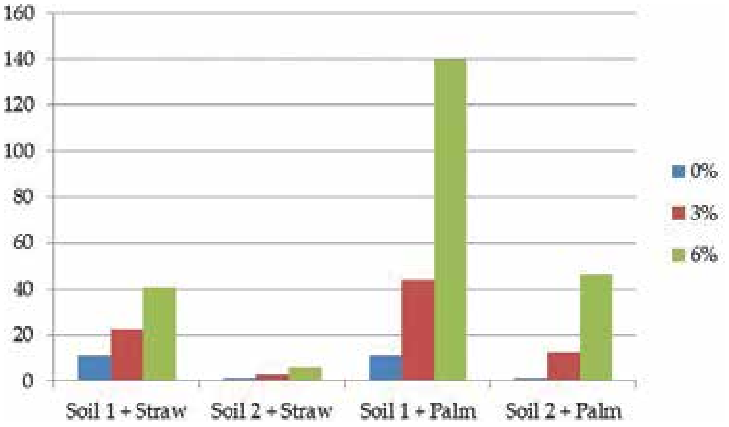


Figure 5. Saturated hydraulic conductivity (in cm/h) in soils amended with hay straw and palm tree leaves.

Figure 5 shows how the addition of agricultural wastes affected the saturated hydraulic conductivity of soils. It is observed that, without the addition of residues, the clay loam soil (soil 2) has a lower value of Khs than the sandy clay loam soil (soil 1). The positive effect of the incorporation of the amendments on the hydraulic conductivity of the two soils used was clear. Hay straw produced a greater increment than palm tree residues in both soils.

This example of addition of vegetable wastes to the soil demonstrates the positive influence on some physical properties, and the importance of recycling of agricultural wastes in origin can help the strategy of zero waste of the European Union and, moreover, improve the quality of our soils.

5. Conclusions

It is important to consider which type of soil characteristics should be improved when applying agricultural wastes. For the physical properties, vegetable wastes with a high content of lignified organic matter can be used successfully, influencing soil density, porosity, and hydraulic conductivity. However, if the objective is to increment the nutrient availability, less lignified and more labile residues may be added to the soil, although in this case a possible imbalance of nutrients in soil may be found.

The main objective in the EU and, in fact, in the planet, is to reduce the production and increase the recycling of agricultural wastes, participating on the valorization of the residues and introducing them in the strategies of the circular economy and zero wastes. Joining soil and organic matter amendments allows us to get better soils and the best agricultural management, favoring the carbon sequestration under the present climate change scenery.

Author details

María Belén Almendro-Candel[1], Ignacio Gómez Lucas[1]*, Jose Navarro-Pedreño[1] and
Antonis A. Zorpas[2]

*Address all correspondence to: ignacio.gomez@umh.es

1 Department of Agrochemistry and Environment, Miguel Hernández University of Elche, Elche (Alicante), Spain

2 Cyprus Open University, Faculty of Pure and Applied Sciences, Environmental Conservation and Management, Laboratory of Chemical Engineering and Engineering Sustainability, Nicosia, Cyprus

References

[1] European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the

Regions. Closing the loop - An EU action plan for the Circular Economy. COM 614 final. 2015. 21 p. Available from: http://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF [Accessed: 2018–04-21]

[2] Kong L. Maize residues, soil quality, and wheat growth in China. A review. Agronomy for Sustainable Development. 2014;**34**:405-416. DOI: 10.1007/s13593-013-0182-5

[3] Cotching WE. Organic matter in the agricultural soils of Tasmania, Australia – A review. Geoderma. 2018;**312**:170-182. DOI: 10.1016/j.geoderma.2017.10.006

[4] Marmo L. EU strategies and policies on soil and waste management to offset greenhouse gas emissions. Waste Management. 2008;**28**:685-689. DOI: 10.1016/j.wasman.2007.09.030

[5] Peltre C, Gregorich EG, Bruun S, Jensen LS, Magid J. 2017. Repeated application of organic waste affects soil organic matter composition: Evidence from thermal analysis, FTIR-PAS, amino sugars and lignin biomarkers. Soil Biology and Biochemistry. 2017;**104**:117-127. DOI: 10.1016/j.soilbio.2016.10.016

[6] Annabi M, Le Bissonnais Y, Le Villio-Poitrenaud M, Houot S. Improvement of soil aggregate stability by repeated applications of organic amendments to a cultivated silty loam soil. Agriculture, Ecosystems and Environment. 2011;**144**:382-389. DOI: 10.1016/j.agee.2011.07.005

[7] Grosbellet C, Vidal-Beaudet L, Caubel V, Charpentier S. Improvement of soil structure formation by degradation of coarse organic matter. Geoderma. 2011;**162**(1–2):27-38. DOI: 10.1016/j.geoderma.2011.01.003

[8] Schjønning P, Thomsen IK. Shallow tillage effects on soil properties for temperate-region hard-setting soils. Soil and Tillage Research. 2013;**132**:12-20. DOI: 10.1016/j.still.2013.04.006

[9] Diacono M, Montemurro F. Long-term effects of organic amendments on soil fertility. A review. Agronomy for Sustainable Development. 2010;**30**:401-422. DOI: 10.1051/agro/200904

[10] Lal R. Soil carbon sequestration impacts on global climate change and food security. Science. 2004;**304**:1623-1627. DOI: 10.1126/science.1097396

[11] Celik I, Ortas I, Kilic S. Effects of compost, mycorrhiza, manure and fertilizer on some physical properties of a Chromoxerert soil. Soil and Tillage Research. 2004;**78**(1):59-67. DOI: 10.1016/j.still.2004.02.012

[12] Herencia JF, García-Galavís PA, Maqueda C. Long-term effect of organic and mineral fertilization on soil physical properties under greenhouse and outdoor management practices. Pedosphere. 2011;**21**(4):443-453. DOI: 10.1016/S1002-0160(11)60146-X

[13] Li Z, Schneider RL, Morreale SJ, Xie Y, Li C, Li J. Woody organic amendments for retaining soil water, improving soil properties and enhancing plant growth in desertified soils of Ningxia, China. Geoderma. 2018;**310**:143-152. DOI: 10.1016/j.geoderma.2017.09.009

[14] Martin MP, Seen DL, Boulonne L, Jolivet C, Nair KM, Bourgeon G, Arrouays D. Optimizing pedotransfer functions for estimating soil bulk density using boosted regression trees. Soil Science Society of America Journal. 2009;**73**:485-493. DOI: 10.2136/sssaj2007.0241

[15] Watts CW, Clark LJ, Poulton PR, Powlson DS, Whitmore AP. The role of clay, organic carbon and long-term management on mouldboard plough draught measured on the Broadbalk wheat experiment at Rothamsted. Soil Use and Management. 2006;**22**:334-341. DOI: 10.1111/j.1475-2743.2006.00054.x

[16] Rico Hernández J, Navarro-Pedreño J, Gómez I. Evaluation of plant waste used as mulch on soil moisture retention. Spanish Journal of Soil Science. 2016;**6**(2):133-144. DOI: 10.3232/SJSS.2016.V6.N2.05

[17] Lal R. Soil structure and sustainability. Journal of Sustainable Agriculture. 1991;**1**(4):67-92. DOI: 10.1300/J064v01n04_06

[18] Young IM, Blanchart E, Chenu C, Dangerfield M, Fragoso C, Grimald M, Ingram J, Monrozier LJ. The interaction of soil biota and soil structure under global change. Global Change Biology. 1998;**4**(7):703-712. DOI: 10.1046/j.1365-2486.1998.00194.x

[19] Allison FE, editor. Soil Organic Matter and its Role in Crop Production. 1st ed. Vol. 3. Amsterdam: Elsevier; 1973. 637 p

[20] Low AJ. Soil structure and crop yield. European Journal of Soil Science. 1973;**24**:249-259. DOI: 10.1111/j.1365-2389.1973.tb00762.x

[21] Rabot E, Wiesmeier M, Schlüter S, Vogel H-J. Soil structure as an indicator of soil functions: A review. Geoderma. 2018;**314**:122-137. DOI: 10.1016/j.geoderma.2017.11.009

[22] Snyder VA, Vázquez MA. Structure. In: Hillel D, editor. Encyclopedia of Soils in the Environment. London: Elsevier; 2005. pp. 54-68. DOI: 10.1016/B0-12-348530-4/00533-6

[23] Bronick CJ, Lal R. Soil structure and management: A review. Geoderma. 2005;**124**(1–2): 3-22. DOI: 10.1016/j.geoderma.2004.03.005

[24] Six J, Elliott ET, Paustian K. Soil structure and soil organic matter II. A normalized stability index and the effect of mineralogy. Soil Science Society of America Journal. 2000;**64**(3): 1042-1049. DOI: 10.2136/sssaj2000.6431042x

[25] Gülser C. Effect of forage cropping treatments on soil structure and relationships with fractal dimensions. Geoderma. 2006;**131**(1–2):33-44. DOI: 10.1016/j.geoderma.2005.03.004

[26] Gülser C, Minkina T, Sushkova S, Kizilkaya R. Changes of soil hydraulic properties during the decomposition of organic waste in a coarse textured soil. Journal of Geochemical Exploration. 2017;**174**:66-69. DOI: 10.1016/j.gexplo.2016.05.014

[27] Chan KY, Heenan DP, So HB. Sequestration of carbon and changes in soil quality under conservation tillage on light-textured soils in Australia: A review. Australian Journal of Experimental Agriculture. 2003;**43**:325-334. DOI: 10.1071/EA02077

[28] Walia MK, Dick WA. Selected soil physical properties and aggregate-associated carbon and nitrogen as influenced by gypsum, crop residue, and glucose. Geoderma. 2018;**320**: 67-73. DOI: 10.1016/j.geoderma.2018.01.022

[29] Hiel MP, Chélin M, Parvin N, Barbieux S, Degrune F, Lemtiri A, Colinet G, Degré A, Bodson B, Garré S. Crop residue management in arable cropping systems under temperate climate. Part 2: Soil physical properties and crop production. A review. Biotechnology, Agronomy, Society and Environment. 2016;**20**(S1):245-256

[30] Holland JM. The environmental consequences of adopting conservation tillage in Europe: Reviewing the evidence. Agriculture, Ecosystems and Environment. 2004;**103**(1):1-25. DOI: 10.1016/j.agee.2003.12.018

[31] Tisdall JM, Oades JM. Organic matter and water-stable aggregates in soils. Journal of Soil Science. 1982;**33**(2):141-163. DOI: 10.1111/j.1365-2389.1982.tb01755.x

[32] Six J, Elliott ET, Paustian K, Doran JW. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Science Society of America Journal. 1998; **62**(5):1367-1377. DOI: 10.2136/sssaj1998.03615995006200050032x

[33] Franzluebbers AJ. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil and Tillage Research. 2002;**66**(2):197-205. DOI: 10.1016/S01 67-1987(02)00027-2

[34] Ramos MC, Nacci S, Pla I. Effect of raindrop impact and its relationship with aggregate stability to different disaggregation forces. Catena. 2003;**53**(4):365-376. DOI: 10.1016/S03 41-8162(03)00086-9

[35] Van den Akker JJ. Soane. B. Compaction. In: Hillel D, editor. Encyclopedia of Soils in the Environment. London: Elsevier; 2005. pp. 285-293. DOI: 10.1016/B0-12-348530-4/00248-4

[36] Barbera AC, Maucieri C, Cavallaro V, Ioppolo A, Spagna G. Effects of spreading olive mill wastewater on soil properties and crops, a review. Agricultural Water Management. 2013; **119**:43-53. DOI: 10.1016/j.agwat.2012.12.009

[37] Nimmo JR. Porosity and pore size distribution. In: Hillel D, editor. Encyclopedia of Soils in the Environment. London: Elsevier; 2005. pp. 295-303. DOI: 10.1016/B0-12-348530-4/00404-5

[38] Blake GR, Hartge KH. Bulk density. In: Klute A, editor. Methods of Soil Analysis, Part 1. 2nd ed. Madison: Soil Science Society of America; 1986. pp. 363-376. DOI: 10.2136/sssa bookser5.1.2ed.c13

[39] Arshad MA, Lowery B, Grossman B. Physical tests for monitoring soil quality. In: Doran JW, Jones AJ, editors. Methods for Assessing Soil Quality, SSSA Special Publication 49. 1st ed. Madison: Soil Science Society of America; 1996. pp. 123-142. DOI: 10.2136/sssaspecpub49.c7

[40] Hu W, Shao MA, Si BC. Seasonal changes in surface bulk density and saturated hydraulic conductivity of natural landscapes. European Journal of Soil Science. 2012;**63**:820-830. DOI: 10.1111/j.1365-2389.2012.01479.x

[41] Dal Ferro N, Sartori L, Simonetti G, Berti A, Morari F. Soil macro- and microstructure as affected by different tillage systems and their effects on maize root growth. Soil and Tillage Research. 2014;**140**:55-65. DOI: 10.1016/j.still.2014.02.003

[42] Connolly RD. Modelling effects of soil structure on the water balance of soil-crop systems: A review. Soil and Tillage Research. 1998;**48**:1-19. DOI: 10.1016/S0167-1987(98)00128-7

[43] Hillel D. Environmental Soil Physics: Fundamentals, Applications, and Environmental Considerations. 1st ed. New York: Academic Press; 1998. 771 p

[44] Moutier M, Shainberg I, Levy GJ. Hydraulic gradient and wetting rate effects on the hydraulic conductivity of two calcium Vertisols. Soil Science Society of America Journal. 2000;**64**:1211-1219. DOI: 10.2136/sssaj2000.6441211x

[45] West LT, Abrew MA, Bishop JP. Saturated hydraulic conductivity of soils in the southern piedmont of Georgia, USA: Field evaluation and relation to horizon and landscape properties. Catena. 2008;**73**:174-179. DOI: 10.1016/j.catena.2007.07.011

[46] Lim TJ, Spokas KA, Feyereisen G, Novak JM. Predicting the impact of biochar additions on soil hydraulic properties. Chemosphere. 2016;**142**:136-144. DOI: 10.1016/j.chemosphere.2015.06.069

[47] Keller T, Sutter JA, Nisse K, Rydberg T. Using field measurement of saturated soil hydraulic conductivity to detect low-yielding zones in three Swedish fields. Soil and Tillage Research. 2012;**124**:68-77. DOI: 10.1016/j.still.2012.05.002

[48] Quin PR, Cowie AL, Flavel RJ, Keen BP, Macdonald LM, Morris SG, Singh BP, Young IM, Van Zwieten L. Oil mallee biochar improves soil structural properties – A study with X-ray micro-CT. Agriculture, Ecosystems and Environment. 2014;**191**:142-149. DOI: 10.1016/j.agee.2014.03.022

[49] Reynolds WD, Bowman BT, Brunke RR, Drury CF, Tan CS. Comparison of tension infiltrometer, pressure infiltrometer, and soil core estimates. Soil Science Society of America Journal. 2000;**64**:478-484. DOI: 10.2136/sssaj2000.642478x

[50] Mwendera EJ, Feyen J. Predicting tillage effects on infiltration. Soil Science. 1993;**155**:229-235

[51] Hansen B, Schjønning P, Sibbesen E. Roughness indices for estimation of depression storage capacity of tilled soil surfaces. Soil and Tillage Research. 1999;**52**:103-111. DOI: 10.1016/S0167-1987(99)00061-6

[52] Smika DE, Unger PW. Effect of surface residues on soil water storage. Advances in Soil Sciences. 1986;**5**:111-138. DOI: 10.1007/978-1-4613-8660-5_2

[53] Blevins RL, Frye WW. Conservation tillage: An ecological approach to soil management. Advances in Agronomy. 1993;**51**:33-78. DOI: 10.1016/S0065-2113(08)60590-8

[54] Yang X, Ikehata K, Lerner R, Hu Y, Josyula K, Chang SX, Liu Y. Agricultural Wastes. Water Environment Research. 2010;**82**(10):1396-1425. DOI: 10.2175/106143010X12756668801338

[55] Candemir F, Gülser C. Effects of different agricultural wastes on some soil quality indexes at clay and loamy sand fields. Communications in Soil Science and Plant Analysis. 2010; **42**(1):13-28. DOI: 10.1080/00103624.2011.528489

[56] Gülser C, Candemir F. Effects of agricultural wastes on the hydraulic properties of a loamy sand cropland in Turkey. Soil Science & Plant Nutrition. 2015;**61**(3):384-391. DOI: 10.1080/00380768.2014.992042

[57] Singh B, Shan YH, Johnson-Beebout SE, Singh Y, Buresh RJ. Crop residue Management for Lowland Rice-Based Cropping Systems in Asia. Advances in Agronomy. 2008;**98**:117-199. DOI: 10.1016/S0065-2113(08)00203-4

[58] Demir Z, Gülser C. Effects of rice husk compost application on soil quality parameters in greenhouse conditions. European Journal of Soil Science. 2015;**4**(3):185-190. DOI: 10.18393/ejss.2015.3.185-190

[59] Anikwe MAN. Amelioration of a heavy clay loam soil with rice husk dust and its effect on soil physical properties and maize yield. Bioresource Technology. 2000;**74**(2):169-173. DOI: 10.1016/S0960-8524(00)00007-9

[60] Eigenberg RA, Doran JW, Niennaber JA, Ferguson RB, Woodbury BL. Electrical conductivity monitoring of soil condition and available N with animal manure and a cover crop. Agriculture, Ecosystems and Environment. 2002;**88**(2):183-193. DOI: 10.1016/S0167-8809(01)00256-0

[61] Turmel MS, Speratti A, Baudron F, Verhulst N, Govaerts B. Crop residue management and soil health: A systems analysis. Agricultural Systems. 2015;**134**:6-16. DOI: 10.1016/j.agsy.2014.05.009

[62] Salinas-García JR, Báez-González AD, Tiscareño-López M, Rosales-Robles E. Residue removal and tillage interaction effects on soil properties under rain-fed corn production in Central Mexico. Soil and Tillage Research. 2001;**59**:67-79. DOI: 10.1016/S0167-1987(00)00187-2

[63] Schutter M, Sandeno J, Dick R. Seasonal, soil type, and alternative management influences on microbial communities of vegetable cropping systems. Biology and Fertility of Soils. 2001;**34**:397-410. DOI: 10.1007/s00374-001-0423-7

[64] Roldán A, Caravaca F, Hernández MT, García C, Sánchez-Brito C, Velásquez M, Tiscareño M. No-tillage, crop residue additions, and legume cover cropping effects on soil quality characteristics under maize in Patzcuaro watershed (Mexico). Soil and Tillage Research. 2003;**72**:65-73. DOI: 10.1016/S0167-1987(03)00051-5

[65] Alvarez R. A review of nitrogen fertilizer and conservation tillage effects on soil organic carbon storage. Soil Use and Management. 2005;**21**(1):38-52. DOI: 10.1111/j.1475-2743.2005.tb00105.x

[66] Kachroo D, Dixit AK. Residue-management practices using fly ash and various crop residues for productivity of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system under limited moisture conditions. Indian Journal of Agronomy. 2005;**50**(4):249-252

[67] Blanco-Canqui H, Lal R. Corn Stover removal for expanded uses reduces soil fertility and structural stability. Soil Science Society of America Journal. 2009;**73**:418-426. DOI: 10.2136/sssaj2008.0141

[68] Ludwig B, Geisseler D, Michel K, Joergensen RG, Schulz E, Merbach I, Raupp J, Rauber R, Hu K, Niu L, Liu X. Effects of fertilization and soil management on crop yields and carbon stabilization in soils. A review. Agronomy for Sustainable Development. 2011;**31**:361-372. DOI: 10.1051/agro/2010030

[69] Agneessens L, De Waele J, De Neve S. Review of alternative management options of vegetable crop residues to reduce nitrate leaching in intensive vegetable rotations. Agronomy. 2014;**4**:529-555. DOI: 10.3390/agronomy4040529

[70] Hardie MA, Cotching WE. Effects of application of poppy waste on spinach yields, soil properties, and soil carbon sequestration in southern Tasmania. Australian Journal of Soil Research. 2009;**47**(5):478-485. DOI: 10.1071/SR08193

[71] Dundar A, Yildiz A. A comparative study on *Pleurotus ostreatus* (Jacq.) P. Kumm. Cultivated on different agricultural Lignocellulosic wastes. Turkish Journal of Biology. 2009; **33**(2):171-179. DOI: 10.3906/biy-0804-2

[72] Temporal-Lara B, Melendez-Pastor I, Gómez I, Navarro-Pedreño J. Wastewater biosolid composting optimization based on UV-VNIR spectroscopy monitoring. Sensors. 2016;**16**: 1-11. DOI: 10.3390/s16111919

[73] Khan GD, Din S, Ramzan M, Hanif M, Hameed M. Influence of tillage and mulching practices on soil physical properties under semi-arid environment. Journal of Environment and Earth Science. 2014;**4**(9):120-124

[74] Melgar R, Benítez E, Nogales R. Bioconversion of wastes from olive oil industries by vermicomposting process using the Epigeic earthworm *Eisenia andrei*. Journal of Environmental Science and Health, Part B - Pesticides, Food Contaminants, and Agricultural Wastes. 2009;**44**(5):488-495. DOI: 10.1080/03601230902935444

[75] Medina J, Monreal C, Barea JM, Arriagada C, Borie F, Cornejo P. Crop residue stabilization and application to agricultural and degraded soils: A review. Waste Management. 2015;**42**:41-54. DOI: 10.1016/j.wasman.2015.04.002

[76] Austin AT, Ballaré CL. Dual role of lignin in plant litter decomposition in terrestrial ecosystems. Proceedings of the National Academy of Sciences of the United States of America. 2010;**107**(10):4618-4622. DOI: 10.1073/pnas.0909396107

[77] European Commission. Guidelines on Best Practice to Limit, Mitigate or Compensate Soil Sealing. European Commission Staff Working Document SWD(2012) Report 101 Final/2. Luxembourg: Publications Office or the European Union; 2012. 62 p. DOI: 10.2779/75498

[78] Manzoni S, Trofymow JA, Jackson RB, Porporato A. Stoichiometric controls on carbon, nitrogen, and phosphorus dynamics in decomposing litter. Ecological Monographs. 2010; **80**:89-106. DOI: 10.1890/09-0179.1

[79] Navarro-Pedreño J, Moral R, Gómez I, Mataix J. Residuos Orgánicos en Agricultura. Ed. Servicio Publicaciones de la Universidad de Alicante; 1995. 155 p

[80] Cao C, Liu SQ, Ma ZB, Lin Y, Su Q, Chen H, Wang JJ. Dynamics of multiple elements in fast decomposing vegetable residues. The Science of the Total Environment. 2018;**616-617**: 614-621. DOI: 10.1016/j.scitotenv.2017.10.287

[81] Klotzbücher T, Kaiser K, Guggenberger G, Gatzek C, Kalbitz K. A new conceptual model for the fate of lignin in decomposing plant litter. Ecology. 2011;**92**:1052-1062. DOI: 10.1890/10-1307.1

[82] Blake GR, Hartge KH. Bulk density. In: Klute A, editor. Methods of Soil Analysis: Part 1—Physical and Mineralogical Methods. Madison: SSSA, ASA. 1986. pp. 363-375. DOI: 10.2136/sssabookser5.1.2ed.c13

[83] Blake GR, Hartge KH. Particle density. In: Klute A, editor. Methods of Soil Analysis: Part 1—Physical and Mineralogical Methods. Madison: SSSA, ASA; 1986. pp. 377-382. DOI: 10.2136/sssabookser5.1.2ed.c14

[84] Danielson RE, Sutherland PL. Porosity. In: Klute A, editor. Methods of Soil Analysis: Part 1—Physical and Mineralogical Methods. Madison: SSSA, ASA; 1986. pp. 443-461. DOI: 10.2136/sssabookser5.1.2ed.c18

Chapter 3

Chromium Species and 3D-Fluorescence Spectroscopy in a Soil Irrigated with Industrial Wastewater

Rosa María Fuentes-Rivas, Francisco Martin-Romero,
Daury García Pulido,
Reyna Maria Guadalupe Fonseca-Montes de Oca,
Janete Moran Ramírez and Jose Alfredo Ramos Leal

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.77181

Abstract

Irrigation of agricultural land with wastewater is beneficial because it incorporates organic matter into the soil, as well as organic ions (such as nitrates, sulfates, and phosphates). However, long-term application causes negative effects such as the accumulation of heavy metals. The wastewater used in the agricultural soils, also incorporates organic refractory compounds, which affect the microbial population and fertility. This chapter aimed to identify the chromium species present in agricultural soil irrigated with wastewater (679.6 mg/L for total chromium and 559.5 mg/L for Cr VI), and characterize the dissolved organic matter in the saturated solution soil. In the soil-saturated solutions (pH 6), the most stable Cr (III) species was Cr_2O_3. These species precipitate and accumulate in the soil in combination with natural organic matter. The highest accumulation of chromium occurred in the first 10 cm of the soil column. The 3D fluorescence analysis exposes the presence of aromatic proteins, microbiological degradation products, and humic and fulvic acids in the soil profile. The excitation-emission matrix (EEM) showed that Cr (VI) species were complexed with humic acids. In the X-ray diffraction analysis, the species Cr_2O_5, Cr_5O_{12}, CrO_2, and Cr_7C_3 were found at depth with the greatest amount of organic matter.

Keywords: wastewater, chromium, agriculture, irrigation, environment, aromatic proteins, humic acid

1. Introduction

Wastewater reuse in farming Mexican represents a valuable resource in agricultural production due to the irrigation supply and considerable nutrients input to the soil. Negative environmental effects may result from long-term wastewater application due to heavy metal accumulation in soils, increasing amounts of highly mobile, and easily mobilizable metal fractions, as well as crops uptake [1, 2]. Among the solid reactive components present in the soil, organic matter (OM), which has a high sorption capacity for metal ions [2–5], plays a very important role in soil fertility. The positive effects of organic matter are due to the fact that it benefits the aggregation of soil particles, improving aeration, permeability, resistance to erosion, and water retention. Regarding the chemical function of organic matter, it is based on its high cation retention capacity, which contributes greatly to the control of soil acidity, nutrient recycling and the detoxification of dangerous compounds such as heavy metals that are incorporated into soils by industrial wastewater [6]. Chromium is among the metals that may be present in wastewater.

Chromium is a trace component in the Earth's crust (0.02%) that is essential for animal and human life, but not for plants. It is a natural element present in water, sediments, rocks, soils, plants, biota, animals, and volcanic emissions. The main oxidation forms of chromium are trivalent chromium and hexavalent chromium, each with opposite properties [7]. The total concentration of chromium in the lithosphere is between 69 and 100 mg/kg [7, 8]. The two forms of chromium have different effects on living organisms: Chromium (III) is apparently useful and harmless at reasonable concentrations, while Chromium (VI) is extremely toxic. Moreover, Chromium (III) is not mobile in soil; therefore, the risks of leaching are negligible.

In solution, Cr (VI) can exist in three different ionic forms: $HCrO_4^-$, CrO_4^{2-}, and $Cr_2O_7^{2-}$. It can also exist in the form of complex anions that are soluble in water and may persist in it. In surface water rich in organic content, Cr (VI) has a much shorter shelf life [9]. The presence of each ionic form of chromium in solution depends on the pH [10]. Chromium is present in soils as water-insoluble $Cr_2O_3 \cdot H_2O$ [11]; only a small part of it can be leached from soil. Chromium (VI), mainly present as chromate ions (CrO_4^{2-}) and dichromate ($Cr_2O_7^{2-}$), is generally mobile and is sometimes part of crystalline minerals [7, 12]. In soil, Cr (VI) tends to be reduced to Cr (III) by organic matter. The chromium present in the environment is mainly derived from human activities.

Chromium (III) converts to Chromium (VI) only in some soils, particularly those that are rich in manganese oxides, poor in organic matter and with high oxidation–reduction potential. In contrast, the conversion of Chromium (VI) to Chromium (III) is very common and easy, and is thus very difficult to find hexavalent chromium forms in the soil solution or in leaching waters [7, 13]. The mobility of chromium in the lithosphere can only be evaluated by considering the adsorption and reduction capacity of soils [4, 13].

Accordingly, the aim of this study was to identify the chromium species present in soil and the saturated solution during irrigation with wastewater and characterize the dissolved organic matter, through the 3D fluorescence spectroscopy analysis, and its evolution in the soil profile.

2. Materials and methods

2.1. Soil sampling and irrigation

Three soil samples were taken in an agricultural area, previously conditioned with the addition of organic matter in order to ensure a high content of organic matter in the soil. Sampling was performed vertically by inserting a PVC tube 10 cm in diameter at a depth of 50 cm at a random point in the area, so that three complete soil columns were obtained. The sampling and transfer was carried out hermetically to guarantee the inviolability of the sample until the arrival at the laboratory. The first profile was used to determine the physicochemical characteristics of the soil: pH, Ce, CEC, MOS, moisture, and texture.

The other two profiles were irrigated with wastewater from an electroplating industry (559.5 mg/L Cr VI and 20.1 mg/L de Cr III); the irrigation was carried out on a single occasion in order to saturate the soil with Cr. About 10-cm deep holes were successively drilled in the soil profiles until reaching a depth of 50 cm. A sample of the saturated solution was obtained from each of these holes to observe the decrease of the concentration of chromium in the saturated solution after crossing 10 cm of soil. The ORP, Cr VI concentration [14], and 3D fluorescence spectrum were determined in the collected solution samples.

2.2. Sampling and characterization of wastewater

The water sampling was carried out in the discharge of wastewater from an electroplating industry, located in the City of Toluca, State of Mexico. A sample composed of 5 L of residual water was collected, which was integrated with five individual samples of 1 L each, taken from the wastewater discharge every 15 min. The parameters, determined according to standard methods [14], were pH, electrical conductivity (EC), nitrates (NO_3–), sulfates (SO_4^{2}), chlorides (C^{1-}), total chromium (by atomic absorption spectrometry) and chromium VI (by diphenylcarbazide spectrophotometry) [14].

2.3. Fluorescence spectroscopy and X-ray diffraction

The 3D fluorescence analysis was performed [15–17]. A Perkin Elmer fluorescence spectrophotometer LS55 was used, with 150 watts xenon lamp as excitation source. In the characterization of the samples, 45 individual emission spectra were obtained at emission wavelengths (λem) between 250 and 600 nm with intervals of 5 nm and, collected at excitation wavelengths (λexc) between 200 and 450 nm. The samples were analyzed at a concentration < 2 mg/L COD [15, 17]. A 290 nm filter was used in all analyses to eliminate Raleigh peak light interference. The excitation-emission matrix (EEM) of distilled water was subtracted from the EEM of the industrial wastewater samples to eliminate interference caused by Raman peaks. In order to verify the presence of chromium retained in the soil, the X-ray diffraction analysis was performed.

2.4. Chromium retention capacity of soil

Batch tests were carried out to determine the Cr accumulation capacity of soil; 1 g of dry soil, sieved to a particle size of 0.002 mm, was placed in a glass tube together with 10 ml of a chromium

(Cr VI) solution at standard concentrations of 5, 10, 15, 20, and 25 mg/L, in continuous stirring and constant temperature of 25°C. Five tests were performed for each depth of the soil column, with a contact time of half an hour. Subsequently, the tubes were centrifuged at 2500 rpm, and the supernatant was filtered, collected, and acidified for Uv–visible spectroscopy [14].

3. Results and discussion

3.1. Physicochemical characteristics of the soil

Figure 1 shows the physico-chemical characteristics of the soil profile. The data obtained show a slight increase of pH as depth increases, with a value of 7.3 in the most superficial area and 7.5 at a depth of 50 cm. These pH values show that the soil is moderately alkaline, suggesting a medium availability of nutrients. The results of the electrical conductivity tests show a remarkable decrease along the soil column; the surface area has a value of 255.09 μS/cm and the deepest layer of 112.95 μS/cm. The lowest conductivity value (105.13 μS/cm) was observed at a depth of 30–40 cm (**Figure 1**). The cation exchange capacity remained constant throughout the soil column, with values of 30.20 Cmol/kg at a soil depth of 40–50 cm, and up to 38.21 Cmol/kg at 10–20 cm depth.

The content of organic carbon (OC) gradually decreased as the depth of the soil column increased: from 9.96 g/kg in the surface layer to 2.29 g/kg a depth of 40–50 cm. The percentage of organic matter (OM) also decreased with increasing depth; the highest value (17.17%) was observed in the surface layer, and the lowest value (3.95%) in the deepest layer. The percentage of humidity, like the OC content, decreased along the soil column by up to 29%, from 22.83% in the surface layer to 16.27% at a depth of 30–40 cm.

Regarding the texture of the different layers of the soil column, we obtained the following results: the most superficial layer (0–10 cm) had sandy loam soil; at depths of 10–20 and 30–40 cm, the soil had a loamy texture, and in the intermediate layers of the column (20–30 cm) and in the lowest layer 40–50 cm, the soil had a loamy-clay texture (**Table 1**).

In general, all layers of the soil column had a loam texture. The literature on the subject states that a soil with medium alkaline pH is a sandy soil; this agrees with the texture data obtained in the present study, which showed a high sand content in all soil samples (**Table 2**). The results of this study also agree with the low amount of natural organic matter reported for these types of soils, as well as with deficiencies of B, Cu, Fe, Mn, Zn, and P [18].

3.2. Physicochemical characterization of industrial wastewater

Table 3 shows the physicochemical characteristics of the wastewater used for irrigation of the soil columns. The concentration of total Chromium and Cr VI in the wastewater was high: 679.6 mg/L for total chromium and 559.5 mg/L for Cr VI. The concentration of copper was 18.5 mg/L; 0.64 mg/L for nitrates; 360.3 mg/L for sulfates; and 272.3 mg/L for chlorides. Electrical conductivity was 1576 μS/cm due to the presence of metals such as chromium, copper, chlorides, and sulfates. The pH of the water (3.4) is congruent with the presence of

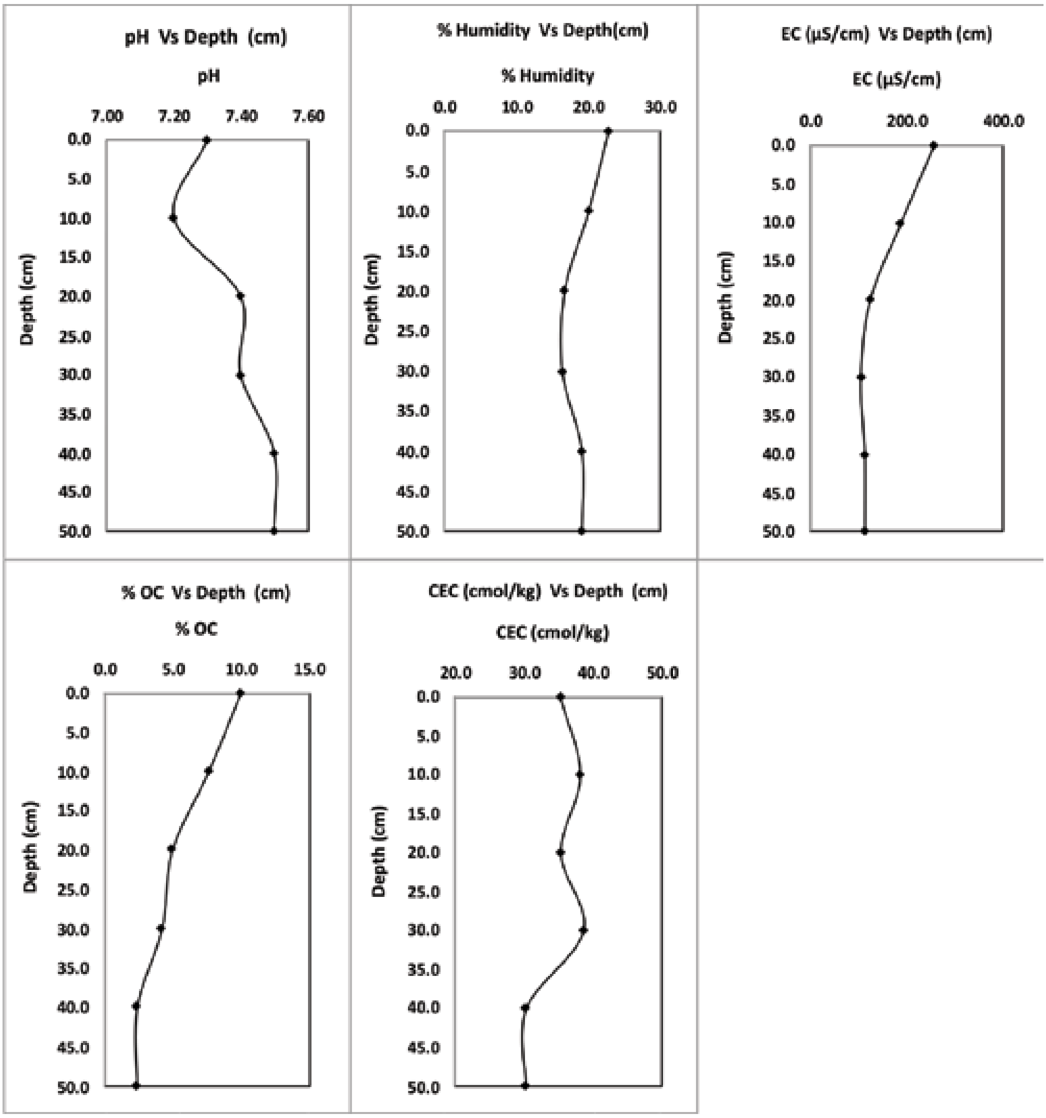


Figure 1. Physical and chemical characteristics of the soil sample as a function of depth. EC = electric conductivity, OC = organic carbon, CEC = cation exchange capacity.

chromium VI, since the species distribution diagram for chromium indicates that the chromium species present in waters with pH values ranging from 1 to 5 is chromium VI. The wastewater studied here came from an electroplating plant in the city of Toluca.

3.3. Concentration of chromium VI in the soil solution throughout the soil column

The concentration of chromium in samples of the soil-saturated solution collected from the soil profile at depth intervals of 10 cm (**Table 4**); it also shows the amount of chromium accumulated in each section of the soil column. The initial concentration of Cr VI in the water used

Soil	Depth (cm)	pH	EC (μS/cm)	CEC (Cmol/Kg)	OC (g/Kg)	OM %	Humidity %
M1	0–10	7.30	255.09	35.22	9.96	17.17	22.83
M2	10–20	7.20	187.93	38.21	7.57	13.05	20.02
M3	20–30	7.40	124.74	35.29	4.90	8.45	16.63
M4	30–40	7.40	105.13	38.66	4.13	7.12	16.27
M5	40–50	7.50	112.91	30.20	2.29	3.95	19.08

M sample.

Table 1. Physicochemical characteristics of the soil column under study.

Sample	Depth (cm)	Clay (%)	Loam (%)	Sand (%)
M1	0–10	10.0	30.0	60.0
M2	10–20	18.0	42.0	40.0
M3	20–30	41.0	46.0	13.0
M4	30–40	11.0	45.0	44.0
M5	40–50	34.0	54.0	12.0

M sample.

Table 2. Textural characteristics of the soil column under study.

Characteristic	Value
pH	3.4
Electrical conductivity (μS/cm)	1576
Cr VI (mg/L)	559.5
Cu (mg/L)	18.5
Nitrates (mg/L)	0.64
Sulfates (mg/L)	360.3
Chlorides (mg/L)	272.3
Total Chromium (mg/L)	*679.6*

Table 3. Physicochemical characteristics of the wastewater used for irrigation.

for irrigation was 559.5 mg/L. The results show that the greatest accumulation of Cr occurred between 0 and 10 cm depth (299 mg/L), followed by the layer at 30–40 cm, with 160 mg/L Cr, a 50% decrease in the concentration of chromium VI present in soil solution.

The data on soil texture showed that the percentage of clay is low at 10–20 cm depths (10%), while at 20–30 cm is four times greater (41%). The percentage of organic matter is 17.17 and 8.45%. The CEC, however, is 35.22 and 35.29%, similar to the rest of the soil column. The highest amount of accumulated chromium was found in the surface layer, which had the lowest percentage of clay. This demonstrates the participation of organic matter in the accumulation of chromium (**Table 4**).

Additional to the irrigation with wastewater, one irrigation was done with a compost solution (100 g of compost/1 L water) in order to observe the effect of dissolved organic matter on the accumulation of chromium in the soil column. The results showed that chromium was absent from the soil-saturated solution at any depth of the soil profile, indicating that the chromium was being immobilized or retained. After this irrigation, one more irrigation was carried out, maintaining the concentration of chromium in the water entering the soil profile at 559.5 mg/L (**Table 5**). In these irrigations, the concentration of Cr VI in the saturated water collected at the outlet of the soil column was lower than in the first irrigation, suggesting a higher accumulation of chromium.

The theoretical amount of chromium that precipitated and accumulated in the soil during the first irrigation was 299 mg; when dissolved organic matter was added to the irrigation water, that amount increased to 326 mg. Using the solution containing dissolved organic matter improved the soil reduction conditions, causing the reduction of Cr (VI) to Cr (III), which produced a precipitate of chromium, either an oxide or hydroxide, that accumulated in the

Depth (cm)	Irrigation		Kd	T (°C)	pH	ORP (mV)
	Ce_s	A				
0–10	260.0	299.0	11.5	23.0	5.7	102.1
10–20	240.0	20.0	0.8	22.0	5.7	103.3
20–30	80.0	160.0	2.0	22.0	5.8	96.5
30–40	40.0	40.0	40.0	22.0	5.9	92.4
40–50	40.0	0.0	0.0	21.0	5.9	91.2

Ce: concentration of Cr in the saturated solution at every 10 cm of depth (mg/L) A: amount of chromium retained (mg).

Table 4. Concentration of Cr VI in the soil-saturated solution (Ce). Retention capacity of Cr. Distribution coefficient of Kd, pH, and ORP along the soil column (q).

Samples	Intensity of fluorescence (Excitation/Emission (nm))			
	Peak A	Peak B	Peaks C and D	Peak F
0–10	158 (340/412)	313 (210/407)	ND	121 (280/414)
10–20	255 (340/412)	540 (210/409)	ND	177 (280/412)
20–30	33 (320/438)	ND	ND	
30–40	67 (335/442)	200 (210/420)	ND	
40–50	93 (330/440)	206 (225/435)	ND	

ND Undefined.

Table 5. 3D-fluorescence characterization of the soil solution.

soil matrix [18, 19]. Of the 559.5 mg/L of chromium that were added to the soil column with the first irrigation, 53% was retained; after adding dissolved organic matter to the irrigation water, the retention percentage reached 58%.

3.4. Irrigation with wastewater

It was observed that the concentration of chromium (VI) in the wastewater decreased along the soil column. **Table 4** shows the concentration of chromium (VI), the oxidation–reduction potential and pH along the soil column. The samples show a direct effect of dissolved organic matter on the soil conditions that facilitate the accumulation of chromium. The irrigation results show that dissolved organic matter improved the soil reduction conditions, which promoted the accumulation by precipitation of chromium species. The soil reduction conditions are represented by the ORP values in the soil-saturated solution at the outlet of the soil column during direct irrigation.

The initial ORP value of the irrigation water was 274.9 mV; it decreased by up to 66% with each additional 10 cm of depth. The pH of the irrigation water changed from 3.4 to 5.6. It should be mentioned that the wastewater used for irrigation stayed in the soil column for 15 min, which shows that the soil had good drainage.

3.5. Chromium species in wastewater and soil solution along the soil profile

The species distribution diagram of Cr VI and Cr III were built based on the ORP and pH data, using the Hydra and Medusa programs [19]. **Figure 2** shows the Eh-pH diagram of chromium in the wastewater; it shows that the $HCrO_4^-$ ion is the Cr VI species that predominated in both oxidized and reduced environments at pH values of 0–6.6. The CrO_4^{2-} ion predominated at values of pH > 6.0. According to the diagram, the Cr III species that predominated in the solution, depending on the pH of the water, was Cr^{3+}. Thus, Cr VI species such as $HCrO_4^-$, and Cr III species such as Cr^{3+}, entered the soil with the irrigation water, the latter in smaller quantities.

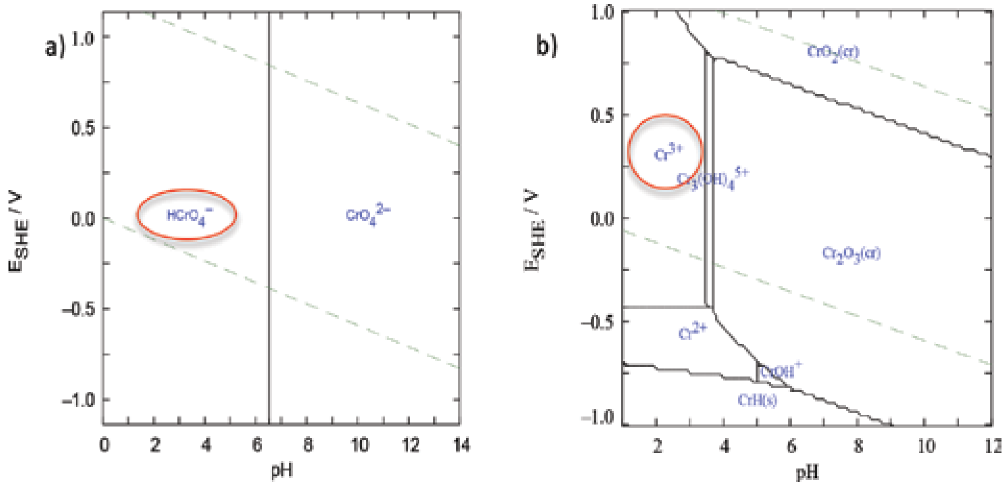


Figure 2. Stability diagram of chromium species (Eh-pH) in wastewater with high chromium content. Cr VI concentration: 10.78 mM; Cr III concentration: 2.31 mM; pH 3.4. (a) Cr VI species and (b) Cr III species.

Figure 3 shows the stability diagrams of chromium (Eh-pH) along the soil column during irrigation with wastewater with high chromium content. As observed in **Figure 4**, and based on the pH values of each soil solution, the predominant Cr III species was Cr_2O_3, and there was no presence of Cr VI species, confirming that chromium III species precipitate and accumulate in soil as chromium oxide combined with natural organic matter [18, 19]. The redox potential measured in the soil solution during the irrigation was between 91.2 and 103.3 mV, with pH values between 5.67 and 5.90. In the species distribution diagram of chromium, these intervals correspond to the area of predominance of Cr_2O_3. The amount of chromium in the solution decreased along the soil profile.

3.6. 3D-fluorescence of dissolved organic matter in the soil solution

The 3D fluorescence spectra of the soil-saturated solution, based on the fluorescence data obtained (**Table 5**), show two peaks: A and B (**Figure 4**). These peaks are located within a

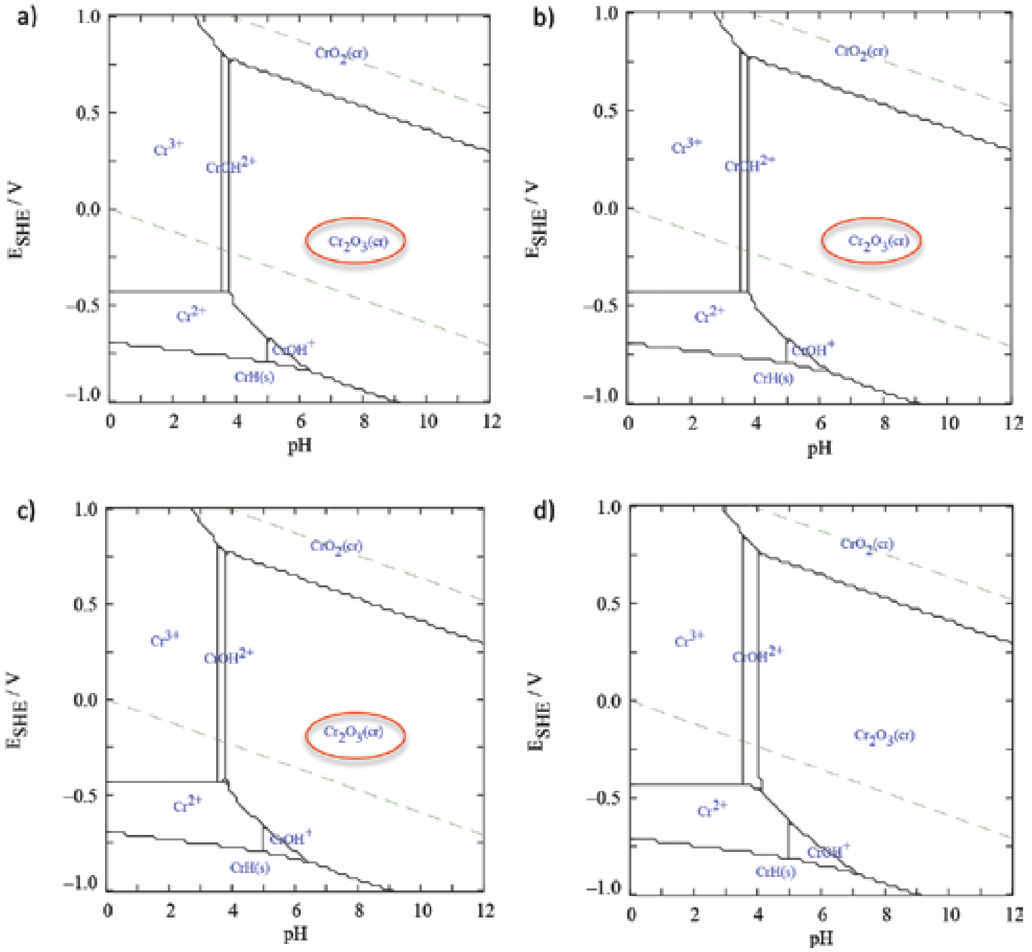


Figure 3. Stability diagram of chromium (Eh-pH) in the soil solution: (a) depth (0–10 cm), ionic strength 0.005 M, [Cr VI] 5.01 mM, [Cr III] 1.07 mM; (b) (10–20 cm), ionic strength 0.004 M [Cr VI] 4.62 mM and [Cr III] 0.99 mM; (c) (20–30 cm), ionic strength 0.001 M [Cr VI] 0.77 mM and [Cr III] 0.17 MM; (d) (30–50 cm), ionic strength 0.001 M [Cr VI] 0.77 mM and [Cr III] 0.17 mM for the entire pH range and for the range of pH measurements and redox potential of the samples.

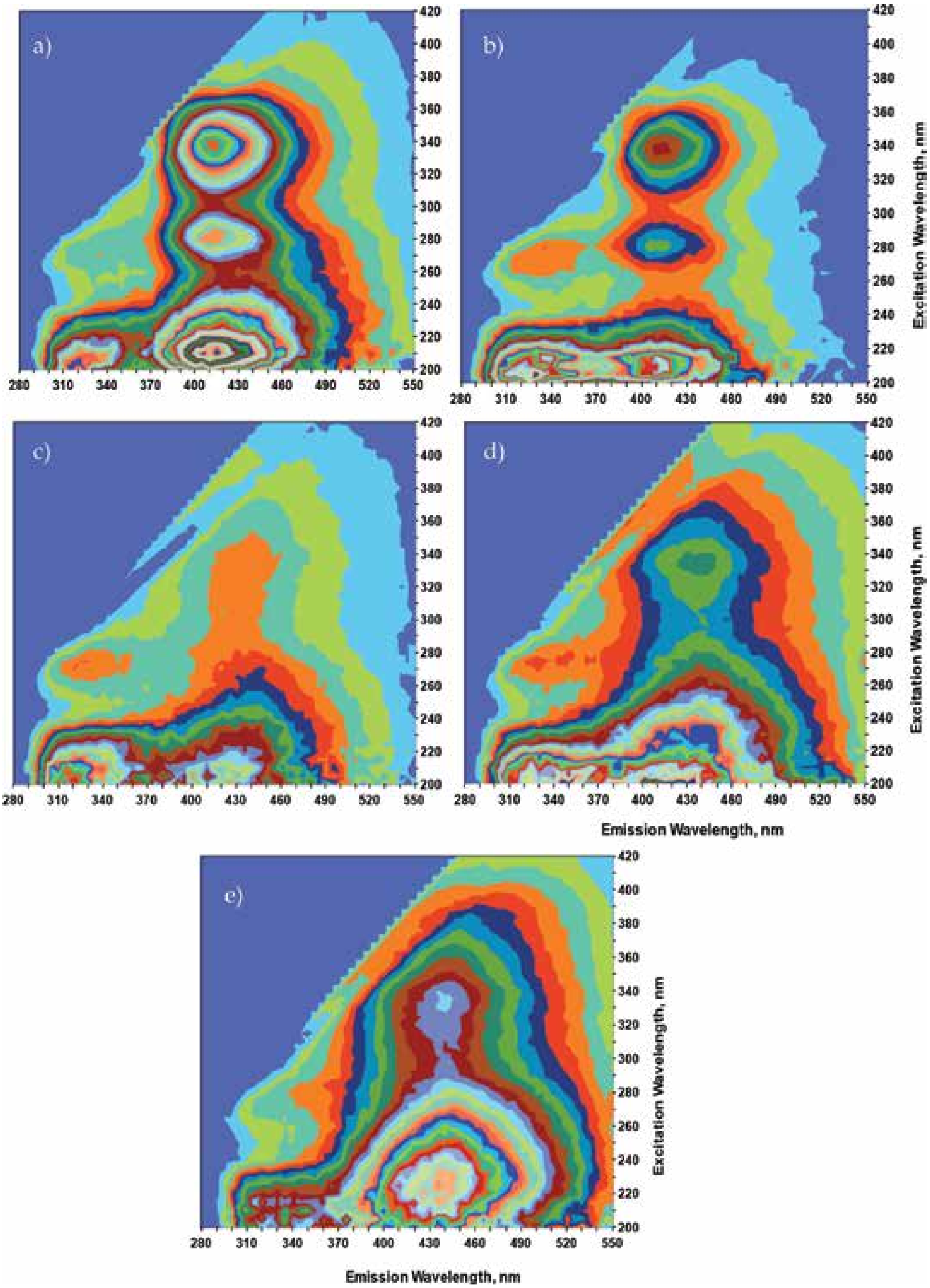


Figure 4. 3D fluorescence spectra of the soil-saturated solution along the soil profile.

range of excitation/emission wavelengths of 320–340 ex/412–440em and 210–225ex/407–435em, with intensities of 33–255 and 200–540, respectively. The A and B peaks are within the regions corresponding to humic and fulvic acids [16]. The spectra did not show peaks of type C and D, which are associated with the presence of organic material of anthropogenic origin. However, a peak (F) between the peaks A and B could be considered a humic acid, given the region in which it is located, although it could also be associated with some organic synthetic material or a complex of Cr and humic acids.

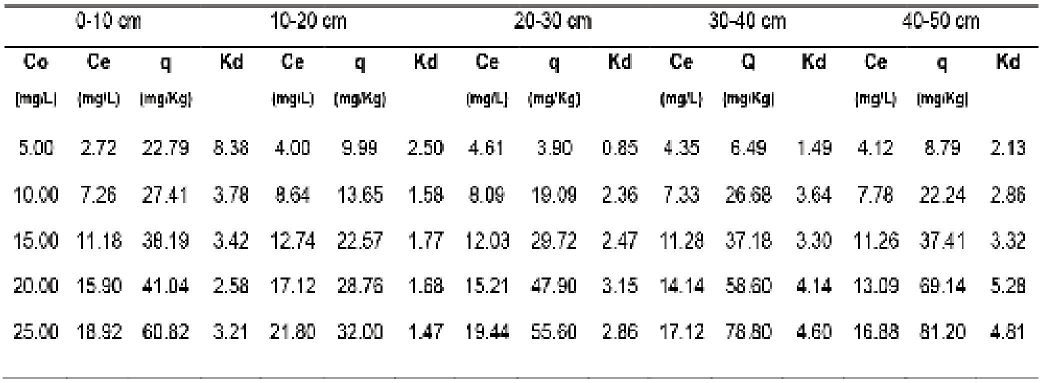
The highest fluorescence intensity was recorded at a depth of 0–20 cm, in agreement with the fact that the surface layer had the greater presence of natural organic matter (**Figure 4**). As mentioned before, the chromium accumulated in the soil profile may combine with two types of natural organic matter, humic and fulvic acids. The fluorescence spectra showed the evolution of humic substances [15, 17]. In the first 20 cm of the soil profile, the fluorescence intensity of humic acids is high (158 at 10 cm and 255 at 20 cm), but decreases with increasing depth by up to 87%. The fluorescence intensity of fulvic acids is higher than that of humic acids (313 and 540) and decreases less with depth (62%).

Because fulvic acids are more mobile than humic acids, it is logical to find them throughout the soil profile (**Figure 4**). These acids can predominate in natural waters and have a high degree of anionic charge, which favors the formation of stable complexes with cations such as chromium [15, 20, 21]. It is worth noting the amount of chromium accumulated in the soil profile (**Table 6**); the greatest accumulation of chromium was observed in the first 10 cm of the column, where there was a greater presence of organic matter and where peak F was observed. At a depth 30–40 cm, the accumulated chromium was only 63% of the level found in the surface layer; however, at this depth, the organic matter content was 60% lower than on the surface layer, while the percentage of clay was the same in both layers.

The fluorescence spectra indicated that most of the dissolved organic matter present in the surface layer and at a depth of 30–40 cm were fulvic acids. As mentioned earlier, fulvic acids are more mobile and tend to form complexes with Cr (III) cations, which suggests that, given the low amount of Cr (III) present in the wastewater used for irrigation, it precipitated mostly in the first 20 cm of the soil profile, which explains its absence from the soil-saturated solution. The Cr (VI) species present in the solution collected at the outlet of the soil column may not have passed enough time in the soil column to convert to Cr (III).

3.7. Chromium retention capacity of the soil

Table 6 shows the chromium retention results of the soil, based on the retention capacity (q) and equilibrium concentrations (Ce) determined by Bach tests at different concentrations of chromium. The table shows that the retention capacity of the soil increased as the equilibrium concentration of chromium increased. However, a constant value was not reached, which is usually observed when the soil reaches a saturation point; this can be explained by the low concentration of chromium in the standard solutions. The results of the Bach tests showed that the dispersion coefficient of chromium in the soil was higher (Kd 8.36) in the surface layer



0-10 cm				10-20 cm			20-30 cm			30-40 cm			40-50 cm		
Co [mg/L]	Ce (mg/L)	q [mg/Kg]	Kd	Ce (mg/L)	q (mg/Kg)	Kd	Ce (mg/L)	q (mg/Kg)	Kd	Ce (mg/L)	Q [mg/Kg]	Kd	Ce [mg/L]	q [mg/Kg]	Kd
5.00	2.72	22.79	8.38	4.00	9.99	2.50	4.61	3.90	0.85	4.35	6.49	1.49	4.12	8.79	2.13
10.00	7.26	27.41	3.78	8.64	13.65	1.58	8.09	19.09	2.36	7.33	26.68	3.64	7.78	22.24	2.86
15.00	11.18	38.19	3.42	12.74	22.57	1.77	12.03	29.72	2.47	11.28	37.18	3.30	11.26	37.41	3.32
20.00	15.90	41.04	2.58	17.12	28.76	1.68	15.21	47.90	3.15	14.14	58.60	4.14	13.09	69.14	5.28
25.00	18.92	60.82	3.21	21.80	32.00	1.47	19.44	55.60	2.86	17.12	78.80	4.60	16.88	81.20	4.81

Table 6. Results of Ce, q and Kd along the soil column.

of the soil column (0–10 cm depth), which had the largest concentration of organic matter and the lowest concentration of chromium (5 mg/L). This behavior shows the affinity of chromium for organic matter. At a depth of 20–30 cm, where the percentage of clay was the largest (41%) and the dispersion coefficient of chromium was Kd 0.85.

Starting at a depth of 20 cm, the dispersion coefficient increased while the concentration of chromium in the solution increased, except for interval of 20–30 cm depth, which showed an opposite behavior. Bach tests have been designed to study adsorption equilibria in a continuously stirred soil suspension. These tests are based on a physical model of a completely dispersed soil particle system where the entire surface of the soil is exposed and available to interact with chromium. These tests do not represent real natural conditions, since they assume a closed system in which soil particles have the highest adsorption capacity, and a practically null flow rate [21–23]. However, they are a good tool to try to represent and understand the behavior of contaminants. The Bach tests performed in this study were carried out with a contact time of 30 min, twice the residence time of the water in the soil column, in order to represent real conditions.

A linear isotherm was used to describe the adsorption processes that took place in the soil; this allowed us to describe the distribution of chromium between the soil and the solution [22, 23]. The isotherms generated by the Bach tests (**Figure 5**) show the retention capacity of chromium in the soil (q) versus the equilibrium concentration of chromium (Ce).

At low concentrations of chromium, the adsorption isotherm for the soil is linear. **Figure 5** shows that with a low concentration of chromium and a contact time range of 0–25 min, 45% of chromium is removed from the solution in the first 10 cm of the soil column, 20% at 10–20 cm, 7.8% at 20–30 cm, 13% at 30–40 cm, and 17% at 40–50 cm.

The removal percentage of chromium from the solution decreased as the concentration of chromium in the solution increased. The removal percentage of chromium also decreased throughout the soil column, with the highest percentage at 20–30 cm depth. Under nonequilibrium

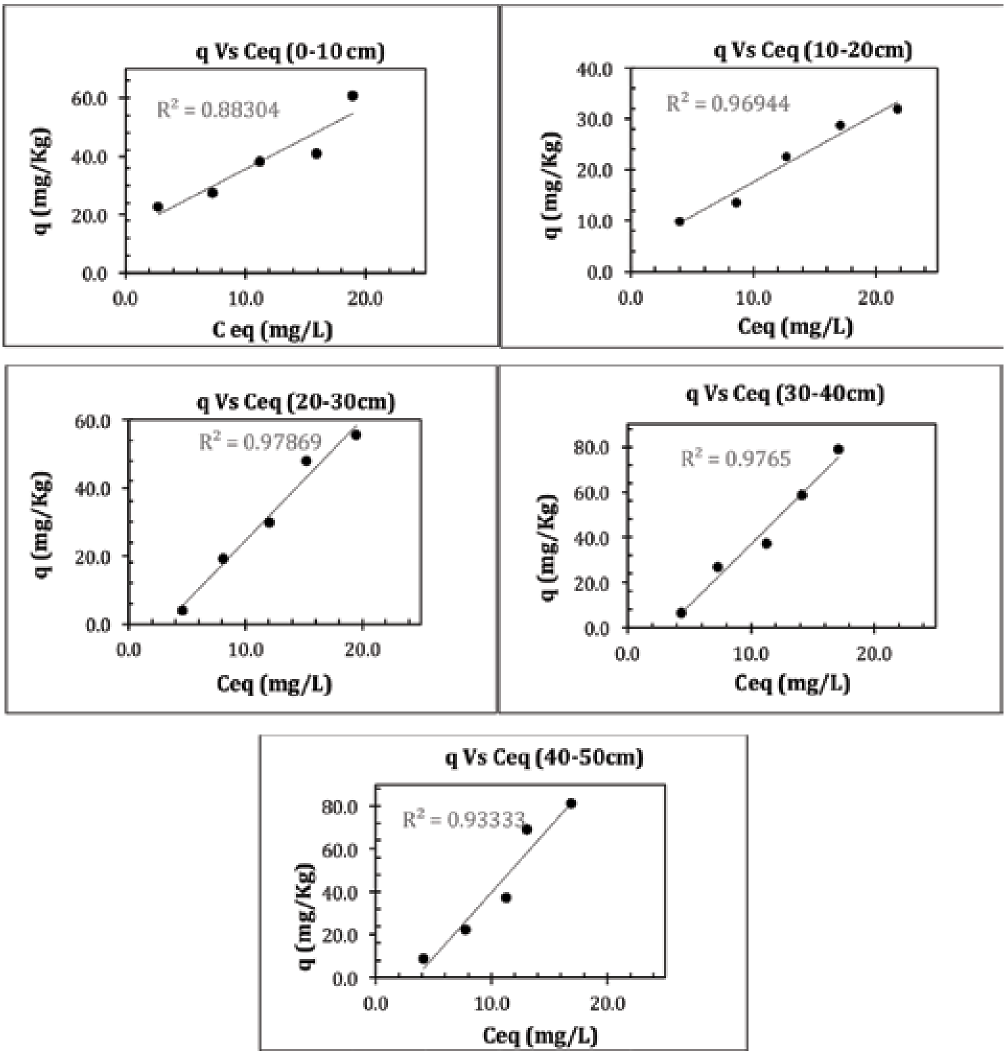


Figure 5. Chromium adsorption isotherms along the soil column. Contact time: 30 min. Temperature: 25°C.

conditions, the highest accumulation of chromium occurred in the first 10 cm of the soil column, in agreement with the results of the Bach tests, which showed that chromium has a high affinity for organic matter, as evidenced by the Kd value (**Table 6**). As mentioned before, the dispersion coefficients determined by the Bach tests decreases with depth in the soil column from 8.38 to 2.13. The fluorescence intensity of humic acids also decreased with depth; the highest fluorescence intensity of these humic substances was recorded in the first 10 cm of the soil column, where the dispersion coefficient was higher.

The dispersion coefficient of humic acids was similar to that of chromium, so it is possible to assume that Cr (VI) species complexed with humic acids or were reduced to Cr (III) in the presence of these humic substances. Moreover, the R^2 values found along the soil column showed that the isotherm can describe the sorption or complexation behavior of chromium with humic acids.

An X-ray diffraction analysis was performed to verify the precipitation of chromium in the soil. The results showed the presence of the species Cr_2O_5, Cr_5O_{12}, CrO_2, and Cr_7C_3 in the soil layer with the greatest amount of organic matter, confirming the removal of chromium by precipitation. Considering that most of the reducers used here and reported in the literature are less effective at alkaline pH values [5], natural organic matter (humic acid) could be used for the remediation of soils and waters contaminated with Cr (VI).

4. Conclusions

The use of a dissolved organic matter solution had a direct effect on the soil reduction conditions, improving the reduction of Cr (VI) to Cr (III) and producing a precipitate of chromium that accumulated in the soil matrix.

In the species distribution diagram of chromium, the oxidation–reduction potential and pH values found in the soil-saturated solutions correspond to the area of predominance of Cr_2O_3, which is not water soluble and is thus difficult to leach.

The chromium accumulated in the soil profile may have combined with natural organic matter such as humic and fulvic acids.

The 3D fluorescence analysis of the soil-saturated solutions showed the presence of natural organic matter (humic and fulvic acids) throughout the soil profile.

The highest accumulation of chromium occurred in the first 10 cm of the soil column, suggesting, like the Bach tests, that chromium has a high affinity for organic matter, as evidenced by the Kd values.

The dispersion coefficient of humic acids was similarly to that of chromium, so it is possible to assume that Cr (VI) species may have complexed with humic acids.

Acknowledgements

This study was funded by Instituto Potosino de Investigación Científica y Tecnológica (IPICYT) and Universidad Autónoma del Estado de México - Centro Interamericano de Recursos del Agua (CIRA).

Conflict of interest

The authors declare is no conflict of interest regarding the publication of this paper.

Author details

Rosa María Fuentes-Rivas[1,4]*, Francisco Martin-Romero[2], Daury García Pulido[3], Reyna Maria Guadalupe Fonseca-Montes de Oca[3], Janete Moran Ramírez[4] and Jose Alfredo Ramos Leal[4]

*Address all correspondence to: rmfuentesr@uaemex.mx

1 Facultad de Geografía, Universidad Autónoma del Estado de México, Toluca, Estado de México, México

2 Departamento de Geoquímica, Instituto de Geología, Universidad Nacional Autónoma de México, México D.F., México

3 Centro Interamericano de Recursos del Agua, Toluca, Estado de México, México

4 División de Geociencias Aplicadas, Instituto Potosino de Investigación Científica y Tecnológica, San Luis Potosí, México

References

[1] Guédron S, Duwig C, Prado BL, et al. (Methyl) mercury, arsenic, and lead contamination of the world's largest wastewater irrigation system: The Mezquital Valley (hidalgo state-Mexico). Water, Air, and Soil Pollution. 2014;**225**:2045. DOI: 10.1007/s11270-014-2045-3

[2] Siebe C, Cifuentes E. Environmental impact of wastewater irrigation in Central Mexico: An overview. International Journal of Environmental Health Research. 2008;**5**(2):161-173. DOI: 10.1080/09603129509356845

[3] Benedetti MF, van Riemsdijk WH, Koopal LK, Kinniburgh DG, Gooddy DC, Milne CJ. Metal ion binding by natural organic matter: From the model to the field. Geochimica et Cosmochimica Acta. 1996;**60**:2503-2513. DOI: 10.1016/0016-7037(96)00113-5

[4] Xing B. Sorption of anthropogenic organic compounds by soil organic matter: A mechanistic consideration. Canadian Journal of Soil Science. 2001;**81**:317-323

[5] Chefetz B, Deshmukh AP, Hatcher PG, Guthrie EA. Pyrene sorption by natural organic matter. Environmental Science & Technology. 2000;**34**:2925-2930. DOI: 10.1021/es9912877

[6] Stevenson FJ. Humus Chemistry: Genesis, Composition, Reactions. New York: John Wiley and Sons; 1982

[7] Sposito G. The Chemistry of Soils. 3rd ed. Unites States of America, New York, NY. Oxford University Press; 2016

[8] Simeonov L, Sargayan V. Soil Chemical Pollution, Risk Assessment, Remediation and Security. 1st ed. Dordrecht, Springer; 2008

[9] Alloway BJ. Heavy Metals in Soils. New York. ISBN 470215984: John Wiley and Sons, Inc.; 1990

[10] Callahan MA, Slimak MW, Gabel NW, May IP, Fowler CF, Freed JR, Jennings P, Durfee RL, Whitemore FC, Maestri B, Mabey WR, Holt BR, Gould C. Water related Environmental Fate of 129 Priority Pollutants. Springfield, VA: Versar, Inc. (EPA-440-4-79-029a, b); 1979

[11] Fishbein L. Source, transport and alterations of metal compounds: An overview. In: Arsenic, beryllium, cadmium, chromium and nickel. Environmental Health Perspectives. 1981;**40**:43-64

[12] Lichtfouse E, Navarrete M, Debaeke P, Souchère V, Alberola C, Ménassieu J. Agronomy for sustainable agriculture. A review, Agron. Sustain. Dev. 2009. 29, 1-6

[13] Navarro García G, Navarro García S. Química Agrícola, Química del suelo y de nutrientes esenciales para las plantas. España: Mundi-Prensa; 2013

[14] American Public Health Association. Standard Methods for the Examination of Water and Wastewater. 21st ed. Washington, DC: American Water Works Association, Water Environment Federation; 2005

[15] Fuentes Rivas RM, Santa Cruz de Leon G, Ramos Leal JA, Morán Ramírez J, Martín Romero F. Characterization of dissolved organic matter in an agricultural wastewater-irrigated soil, in semi-arid Mexico. Revista Internacional de Contaminación Ambiental. 2017;**33**(4):575-590. DOI: 10.20937/RICA.2017.33.04.03

[16] Westerhoff P, Chem W, Esparza M. Fluorescent analysis of a standard fulvic acid tertiary treated wastewater. Journal of Environmental Quality. 2001;**30**:2037-2046 Available from: https://www.agronomy.org/publications/jeq/abstracts/30/6/2037

[17] González Rebollar JL, Chueca Sancho A. Características generales y uso en programas de desarrollo de tierras áridas y semiáridas. Madrid, España: Consejo Superior de Investigaciones Científicas, Fundación Ramón Areces; 2010

[18] Petronio BM, Cosma B, Mazzucetelli A, Rivaro P. A multimethod approach to study humic compounds and metal speciation in marine sediment samples. International Journal of Environmental Analytical Chemistry. 1993;**54**(1):45-56

[19] Puigdomenech I. Medusa Software; 2009-2011. Available from: https://sites.google.com/site/chemdiagr/ [Accessed: 23 August, 2012]

[20] Stevenson FJ. Humus Chemistry: Genesis, Composition, Reactions. New York: John Wiley & Sons; 1994

[21] Schnitzer M. Binding of humic substances by soil minerals colloids. In: Huang PM, Schnitzer M, editors. Interacions of Soil Minerals with Natural Organics and Microbes. SSSA Spec. Publi. 17. Madison, WI: SSSA; 1986

[22] Morell I, Candela L. Plaguicidas: Aspectos ambientales, analíticos y toxicológicos. Col. Summa. 1998;**5**:386

[23] Yurkow EJ. Photochemical reduction of hexavalent chromium in glycerol-containing solutions. Environmental Pollution. 2002;**117**:1-3

Biochar and Animal Manure Impact on Soil, Crop Yield and Quality

George F. Antonious

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.77008

Abstract

Four low-cost organic soil amendments (chicken manure, CM; horse manure, HM; yard water, YW; and sewage sludge, SS) that are generated daily in large amounts, and native bare soil were planted with tomato (*Solanum lycopersicum* var. Mountain spring) seedlings of 52 days old in raised black plastic-mulch. Each of the 5 treatments was also mixed with biochar to make a total of 10 treatments in a randomized complete block design (RCBD). Results revealed that total fresh weight of tomato fruits collected after three harvests from CM and CM mixed with biochar significantly ($P < 0.05$) increased, whereas yield obtained from HM was the lowest indicating a positive effect of CM on the growth and yield of tomato. HM increased soil urease activity, while CM and SS increased soil invertase activity. Total marketable tomato yield of biochar amended soils was increased by 63 and 20% in HM and YW treatments, respectively compared to other soil treatments. Ascorbic acid (vitamin C) was greatest in fruits of plants grown in CM amended soil. Results of this investigation may help limited-resource farmers in selecting an affordable soil management practice to enhance crop yield, crop nutritional composition, and soil microbial activity.

Keywords: low cost fertilizer, soil amendments, sewage sludge, chicken manure, horse manure, total phenols, vitamin C, soluble sugars

1. Introduction

Recycling animal manure for use as a low-cost organic fertilizer has resulted a positive effect on the growth and yield of a wide variety of crops and promoted the restoration of ecologic and economic functions of soil. The organic matter (OM) content of composted animal manure is high and its addition to agricultural soils often improves soil physical, chemical, and biological properties [1]. Soil organic amendments alleviate OM that improves the properties of soils through increasing nutrient availability and water holding capacity, total pore space, aggregate stability, erosion resistance, temperature insulation, and decreasing soil density. Antonious [1] reported that sewage sludge (SS) and chicken manure (CM), that must be disposed, are excellent fertilizers.

Tomatoes (*Solanum lycopersicum*, formerly *Lycopersicon esculentum* Mill) belong to the Solanaceae family. Tomato has achieved a remarkable status among other vegetables because of its rich nutritional composition and widespread consumption. It is one of the major vegetable crops grown in almost every country of the world. Fresh tomato fruits contain several nutritional compounds including vitamin C (ascorbic acid) and minerals [2] and have been shown to reduce the risks of cardiovascular diseases and certain types of cancer, such as prostate, lung, and stomach cancers [3]. Accordingly, enhancing the nutritional value of fresh tomatoes and tomato products require frequent investigations to evaluate the influences of agricultural practices, such as the use of fertilizers, organic soil amendments, and the environmental conditions on tomato yield and fruit quality. It was demonstrated that increasing N fertilization under field conditions reduced the fruit vitamin C concentration [4]. This is due to the fact that the high N concentration in the fertilizers favors plant leaf area development, thereby lessening light penetration in the canopy and fruit vitamin C development. Similarly, the negative effects of N application on vitamin C contents occur in other vegetables such as potatoes [5]. The typical taste of tomato is mainly attributed to soluble sugars, organic acids and volatile compounds. Sugars are important macronutrients of the human diet and plants. During tomato ripening total soluble solids (TSS), such as sugars (fructose and glucose) are found to be predominant in domesticated tomato fruits. Tomato possesses a wide range of bioactive compounds as a pool of antioxidants that have positive effects on health, associated with their anti-carcinogenic and antiatherogenic potential [6]. These bioactive compounds include carotenoids (vitamin A), ascorbic acid (vitamin C), phenolic compounds, and tocopherols (Vitamin E), which are at higher concentrations in the skin followed by seed and pulp fractions [7]. In addition, concentrations of bioactive compounds in tomato fruit are significantly influenced by tomato genotype [8, 9], environmental factors and agricultural techniques [10]. Regarding tomato phenolic compounds content, chlorogenic acid and rutin have been found to be the most important flavonoids in tomato. Butta and Spaulding [11] found high concentrations of total phenols in tomato fruits at the early stages of fruit development, then phenols concentration declined rapidly during fruit ripening, although other authors have shown that the content of total phenols remained stable during ripening [12].

The literature review verified the potential of biochar, a product of wood pyrolysis, applications for improving N input in agricultural systems, while indicating the needs for long-term field studies to better understand the effect of biochar on biological N_2 fixation. When biomass, such as wood, manure, or leaves, is heated in a closed container with little or no available air, this process is known as pyrolysis. Research results indicated that the conversion of biomass into biochar can not only result in renewable energy (synthetic gas and bio oil), but also decrease the content of CO_2 in the atmosphere [13]. When biochar was used in column leaching experiments to assess its ability to hold nutrients, results indicated that biochar effectively reduced the total amount of nitrate (NO_3), ammonium (NH_4), and phosphate in leachates by 34, 35, and 21%, respectively, relative to native soil alone [14]. The adsorption of N by biochar particles decreases NH_4 and NO_3 loss during composting and after manure applications, providing a mechanism for releasing nitrogen fertilizers in a slow release process [15]. Biochar is a porous and hygroscopic material in nature. These properties make biochar very effective at retaining water-soluble nutrients and make it an environment for many beneficial soil microorganisms. Studies have shown that foliar N concentrations of crops decreased when biochar was added to soil [16]. Rondon et al. [17] showed the potential of biochar applications for managing N input in agricultural systems, while indicating the requirements for more field studies to provide more explanations and understanding of biochar effects on soil biological N_2 fixation.

Regarding the need for healthy food, the demand for low cholesterol meat products and high protein sources, as well as agricultural production and economic incentive have led to a tremendous expansion in the worldwide poultry industry [18]. Due to the rapid growth in the poultry industry. Chicken manure (CM) generation is currently accessible in increasing quantities, resulting in unplanned disposal to soil with potential negative environmental consequences [19]. Manures, especially poultry litter and feedlot manure, may raise or maintain pH in acidic and near neutral soils via a liming effect because they contain some $CaCO_3$, which originates in the animal diet [20]. Animal manures are not just a waste material requiring disposal, but a crucial raw material needed to enhance plant production. If animal manure applied properly, it can replace significant amounts of mineral fertilizers and save energy. Over a billion tons of animal manure is produced annually in the US [21]. Organic animal manure is a rich source of plant nutrients and soil amendment when used at the adequate rate of application. Organic waste is a source of plant macro- and micronutrients, organic matter (OM), recovers soil quality, and increases soil pH in acid soils. However, nutrients, such as P and N build up in the soil if application rates are higher than the nutrient requirements of the intended crops. An increase of organic waste originated from different humans and productive activities is a continuous concern. Waste application to soil is proposed as a solution to disposal problem. This practice is popular in the agricultural fields because of the value of this waste as organic fertilizer.

2. Sewage sludge, horse manure, chicken manure, and vermicompost: an overview

2.1. Municipal sewage sludge

Municipal sewage sludge (SS), also known as biosolids (**Figure 1**) is derived from wastewater treatment plants in which wastewater, primarily derived from domestic sources or discharges from commercial and industrial enterprises. Most of these enterprises carry out pretreatments prior to discharging wastes into the conventional community sewer system. As a result of pretreatment, total fertilizer nutrient concentration rarely exceeds 10% in most manure sources and frequently is a fraction of that. Commercial fertilizers usually contain about 30% nutrients by weight. Low nutrient concentration increases the time and cost of transportation and land application [22]. Nutrients in most commercial fertilizers are designed to be rapidly available to crops when applied to the soil. Whereas, the organic nitrogen fraction of manure reduces the availability and predictability of the manure as a nitrogen source because the availability of organic nutrients is dependent on soil microbial activity. In addition, the chemistry of manure makes inorganic nitrogen in manure prone to volatilization losses when it is surface applied. Successful use of organic manure fertilizer requires adjusting application rates to account for reduced nutrient availability.

Figure 1. Metropolitan wastewater treatment plants in Louisville, Kentucky turned municipal sewage sludge into package of organic fertilizer "Louisville green" available in stores.

Organic manure products sold as commercial crop fertilizers have nutrients concentrations typically vary spatially and over time within the manure storage facilities making it hard to meet fertilizer needs. Accordingly, calculating the recommended rate of organic fertilizer application is a challenge when farmers follow the label instructions. Should farmers apply a rate that on average supplies the target nutrients rate or use a rate of application that insures the entire field gets at least the needed fertilizer rate? The first strategy insures portions of the field will have nutrient deficits, an economic liability to the farmer; the second strategy maximizes yield but also insures that part of the field will have nutrient excess and a water quality liability [22]. Biosolids have become less contaminated with trace metals and organic compounds [23]. In wastewater treatments plants solids are removed during primary and secondary treatment. SS product is usually incinerated, landfilled or further treated. Further treatment may consist of digestion, composting or alkaline stabilization. After treatment, this material is called biosolids. Biosolids contain inorganic materials, plant nutrients, trace elements, and organic compounds.

2.2. Chicken manure

Tremendous expansion in the poultry industry occurs worldwide [18]. Due to the fast expansion in the poultry industry, production of poultry manure (**Figure 2**) has increased significantly. Chicken manure (CM), which is the most abundant poultry manure, is a mixture of feces, waste feed, feathers and bedding material, and contains essential plant nutrients making it an organic source of nutrients. For example, N, P, and potash (K) are approximately 8.5% of the weight of poultry litter. Though beneficial as an organic amendment, the huge quantities being produced in poultry farms have resulted in unplanned disposal of this manure to the soil in some cases, where it poses environmental challenges like eutrophication, air pollution, emission of greenhouse gasses and production of phytotoxic substances [19, 24, 25]. On the other hand, animal manure like poultry manure have been found to contain potentially harmful trace elements like arsenic, copper and zinc, which originate from the chemicals used to treat diseases in commercial chicken production [25]. Broiler chicken litter is a source of trace elements that can potentially accumulate in the soil after repeated applications and this is why it is important to test for poultry manure composition before direct application to farm lands. In addition, arsenic (As) which is a severe carcinogenic compound [26] is a feed additive in conventional raised broilers

Figure 2. Chicken manure waste turned into package of organic fertilizer available in stores.

used to control protozoan parasites and to enhance poultry weight gain. Despite this, CM can be effective sources of essential plant nutrients such as N and P, and as a source of soil organic carbon. The phytotoxicity in some plants grown in CM amended soils indicated the need for further trials to reduce its toxic impact through composting and/or vermicomposting to improve nutrient content and reduce the phytotoxicity to growing plants [19].

2.3. Yard waste compost, vermicompost, and horse manure

2.3.1. Yard waste compost

Recycling agricultural waste for use in crop production has become a vital component of organic agriculture. In the US, about 95% of food scraps and 42% of yard waste (**Figure 3A**) are currently used in landfill [27]. There are some concerns about the varying composition of yard waste by region and by season. The Department of Environmental Protection in Pennsylvania [28] estimated that, during the summer, grass clippings constitute up to 50% of municipal waste. In the fall, leaves make up 60–80% of the material in this category. Many communities ban dumping and outdoor burning of plant materials such as leaves and tree branches. Accordingly, composting and mulching have become a management way to recycle yard waste as economical soil amendment to improve garden soils and growing plants.

2.3.2. Vermicomposting or worm castings

The interaction of earthworms with microorganisms and other fauna within a decomposer, especially designed for this incubation process, produces a product known as **v**ermicomposting (**Figure 3B**). Vermicomposting accelerates the stabilization of organic matter (OM) and its physical and biochemical properties. Physical participation in degrading organic substrates results in fragmentation, thereby increasing the surface area of action, turnover and soil aeration. The degradation of OM is carried out by enzymatic secretions by microorganisms. This process is enriched by transport of inorganic and organic materials. The benefit of vermicomposting is the recycling of organic wastes, like animal wastes [29, 30], crop residues [31], and industrial wastes [32–35] for use as N fertilizer. Anoop et al. [35] concluded that cow dung and biogas plant slurry can be used as a raw material in vermicomposting. The NPK elements and C/N ratio of vermicompost revealed its agronomic value as organic soil conditioner. Accordingly, many investigators reported that vermicompost has important properties that can be explored as a new technology for converting organic wastes into a product rich in plant nutrients [35].

2.3.3. Horse manure

Approximately 75% of horse farms utilize or store horse manure (HM) on-site as grasslands and this is the primary means of disposal [36]. Equine waste produces odors and could contaminate water natural sources via runoff during storage or after land application [37, 38]. Due to the importance of storing waste for potential use in agricultural production systems, an increasing cost is tolerated by the farmer to handle this material for potential use [39]. The disposal of HM (**Figure 3C)** in some Germany regions became increasingly difficult for the owners during the last years due to the lack of arable land and its low fertilizer quality. Additionally, equitation becomes more and more popular in urban areas. This leads to an increase in horse barns and an excess of HM in these regions, which causes a sharp rise in manure removal costs. The composition of HM is dependent on the bedding material and the frequency of stall cleaning. HM is a good source of nitrogen because of its suitable C/N ration that can be also explored for the digestion of nitrogen rich organic waste such as liquid pig manure and poultry manure [40].

Figure 4 shows some of the crops grown with organic fertilizers. Peppers grown in sewage sludge amended soil (**Figure 4A**), peppers grown in chicken manure amended soil (**Figure 4B**), eggplants grown in horse manure amended soil (**Figure 4C**), kale and collards grown in yard waste amended soil (**Figure 4D**). The increase in crop yield due to incorporation of organic amendments in agricultural production systems reduces the need of synthetic inorganic fertilizers.

Figure 3. Yard waste compost (A), vermicompost (B), and horse manure (C) organic fertilizers.

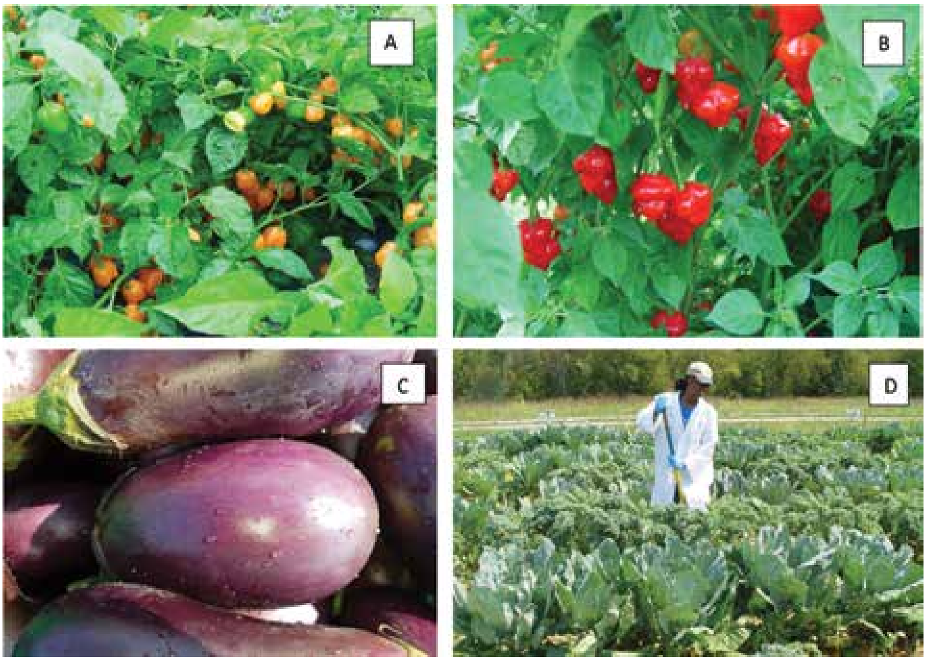
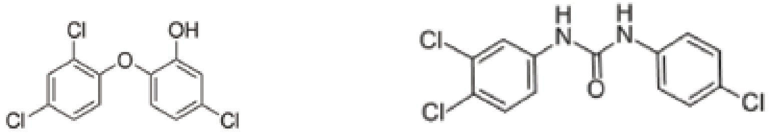


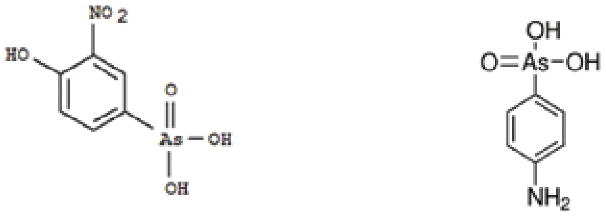
Figure 4. Crops grown with animal manure: (peppers (A) grown with sewage sludge; peppers grown with chicken manure (B); eggplants grown with horse manure (C); kale and collards grown in yard waste compost (D) under field condition at Kentucky State University HR Benson Research and Demonstration Farm (Franklin County, Kentucky, USA).

2.4. Antibiotics in animal manure

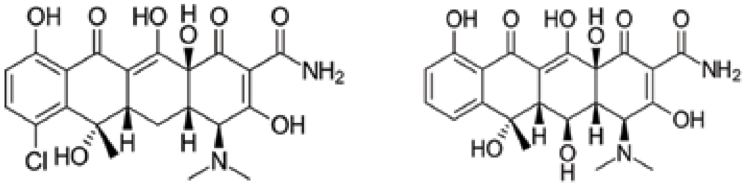
The American Association of Concerned Scientists reported that 11.2–12.8 million kg of antibacterial compounds were used for on-farm animals for medicinal purposes [41] in 1 year alone. Because pharmaceuticals (**Figure 5**) do not metabolize completely in the animal body, they excrete with urine and feces either in their native form or in the form of metabolites [42]. Increased fertilization of farmland with organic fertilizers such as municipal SS, CM, HM and cow manures contribute to the introduction of antibiotics into soil used for growing plants, surface water (through runoff), groundwater (through leaching), and into edible plants or other living organisms through bioaccumulation. These pharmaceuticals can generate a number of negative consequences. Pharmaceuticals in agricultural production systems are one of the emerging contaminants [43]. Among all groups of veterinary pharmaceuticals, antibiotics exert significant influence on soil microorganisms that recycle waste. Once introduced to the soil, they might affect the structure and function of bacterial communities and the development and spread of antibiotic resistance. Numerous studies have documented changes of soil microbial community structure due to exposure to antibiotics in the environment [44]. According to Masse et al. [45], the most persistent groups of pharmaceuticals are tetracyclines (TC_S, $T_{1/2} > 100$ days). The presence and persistence of chlortetracycline, tetracycline, oxytetracycline, and other members of the TCs in animal manures used as organic soil amendment might remain in soils for many years [45, 46], due to their strong sorption to the soil particles. There is a lack of information on the behavior of pharmaceuticals and veterinary medicine in soils and fertilizers used in agricultural production and their potential risk to human health [47].



Triclosan [2, 4, 4'-trichloro-2'- **Triclocarban** [3, 4, 4'-trichlorocarbanilide] Hydroxydiphenyl ether]



Roxarsone [4-Hydroxy-3-nitrobenzenearsonic acid **4-Aminophenyl arsonic acid**



Chlortetracycline **Oxytetracycline**

Figure 5. Pharmaceuticals used in animal feeding operations to protect against bacterial and disease infection.

2.5. Trace metals in animal manure

Animal manure is a source of valuable plant nutrients, but also a source of air and soil pollution and a threat to aquifers and surface waters unless managed carefully to minimize nutrient loss [48]. In addition, animal manures such as municipal SS is a source of trace metals [49] that might accumulate in edible plants when SS is used as an organic fertilizer and might also contaminate our natural water resources with trace metals. To avoid direct leakage to water abstraction plants or groundwater, manure must not be applied 50 feet (15 m) from potable water wells and 200 feet (60 m) uphill of conduits to groundwater. Furthermore, special care must be taken when applying manure to fields with high leaching potential or within 1000 feet (305 m) of municipal wells [50].

Studies carried out by Gondek et al. [51] revealed that composting of organic materials has a significant effect on changes in mobile forms of heavy metals. The authors found that biochar and municipal SS added to maize straw immobilized Cd and Pb soluble forms due to addition of biochar, whereas maize straw and SS alone did not impact cd and Pb mobility.

2.6. Application of biochar in agricultural production

Currently little information exists in the literature if biochar addition to soil as organic amendment can reduce the plant uptake of trace-elements and reduce toxic metals bioavailability to edible plants. Such practice, if found effective, can assist in management of contaminated agricultural and urban soils from current and past use of municipal SS and might be also useful in mining reclamation. Acidification can affect both the soil biota and biogeochemical processes, thus decreasing agricultural production [52, 53]. Biochar has been reported to modify soil quality characteristics, thereby increasing crop yields [54]. Because it is usually alkaline in nature, biochar can increase the pH of acidic soils [55, 56]. Furthermore, biochar application has also been promoted as a means of contributing to the mitigation of climate change by reducing soil N_2O emissions [53, 57, 58]. Biochar addition changed soil chemical properties, including increasing soil pH, total nitrogen (TN), total carbon (TC), C/N ratio, and cation-exchange capacity (CEC), and shifted the bacterial community composition. As biochar has been considered unlikely to be used by soil microbes [59], and it cannot directly impact soil microbial community. Therefore, biochar may affect soil microbial community via improving soil chemical properties [53].

When used in acidified soil amelioration, biochar can increase crop yield through improving soil chemical conditions and changing the availability of nutrients. It can also impact soil microbial community by increasing diversity of soil microbes and changing relative abundances of their taxa) via changing soil chemical properties, thus influencing soil nutrient (e.g., C, N) cycling and controlling greenhouse gas emissions. By contrast, biochar can also enhance soil N losses to the atmosphere by stimulating both nitrification and denitrification, thus decreasing the efficiency of N-fertilizer utilization. Therefore, the effect of biochar on the efficiency of N fertilizer should be considered when it is widely recommended as soil amendment [53].

2.7. Animal manure and agricultural waste application: An overview

Gómez-Muñoz et al. [60] reported that, when diverse types of urban waste (human urine, sewage sludge, composted household waste) and agricultural wastes (cattle slurry, farmyard manure and deep litter) applied annually for 11 years (at normal and accelerated rates), soil water retention and total carbon improved. Cattle manure, sewage sludge and composted household waste increased soil total N by 13–131% compared to the mineral fertilizer (NPK). The interaction of biochar and compost used in agricultural practices affect each other's properties. Biochar could change the physicochemical properties, microorganisms, degradation, mummification and gas emission of composting, such as the increase of nutrients, cation exchange capacity (CEC), organic matter and microbial activities. Composting and addition of animal manure to biochar could change the characteristic properties of biochar such as its surface polar and non-polar attractions sites, ion-exchange sites, and electrostatic attraction functional groups (**Figure 6**), such as the improvement of nutrients availability, CEC, functional groups on biochar surface and soil organic matter (OM). These changes would potentially improve the efficiency of the biochar and remediation of pollution [61].

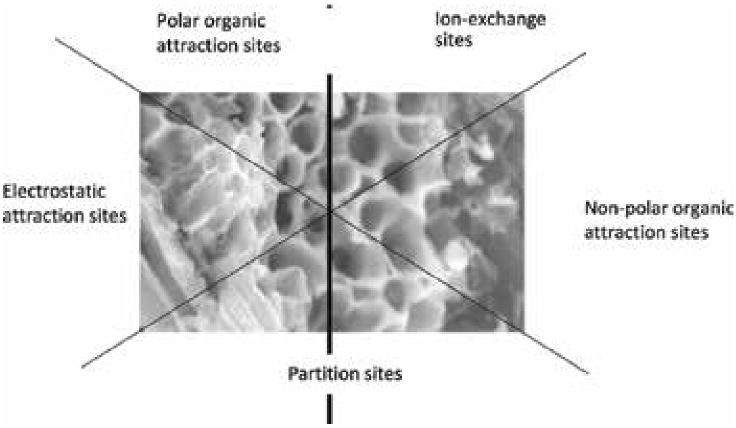


Figure 6. Schematic diagram of biochar showing its electrostatic attraction sites, ion-exchange sites, polar and non-polar attraction sites collectively known as surface functional groups.

3. Experimental studies conducted at the University of Kentucky South Farm (Fayette County, Kentucky)

3.1. Impact of animal manure on tomato yield

Tomato (*Solanum lycopersicum* var. Mountain Spring) seedlings of 52 days old were planted in raised, plastic-mulched, freshly tilled soil at 18 inch in-row spacing. The entire study area contained 30 plots (3 replicates × 10 treatments). Each treatment was replicated three times in a randomized complete block design (RCBD) with the following treatments: (1) control (NM no-mulch untreated soil); (2) sewage sludge (SS); (3) horse manure (HM); (4) chicken manure (CM); and (5) yard waste compost (YWC). Each of the five treatments was also mixed with 1% (w/w) biochar obtained from Wakefield Agricultural Carbon (Columbia, MO) to make a total of 10 treatments. The soil in six plots was mixed with SS obtained from the Metropolitan Sewer District, Louisville, KY at 5% N on dry weight basis [62, 63]. Six plots were mixed with CM obtained from the Department of Animal and Food Sciences, University of Kentucky, Lexington, Kentucky at 5% N on dry weight basis. The soil in six plots was mixed with HM obtained from the Kentucky horse park, College of Agriculture, University of Kentucky, Lexington, Kentucky at 5% N. The soil in six plots was mixed with YWC at 5% N and the native soils in six plots was used as a no-mulch (NM) control treatment (roto-tilled bare soil) for comparison purposes. Biochar was mixed in three plots in each of the soil amendments, while other three plots in each soil amendment were left without biochar for comparison purposes. Soil amendments were added to native topsoil, mixed, and rototilled to a depth of 15 cm of top soil. The plots were hand transplanted with tomato and irrigated by a uniform drip irrigation system. Fruits were harvested three times during the growing season on August 3, August 19, and September 8, 2016. At each harvest, fruits were collected, weighed and counted. Data were statistically analyzed using ANOVA and the means were compared using Duncan's multiple range test [64].

3.1.1. Research findings

Plants grown in soil fertilized with CM had 8.2, 15.8, and 1.3 kg fruits/3 plants in harvest 1, harvest 2, and harvest 3, respectively (**Table 1**). Whereas, biochar added to CM, HM, and NM native soil did not alter tomato yield in harvest 1 ($P > 0.05$). Accordingly, the synergistic effects of biochar mixed with soil amendments used in this study was not observed after biochar addition in harvest 1. This could be due to the low amount of biochar (1% w/w) used in each treatment. Results of harvest 1 also revealed that the addition of biochar to SS and YW treatments significantly increased fruit yield from 5.2 kg and 3.9 to 6.3 and 5.7 kg/3 plants, respectively, indicating a positive effect of biochar on the growth and yield of tomato grown in SS and YW treatments. In harvest 2, plots fertilized with HM mixed with biochar revealed a significant increase ($P < 0.05$) in tomato yield. Whereas, biochar added to other soil treatments did not promote tomato yield (**Table 1**). In harvest 3, the synergistic effect of biochar was observed in HM and NM native soil (**Table 1**). However, total weight of tomato fruits collected after three harvests presented in **Figure 7** revealed that HM and YW amended with biochar significantly ($P < 0.05$) increased tomato yield compared to other treatments indicating a positive effect on the growth and yield of tomato.

Overall tomato three harvests, the synergistic effects of biochar was only observed in HM and YW amended soils (**Figure 7**). Total marketable tomato yield of biochar amended soils was increased by 63 and 20% in HM and YW treatments, respectively compared to other soil treatments. Regardless of soil treatments, it could be concluded that harvest 2 had the greatest yield and greatest number of fruits compared to the other two harvests (**Figure 8**).

Soil	**Weight of fruits, g Plants^{-3}**		
Treatment	Harvest −1	Harvest −2	Harvest −3
CM	8145.3 ± 413	15806.2 ± 1227	1326.1 ± 354
CM-Biochar	8261.5 ± 218	14761.4 ± 937	1218.6 ± 158
HM	4932.7 ± 356	8423.8 ± 1154	839.7 ± 360
HM-Biochar	4901.9 ± 556	15623.2 ± 1644	2618.7 ± 466
NM	744.7 ± 555	14555.7 ± 597	534.7 ± 353
NM-Biochar	4077.4 ± 94.3	12782.2 ± 939	2913.6 ± 278
SS	5139.1 ± 187	16094.9 ± 566	1505.9 ± 347
SS-Biochar	6287.7 ± 432	13858.8 ± 274	625.2 ± 166
YW	3925.7 ± 96	13636.5 ± 1285	690.4 ± 503
YW-Biochar	5711.9 ± 380	14788.6 ± 1244	1466.6 ± 503

Statistical comparisons were carried out among soil management practices using SAS procedure. Each value is an average of three replicates ± std. error.

Table 1. Average weights of tomato fruits collected at three harvests from plants grown under 10 soil management practices at the University of Kentucky South Farm (Fayette County, Kentucky, USA).

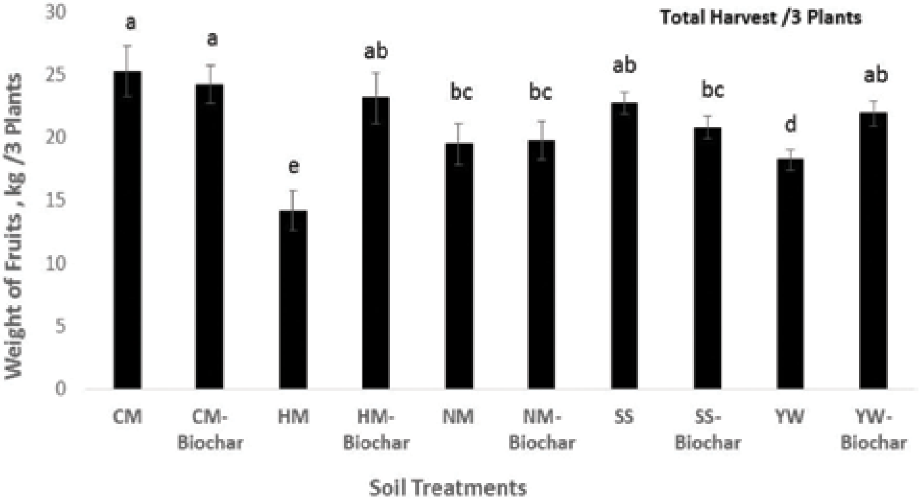


Figure 7. Total weights of tomato fruits collected from three harvests of tomato plants grown under 10 soil management practices. Statistical comparisons were carried out among soil treatments using SAS procedure. Values accompanied by the same letter(s) are not significantly ($P > 0.05$) different. Each value is an average of three replicates ± std. error.

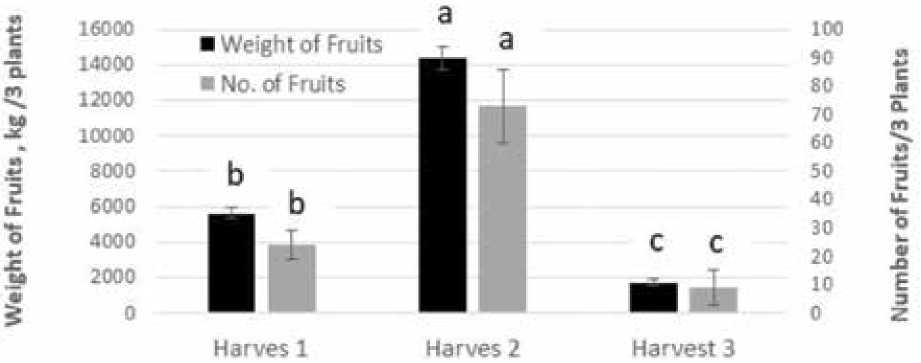


Figure 8. Overall tomato fruit harvests of three plants grown at the university of Kentucky south farm, regardless of soil treatments. Statistical comparisons were carried out among three harvests using SAS procedure. Values accompanied by the same letter(s) are not significantly ($P > 0.05$) different. Each value is an average of 10 treatments ± std. error.

The use of organic wastes is also being encouraged for by different environmental organizations world-wide to preserve the sustainability of agricultural systems [65]. These two authors conducted a greenhouse experiment to assess the effect of CM on soil chemical properties and yield of spinach. They concluded that CM is a potential source of plant nutrients. Their study provided insights to critical threshold values in response to the optimum yield in spinach and uptake of N and P on leaves particularly at high CM application rate. The results indicated an increase in spinach yield as measured in dry matter content. In addition, the use of 15 different amendment combinations that contain equal amounts of carbon (C), were applied through CM compost, charcoal, and forest litter during four cropping cycles with rice and sorghum. The authors reported that CM amendments resulted in the highest ($P < 0.05$) cumulative crop yield

(12.4 Mg ha^{-1}) over four seasons. Most importantly, surface soil pH, P, Ca, and Mg were significantly enhanced by CM addition. Antonious et al. [63] also reported that CM enhanced yield and quality of field-grown kale and collard greens. CM is preferred among other animal wastes because of its high concentration of macro-nutrients [66]. Poultry litter is poultry manure mixed with the bedding (wood shavings, rice hulls, etc.) that is scooped up when the houses are cleaned. Chicken litter nutrient composition depends on the technique used for clean-out the house, methods of litter storage, and many other factors, such as storage house air conditions. An average nutrient percentage content of 3-3-2 means that an average ton of poultry litter contains 60 pounds of nitrogen, 60 pounds of phosphate (P_2O_5) and 40 pounds of potash (K_2O) per ton of litter. Poultry litter may contain nearly small amounts of essential elements needed for plant growth and composition. Such as sulfur, but the amounts are usually small. Due to the increased prices of inorganic fertilizers, farmers interest in using poultry litter as organic fertilizer has also risen sharply.

Due to the consumer demand of chicken meat, chicken manure from chicken condensed feeding operations has become available in increasing quantities for utilization in agricultural production systems as organic fertilizer. While the use of organic wastes has been in practice for centuries world-wide and in the recent times, there still exists a need to assess the potential impacts of CM on soil chemical properties and crop yield and in particular evaluating the critical application levels. Moreover, the need and utilization of CM has overtaken the use of other animal manure (e.g., pig manure, horse manure, and cow manure) because of its high content of N, P, and K [67]. Escalating prices of inorganic fertilizers due to the increase in the fuel prices has also prompted the use of CM and other animal manure. Accordingly, knowledge about the environmental problems and adoption of appropriate solutions and practices to enhance and protect soil quality require timely delivery of research and educational technology.

3.2. Impact of animal manure on tomato fruit nutritional composition

Fruits and vegetables contain various vitamins and nutrients important for human health. Discovery of phytochemicals with antioxidant properties and their health promoting benefit have paved the way to a food revolution and promising for an age of food with nutritional composition and good health [68]. Tomato (*Solanum lycopersicum*), among antioxidant-rich commodities, has achieved a spectacular status because of its rich composition and widespread consumption. It is one of the major vegetable crops, grown in almost every country of the world. Studies indicated that regular intake of cooked tomato as a part of the vegetable regime appears to be the major nutritional factor accounting for lower risk of prostate cancer, digestive tract cancer and coronary heart diseases in the Mediterranean region. In tomato fruits and most vegetables, ascorbic acid (vitamin C) and phenols that have antioxidant properties protect animals and humans from various diseases. Lycopene, constituting 80–90% of the total carotenoid content present in tomatoes and tomato products, has been believed to contribute to the reduced risks of some types of cancers. Vitamin C (ascorbic acid) in tomato fruits provides about 40% of the required dietary allowance for human health. As a result, enhancing the levels of these healthy chemicals in tomato fruits may form an efficient way to improve human health conditions. In response to this opportunity, numerous investigations have been conducted to identify the factors influencing the contents of lycopene and vitamin C in tomatoes. The results demonstrated consistent differences in lycopene and vitamin C content between tomato cultivars, which can be magnified by agricultural management. A relationship has been established associating electrical conductivity (EC) and light intensity with lycopene and vitamin C content in tomato fruits. Generally, moderate EC growing conditions enhance tomato health quality; solar radiation is favorable to lycopene and vitamin C accumulation, whereas strongly intense light exposure inhibits lycopene synthesis. Temperatures beyond the optimum temperature range may inhibit lycopene biosynthesis. However, the effects of temperature on vitamin C content are not always conclusive. The effects of nutrients (N, P, K, and Ca) and water availability have also been reviewed, but results are sometimes contradictory. Up-to-date studies dealing with soil amendments and vitamin C, phenols, and sugars contents in tomato fruits are reviewed in this chapter. Previous studies indicated that increasing both P and N application (up to 140 kg P ha^{-1} and 150 kg N ha^{-1}, respectively) significantly increased the vitamin C content of tomato fruits [10]. Concentrations of vitamin C varied significantly among plant species and among plants grown under different animal manures. Ascorbic acid in tomato fruits (**Figure 9**) was greatest in plants grown in CM amended soils compared to NM un-amended soil.

Tomatoes also contain moderate amounts of water-soluble phenolic, flavonoids (quercetin, kaempferol and naringenin) and the hydrocinnamic acids (caffeic, chlorogenic, ferulic and *p*-coumaric acids), mainly concentrated in skin [69, 70]. Polyphenols are secondary metabolites of plants that contain in their structure the aromatic ring with one or more phenolic groups. Such molecules have great antioxidant potential. The phenolics of tomatoes are found to occur in the skin. Total phenols in tomato fruits of plants grown in amended soils were significantly

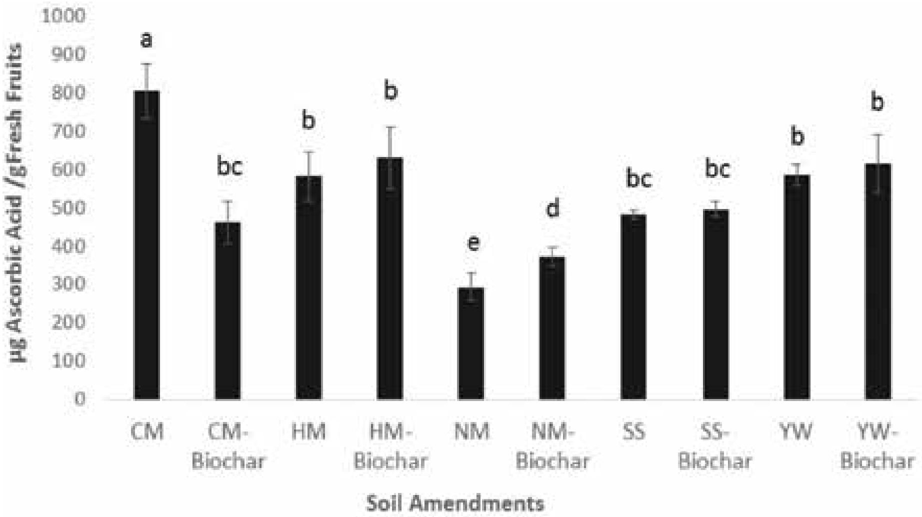


Figure 9. Concentrations of ascorbic acid (vitamin C) in tomato fruits of plants grown under different soil management practices. Statistical comparisons were carried out among soil treatments using SAS procedure. Values accompanied by the same letter(s) are not significantly ($P > 0.05$) different. Each value is an average of three replicates ± std. error.

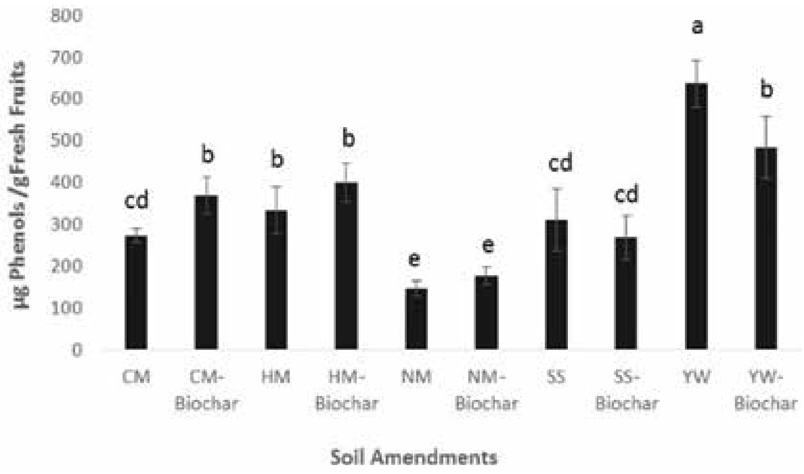


Figure 10. Concentrations of total phenols in tomato fruits of plants grown under different soil management practices. Statistical comparisons were carried out among soil treatments using SAS procedure. Values accompanied by the same letter(s) are not significantly ($P > 0.05$) different. Each value is an average of three replicates ± std. error.

($P < 0.05$) greater compared to NM un-amended soil (**Figure 10**). Concentration levels of soluble sugars in tomato fruits (**Figure 11**) revealed also that YW compost provided the highest concentrations of total phenols among the other amendments tested.

However, one can ask whether the higher content of vitamin C, phenols, and soluble sugars in plants grown in animal manure treatments is due to higher synthesis of these water soluble compounds by plants grown in organic manure, or due to increased absorption from soil by the plants roots, or these compounds were found in the plants due to their presence in native

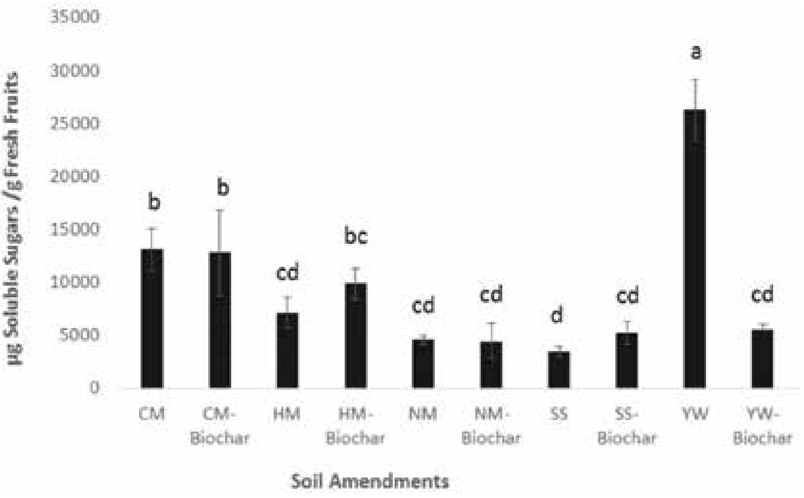


Figure 11. Concentrations of soluble sugars in tomato fruits of plants grown under different soil management practices. Statistical comparisons were carried out among soil treatments using SAS procedure. Values accompanied by the same letter(s) are not significantly ($P > 0.05$) different. Each value is an average of three replicates ± std. error.

soil (soil origin)? Or this increase might be due to increased soil organic matter and microbial activity. Based on the results in **Figures 9** and **10**, plants grown in NM bare soil (control plants) contained the lowest concentrations of the two phytochemicals (vitamin C and phenols) compared to the plants grown in animal manure amended soils. Therefore, the native soil used in this study is not the source of these three compounds. SS, CM, and HM contain many enzyme substrates such as urea, sucrose, and phosphates compounds that activate soil enzymes, such as urease, invertase, and phosphatase, respectively. Accordingly, the pronounced differences in vitamin C and phenols concentrations found among tomato fruits of plants grown under the different soil amendments tested could be attributed to increased microbial activity and the enzymes they produce. Many reasons have been suggested for this variability, but none of them have been extensively investigated. In either way, the use of animal manure such as municipal waste compost is an economic way to recover nutrients, reduce dependence on inorganic fertilizers, reduce dunghill areas of disposal, and eliminate unpleasant smell [71].

3.3. Impact of agricultural waste on soil enzymes (urease and invertase) activity

Animal manures used as organic soil amendments protect soil microorganisms, soil biological processes, improve soil quality, and increase agricultural productivity [72]. There are three enzymes in soil play a significant role in the N, C, and P cycles. These three enzymes are, urease (urea amidohydrolase, EC 3.5.1.5) is the enzyme that catalyzes the hydrolysis of urea to carbon dioxide (CO_2) and ammonium (NH_4^+) ions. Urease breaks-down and converts N from its organic form into inorganic N by hydrolysis of urea or organic forms of N into ammonia. Invertase (β-D-fructofuranosidase) is ubiquitous enzyme in soils. The activity of these two soil enzymes (urease and invertase) in soil is responsible for the release of C and N needed for the growth and proliferation of soil microorganisms and the enzymes they produce. Phosphatases, a group of enzymes that catalyze the hydrolysis of esters and anhydrides of phosphoric acid

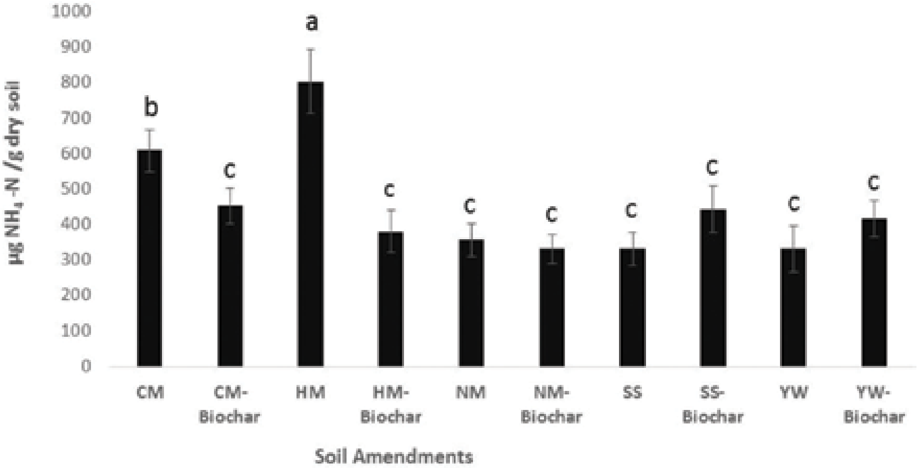


Figure 12. Urease activity expressed as μg NH_4–N released g^{-1} dry soil. Statistical comparisons were carried out among soil management practices using SAS procedure. Values accompanied by the same letter are not significantly ($P > 0.05$) different. Each value is an average of three replicates ± std. error.

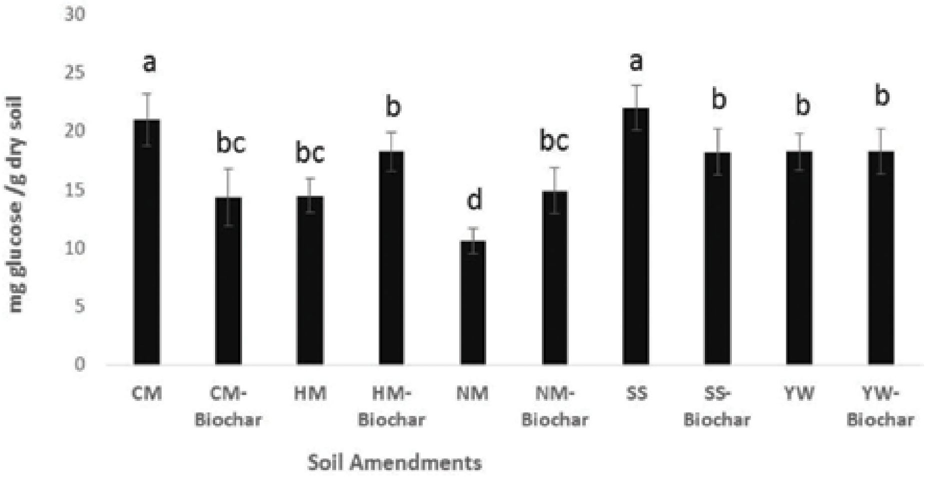


Figure 13. Invertase activity expressed as mg glucose released g^{-1} dry soil. Statistical comparisons were carried out among soil management practices using SAS procedure. Values accompanied by the same letter(s) are not significantly ($P > 0.05$) different. Each value is an average of three replicates ± std. error.

(H_3PO_4), catalyze the hydrolysis of organic phosphate esters to orthophosphate, and thus constitute an important link between biologically unavailable and bioavailable P pools in the soil. Phosphatases are ubiquitous in soil and are produced by microorganisms in response to low levels of inorganic phosphates. Bacteria, fungi, protozoa, and algae secrete soil enzymes such as dehydrogenases, invertase, urease, cellulase, amylases, and phosphatases capable of degrading xenobiotics in soil and water systems improving soil health and plant production.

This investigation revealed that CM and HM increased the activities of soil urease (**Figure 12**), due to the break-down of urea by urease and the release of ammonium ions (NH_4^+–N). Whereas, CM and SS increased soil invertase activity (**Figure 13**).

Acknowledgements

The author would like to thank Steven Diver, Eric Turley, and the University of Kentucky farm crew for their assistance in growing tomato under field conditions. This investigation was supported by a USDA/NIFA Award No. KYX-10-13-48P to Kentucky State University.

Author details

George F. Antonious

Address all correspondence to: george.antonious@kysu.edu

College of Agriculture, Food Science, and Sustainable Systems, Division of Environmental Studies, Kentucky State University, Frankfort, KY, USA

References

[1] Antonious GF. Chapter 7: Organic fertilizers: From basic concepts to applied outcomes. In: Larramendy ML, Soloneski S, editors. Soil Amendments for Agricultural Production. Rijeka, Croatia: Intech; 2016. pp. 157-187. ISBN: 978-953-51-4701-5

[2] Petro-Turza M. Flavor of tomato and tomato products. Food Reviews International. 1986; **2**(3):309-351

[3] Canene-Adams K, Campbell JK, Zaripheh S, Jeffery EH, Erdman JW. The tomato as a functional food. The Journal of Nutrition. 2005;**135**(5):1226-1230

[4] Kaniszewski S, Rumpel K. Effect of nitrogen fertilization and irrigation on yield, nitrogen status in plants and quality of fruits of direct seeded tomatoes. Acta Horticulturae. 1987; **200**:195-202

[5] Weston LA, Barth MM. Preharvest factors affecting postharvest quality of vegetables. HortScience. 1997;**32**:812-816

[6] Omoni AO, Aluko RE. The anti-carcinogenic and anti-atherogenic effects of lycopene: A review. Trends in Food Science & Technology. 2005;**16**(8):344-350

[7] Toor RK, Savage GP. Antioxidant activity in different fractions of tomatoes. Food Research International. 2005;**38**(5):487-494

[8] George B, Kaur C, Khurdiya DS, Kapoor HC. Antioxidants in tomato (*Lycopersicum esculentum*) as a function of genotype. Food Chemistry. 2004;**84**(1):45-51

[9] Lenucci MS, Cadinu D, Taurino M, Piro G, Dalessandro G. Antioxidant composition in cherry and high-pigment tomato cultivars. Journal of Agricultural and Food Chemistry. 2006;**54**(7):2606-2613

[10] Dumas Y, Dadomo M, Di Lucca G, Grolier P. Effects of environmental factors and agricultural techniques on antioxidant content of tomatoes. Journal of the Science of Food and Agriculture. 2003, 2003;**83**(5):369-382

[11] Buta JG, Spaulding DW. Endogenous levels of phenolics in tomato fruit during growth and maturation. Journal of Plant Growth Regulation. 1997;**16**(1):43-46

[12] Slimestad R, Verheul MJ. Content of chalconaringenin and chlorogenic acid in cherry tomatoes is strongly reduced during postharvest ripening. Journal of Agricultural and Food Chemistry. 2005;**53**(18):725

[13] Fraser B. High-tech charcoal fights climate change. Environmental Science & Technology. 2010;**44**(2):548-549

[14] Yao Y, Gao B, Zhang M, Inyang M, Zimmerman AR. Effect of biochar amendment on sorption and leaching of nitrate, ammonium, and phosphate in a sandy soil. Chemosphere. 2012;**89**(11):1467-1471

[15] Clough T, Condron L, Kammann C, Müller C. A review of biochar and soil nitrogen dynamics. Agronomy. 2013;**3**(4):275-293

[16] Lehmann J, Pereira da Silva J Jr, Steiner C, Nehls T, Zech W, Glaser B. Nutrient availability and leaching in an archaeological anthrosol and a ferralsol of the central amazon basin: Fertilizer, manure and charcoal amendments. Plant and Soil. 2003;**249**(2):343-357

[17] Rondon MA, Lehmann J, Ramírez J, Hurtado M. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char additions. Biology and Fertility of Soils. 2006;**43**(6):699-708

[18] Manu JM, Barminas JT, Aliyu BA, Osemeahon SA. Influence of ferrous sulfate hepta hydrate on poultry manure pH and microbial life to reduce ammonical odors. Archives of Applied Science Research. 2013;**5**(3):197-203

[19] Ravindran B, Mupambwa HA, Silwana S, Mnkeni PNS. Assessment of nutrient quality, heavy metals and phytotoxic properties of chicken manure on selected commercial vegetable crops. Heliyon. 2017;**3**(12):e00493

[20] Moore PA, Edwards DR. Long-term effects of poultry litter, alum-treated litter, and ammonium nitrate on aluminum availability in soils. Journal of Environmental Quality. 2005;**34**(6):2104

[21] Zhang H, Schroder J. Animal manure production and utilization in the US. In: Applied Manure and Nutrient Chemistry for Sustainable Agriculture and Environment. Netherlands: Springer; 2014. pp. 1-21

[22] Lory JA, Massey R. Using Manure as a Fertilizer for Crop Production. United States Environmental Protection Agency (EPA). 2006. Available from: https://www.epa.gov/sites/production/files/2015-07/documents/2006

[23] Epstein E. Land Application of Sewage Sludge and Biosolids. Boca Raton: Taylor & Francis, CRC Press; 2003

[24] Ravindran B, Mnkeni PNS. Bio-optimization of the carbon-to-nitrogen ratio for efficient vermicomposting of chicken manure and waste paper using *Eisenia fetida*. Environmental Science and Pollution Research. 2016;**23**(17):16965-16976

[25] Bolan NS, Szogi AA, Chuasavathi T, Seshadri B, Rothrock MJ, Panneerselvam P. Uses and management of poultry litter. World's Poultry Science Journal. 2010;**66**(04):673-698

[26] Nigra AE, Nochman KE, Love DC, Grau-Perze M, Navas-Acein A. Poultry consumption and arsenic exposure in the U.S. population. Environmental Health Perspectives. 2017;**125**(3):370-377

[27] Brown S. Greenhouse gas accounting for landfill diversion of food scraps and yard waste. Compost Science & Utilization. 2016;**24**(1):11-19

[28] Pennsylvania Department of Environmental Protection. Yard Waste & Composting. Available from: http://www.dep.pa.gov/business/land/waste/recycling/Pages/default.aspx

[29] Loh T. Vermicomposting of cattle and goat manures by *Eisenia foetida* and their growth and reproduction performance. Bioresource Technology. 2005;**96**(1):111-114

[30] Molina MJ, Soriano MD, Ingelmo F, Llinares J. Stabilisation of sewage sludge and vinasse bio-wastes by vermicomposting with rabbit manure using *Eisenia fetida*. Bioresource Technology. 2013;**137**:88-97

[31] Bansal S, Kapoor KK. Vermicomposting of crop residues and cattle dung with *Eisenia foetida*. Bioresource Technology. 2000;**73**(2):95-98

[32] Kaushik P, Garg VK. Vermicomposting of mixed solid textile mill sludge and cow dung with the epigeic earthworm *Eisenia foetida*. Bioresource Technology. 2003;**90**(3):311-316

[33] Yadav A, Garg VK. Bioconversion of food industry sludge into value-added product (vermicompost) using epigeic earthworm *Eisenia fetida*. World Review of Science Technology and Sustainable Development. 2010;**7**(3):225

[34] Garg VK, Suthar S, Yadav A. Management of food industry waste employing vermicomposting technology. Bioresource Technology. 2012;**126**:437-443

[35] Yadav A, Gupta R, Garg VK. Organic manure production from cow dung and biogas plant slurry by vermicomposting under field conditions. International Journal of Recycling of Organic Waste in Agriculture. 2013;**2**(21):3-7

[36] Westendorf ML, Joshua T, Komar SJ, Williams C, Govindasamy R. Case study: Manure management practices on New Jersey equine farms. The Professional Animal Scientist. 2010;**26**(1):123-129

[37] Airaksinen S, Heiskanen M, Heinonentanski H. Contamination of surface run-off water and soil in two horse paddocks. Bioresource Technology. 2007;**98**(9):1762-1766

[38] Romano PV, Krogmann U, Westendorf ML, Strom PF. Small-scale composting of horse manure mixed with wood shavings. Compost Science & Utilization. 2006, 2006;**14**(2):132-141

[39] Wartell BA, Krumins V, Alt J, Kang K, Schwab BJ, Fennell DE. Methane production from horse manure and stall waste with softwood bedding. Bioresource Technology. 2012;**112**: 42-50

[40] Mönch-Tegeder M, Lemmer A, Oechsner H. Enhancement of methane production with horse manure supplement and pretreatment in a full-scale biogas process. Energy. 2014; **73**:523-530

[41] Dzierzawski A. Potrzeba racjonalnego stosowania antybiotyko'w w praktyce weterynaryjnej. Zycie Weter. 2012;**87**:316-321

[42] Martínez-Carballo E, González-Barreiro C, Scharf S, Gans O. Environmental monitoring study of selected veterinary antibiotics in animal manure and soils in Austria. Environmental Pollution. 2007;**148**:570-579

[43] Campo J, Picó Y. Emerging contaminants. In: Advanced Mass Spectrometry for Food Safety and Quality. Valencia, Spain: Elsevier; 2015;**68**:515-578

[44] Łukaszewicz P, Maszkowska J, Mulkiewicz E, Kumirska J, Stepnowski P, Caban M. Impact of veterinary pharmaceuticals on the agricultural environment: A re-inspection. In: Reviews of Environmental Contamination and Toxicology. Switzerland: Springer International Publishing; 2016. pp. 89-148

[45] Massé D, Saady N, Gilbert Y. Potential of biological processes to eliminate antibiotics in livestock manure: An overview. Animals. 2014;**4**(4):146-163

[46] Chen C, Li J, Chen P, Ding R, Zhang P, Li X. Occurrence of antibiotics and antibiotic resistances in soils from wastewater irrigation areas in Beijing and Tianjin, China. Environmental Pollution. 2014;**193**:94-101

[47] Liu FJ, Li SX, Zheng FY, Huang XG, Zuo YG, Tu TX, Wu XQ. Risk assessment of nitrate and oxytetracycline addition on coastal ecosystem functions. Aquatic Toxicology. 2014; **146**:76-81

[48] Sutton MA, Oenema O, Erisman JW, Leip A, van Grinsven H, Winiwarter W. Too much of a good thing. Nature. 2011;**472**(7342):159-116

[49] Antonious GF, Turley ET, Kochhar TS. Testing bioaccumulation of Cd, Pb, and Ni in plants-grown in soil amended with municipal sewage sludge at three Kentucky locations. JSM Environmental Science & Ecology. 2017;**5**(1):1039. 1-10

[50] Sommer SG, Oenema O, Matsunaka T, Jensen LS. Regulations on animal manure management. In: Animal Manure Recycling: Treatment and Management. Chichester, West Sussex, United Kingdom: John Wiley & Sons, Ltd.; 2013. pp. 25-40

[51] Gondek K, Mierzwa-Hersztek M, Kopeć M. Mobility of heavy metals in sandy soil after application of composts produced from maize straw, sewage sludge and biochar. Journal of Environmental Management. 2018;**210**:87-95

[52] Pietri JCA, Brookes PC. Relationships between soil pH and microbial properties in a UK arable soil. Soil Biology and Biochemistry. 2008;**40**(7):1856-1861

[53] Xu HJ, Wang XH, Li H, Yao HY, Su JQ, Zhu YG. Biochar impacts soil microbial community composition and nitrogen cycling in an acidic soil planted with rape. Environmental Science & Technology. 2014;**48**(16):9391-9399

[54] Novak JM, Cantrell KB, Watts DW, Busscher WJ, Johnson MG. Designing relevant biochars as soil amendments using lignocellulosic-based and manure-based feedstocks. Journal of Soils and Sediments. 2013;**14**(2):330-343

[55] Khan S, Chao C, Waqas M, Arp HPH, Zhu YG. Sewage sludge biochar influence upon rice (*Oryza sativa* L.) yield, metal bioaccumulation and greenhouse gas emissions from acidic paddy soil. Environmental Science & Technology. 2013;**47**(15):8624-8632

[56] Rees F, Simonnot MO, Morel JL. Short-term effects of biochar on soil heavy metal mobility are controlled by intra-particle diffusion and soil pH increase. European Journal of Soil Science. 2013;**65**(1):149

[57] Cayuela ML, Sánchez-Monedero MA, Roig A, Hanley K, Enders A, Lehmann J. Biochar and denitrification in soils: When, how much and why does biochar reduce N_2O emissions? Scientific Reports. 2013;**3**(1)

[58] Nelissen V, Saha BK, Ruysschaert G, Boeckx P. Effect of different biochar and fertilizer types on N_2O and NO emissions. Soil Biology and Biochemistry. 2014;**70**:244-255

[59] Thies JE, Rillig MC. Characteristics of biochar: Biological properties. In: Lehmann, Joseph, editors. Biochar for Environmental Management: Science and Technology. London: Earthscan; 2009. pp. 85-105

[60] Gómez-Muñoz B, Magid J, Jensen LS. Nitrogen turnover, crop use efficiency and soil fertility in a long-term field experiment amended with different qualities of urban and agricultural waste. Agriculture, Ecosystems & Environment. 2017;**240**:300-313

[61] Haipeng W, Cui L, Guangming Z, Jie L, Jin C, Jijun X, Juan D, Xiaodong L, Junfeng L, Ming C, Lunhui L, Liang H, Jia W. The interactions of composting and biochar and their implications for soil amendment and pollution remediation: A review. Critical Reviews in Biotechnology. 2017;**37**(6):754-764

[62] Gent MPN. Growth and composition of salad greens as affected by organic compared to nitrate fertilizer and by environment in high tunnels. Journal of Plant Nutrition. 2002;**25** (5):981-998

[63] Antonious GF, Turley ET, Hill RR, Snyder JC. Chicken manure enhanced yield and quality of field-grown kale and collard greens. Journal of Environmental Science and Health. 2014;**B49**(4):299-304

[64] SAS Institute Inc. SAS/STAT Guide; Version 6.4. Cary, NC: SAS Inc.; 2016

[65] Dikinya O, Mufwanzala N. Chicken manure-enhanced soil fertility and productivity: Effects of application rates. Journal of Soil Science and Environmental Management. 2010;**1**(3):46-54

[66] Duncan J. Composting chicken manure. WSU Cooperative Extension, King County Master Gardener and Cooperative Extension Livestock Advisor. Pullman: Washington State University; 2005

[67] Habimana S, Uwamahoro C, Uwizerwa JB. Influence of chicken manure and NPK (17-17-17) fertilizer on growth and yield of carrot. Netherlands Journal of Agricultural Science. 2014; **2**(4):117-123

[68] Rodriguez-Amaya DB, Amaya-Farfan J, Kimura M. Carotenoid composition of Brazilian fruits and vegetables. Acta Horticulturae. 2007;**744**:409-416

[69] Martínez-Valverde I, Periago MJ, Provan G, Chesson A. Phenolic compounds, lycopene and antioxidant activity in commercial varieties of tomato (*Lycopersicum esculentum*). Journal of the Science of Food and Agriculture. 2002;**82**(3):323-330

[70] Minoggio M, Bramati L, Simonetti P, Gardana C, Iemoli L, Santangelo E, Pietta PG. Polyphenol pattern and antioxidant activity of different tomato lines and cultivars. Annals of Nutrition and Metabolism. 2003;**47**(2):64-69

[71] Aladjadjiyan A, Penkov D, Verspecht A, Zahariev A, Kakanakov N. Biobased fertilizers—Comparison of nutrient content of digestate/compost. Journal of Agriculture and Ecology Research International. 2016;**8**(1):1-7

[72] Cox D, Bezdicek D, Fauci M. Effects of compost, coal ash, and straw amendments on restoring the quality of eroded Palouse soil. Biology and Fertility of Soils. 2001;**33**(5):365-372

Section 3

Biofuels from Agricultural Waste

Chapter 5

Significance of Agricultural Residues in Sustainable Biofuel Development

Nurudeen Ishola Mohammed,
Nassereldeen Kabbashi and Abass Alade

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.78374

Abstract

Bioenergy resources are considered clean and are an integral part of efforts to address the menace of climatic, economic, environmental, and social security challenges consequential from the utilization of fossil fuel, which is currently the main energy source. Bioenergy and biofuel utilizing biomass such as biorefinery, plant materials and manure, and waste resources for application as renewable fuels for transportation and for power generation can ensure a sustainable, low-carbon alternative to fossil fuels. Bioenergy is among the major plan to strategically phase out electricity generation from coal as well a comprehensive climate plan through carbon capture and other measures. Biomass selection sustainably has been advocated over time and reaction pathways are the other area of intensified effort for an economical and environmentally synthesized process. Besides, the use of agricultural residues and manure to produce bioenergy offers a significant opportunity for local and regional economies. In this chapter, various agricultural biomass residues which are an important energy resource are presented and the several studies where they have been explored in various locations of the world considering different approaches had been presented. Crop residues, in particular, are one of the largest biomass resources globally and the best options for use to produce bioenergy depending on local factors, including the type and scale of resources in each location are therein enumerated. It is observed that agricultural residues are an important resource for future biofuel and bioenergy generation sustainably.

Keywords: agricultural residues, bioenergy, biofuel, bioelectricity, future prospects

1. Introduction

As at 2012, world basic energy supply touched 560 EJ, corresponding to about 19,000 Mtce [1]. Of this energy supply, more than two-third is made up of fossil fuels, nuclear power was made up of 5% while 3% was renewable energy comprising hydropower, geothermal, solar, wind, and tidal. The balance is made up almost entirely of biomass and waste, which amounted to 10% of the world market. This portion of the energy considerably provided about 56EJ/y of the energy supplies; an amount, which is equal to three times the energy contributed by all other renewable energies in totality. However, considering resource report and reserves, biomass did not comparatively attract desired interest and data are not as extensively available as those for oil, gas, and coal, although reasonably good data are available for the demand and supply of biomass [2, 3].

Of importance is the renewable energy resources meant for locomotion and generation of electric power to curb the menace of climatic, economic, environmental and political concerns associated with the combustion of fossil fuel. Bioenergy, which is the utilization of bio-based materials, including plant materials and manure, to produce renewable fuels for transportation and to generate electricity sustainably. This fuel is characterized with low-carbon emission compare to fossil fuels while communities also stand to benefit immensely from the sale of this local resource [4]. Bioenergy is among the various policies put in place to reduce the dependence on the use of fossil fuel and it has been propose to cut US. oil use in half by 2030, and consequently, this practice will ensure the propensity of phasing out coal as electricity producing feedstock. An important key to exploring biomass resources sustainably is to focus on the right ones, and to develop them in holistic ways and at appropriate measures [5].

Cellulosic biomass may be derived from agricultural sources, such as crop residues and perennial energy grasses, as well as forest sources, such as forest residues and woody biomass. Crop residues mainly include corn stover, wheat straw, and rice straw. Because these resource is by-products of crop production, their collection and utilization ensures sustainable practice and does not result in food energy feud and land competition. Therefore, the negative effects of cellulosic biomass production from crop residues on food prices can be expected to be negligible. Although cellulosic feedstocks differ significantly in their environmental performance [5], they can provide commensurate advantage and prospect for various environmental benefits when compared with the coal they will substitute [6]. China is a major producer of corn, wheat, and rice. It produced about 20% of the world's corn and wheat, and 26% of the world's rice, in 2010 [7]. Therefore, China is among the nation that can ensure universal practice of potential production of a large amount of crop residues, which can reduce the nation's reliance on coal as a major energy source.

The union of concerned Scientists evaluated the magnitude of biomass resource potentially feasible from the united states production capacity in a bid to possibly comprehend the main biomass feedstock as well as the operational scales in order that the synthesized biofuel carefully balances the energy and environmental trade-offs. It was discovered that the nation could harness nearly 680 million tons of biomass resources annually up to 2030 [8]. This resource was sufficiently observed to be suitable to generate well above 10 billion gallons of ethanol, or 166 billion kilowatt-hours of electricity, which is equivalent to about 4% of total US. power consumption in 2010. Agricultural biomass has been earmarked to be an important energy resource in this wise [9]. Among the feedstocks available in abundance to the US are the crop residues and the choice of selecting the appropriate agricultural biomass and manure for bioenergy production is a measure of some factors, which may include the type and scale of resources in each location. The use of agricultural residues and manure to produce bioenergy offers a significant edge for local and regional economies.

Currently, 17% of the global population remains without electricity an amount, which is estimated to be about 1.2 billion people [10]. The climatic and geographical hindrances prevent easy accessibility to rural or remote areas where mainstream of this estimates reside; this constraint hampers the extension of power grids to these locations. An alternative to this problem is the exploration of renewable energy sources, which are increasingly the source of electricity for isolated systems in rural areas [10]. The physicochemical characteristics of biomass make it an attractive source to be harnessed for energy generation [11].

2. Agricultural residues

Agricultural residues are carbon-based materials generated as a byproduct during the harvesting and processing of agricultural crops. Agricultural residues which are produced during harvesting are primary or field-based residues while those produced along with the product during processing are secondary or processed based residues. Agricultural residues are heterogeneous, varying in bulk density, moisture content, particle size and distribution relative to operational handling. They are usually fibrous, low in nitrogen and vary with geographical location [12]. These field residues are occasionally utilized as fertilizer, for erosion control and as fodder for livestock. Almost half of these resource are combusted on the farm prior to the commencement of another farm season.

Process residues offer high prospect as an energy source. Chemical composition of any crop residue varies depending on several factors among, which may include species, age of residue or period of harvest, physical composition including length of storage and harvesting practices [13, 14]. Agricultural residues are produced as a waste product from food crops such as maize, wheat, sunflowers, and so on. Currently, only small proportion of these residues are being used by farmers as feed for livestock and the rest of these are plowed back into the soil or burned to get rid of the huge volumes of biomass before planting the next crop. The biggest advantage of utilizing agricultural residues is that it does not compete with the production of food, and if it can become a by-product that can be utilized economically for the production of energy, it will result in lower food prices. It is estimated that roughly one ton of residue is produced for every ton of grain harvested [15].

2.1. Crop residues

Apart from the grains of crops such as corn, wheat, and rice which as sourced for food, the remnants or left over from the processing of these grains also serve as an important resource.

These residues generally makeup at least 50% by mass of the biomass in US grown crops. Over time, these resources have been sourced for animal bedding, combusted, or allowed to decay on farmlands. The recent development for use of the biomass residues for ethanl production or electricity generation sequel to scientific discovery has raised hope for the resource for both economical and environmental benefits. Significantly, the US agriculture can probably support up to 155 million tons of residues for producing bioenergy in 2030 [8]. Without the need of additional land requirement since these residues is by-product of major crops [16].

Residues are known to offer a lot of advantages ranging from erosion prevention and mitigation against soil carbon depletion, their use for soil bioenergy production may adversely impact on these benefits, therefore, their utilization should be subject to certain circumstances, and even then, only at a predetermined magnitude. The amount of residues that can be collected is subjective and depends on several conditions relative to the farmland, this should be considered sustainably as removal of too much resdiues may cause exposure of the land to excessive erosion while too less or no removal of the residues can inadvertently prevent soils from drying in spring, thereby affect the planting season.

Removal of residues for bioenergy potential and application can impact negatively on other agricultural practices. The environment could be worsen as a result of excessive exposure of the farmland. In order to minimize the effect of this, farmers can employ various strategies to curb the effect. For instance they can use no-till farming and indulge in cover cropping to decrease soil erosion and water pollution. This will enhance agricultural production sufficiency while also provide abundantly the amount of residues for bioenergy biofuel production [17].

In corn-growing regions, large quantities of corn stover—leaves and stalks left over after corn is harvested—are available to produce ethanol. Corn residues are abundant near existing facilities fitted to produce and distribute ethanol made from corn grain. Indeed, companies are building the first three commercial-scale efforts to produce ethanol from agricultural residues near such existing facilities in Iowa and Kansas. Producing ethanol from corn grain and corn stover at the same location can reduce the use of natural gas and electricity by the combined facility, curbing the environmental footprint of the fuel [18].

2.2. Waste from livestock

Livestock raised in very large confined animal feeding operations generate an enormous amount of manure, which can be used for bioenergy, but also frequently pollute water supplies in many locations. Fortunately, on the smaller end of the livestock production scale, farmers convert manure into biogas with the aid of anaerobic digesters resulting in both economic and environmental paybacks. The biogas can be employed to provide heat and power on the farm, or it can be further purified and sold as renewable natural gas for use elsewhere. Prospect of anaerobic digesters for biogas production from manure can enhance water quality, reduce obnoxious greenhouse gas from manure, and assist farmers to fixate nutrients to the soil. In the United States, reports show that almost 60 million tons of manure can be adopted to produce bioenergy in 2030 [8].

This resource is best used close to where livestock produces it, and would ideally be integrated with crop production. Crop residues do not usually appear in official statistics hence an estimate of the amount of crop residues produced are usually deduced based on production data [19, 20]. Available data for processing residues is generally poor, due to a wide variety of processing techniques producing an array of different stocks of residues [21, 22]. The ratio between main product and residue vary depending on a set of factors including variety, moisture content, nutrient supply, and use of chemical growth regulators among others. In reality, there are factors which limit the use of certain residues for bioenergy production such as scattered abundance, technical constraints, ecosystem functions, and other demands such as animal fodders, fertilizer, domestic heating, and cooking for which the application of the resource is being explored for.

Bentsen et al., presented a report relative to the production data of some crops which were combined with the residue-to-product ratios (RPR) of the different crops to obtain the amount of residues for each annual crop and from perennial plantation crops. The analysis showed that the estimated total amount of crop residue that is potentially available for energy was 150 million tonnes. Using 30% conversion that is typically obtained in biomass to energy conversion systems efficiency and the heating value data, these residues can generate about 0.60 EJ, which is equivalent to 34% of the current energy consumed in Nigeria.

3. Bioenergy potentials

In accordance to the report of World Health Organization (WHO), United Nations Development Program (UNDP), 1.5 billion people, implying an estimated one-quarter of the world's population, do not have access to electricity [23]. In order to meet the UNDP millenium development goals, modern energy service need be supply to about two billion people. Lack of accessible and uninterrupted electricity supply and liquid transportation fuels undermines undeveloped and developing countries deleteriously, where population density is high and access to resources is low. About 2 billion people require on solid fuels (**Figure 1**), which are employed primarily for cooking and heating purposes. This development of combusting biomass environmental pollution and health issues. In the long run, the effect incurs health costs, where the main victims are the woman and children, due to the burning of solid fuels in poorly ventilated housing [23–25].

Contrarily, developed nations sourced for bioenergy to combact the menace of environmental pollution due to CO_2 emission and possibly reduce it and provide domestic energy [26]. Energy crops with potential to generate high-yielding lignocellulosic biomass have been studied by [27]. Exploration of the special energy crops in developing countries may possibly displace food crops resulting in food-energy fued [28–30]. Food security, as well as energy provision from these crops, can be ensured when the degraded farmlands are used to grow crops after the deforestation, which can result in CO_2 emissions as a result of excessive land use [31]. Hence, opportunities abound from dual cropping process, which can enhance agricultural productivity by generating bioenergy from agricultural waste while food production is ensured.

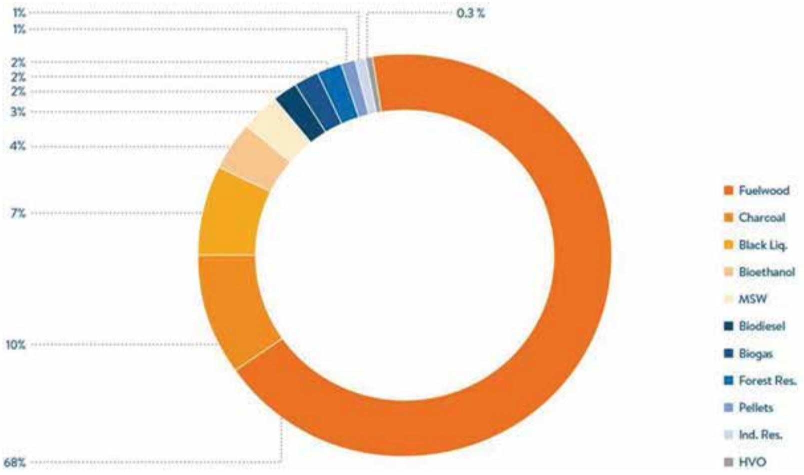


Figure 1. Primary energy supply of biomass resources globally in 2013 (WBA Global Bioenergy Statistics 2016). Source: Based on data from World Bioenergy Association (2016).

Albeit the enormous advantages of using agricultural residues as a waste stream [32], Kim and Dale opined that clearing the farm of some types of agricultural residues may result in some serious environmental concerns [26]. For instance, recurrent continual harvesting of total above ground biomass from annual cereal crops can ultimately reduce soil organic matter, causing long-term degradation of soil fertility, and rapidly promoting CO_2 emissions [33]. However, an example of removing partial residues has been demonstrated for rice (*Oryza sativa*) grain husks in India, which are gasified in small-scale ecofriendly units to produce electricity for users spending approximately $2 a month for energy [34]. Such a model for renewable energy could serve globally as an inexpensive decentralized energy mechanism.

In exploring parallel circumstances, environmental factors such as temperature, rainfall, and altitude affect the production of crop from different locations. Thus, identification of source feedstocks suitable for dual-use cropping and that are available in regions with energy scarcity is imperative. In this regard, an existing dual-use feedstock that is underused is endocarp tissues from horticultural fruit crops. For instance, the endocarp of a drupe fruit is the inedible shaft of the fruit that encloses the seed, and which is mostly thrown out after processing. The hardened drupe endocarp is made up of predominantly lignin content of any woody feedstock which can be as high as 50% wt/wt [35, 36].

In biofuel synthesis, lignin offers much higher energy content compared to cellulosic biomass [37, 38]. In practice these crops are majorly horticultural crops. The geographical distribution of selected crops and their individual potential for bioenergy synthesis was studied by Mendua et al. [35] The considered crops include coconut (*Cocos nucifera*), mango (*Mangifera indica*), olive (*Olea europaea*), walnut (*Juglans* spp.), pistachio (*Pistacia vera*), cherry (*Prunus cerasus*, *P. avium*), peach (*P. persica*), plum (*P. domestica*, *P. salicina*), apricot (*P. armeniaca*), and almond (*P. dulcis*). The focus of the study was to determine the relationship between diversity of endocarp and the proliferation of energy insufficiency by investigating the potential of endocarp biomass for energy [39].

The prospect of biomass feedstock for synthesis of biofuel and as starting materials for industrial processes cannot be overemphasized, following this development; experts forecast the potential of agricultural residues in augmenting the energy need globally in the near future thereby accounting for a significant part of international agricultural transactions in the nest few decades. However, the cost of petroleum product is usually the yardstick for evaluating the economic viability of bioenergy, although social ane environmental concerns are possible factors that can possibly fast track the schedule [39].

3.1. Biomass conversion processes

3.1.1. Biochemical conversion process

Typically, biomass composition is usually considered from three major components namely, cellulose, hemicellulose, and lignin (**Table 1**). The process of biochemical transformation processes of biomass is aimed at the disruption of the hemicellulose part in order to enable easy reachability to the cellulose, however, there is no alteration done to the lignin component [21]. Nevertheless, the lignin fraction can be converted to important fuel using a thermochemical conversion mean. Anaerobic digestion and fermentation are the two biochemical methods where biomass is converted into a valuable substance (**Table 2**).

Anaerobic digestion is an important conversion method appropriate for bioenergy synthesis from agricultural residues and some other organic products [40]. It has been researched

Crop	Residues	Residue	Composition	(Dry weight basis)
		Cellulose	Hemicellulose	Lignin
Rice	Straw, husk, stalk	0.36	0.24	0.16
Maize	Cob, husk, stalk, stover	0.35	0.23	0.19
Soybean	Husk, stalk	0.40	0.16	0.16
Groundnut	Husk	0.30	0.30	0.40
Hazelnut	Husk shell	0.30	0.16	0.53
		0.26	0.30	0.43
Tobacco	Stalk, leaf	0.36	0.34	0.12
Sunflower	Stalk, head	0.48	0.35	0.17
Almond	Shell	0.51	0.29	0.20
Wheat	Pods, stalk	0.38	0.27	0.18
Sugar cane	Baggasse, top and leaves	0.44	0.32	0.24
Cotton lint and cotton seed	Boll, shell, husk, stalks	0.80	0.20	—
Grasses	Straw	0.40	0.50	0.10
Barley	Straw	0.46	0.23	0.16

Table 1. Some crop residue and their lignocellulosic composition [71, 72].

Conversion processes		**Biomass**	**Components**	
	Fat and oils	Protein	Sugar and starch	Lignocellulosic
Direct combustion	✓			✓
Anaerobic digestion	✓	✓	✓	Cellulose only
Fermentation		✓	✓	Cellulose only
Transesterification	✓			
Pyrolysis	✓	✓	✓	✓
Gasification	✓	✓	✓	✓

Table 2. Primary biomass conversion process and processed biomolecules [21].

extensively in the production of bioenergy for both domestic and industrial applications [41]. The process involves the utilization of microorganism for conversion of moist organic substance in an anaerobic environment to generate CO_2, biogas and some other impurities such as hydrogen sulfide [21]. Along the product a waste stream digestate is generated which are usually utilized as manure of the farmland. The generated biogas is characterized with high-energy content of one-third of the lower heating magnitude of the feedstock from which it is produced [42]. In the quest for renewable energy production in the form of biogas, this method has been studied succinctly. Moreover, there is inherent advantage of carbon capture for CO_2 mitigation [39, 41]. Among the various biomass resources that has been investigated, algae stand prominent as an agricultural residue producing significant amount of biogas in many locations of the world [39].

Besides, another vital approach of biomass conversion is an enzymatic controlled anaerobic process [43], which is employed in the synthesis of bioethanol from lignocellulosic biomass. In this process, the first action is the pretreatment of the raw biomass and subsequent hydrolysis prior to fermentation process. The cellulosic component of the biomass is transformed into glucose via enzymatic hydrolysis converts the cellulose component of the biomass into glucose while the hemicellulose part affords pentose and hexoses. Microorganism then converts the glucose into ethanol. This is affected by the action of biological catalysts to turn fermentable sugars to important chemicals (usually alcohols or organic acids). The most essential product of fermentation has been ethanol; however, there are some other useful substances such as hydrogen, methanol, and succinic acid that are generated. The major fermentation substrates are hexoses, which are mostly glucose, while modified fermentation organisms are used to convert pentose, glycerol, and other hydrocarbons to ethanol [44].

Furthermore, fermentation process is a conventional and extensively considered method in the treatment of waste streams, as well as for ethanol synthesis from agricultural residues, such as corn cobs and sugar beets [43]. Using fermentation sugars in sugarcane as feedstock, Brazil established a successful bioethanol plant. In 2011, about 5.57 billion gallons of ethanol is generated as fuel from this program, an equivalent of about 24.9% of the world's total ethanol utilization in form of fuel [21].

Transesterification reaction is used to synthesize biodiesel by employing the ethanol along with large branched triglycerides into smaller straight-chain molecules usually in the presence of a catalyst [40]. The biodiesel produced is used in diesel engines either pure or in blend with fossil diesel. In spite of the success recorded in various part of the world, biodiesel production in commercial scale is still at evolving stage in Africa [40, 45] despite the myriad of feedstock available and the potential of this important biofuel.

3.1.2. Thermochemical conversion processes

Various other methods of thermochemical conversion processes for biomass conversion abounds, which are carried out at supercritical temperature and pressure and are usually at higher reaction condition compared to biochemical processes [46]. This process has been employed to generate a number of important bio-based products. These methods include direct combustion, pyrolysis, gasification and hydrothermal liquefaction (**Table 2**).

An important method for biomass conversion via thermochemical route is direct combustion methods is employed to produce the major bioenergy resource of the world accounting well above 97% of world bioenergy index [43]. It is the most common way of extracting energy from biomass. Direct combustion methods produce energy only in the form of heat and electric power as such it is not employed for biofuel production [47] and it considered several feedstocks such as energy crops, agriculture residues, forest residues, industrial and other wastes [48].

Another production process is pyrolysis, which is an important biomass conversion method that heralds the combustion or gasification of solid fuels. It comprises of thermal degradation of biomass feedstock at temperatures of about 350–550°C, under pressure, in air tight compartment [21]. This approach affords three fractions: liquid fraction (bio-oil), solid (largely ash), and gaseous fractions. Pyrolysis has been useful over time in charcoal production, however, it is only been recently considered due to the mild temperature and short residence time [49]. The product generated from the fast pyrolysis technic is known to be made up of more than two-third of the feedstock in liquid content and is suitable for use in engines, machinery and myriads of other applications [49]. An integrated approach where fast-pyrolysis can be co-processed with fossil fuel in conventional refinery is the current trends in research in which refined hydrogen can be utilized for blend to upgrade the oil into locomotive fuels and, in turn, some gases of pyrolysis are employed in the refinery [42, 50]. The feasibility of this approach is a measure of the comparable cost of natural gas, biomass feedstock, and incremental capital costs. Co-processing of petroleum with renewable agricultural residues offers advantages from both technological and economic considerations.

Subject to sustainable practices and advocacy as well as the availability of feedstock, the utilization of biomass feedstock in biofuel and bioenergy production promise to be prominent approach and the generated biofuel products are known to be comparative in characteristic feature with petroleum products. The first large-scale plant facility employing fast pyrolysis and bio-crude refining method in the United States amounting to about $215 million projects is the KiOR Inc. plant situated in Columbus, Mississippi [50].

Pyrolysis of biomass and their direct liquefaction method with water are often used mistaking to mean the same thing; however, there exist a striking difference between the two processes. Although they are both thermochemical conversion methods that involve the alteration of various components of biomass into liquid products. Whence liquefaction involves decomposition of macro-molecule feedstock into smaller fragments of light molecules where an appropriate catalyst is employed in the conversion. Subsequently, the unstable smaller fragments are re-polymerized into oily constituent with comparable molecular weights with fossil equivalent. Whereas in pyrolysis, the generated fragments are instantaneously merged to an oily compound and the use of catalyst is predominantly may be subject to necessity [43].

4. Global biofuel and bioenergy scenarios

The potential for bioenergy generation from agricultural residues is being studied intensively and many studies have been conducted on both a regional and a global scale. In most cases, the outcomes of these studies vary considerably because of factors, such as the residue to product ratio and the sustainable removable amount of residues, used to calculate potentials range substantially.

So far, a lot of studies in different countries have been conducted for the assessment of availability of residual biomass. Scarlat et al. [51] assessed the availability of residual biomass of agricultural and forest crops suitable for bioenergy synthesis in Romania. Crop yield, variation multi-annual yield, environmental and economic constraints, and competitive uses were the various measures utilized to estimate agricultural residues. A comparable work was developed by Shonhiwa [52] who explored the magnitude of biomass available for energy production using thermochemical conversion technologies in Zimbabwe. Besides, Iye and Bilsborrow [53] evaluated the propensity of agricultural residues in Nigeria based in six areas; three situations were considered subject to the collection and availability of biomass proportion.

Moreover, in Argentina energy potential of residual biomass derived from herbaceous and horticultural crops was studied by Roberts et al. [54]. In Colombia, several studies were carried out to determine the features of residues from agriculture, animal, forestry, and municipal solid waste in order to evaluate its energy potential [11, 55]. Subject to the geographical location of Colombia tropics, Colombia has comparative advantages in the production of agricultural and forest biomass and its potential is sufficient to satisfy the energy demands [56].

As an example, Hiloidhari assumes a RPR of 2 for maize [57], whereas the IEA considers a RPR of 1.5 [58] while Kim et al. adopted a ratio of 1 [59]. Similarly, the fraction of the produced residues that can be detached in a sustainable manner is in the range of 20 [60] to 50% [61] although 70% is recorded in some studies [62]. Apparently, this has a huge impact on the resulting propensity for bioenergy production.

Furthermore, numerous works have assessed the technical feasibility of crop residue production in China. Jiang et al. [63] used a GIS-based approach to examine the availability of crop residues in China. A number of cereal crop were considered and the findings demostrated China potential to provide about 506 million dry biomass metric tons of the residues annually. In another study, Qiu et al. [64] adopted remote sensing data and reported about 729 million MT crop residues in 2010, of which about 20–45% of this amount could substitute coal subject to regional utilization and customary needs of crop residues. Liu et al. [65] discovered that about 630 million MT of crop residues was harvested annually over a decade between 1995 and 2005. The observable dicotomy is as a result of the several factors such as considered crops, assumptions relative to crop-to-residue ration, and residue collection methodology, which is evidence in the estimated technical availability of crop residues available in the results.

In estimation of the technical potential of crop residues production, production cost of the residues and the cost of feedstock were never considered in past reports. In certainty, farmers' preparedness to collect crop residues rely significantly on the yields and production costs of crop residues as well as on the biomass prices provided in the market. Specifically, the biomass prices offered must cover the costs of collecting crop residues. In this regard, Chen [66] examined the potential yield of each type of crop residue in China at various prices and subsequently, estimated the collective supply of crop residues at these prices. As regards the crop residues, different residues were considered as potential residues and due to the inherent yield and cost uncertainty, they derived the supply curves of the crop residues using alternative assumptions about the production costs of crop residues and residue collection technology.

In Tanzania, the major commercially sourced after agricultural crops include sugar, cotton, tea, cashew nut, tobacco, coffee, and sisal. Significant amounts of residues from these crops have been utilized for the cogeneration of electricity in the sugar sector. Convesely, only a small amount of sisal residues had been utilized as substrate in a pilot biogas plant to generate electricity since 2008. Moreover, almost all biomass can be converted into energy; crop residues are not an exception. The types of residues available for energy generation in the commercial crop sector in Tanzania were bagasse, coffee husks, cashew nut shells, tobacco stems and sisal pulp [67].

The energetically available share of these residues was determined by the termed non-energy applications, whence the energy content of residues is influenced by the plant structure and the moisture content of the residue. Considering the account of these different parameters, the heating value for every tonne of dry matter had been reported. Although they submitted to probability of the estimation due to expedient losses during collection and transportation, the upper bound demonstrated that all residue types contain a incredible energy propensities. The combined potential of 6053 TJ is equivalent to 1680 Gigawatt hours (GWh). This estimated maximum potential is equivalent to over 37% of the country's electricity generation of 4553 GWh in 2008 [68].

5. Future prospects

Significantly, the role of biofuels and bioelectricity as an important sustianble fuel in today's fuel and electricity grid cannot be underestimated due to their presumed potential to revolutionize the bioenergy sector. Researchers in various research institutions around the world are engaging in unprecedented investigation on converting biomass into biofuels and other chemicals and products. For instance, reserachers of diverse field of specialization at the Biocentury research farm, Iowa State University are currently investigating new approaches for conversting agricultural residues and other advanced feedstocks into biofuels, while social scientists are preoccupied with the analysis of the economic blueprint of bioenergy on Iowa agriculture.

In developing the technological practices and policies, there is the need to use agricultural biomass resources responsibly to ensure that communities across the every location and agencies benefit both financially and environmentally while the nation abates its oil and coal use and global warming emissions. However, achieving this quest will require private investment and smart public policy.

The IEA World Energy Outlook [69] suggested that renewables could form an integral proportion of the global primary energy mix in the near future, up to a fifth of demand (**Figure 2**), while coal could provide a quarter by 2040. A great deal of this renewable energy could be from hydroelectricity, solar PV, and wind power while cofiring practices of biomass could augment these sources while not requiring the premature retirement of coal assets, many of which are still in the early days of operation in places Asia. Cofiring solid fuel with coal is a relatively low-cost, relatively safe method of adding biomass capacity without a major

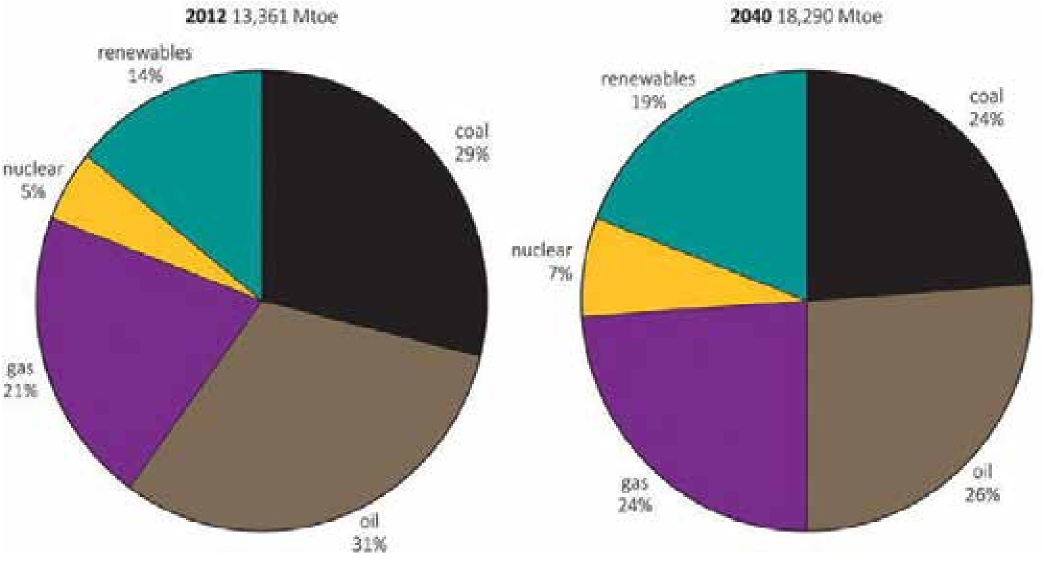


Figure 2. A comparable projection of the primary energy demand in the world in 2040 (Source: [70]).

disbursement of capital expenditure compared to a dedicated biomass plant. In an effort to compare the different global biomass resource, a presentation of specific types of biomass that exist and identification of those best suited for combustion for power generation is imperative. Numerous practices have been suggested to ensure a sustainable practice. This biomass resource can be combined with any fossil-fuel in any of the following practice, such as:

- Cofiring solid biomass particles with coal;
- Mixing with synthesis gas; and
- Landfill gas or biogas with natural gas.

6. Conclusion

Bioenergy is derived from biomass, which can be deployed as solid, liquid, and gaseous fuel for a wide range of uses including heating, electricity, and cooking. It can also provide substantial climate change mitigation benefits when developed appropriately, and therefore, can be instrumental in working toward the attainment of the Paris Agreement goals. Among the variously available resource, agricultural wastes are biomass considered in on-going research for biofuel and bioenergy production as well as synthesis of important chemicals for industrial applications. These resources are relatively abundant around the world and can serve a dual purpose of energy production and environmental protection.

Moreover, the quantity of residues originating from the food processing is usually huge, and their exploration for energy generation can provide a considerable volume of renewable energy. Nevertheless, current application of these residues includes utilization as livestock feed, promoting the production of highly valued meat and dairy products. These commodities are important sources of protein in the human diet, and cannot be left out without affecting the quality of food consumption. Hence, exploring residues for non-feed purposes such as biofuel and bioelectricity requires adaptations in the food system to compensate for protein losses. Therefore, based on the available reports in literature and the various policies for sustainable practices that is geared toward pollution mitigation. Hence, these residues are important feedstocks of immense potential for sustainable biofuel and bioenergy production.

Acknowledgements

The authors would like to express our gratitude to Dr. Olorunnisola Kola Saheed for his effort in taking time to read through the manuscript and providing his valuable technical inputs.

Conflict of interest

The authors declare that there is no conflict of interest in the chapter whatsoever.

Author details

Nurudeen Ishola Mohammed[1]*, Nassereldeen Kabbashi[1] and
Abass Alade[2]

*Address all correspondence to: sholanourou@yahoo.com

1 Bioenvironmental Engineering Research Centre (BERC), Department of Biotechnology Engineering, Faculty of Engineering, International Islamic University Malaysia, Jalan Gombak, Kuala Lumpur, Malaysia

2 Chemical Engineering Department, Faculty of Engineering and Technology, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria

References

[1] IEA CCC. Author's Analysis. London, UK: IEA Clean Coal Centre; 2014

[2] Barz1 M, Delivand MK. Agricultural residues as promising biofuels for biomass power generation in Thailand. Journal of Sustainable Energy & Environment Special Issue. 2011:21-27

[3] Ben-Iwo J, Manovic V, Longhurst P. Biomass resources and biofuels potential for the production of transportation fuels in Nigeria. Renewable and Sustainable Energy Reviews. 2016;**63**:72-192

[4] Kumar Ghosh S. Biomass & bio-waste supply chain sustainability for bio-energy and bio-fuel production. Procedia Environmental Sciences. 2016;**31**:31-39

[5] Jekayinfa SO, Scholz V. Assessment of availability and cost of energetically usable crop residues in Nigeria. In: Paper presented at Conference on International Agricultural Research for Development; Tropentag: University of Kassel-Witzenhausen and University of Gottingen; 2007. pp. 9-11

[6] Brent A. The agricultural sector as a biofuels producer in South Africa. In: Understanding the Food Energy Water Nexus. South Africa: WWF-SA; 2014

[7] Marrison I, Larson ED. A preliminary estimate of the biomass energy production potential in Africa in 2025. Considering projected land needs for food production. Biomass and Bioenergy. 1996;**10**:337-351

[8] Union of Concerned Scientists (UCS). The Promise of Biomass: Clean Power and Fuel—If Handled Right. Cambridge, MA: Department of Energy (DoE); 2012

[9] Terrapon-Pfaff JC. Linking energy- and land-use systems: Energy potentials and environmental risks of using agricultural residues in Tanzania. Sustainability. 2012;**4**:278-293. DOI: 10.3390/su4030278

[10] IEA - International Energy Agency. World Energy Outlook 2015, Executive Summary. Paris, France: IEA; 2015

[11] Escalante H, Orduz J, Zapata H, Cardona M, Duarte M. Atlas: The Energy Potential of Biomass Residual in Colombia. Bucaramanga, Santander, Colombia: AIDIC; 2010

[12] Smith OB. Utilization of crops residues in the nutrition of sheep and goats in the humid tropics of West Africa. In: Atta Krah AN, Reyholds L, editors. Sheep and Goat Meat Production in the Humid Tropics of West Africa; Yamoussoukro; 21-25 September, 1987. FAO Animal Production and Health Paper; 1989

[13] Cooper CJ, Laing CA. A macro analysis of crop residue and animal wastes as a potential energy source in Africa. Journal of Energy in Southern Africa. 2007;**18**(1):10-19

[14] OECD/IEA. Sustainable Production of Second—Generation Biofuels, Potential and Perspectives in Major Economies and Developing Countries, Information Paper. Paris: IEA; 2010

[15] Virmond E, Rocha JD, Moreira RFPM, José HJ. Valorization of agroindustrial solid residues and residues from biofuel production chains by thermochemical conversion: A review, citing Brazil as a case study. Brazilian Journal of Chemical Engineering. 2013; **30**(02):197-229

[16] United States Department of Agriculture USDA. Crop residue removal for biomass energy production: Effects on soils and recommendations. Soil Quality-Agronomy Technical Note. 2006;**19**:1-7

[17] Wiggins DR, Singer JW, Moore KJ, Lamkey KR. Response of continuous maize with Stover removal to living mulches. Agronomy Journal. 2012;**104**:917 925

[18] U.S. Department of Energy. In: Langholtz MH, Stokes BJ, Eaton LM, editors. Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy. Oak Ridge, TN: Oak Ridge National Laboratory; 2016, 2016. 448p

[19] FAOSTAT. Food and Agricultural Organisation of United States. Rome: FAO Statistics Division; 2012

[20] NASS. Collaborative Survey on National Agricultural Sample Survey 2010/2011. Abuja: National Bureau of Statistics and Federal Ministry of Agriculture and Rural Development; 2012

[21] Simonyan KJ, Fasina O. Biomass resources and bioenergy potentials in Nigeria. African Journal of Agricultural Research. 2013;**8**(40):4975-4989

[22] Eisentraut A. Sustainable Production of Second-Generation Biofuels. Information Paper. Paris: International Energy Agency (IEA); 2010

[23] Legros G et al. The Energy Access Situation in Developing Countries. A Review Focusing on the Least Developed Countries and Sub-Saharan Africa. New York: WHO-UNDP; 2009

[24] Gronewold N. One-quarter of world's population lacks electricity. Scientific American. 2009;(Nov):4

[25] Gustafsson Ö et al. Brown clouds over South Asia: Biomass or fossil fuel combustion. Science. 2009;**323**:495-498

[26] Tilman D et al. Energy. Beneficial biofuels—The food, energy, and environment trilemma. Science. 2009;**325**:270-271

[27] Heaton EA, Dohleman FG, Long SP. Meeting US biofuel goals with less land: The potential of Miscanthus. Global Change Biology. 2008;**14**:2000-2014

[28] Naylor RL et al. The ripple effect: Biofuels, food security, and the environment. Environment. 2007;**49**:30-43

[29] Battisti DS, Naylor RL. Historical warnings of future food insecurity with unprecedented seasonal heat. Science. 2009;**323**:240-244

[30] Rajagopal D, Sexton SE, Roland-Holst D, Zilberman D. Challenge of biofuel: Filling the tank without emptying the stomach? Environmental Research Letters. 2007;**2**:044004

[31] Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P. Land clearing and the biofuel carbon debt. Science. 2008;**319**:1235-1238

[32] Koltermann A, Kraus M, Rarbach M, Reisinger C, Zavrel M, et al. Cellulosic ethanol from agricultural residues—An advanced biofuel and biobased chemical platform. JSM Biotechnology And Bioengineering. 2014;**2**(1):1024

[33] Lal R. Soil erosion and carbon dynamics. Soil and Tillage Research. 2005;**81**:137-142

[34] Bornstein D. A light in India. New York Times. 2011

[35] Mendua V, Tom Shearina T, Elliott Campbell J Jr, Stork J, Jae J, Crocker M, Huber G, DeBolt S. Global bioenergy potential from high-lignin agricultural residue. PNAS. 2012; **109**:4014-4019

[36] Dardick CD et al. Stone formation in peach fruit exhibits spatial coordination of the lignin and flavonoid pathways and similarity to *Arabidopsis dehiscence*. BMC Biology. 2010;**8**:13

[37] Raveendran K, Ganesh A. Heating value of biomass and biomass pyrolysis products. Fuel. 1996;**75**:1715-1720

[38] White R. Effect of lignin content and extractives on the higher heating value of wood. Wood and Fiber Science. 1987;**19**:446-452

[39] Dutta K, Daverey A, Lin JG. Evolution retrospective for alternative fuels: First to fourth generation. Renewable Energy. 2014;**69**:114-122

[40] Ishola MM, Brandberg T, Sanni SA, Taherzadeh MJ. Biofuels in Nigeria: A critical and strategic evaluation. Renewable Energy. 2013;**55**:554-560

[41] Ward AJ, Lewis DM, Green FB. Anaerobic digestion of algae biomass: A review. Algal Research. 2014;**5**:204-214

[42] Brasil. Brazilian Agroenergy Plan 2006-2011/Ministry of Agriculture, Livestock and Food Supply, Secretariat for Production and Agroenergy. Brasília, DF: Embrapa Publishing House; 2006. p. 108

[43] Demirbas A. Bio-refineries: Current activities and future developments. Energy Conversion and Management. 2009;**50**:2782-2801

[44] Amigun B, Musango JK, Stafford W. Biofuels and sustainability in Africa. Renewable and Sustainable Energy Reviews. 2011;**15**:1360-1372

[45] Nigam PS, Singh A. Production of liquid biofuels from renewable resources. Progress in Energy and Combustion Science. 2011;**37**:52-68

[46] Ullah K, Kumar Sharma V, Dhingra S, Braccio G, Ahmad M, Sofia S. Assessing the lignocellulosic biomass resources potential in developing countries: A critical review. Renewable and Sustainable Energy Reviews. 2015;**51**:682-698

[47] Elbehri A, Segerstedt A, Liu P. Biofuels and the Sustainability Challenge: A Global Assessment of Sustainability Issues, Trends and Policies for Biofuels and Related Feedstocks. Rome; FAO: 2013

[48] Bridgwatera V. Review of fast pyrolysis of biomass and product upgrading. Biomass and Bioenergy. 2012;**38**:68-94

[49] IRENA. Road Transportation: The Cost of Renewable Solutions. Bonn: IRENA; 2013

[50] Al-Sabawi M, Chen J. Hydro processing of biomass-derived oil sand their blends with petroleum feedstocks: A review. American Chemical Society. 2012;**26**:5373-5399

[51] Scarlat N, Blujdea V, Dallemand J. Assessment of the availability of agricultural and forest residues for bioenergy production in Romania. Biomass and Bioenergy. 2011;**35**:3-34

[52] Shonhiwa C. An assessment of biomass residue sustainably available for thermochemical conversion to energy in Zimbabwe. Biomass and Bioenergy. 2013;**52**:1-184

[53] Iye E, Bilsborrow P. Assessment of the availability of agricultural residues on a zonal basis for medium- to large-scale bioenergy production in Nigeria. Biomass and Bioenergy. 2013;**48**:66-74

[54] Cáceres KR, Blanco Patiño FG, Araque Duartea JA, Kafarov V. Assessment of the energy potential of agricultural residues in non-interconnected zones of Colombia: Case Study of Chocó and Putumayo. Chemical Engineering Transactions. 2016;**50**:349-354. DOI: 10.3303/CET1650059

[55] Gonzalez-Salazar MA, Morini M, Pinelli M, Spina P, Venturini M, Finkenrath M, Poganietz W. Methodology for estimating biomass energy potential and its application to Colombia. Applied Energy. 2014;**136**:781-796

[56] CORPOEMA. Formulating a Development Plan for Non-Conventional Energy Sources in Colombia (PDFNCE). Bogotá, Colombia: AIDIC; 2010

[57] Hiloidhari M, Baruah DC. Rice straw residue biomass potential for decentralized electricity generation: A GIS based study in Lakhimpur District of Assam, India. Energy for Sustainable Development. 2011;**15**(3):214-222

[58] IEA. Sustainable Production of Second-Generation Biofuels. Paris: IEA; 2010

[59] Kim S, Dale BE. Global potential bioethanol production from wasted crops and crop residues. Biomass and Bioenergy. 2004;**26**:361-375

[60] Hiloidhari M, Baruah DC. Crop residue biomass for decentralized electrical power generation in rural areas (Part 1): Investigation of spatial availability. Renewable and Sustainable Energy Reviews. 2011;**15**:1885-1892

[61] Fischer G, Hizsnyik E, Prieler S, van Velthuizen H. Assessment of Biomass Potentials for Biofuel Feedstock Production in Europe: Methodology and Results. Work Package 2ebiomass Potentials for Bio-Fuels: Sources, Magnitudes, Land Use Impacts REFUEL. Petten: Refuel; 2007

[62] Euler W. South African Biomass Availability Case Study. London: IIED; 2010

[63] Jiang D, Zhuang D, Fu J, Huang Y, Wen K. Bioenergy potential from crop residues in China: Availability and distribution. Renewable and Sustainable Energy Reviews. 2012; **16**:1377-1382

[64] Qiu H, Sun L, Xu X, Cai Y, Bai J. Potentials of crop residues for commercial energy production in China: A geographic and economic analysis. Biomass and Bioenergy. 2014;**64**: 110-123

[65] Liu H, Jiang GM, Zhuang HY, Wang KJ. Distribution, utilization structure and potential of biomass resources in rural China: With special references of crop residues. Renewable and Sustainable Energy Reviews. 2008;**12**:1402-1418

[66] Chen, X. Assessment of the Potential Biomass Supply for Crop Residues in China. Environment for Development. China; EfD; 2015

[67] Nonhebel S. Energy from agricultural residues and consequences for land requirements for food production. Agricultural Systems. 2007;**94**:586-592

[68] International Energy Agency (IEA). Electricity/Heat Data for Tanzania; Paris, France: IEA; 2008. Available online: http://www.iea.org/stats/electricitydata.asp

[69] Deng YY, Koper M, Martin Haigh M, Dornburg V. Country-level assessment of long-term global bioenergy potential. Biomass and Bioenergy. 2015;**74**:253-267

[70] IEA. Clean Coal Centre—World Forest and Agricultural Crop Residue Resources for Cofiring. Northfields London SW18 1DD, United Kingdom: IEA; 2015

[71] Muth DJ, McCorkle DS, Koch JB, Bryden KM. Modeling sustainable agricultural residue removal at the subfield scale. Agronomy Journal. 2012;**104**:970-981

[72] Bentsen NS, Felby CC, Thorsen BJ. Agricultural residue production and potentials for energy and materials services. Progress in Energy and Combustion Science. 2014;**40**:59-73

Chapter 6

Bio-Drying of Biodegradable Waste for Use as Solid Fuel: A Sustainable Approach for Green Waste Management

Mutala Mohammed, Augustine Donkor and
Ismail Ozbay

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.77957

Abstract

The potential for thermal recovery of waste is increasingly gaining impetus among researchers and industries across the globe especially in many developed countries. However, in processing waste for energy recovery, the type and nature of input waste materials particularly those with high moisture content have a significant impact in determining the quality, environmental profile of the waste as well as the thermal properties of the final product. Bio-drying, as a waste to energy conversion technology, tends to reduce moisture content of waste while maintaining the energy content of the processed waste. The current study investigates the effect of input materials (biogenic and non-biogenic materials) on the energy and biogenic contents of waste material by bio-drying process. The results indicated a positive correlation between biogenic and energy contents of the input materials with some variations observed. Further analysis showed that, high proportion of food waste in the waste mix indicated a slight difference in biogenic and energy contents. Conversely, the same proportion of paper in the waste mix showed similar biogenic content with slight variation in energy content.

Keywords: bio-drying, biogenic content, energy content, waste, fuel

1. Introduction

Waste is unavoidable as long as human continues to live and engaged in economic activities. Most of the waste generated are either recycled or dumped in landfills, where it decomposes over a period of decades or even centuries. More than 50% of the energy content of municipal solid waste (MSW) originates from biogenic matter both in developed and developing countries. However, the disposal of the organic fraction of waste in landfill has dire consequences on the environment including the generation of methane, which can pose a threat or contribute to the greenhouse effect. Some landfills have sought to collect methane, which may be used for fuel; nonetheless, the conversion to methane takes place on long time scales, wastes much of the internal energy of the waste, and is rather ineffective in recovering much of the available energy content of the waste.

The search for sustainable solutions for biodegradable waste management represents a challenge not only for the waste management sector but also for the agricultural and industrial sectors. The enormity of this problem intertwined with the aforementioned issues associated with landfilling led to the introduction of the Landfill Directive of 1999 by the European Union (EU). According to the Landfill European Directive 1999/31/EC, member states are required to only landfill wastes that have been preliminary subjected to treatment or require a phased reduction in the amount of biodegradable waste disposed of to landfill [1]. Biodegradable waste refers to any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard [2]. Similarly, the Energy Information Administration (EIA) of the Environmental Protection Agency (EPA) of the United States defines biodegradable/biogenic waste as any waste produced by biological processes of living organisms. Based on the definition by the EU and inter alia [3, 4], it is clearly that the concept of biodegradable waste is wide and regards not only the production of food waste at household level; however, it includes all agricultural waste. The UNEP estimates that the decay of organic proportion of municipal solid waste contributes about 5% of global Greenhouse Gas (GHG) emissions annually [5]. In curbing this menace, a number of technologies for waste treatment such as composting (organic fertilizer), landfilling, anaerobic digestion and thermal methods have been developed [6]. However, the implementation of some of these techniques has been hindered due to the high implementation costs and other related environmental concerns.

By virtue of these concerns and in line with the new European Union Landfill Directive (1999/31/EC), this has motivated research into the development of technologies to reduce the impact associated with landfilling of waste [7–9]. Consequently, composting has been identified as an alternative method for transforming the organic fraction of waste into a potentially safe, stable and sanitary product that can be used as a soil amendment or an organic fertilizer [10]. Nonetheless, high operational cost, low quality of final product and long residence time (30-50 days) associated with composting have hindered wider application of this technology as inept for waste treatment [11, 12].

Energy from the biogenic part of waste is considered as one of a number of options that either have the greatest potential to help in a cost effective and sustainable way in waste management. Although, energy recovery may not be the first option according to the waste hierarchy, this option becomes paramount when the material is generated and considered as waste [13]. The EU directive categorized waste incineration either as a disposal or energy recovery technology depending on the energy efficiency of the incineration plant [14]. Thus, the operation and design of the aforementioned process highly require the knowledge of its thermal properties or the biogenic fraction of the waste. The carbon stored in waste originated from biological sources is refers to as biogenic carbon. However, biodegradable waste with high moisture content is often difficult to utilize the full energy potential of the waste due to its limited lower heating value (3–6.7 MJ/kg) [15].

The carbon content of any waste depends on the waste components. The relative proportions of biogenic and fossil carbon also depend upon the waste components, as do other important factors such as the calorific value or energy content. The calorific value of waste is how much (chemical) energy is stored in the waste per tonne that could potentially be converted into useful electrical or heat energy when burned. The term calorific value is synonymous to the heating value. The higher the calorific value, the more energy can potentially be captured from the waste. Different waste components have different individual calorific values i.e. food waste tends to have a relatively low value due to its high water content while plastic has much higher energy content. The variation of different proportions of these wastes will therefore significantly impact on the overall calorific value. This brings to forth the composition of waste as it affects many of the overall properties of the waste including both the calorific value and the biogenic content of the fuel.

According to literature, a number of pre-treatment technologies such as Mechanical Sorting Plant, Mechanical Biological Treatment (MBT) and Mechanical Heat Treatment (MHT) have been research and developed. These treatment techniques apply mechanical sorting and processing techniques to remove recyclates, moisture, and shred and/or homogenize the waste to create some kind of refuse derived fuel (RDF) or solid recovered fuel (SRF). However, in this study, bio-dried material obtained from bio-drying process was used to ascertain the fuel properties of the final product. Bio-drying technology, as a waste to energy conversion technology, aims at removing water by microbial activities, is regarded as a good option in reducing the moisture content of wet organic wastes [16]. The essence of this technology is to reduce the volume of waste sent to landfills which in turn will benefit short time storage and transportation, and provides alternative energy source as fuels for industries.

Whereas some technologies can cope with a broad range of calorific values and water content of the waste fuel, others require much more specific levels to operate efficiently. Additionally, the biogenic content of waste also affects the technologies that are suitable to deliver environmental benefits. Thus, having a good understanding of composition in terms of calorific value and biogenic content is essential for planning and designing energy from waste solution. Hence, the main objective of this research is to characterize bio-dried material produced by bio-drying from biodegradable/biogenic and non-biodegradable/non-biogenic materials based on biogenic and energy content of the waste material.

2. Bio-drying process

Bio-drying, a concept similar to composting, aims at removing or reducing water from biodegradable waste with high water content and increasing the treatability and subsequent utilization value of the bio-dried material. In other words, it is the utilization of the heat released during the decomposition of biodegradable waste in order to reduce the moisture content and partially stabilize the waste. The removal or reduction of moisture contents in bio-drying process involves evaporation of liquid water through aerobic decomposition of the organic material or reduction of water vapor via aeration [17–21]. This mechanism is accomplished by relying on microorganisms, both bacteria and fungi to biologically degrade the organic component in order to reduce the moisture content while maintaining the energy content [22]. Therefore, metabolic heat production, air convection and molecular diffusion of oxygen and water vapor are the main mechanisms involved in water removal from wet wastes under bio-drying [23].

The importance of bio-drying process of waste includes:

- Pre-treatment
- Short residence time
- Partial biostabilization
- Increasing energy content
- High quality solid fuel production
- Reduce volume of waste to be landfilled
- Reduce green house emissions

Compared to traditional composting process, the essential distinguish feature of bio-drying is the application of a higher ventilation rate to reduce moisture content by using the heat generated during the aerobic degradation process as well as forced aeration [24]. Also, the output from composting is stabilized organic material whereas that of bio-drying is partially stabilized. Bio-drying also has added advantage of pre-treating the waste at the lowest possible retention time to produce a high quality solid fuel. Furthermore, bio-drying process tends to increase the energy content of the bio-dried material by reducing the moisture content in the waste matrix and preserving most of the calorific value or energy content of the organic matter present through minimal biodegradation [25]. Besides these benefits, bio-drying process also renders the output material more suitable for short-term storage and lessens the transportation cost by reducing its weight via moisture loss and partially biostabilizing it. In contrast, composting is used to stabilize the biodegradable organic material of waste prior to landfill disposal, minimizing leachate and landfill gas generation. It is also used to produce humus-like compost that can beneficially and safely apply to land. The difference between composting and bio-drying also depends on the control parameters including temperature, oxygen content, air flow rate, and moisture content. In order to ensure high degradation performance for the former, the temperature, oxygen concentration, and moisture content should be kept within an optimal range whereas for the latter, the process should be managed to accelerate drying and to reduce organic matter degradation.

2.1. Factors affecting bio-drying process

2.1.1. Moisture content

Moisture content of the waste is considered as a single critical parameter for evaluating the efficiency of bio-drying process. The moisture content influences microbial activity and biodegradation of the organic component during bio-drying process. Despite the fact this technology is considered as a zero leachate approach, it is likely that a limited amount of free water may seep through the waste matrix and collected at the bottom of the bioreactor as leachate [11]. Bio-drying has mostly been studied for MSW (municipal solid waste) [24, 26–29], pulp and paper [23, 30, 31] and, garbage residues and sewage sludge [32–34] with 50–70% as the optimal initial moisture content range for bio-drying process [12, 28, 34]. The initial moisture content is important because microbial activity is impeded due to high initial moisture content favoring anaerobic conditions because water rather than air fills pore space limiting oxygen transport within the matrix, whereas low moisture content slows down the activity of the microorganisms resulting in reduce bio-drying performance. Conversely, if initial moisture content is low, microbial activity is slowed due to insufficient moisture which could results in reduced drying performance. It is suggested that, in order to improve the water content reduction and accelerated biodegradation of MSW with high water content, supplemented a hydrolytic stage prior to aerobic degradation and inoculated the biomass with the bio-drying products as leachate [29]. However, the concept of bio-drying has not been fully understood with regards to bio-drying of organic waste of high moisture content including food waste [11, 25], leaving a research gap to be filled.

Most organic wastes like dewatered sewage sludge, food waste and garden waste contain abundant water with a typical moisture content around 80% or higher, and this excessive moisture affects particle aggregation, causes packing and reduces void space, which all prevents efficient air movement throughout the matrix and limits aerobic decomposition [35, 36].

2.1.2. Air-flow rate

According to literature, it has been established that air-flow rate is the main operational parameter used both in laboratory and commercial applications for process control in bio-drying process. The air-flow rate has a direct influence on the matrix temperature and drying efficiency. The effect of air-flow rate on bio-drying has recently been studied extensively by several researchers. On the one hand, a higher air flow rate leads to higher heat loss, resulting in a decrease in the matrix temperature, which is unfavorable for water evaporation. On the other hand, an increase in the airflow rate will also increase the amount of water carried, improving the water loss. Adani et al. [26] and Roy [37] established that high air-flow rate contributes to effective and fast drying, and high calorific value. In another study, the simultaneous effect of initial moisture content and airflow rate on bio-drying of sewage sludge was investigated, and the results revealed that initial moisture content has a stronger effect on bio-drying, affecting the temperature and improving the water removal [38].

Skourides et al. [39] investigated the agitated bio-drying of the organic fraction of municipal solid and the results showed maximum drying rate achieved for the highest aeration rates used (120 m^3/h), leading to lower final moisture content levels (20% w/w from an initial 40% w/w) with a short retention time of less than 7 days. In a similar study to investigate the effect of air-flow on the bio-drying of gardening wastes, it was found that higher air-flow rate corresponds to greater weight loss (40–57% weight loss) and leachate production at low air-flow. Even though higher air-flow rate causes higher water removal, it was further stressed that it is imperative to identify the optimal air-flow rate for bio-drying, since excessively high air-flow rate may induces physical drying [40]. It is shown that forced aeration during sewage sludge bio-drying controlled the matrix temperature and improved evaporation, establishing it as a vital parameter influencing water loss [18]. In effect, an increase in the air-flow rate increases the amount of water carried, improving the water loss and an output with high calorific value. Likewise, low air-flow rates result in decomposition without significant moisture removal.

2.1.3. Temperature

It is well established that the supplied of air during bio-drying in one direction contributes to the appearance of temperature gradients, resulting in a lack of homogeneity in the moisture and energy content of the final product [26, 41]. However, it was suggested in another study that daily inversion of airflow in bio-drying by means of reactors eliminates marked temperature differences and leads to a homogeneous final product [41]. An increase in air flow rate at the inlet had positive contribution to moisture loss from the waste but had no effect on temperature and calorific values [25].

Frei et al. [23] and Navaee-Ardeh et al. [31] indicated that high temperatures (>55°C) during bio-drying process enhance the conversion of moisture to vapor and also facilitate the vapor pressure of the air-flow passing through the matrix to carry more moisture out. Accordingly, the biodegradation potential of a bulking agent (BA) would significantly influence the bio-drying process by the biogenerated heat. Additionally, the physical structure and moisture content of the materials are influenced by the decay of bulking agents. A study to investigate the effect of BA particle and controlled temperature on sludge bio-drying concluded that small-particle-sized bulking agent coupled with high matrix temperature was more beneficial for volatile solid degradation whereas large-particle-sized bulking agent resulted in poor biodegradation [42].

2.1.4. Bulking agents

Additionally, the use of bulking agent (BA) plays a crucial role in bio-drying process. The use of BA adjusts the initial moisture content and facilitates air movement due to the increase in voids ratio. It effects on bio-drying has been demonstrated by some authors. A number of different materials as bulking agents have been used by different researches including bark to bio-dry sewage sludge [23], and sawdust and/or straw [43, 44]. Yang et al. [34] revealed that air-dried sludge possesses a more suitable biodegradation potential than shredded rubber and sawdust when used as BA due to its porous nature and high water holding capacity. In short, the smaller or finer the particles, the stronger the water holding capacity of the substrate. Moreover, BA is important for regulating the matrix porosity and enabling air flow to carry away the water vapor passing through the matrix. For effective bio-drying, it is important to consider the physical structure as well as biodegradability of the bulking agent. In another study, rice straw of different sizes as BA was used in sludge bio-drying and it was reported that small-particle size BA reduced the water content by 0.3% more compared to the large particle size BA [42]. It is revealed that straw has substantial biodegradation potential in bio-drying process while sawdust has poor capacity to be degraded [44]. In order to improve the efficiency of bio-drying, it is important to consider the physical structure as well as the biodegradability when selecting a material as BA. Colomer-Mendoza et al. [40] observed that adding 15% of BA

Substrate	Residence time (days)	Weight loss (%)	Moisture loss (%)	Reference
Household waste + plant materials (straw, grass, branches, −shrubs)	10	na	50%	[25]
Agricultural harvest + gardening waste	12–30	<50%	na	[40]
Garden waste	20	<40–57%	<40–60%	[46]
MSW	14	41%	na	[24]
Sewage sludge + bio-dried + sawdust	20	<20%	>35.5%	[18]
MSW	13	49.16	32.65%	[27]
Food waste + pruning waste	7	36.7–56.8%	10.32–48.9%	[47]
Sludge + MSW + harvest waste	8-9	na	na	[26]

na, not available.

Table 1. Summary of bio-drying of different waste materials.

to gardening waste resulted in 25% moisture reduction. It is proposed that BA of small particle size is preferred due to its adequate porosity and internal homogeneous porous size distribution within the matrix. These features enhance effective waste absorption. However, it should be pointed out that, the use of small particle size BA can cause compaction during bio-drying which can have adverse effect on moisture removal [45]. **Table 1** shows a summary of waste materials used in bio-drying process and their effect on weight and moisture loss.

3. Materials and method

Different waste compositions obtained from bio-drying process (i.e. bio-dried material) consisting of biogenic and non-biogenic materials were used to assess the biogenic carbon and energy content of the bio-dried materials. The biogenic materials included food waste, paper and pruning waste, while plastic (light density polyethylene – LDPE) was considered as a non-biogenic material. These materials were varied at different proportions by weight in the bio-drying experiment and their impact on biogenic and calorific value was determined. **Tables 2** and **3** show the composition and physico-chemical properties of the different waste materials. The proportion of the waste components varied in the range of 30–90, 20–80, 5–50 and 30–60% for food waste, paper, plastic and pruning waste respectively. To further test more extreme conditions, two additional (T10 and T11) experiments were conducted with only biogenic and non-biogenic materials as the waste materials, respectively. Prior to mixing, the materials were separately shredded into 15×35, 2×14, 5×10 and 15 mm in diameter for food waste, paper, plastic and pruning waste respectively. The bio-drying experiments were carried out for a period of 7 days. A constant and uninterrupted air-flow rate (15 $m^3 h^{-1}$) was used in all the trials using a whirlpool pump connected to the bottom of the reactor with an air-flow meter. After the bio-drying process, bio-dried samples were analyzed for the moisture, biogenic and energy content. The moisture content of the substrate was analyzed following the

Mixture	Composition (%)	
	Biogenic mix	Non-biogenic mix
T1	85	15
T2	65	35
T3	50	50
T4	80	20
T5	75	25
T6	90	10
T7	80	20
T8	94	6
T9	84	16
T10	100	—
T11	—	100

Table 2. Composition of waste.

Parameter	Unit	Food waste	Paper	Plastic	Pruning waste
Moisture content	% (a.r)	91.48	5.40	0.94	8.43
Ash content	% (a.r)	25.33	18.64	2.05	6.36
Biogenic content	% (a.r)	72.73	72.34	—	92.31
Non-biogenic content	% (a.r)	1.94	9.02	96.44	1.33
Bulk density	kg/m^3 (a.r)	464.18	100.46	346.50	204.14
Calorific value	MJ/kg (a.r)	0.11	12.51	44.65	16.01

Table 3. Physico-chemical properties of raw material.

ASTM–D 3173 standard (105°C) using moisture analyzer (Precisa, XM 50), whereas the heat value of the bio-dried material was determined using IKA C-7000 model calorimeter (IKA Laboratory Equipment, Werke Staufen, Germany), in accordance with EN 15400 standard. It is worth mentioning that, due to the heterogeneous nature of the waste, the weighted average method was employed in determining the initial moisture content of the waste matrix, since it was impossible to get a typical sample from the heterogonous mixture of the waste, a similar procedure employed by Shuqing et al. [48]. Elemental analysis was analyzed with Thermo Scientific Flash 2000 Elemental Analyzer (Thermo Fisher Scientific Inc., Bremen, Germany).

Three different methods are employed for the determination of biogenic content of solid recovered fuels/bio-dried materials according to the technical specifications CEN/TS 15440:2006 (CEN, 2006). These include Selective Dissolution Method (SDM), Manual Sorting Method (MSM) and ^{14}C Method. In the present study, the biogenic and non-biogenic content of the waste matrix in different proportions was analyzed by SDM. The latter and former were determined based on Eqs. (1) and (2). The basic principle of this method is that the biogenic in bio-dried material selectively dissolves and oxidizes in H_2SO_4/H_2O_2, while the non-biogenic (fossil material) and the inert material remains in the residue. Furthermore, the relationship between the biogenic and energy content of the bio-dried were established.

$$X_B = \left[1 - \left\{\frac{m_{residue} - m_{residue\text{-}ash}}{m_S} + \frac{A_S}{100}\right\}\right] \times 100 \tag{1}$$

$$X_{NB} = 100 - X_B - A_S \tag{2}$$

where X_B = Biogenic content (%); X_{NB} = Non-biogenic content (%); m_{residue} = Mass of residue (g); $m_{\text{residue-ash}}$ = Mass of residue and ash (g); A_S = Ash content of sample (%); m_S = Mass of dry sample (g).

4. Results and discussion

It is an established fact that combustible non-biogenic materials are characterized by higher heat content per unit weight than combustible biogenic materials. Consequently, the ratio of biogenic to non-biogenic material proportion can have a considerable effect on the heat content of a waste material intended for combustion purpose [40, 49]. **Figure 1** shows the relationship between moisture content and calorific value. The moisture content is a key parameter, as it affects both the biogenic carbon content and the effective heating value of the combustible waste. The moisture content of the bio-dried material varied between 8.59 and 50.93%, whereas that of the extreme conditions was 91.48 and 0.94% for biogenic (food waste) and non-biogenic materials, respectively (**Table 3**). It should be pointed out that the two extreme conditions were just raw materials without been subjected to bio-drying process. It can be seen that as the share of biogenic waste in the waste matrix gradually decrease, a corresponding trend in moisture content could be expected. Additionally, depending on the amount of food waste in the waste mix of the biogenic material, a decrease or increase in moisture content could be envisaged since the food waste contributes the highest initial moisture content to the biogenic waste mix.

The results revealed a positive correlation between moisture content and calorific value ($R^2 = 0.85$). As indicated earlier, the amount of biogenic waste had a significant impact on the former and latter. A discrepancy was observed in T3 and T5 in terms of moisture content and calorific value. Even though T3 had the lowest moisture content, T5 had the highest calorific value. The possibly reason was that the difference in food waste in both trials versus the other waste types in the biogenic mix was high enough to induce significant difference in the observed levels of calorific value, with approximately same non-biogenic mix. This suggest that, depending on the amount of food waste in the biogenic mix, the moisture content and calorific value of the bio-dried material could be significantly affected, regardless of the amount of non-biogenic waste in the waste matrix.

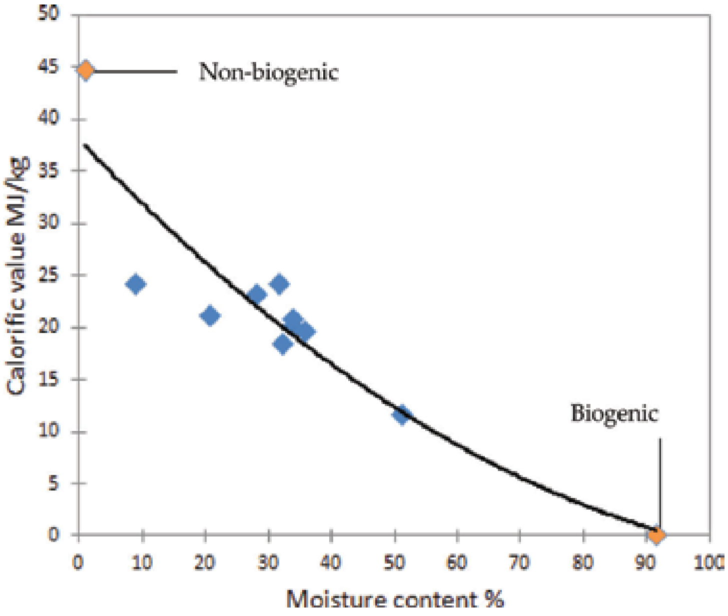


Figure 1. Calorific value as a function of moisture content of bio-dried materials.

However, a relatively slight deviation was observed in the trend for certain composition of waste particularly in instances where there is an absence of pruning waste and slightly decrease in food waste. This is probably attributed to the pruning waste having the highest proportion of biogenic carbon content of all the waste types, thus having a proportionally greater impact on biogenic carbon content of the waste matrix relative to its calorific value.

As shown in **Table 2**, a range of waste composition was developed to examine their impact on biogenic content and calorific value. The elemental analysis of carbon, hydrogen, oxygen, nitrogen and sulfur are presented in **Table 4**. The results indicated that carbon and oxygen were the most dominated elements in the raw materials, with biodegradable waste such as food waste, pruning waste and paper composed at 32.55, 37.14 and 64.72% of the total weight, respectively. The non-biogenic material (plastic) had the highest carbon content of 68.55%. Nitrogen was measured in high contents in food waste with paper as the lowest. The hydrogen content of the raw materials ranged from 5.17% to 12.90%, with plastic having the highest hydrogen content. Food

Parameter	Food waste	Paper	Plastic	Pruning waste
Carbon	32.55	64.72	68.55	37.14
Nitrogen	2.97	0.32	0.99	1.10
Hydrogen	5.17	5.49	12.90	8.09
Oxygen	33.85	10.79	15.46	47.30
Sulfur	0.07	0.04	0.05	0.01

Table 4. Elemental composition of raw materials.

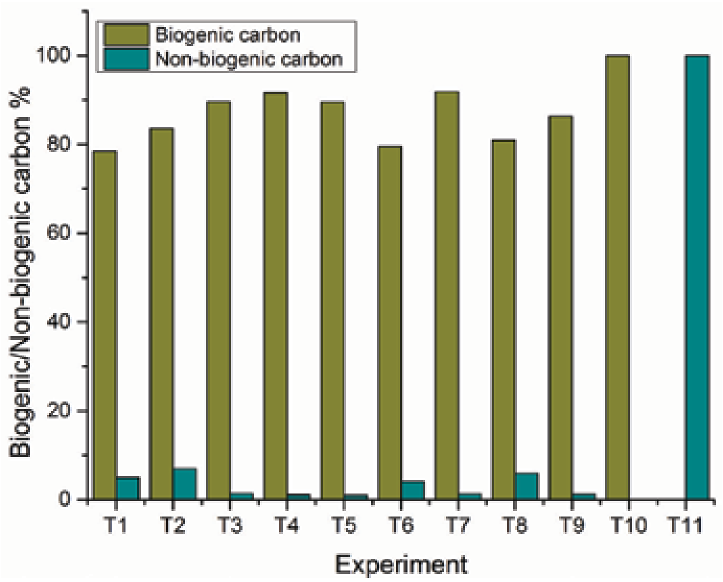


Figure 2. Biogenic and non-biogenic carbon content of bio-dried materials.

waste had the highest sulfur content relative to the other raw materials. Oxygen was dominant in pruning and food waste with lowest oxygen content recorded in paper (10.79%), indicating the presence of inorganic or low oxygen content organic molecules in papers. The results of the elemental analysis obtained in this study are consistent with those reported by Komilis et al. [49].

Figure 3 shows the relationship between calorific value and biogenic carbon content of the different composition of waste. The different compositions resulted in a wide range of biogenic carbon content and calorific value. The non-biogenic carbon content in the waste matrix ranged between 1 and 7%, with T2 having the highest non-biogenic content (**Figure 2**). This was attributed to the low contribution of paper and pruning waste to the waste matrix of the biogenic mix, which were the major contributors to the biogenic carbon content of the bio-dried materials. On the other hand, T7 had the highest biogenic carbon content of 91.84%. The reason was associated with the amount of food waste relative to the other the biogenic waste materials in the biogenic mix. Similarly, two extremes conditions of biogenic (T10) and non-biogenic (T110 waste were considered. It is evident that the proportion of the different waste components in the waste matrix had significant impact on the biogenic content and the calorific value as well. It can be seen that the former reduces as the amount of biogenic source in the waste mix reduces whiles the latter increases as the calorific value of non-biogenic source due to the high moisture content. The results revealed a very highly positive correlation between biogenic content and calorific value ($R^2 = 0.87$). It should be pointed out that the amount of food waste as a biogenic material in the waste mix impacted on the calorific value of the bio-dried materials due to its high initial moisture content. Additionally, it should also be emphasized that pruning waste and paper were the major contributors to the biogenic content of the bio-dried materials. For instance, it is clearly that T1 contained higher proportion of pruning waste and paper as compared to bio-dried material obtained in T9. The biogenic content herein refers to the non-fossil based carbon content. It is suggested that any material with a calorific value that

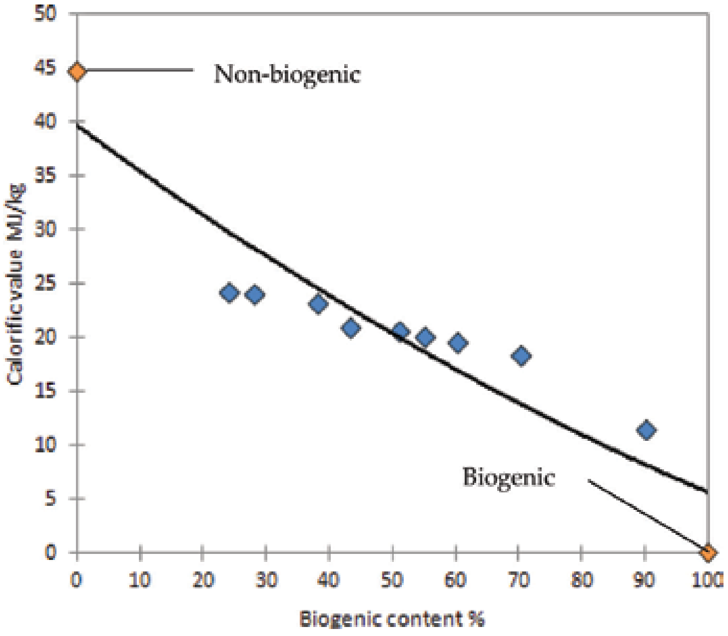


Figure 3. Calorific value as a function of biogenic carbon content of bio-dried materials.

exceeds the range of 1–6 MJ/kg could be considered for combustion purpose [50]. Accordingly, waste-to-energy technology can be applied to recover energy from the bio-dried material.

5. Conclusions

Biogenic materials have the potential to serve as an alternative energy source. In this study, bio-dried materials obtained from biogenic and non-biogenic sources by bio-drying process were analyzed to assess its potential for energy recovery. Bio-dried material obtained from different composition of waste materials were assessed with regards to biogenic carbon and energy content. The composition of biogenic source in the waste matrix was found to significantly impact on the nature of the bio-dried material produced due to its high moisture content, particularly food waste. Moreover, high amount of biogenic source in the waste mix corresponded to high moisture content and lower calorific value. Food waste significantly impacted on the biogenic carbon content of the bio-dried material, whereas paper and pruning waste were identified as the positive main contributors to the biogenic carbon content of the bio-dried material obtained. It was further revealed that, notwithstanding the amount of non-biogenic source in the waste matrix, the proportion of food waste could have an effect on the moisture content and calorific value of the final product. Based on the energy content of the bio-dried material obtained, the final product could be used as an energy source in combustion process which could lead to reduction in over reliance on fossil fuel. Additionally, optimization of the waste materials would enhance the biogenic and energy content of the bio-dried material. Bio-dried material obtained from waste would therefore be a better sustainable environmental solution than landfill provided the waste being used has the right biogenic content and a plant is efficient at turning that waste into useable energy. Finally, this technology will help mitigate environmental pollution from the disposal of biodegradable waste.

Acknowledgements

The authors would like to thank the Scientific and Research Unit (BAP) of University of Kocaeli for the financial support.

Conflict of interest

The authors declare no conflict of interest.

Author details

Mutala Mohammed[1]*, Augustine Donkor[2] and Ismail Ozbay[1]

*Address all correspondence to: mutbaby@gmail.com

1 Department of Environmental Engineering, University of Kocaeli, Kocaeli, Turkey

2 Department of Chemistry, University of Ghana, Accra, Ghana

References

[1] EC. 2001. Council Directive 1999/31/EC concerning landfilling of waste on the landfill of waste. Avalable from: <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31999L0031&from=EN> [Accessed: 2016-05-15]

[2] Council Directive 1999/31/EC. Council Directive 1999/31/EC of 26 April 1999 0n the landfill of waste. Official Journal L 182, 16/7/1999, pp. 1-19. Available from: http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1999:182:0001:0019:EN:PDF. [Accessed: 2017-11-10]

[3] Stuart T. Waste—Uncovering the Global Food Scandal. London: Penguin Books; 2009. ISBN: 978-0-141-03634-2

[4] Gustavsson J, Cederberg C, Sonesson U. Global Food Losses and Food Waste: Extent, Causes and Prevention. Rome, Italy: Food and Agriculture Organization of the United Nations; 2011

[5] UNEP. Waste: Investing in energy and resource efficiency. In Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. 2011. pp. 286-329. Available from:http://www.unep.org/greeneconomy/Portals/88/documents/ger/ger_final_dec_2011/8.0 WASWaste.pdf. [Accessed: 2017-06-30]

[6] Laner D, Crest M, Scharff H, Morris JWF, Barlaz MA. A review of approaches for the long-term management of municipal solid waste landfills. Waste Management. 2012;**32**:498-512

[7] European Commission. Being wise with waste: The EU 's approach to waste management, 2010, pp. 1-16. Available from: http://ec.europa.eu/environment/waste/pdf/WASTE%20BROCHURE.pdf. [Assessed: 2017-06-30]

[8] Torretta V, Ionescu G, Raboni M, Merler G. The mass and energy balance of an integrated solution for municipal solid waste treatment. WIT Transactions on Ecology and Environment. 2014;**180**:151-161

[9] Zhao P, Shen Y, Ge S, Yoshikawa K. Energy recyclingfrom sewage sludge by producing solid biofuel with hydrothermal carbonization. Energy Conversion and Management. 2014;**78**:815-821

[10] Zhang L, Sun XY, Tian Y, Gong XQ. Effects of brown sugar and calcium superphosphate on the secondary fermentation of green waste. Bioresource Technology. 2013;**131**:68-75

[11] Velis CA, Longhurst PJ, Drew GH, Smith R, Pollard STJ. Biodrying for mechanical-biological treatment of wastes: A review of process science and engineering. Bioresource Technology. 2009;**100**(11):2747-2761

[12] Liang C, Das KC, McClendon RW. The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend. Bioresource Technology. 2003;**86**:131-137

[13] Ma J, Zhang L, Li A. Energy-efficient co-biodrying of dewatered sludge and food waste: Synergistic enhancement and variables investigation. Waste Management. 2016;**56**:411-422

[14] EC (European Commission). Environmental, Economic and Social Impacts of the Use of Sewage Sludge on Land. Final Report. Part I. 2008. <http://ec.europa.eu/environment/waste/sludge/pdf/part_i_report.pdf>. [Accessed: 2017-06-30]

[15] Cheng HF, Zhang YG, Meng AH, Li QH. Municipal solid waste fueled power generation in China: A case study of waste-to-energy in Changchun city. Environmental Science & Technology. 2007;**41**:7509-7515

[16] Zhang DQ, He PJ, Yu LZ, Shao LM. Effect of inoculation time on the bio-drying perfor mance of combined hydrolytic-aerobic process. Bioresource Technology. 2009;**100**:1087-1093

[17] Bernal MP, Alburquerque JA, Moral R. Composting of animal manures and chemical criteria for compost maturity assessment—A review. Bioresource Technology. 2009;**100**(22):5444-5453

[18] Cai L, Chen TB, Gao D, Zheng GD, Liu HT, Pan TH. Influence of forced air volume on water evaporation duringsewage sludge bio-drying. Water Research. 2013;**47**(13):4767-4773

[19] Huet J, Druilhe C, Trémier A, Benoist JC, Debenest G. The impact of compaction, moisture content, particle size and type of bulking agent on initial physical properties of sludge-bulking agent mixtures before composting. Bioresource Technology. 2012;**114**:428-436

[20] Velis CA, Longhurst PJ, Drew GH, Smith R, Pollard SJT. Production and quality assurance of solid recovered fuels using mechanical-biological treatment (MBT) of waste: A

comprehensive assessment. Critical Reviews in Environmental Science and Technology. 2010;**40**(12):979-1105

[21] Zhao L, Gu WM, He PJ, Shao LM. Effect of air-flow rate and turning frequency on biodrying of dewatered sludge. Water Research. 2010;**44**:6144-6152

[22] Sadaka S, VanDevender K, Costello T, Sharara M. Partial Composting for Biodrying Organic Materials. Agricultural and Natural Resources, University of Arkansas; 2011;FSA1055 <https://www.uaex.edu/publications/PDF/FSA-1055.pdf>. [Accessed: 2017-12-15]

[23] Frei KM, Cameron D, Stuart PR. Novel drying process using forced aeration through a porous biomass matrix. Drying Technology. 2004;**22**(5):1191-1215

[24] Tambone F, Scaglia B, Scotti S, Adani F. Effects of biodrying process on municipal solid waste properties. Bioresource Technology. 2011;**102**(16):7443-7450

[25] Zawadzka A, Krzystek L, Stolarek P, Ledakowicz S. Biodrying of organic fraction of municipal solid wastes. Drying Technology. 2010;**28**:1220-1226

[26] Adani F, Baido D, Calaterra E, Genevini P. The influence of biomass temperature on biostabilization—Biodrying of municipal solid waste. Bioresource Technology. 2002;**83**:173-179

[27] Bilgin M, Tulun S. Biodrying for municipal solid waste: Volume and weight reduction. Environmental Technology. 2015;**36**(13):1691-1697

[28] Tom AP, Pawels R, Haridas A. Biodrying process: A sustainable technology for treatment of municipal solid waste with high moisture content. Waste Management. 2016;**49**:64-72

[29] Zhang DQ, He PJ, Jin TF, Shao LM. Bio-drying of municipal solid waste with high water content by aeration procedures regulation and inoculation. Bioresource Technology. 2008;**99**:8796-8802

[30] Frei KM, Cameron D, Jasmin S, Stuart PR. Novel sludge drying process for cost effective on-site sludge management. Pulp & Paper Canada. 2006;**107**:47-53

[31] Navaee-Ardeh S, Bertrand F, Stuart PR. Emerging biodrying technology for the drying of pulp and paper mixed sludges. Drying Technology. 2006;**24**:863-878

[32] Hansjoerg H, Boeddeker HJ, Gurudas S, Schaefer K, Roth B, Roth J. Process and apparatus for biological drying of residual waste, sewage sludge and/or biomass. European Patent EP1408021. 14-04-2004. European Patent Office; 2004. p. 5

[33] Sen R, Annachhatre AP. Effect of air flow rate andresidence time on biodrying of cassava peel waste. International Journal of Environmental Technology and Management. 2015;**18**(1):9-29

[34] Yang B, Zhang L, Jahng D. Importance of initial moisture content and bulking agent for biodrying sewage sludge. Drying Technology. 2014;**3**:135-144

[35] Luo W, Chen TB, Zheng GD, Gao D, Zhang YA, Gao W. Effect of moisture adjustments on vertical temperature distribution during forced-aeration static-pile composting of sewage. Resource Conversation and Recycling. 2008;**52**(4):635-642

[36] Chang JI, Chen YJ. Effects of bulking agents on food waste composting. Bioresource Technology. 2010;**101**(15):5917-5924

[37] Roy G. Technical and economic modelling of a biodrying batch reactor [Master's Thesis]. Montréal, Canada, French: Ecole Polytechnique de Montréal; 2005

[38] Huiliñir C, Villegas M. Simultaneous effect of initial moisture content and airflow rate on biodrying of sewage sludge. Water Research. 2015;**82**:118-128

[39] Skourides I, Theophilou C, Loizides M, Hood P, Smith SR. Optimisation of advanced technology for production of consistent auxiliary fuels from biodegradable municipal waste for industrial purposes. Waste 2006; 19-21 September 2006; Sustainable Waste and Resource Management; Stratford-upon-Avon, UK. 2006. Paper 2B-14.40

[40] Colomer-Mendoza FJ, Herrera-Prats L, Robles-Martinez F, Gallardo-Izquierdo A, Pina-Guzman AB. Effect of airflow on biodrying of gardening wastes in reactors. Journal of Environmental Sciences. 2013;**25**(5):865-872

[41] Sugni M, Calcaterra E, Adani F. Biostabilization—Biodrying of municipal solid waste by inverting air-flow. Bioresource Technology. 2005;**96**:1331-1337

[42] Zhao L, Gu W, Shao L, He P. Sludge bio-drying process at low ambient temperature: Effect of bulking agent particle size and controlled temperature. Drying Technology. 2012;**30**:1037-1044

[43] Choi HL, Richard TL, Ahn HK. Composting high moisture materials: Biodrying poultry manure in a sequentially fed reactor. Compost Science and Utilization. 2001;**9**(4):303-311

[44] Zhao L, Gu WM, He PJ, Shao LM. Biodegradation potential of bulking agents used in sludge biodrying and their contribution to bio-generated heat. Water Research. 2011;**45**(6):2322-2330

[45] Gea T, Barrena R, Artola A, Sánchez A. Optimal bulking agent particle size and usage for heat retention and disinfection in domestic wastewater sludge composting. Waste Management. 2007;**27**(9):1108-1116

[46] Colomer-Mendoza FJ, Robles-Martínez F, Herrera-Prats L, Gallardo A, Bovea MD. Biodrying as a biological process to diminish moisture in gardening and harvest wastes. Environment Development and Sustainability. 2012;**14**(6):1013-1026

[47] Mohammed M, Ozbay I, Durmusoglu E. Bio-drying of green waste with high moisture content. Process Safety and Environmental Protection. 2017;**111**:420-427

[48] Shuqing Z, Wenxiong H, Ran Y, Song Y. The effect of bio-drying on heating values of municipal solid waste. Advance Materials Research. 2014;**1010-1012**:537-546

[49] Komilis D, Evangelou A, Giannakis G, Lymperis C. Revisiting the elemental composition and the calorific value of the organic fraction of municipal solid wastes. Waste Management. 2012;**32**:372-381

[50] Tian WD, Wei XL, Wu DY, Li AJ, Sheng HZ. Analysis of ingredient and heating value of municipal solid waste. Journal of Environmental Sciences. 2001;**13**(1):87-91

Section 4

Sustainability and Risk Assessment

Post-Treatment and Microbial Risk Assessment of Compost for Food Production

Hamidatu S. Darimani and Ryusei Ito

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.78216

Abstract

The compost withdrawn from a composting toilet still contains pathogens and therefore requires a post-treatment unit to treat the compost prior to reuse on an agricultural land. A quantitative microbial risk assessment with Monte Carlo technique was conducted to evaluate the risk of infectious disease and length of time required for the post-treatment. The incidental ingestion of compost (0.5–0.8 g) in a scenario of worst case was evaluated. High temperature was efficient in reducing the risk of pathogens; however, the temperature distribution in the unit (steel box) was not sufficient to reduce pathogens. Therefore, to efficiently reduce pathogens during the post-treatment and also reduce the time of treatment, the steel box needs an insulator to maintain the temperature. The guidelines for the design of the post-treatment facility are: for *Ascaris*, the steel box and the lower temperature −5, −10 and −15°C, post-treatment requires approximately 295 h to achieve the safe level of 10^{-4} pppy. For norovirus, post-treatment requires approximately 845 h for the scenarios to achieve a safe level. *Salmonella* requires 969.5 h, for all scenarios to reach a safe level.

Keywords: post-treatment, risk assessment, compost, pathogens, temperature

1. Introduction

Compost of human faeces used as fertiliser can be harmless and useful because it becomes part of nutrient recovery. A pilot model of a composting toilet was installed in a rural region of Burkina Faso to perform a source recycling system which makes compost from human faeces. Initial experiments were performed on some samples taken from the composting toilet. Results showed that pathogens such as bacteria and parasites still remained in the compost after withdrawal from the rural model of composting toilet after 3 months of operation. Therefore, post-treatment of the collected compost is required to minimise the health risk when recycling the faeces as fertiliser on farmland. For the inactivation of pathogens, several methods of treatments are proposed, including heating, drying, chemical treatments, treatment by worms, long storage times, etc. In low income countries some people cannot pay materials for post-treatment, however, they have abundant solar energy. Therefore; this study proposes a solar disinfection unit to inactivate the pathogens. The operation condition to inactivate pathogens should be designed based on the risk assessment by setting a safe level of pathogens concentration in the compost after post-treatment.

Norovirus, *Ascaris* eggs and *Salmonella* were selected as reference pathogens in this study. Noroviruses are a major cause of human gastroenteritis, and they are frequently associated with food, water contamination [1] and accidental ingestion. *Ascaris* infections are very common in developing countries. One fertile egg can cause infection of Ascariasis to humans. The carrier state of *Salmonella typhi* is defined as persistent shedding in faeces for greater than 12 months [2].

These enteric infections can be transmitted through the compost from faeces to the human body with pathogenic species. Quantitative microbial risk assessment (QMRA) has been widely used to establish the health risks associated with wastewater reuse in both developed and developing regions under different scenarios. The QMRA-Monte Carlo techniques (QMRA-MC) based on the work of Haas et al. [3] was used to estimate risk in this study.

The objectives of this study are to perform risk assessment for the design of the post-treatment unit by using the QMRA-MC and to determine the treatment time to reach the safe level of pathogens in the compost.

2. Material and methods

2.1. Post-treatment unit

People would collect the compost from the rural model of composting toilet with urine diversion (**Figure 1**) in the pilot families and used it in their gardens as fertiliser. Application of the post-treatment would be achieved by spreading the compost evenly in the steel box as shown in **Figure 2**, and leaving it under the sunshine. The steel box was fabricated with a length of 60 cm, a width of 40 cm, and a depth of 10 cm. The total volume of the box is 24 L. The steel box has steel septa which facilitate deep penetration of heat to compost. The steel box is painted black in colour to aid in the absorption of heat. The steel box does not have a solar concentrator [4, 5]. The temperature distribution of the compost in the box was measured at 3 positions which were 1, 5, and 10 cm from the surface.

2.1.1. Scenarios for reuse of compost

During the utilisation of the compost, people may accidentally ingest compost with the pathogens orally. The people exposed to the pathogens would have diseases with a probability estimated by risk assessment. The temperature distribution was considered at 3 positions as top,

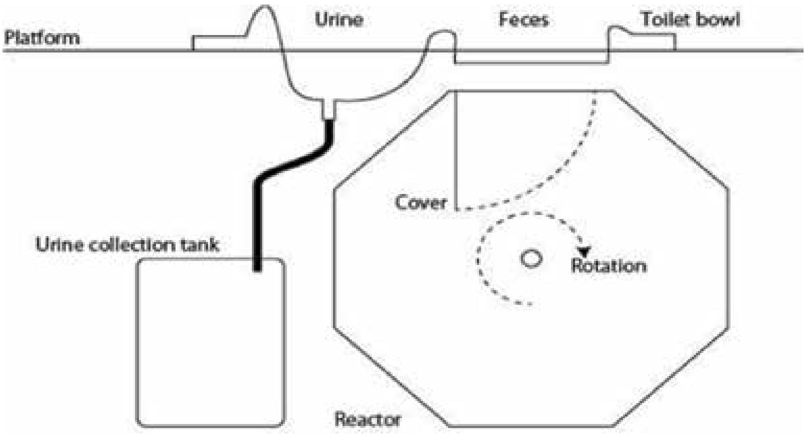


Figure 1. Arrangement of the composting toilet.

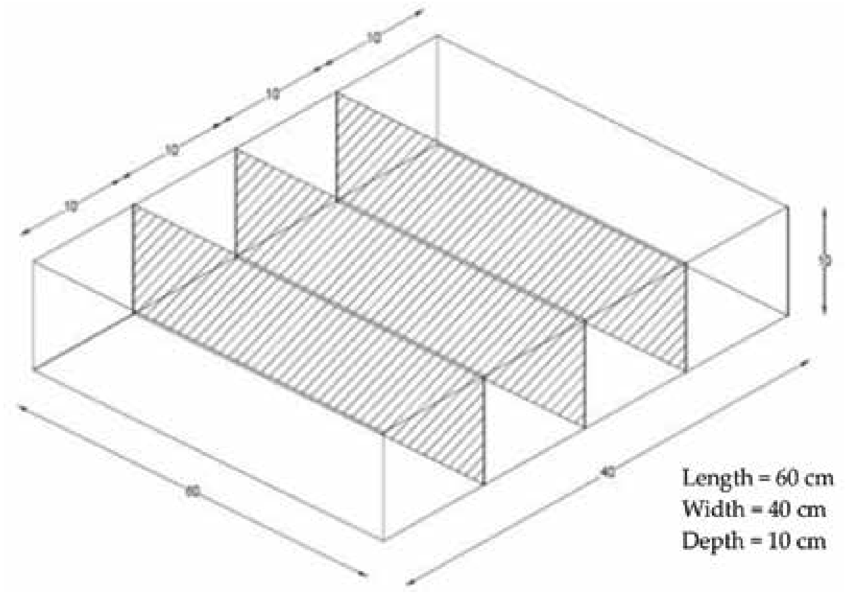


Figure 2. A proposed compost solar sanitisation installation that could reduce the heat loss [4].

middle and bottom at 1, 5 and 10 cm depth from the top surface, respectively. A basic scenario was set at actual temperature in the steel box (S1) as a post-treatment for the assessment. For investigating the effect of temperature, 3 temperature levels, such as −5°C lower temperature as S2, −10°C lower temperature as S3 and −15°C lower temperature as S4 derived from the temperature measured in the steel box, were considered in this simulation, because the temperature varied by weather conditions. For the calculation of concentration in the compost, the inactivation rates coefficient from the previous measurement were used [6]. The details of the ingestion model are as follows:

- To consider the worst case, 50,000 eggs/g in wet faeces is excreted from a heavily infested person [7]. The value of the initial concentration of *Ascaris* eggs was 336 eggs/g-dry compost. This number was estimated by multiplying the number of eggs excreted per gram (50,000 eggs/g) by the 100 g of compost dividing by the bulk density of the compost.
- Highly infested person of viral infection excretes a maximum of 10^{11} viral copies/g in faeces from highly infected person [1, 8, 9] was used for the risk assessment taking account of the highest risk. Assuming this concentration, the initial concentration was estimated at 6.72×10^8 viral copies/g-dry compost. This number was estimated by multiplying the number of norovirus excreted per gram (10^{11} viral copies/g) by the 100 g of the compost and dividing by bulk density of the compost.
- Concentration of *Salmonella* spp. in faeces is 10^4–10^{10} per gram of faeces [3]. Assuming this concentration, the initial concentration was estimated at 6.72×10^7 CFU/g-dry compost. This number was estimated by multiplying the number of *Salmonella* excreted per gram (10^{10} CFU/g) by the 100 g of the compost and dividing by bulk density of the compost.
- Ingestion rate of compost is 150–800 mg/event. This is used in the risk assessment of dioxin in soil ingestion rate [10].
- Post-treatment would be done every 4 months.
- The concentration of pathogens in the compost after the post treatment was estimated using the first-order kinetic model from the earlier studies on *Ascaris* eggs and indicator MS2 bacteriophage inactivation and *E. coli*. The data from these experiments were used to re-estimate the inactivation rate co-efficient [6].
- The moisture content of all treatments was 50%.

2.1.2. Hazard identification

Farmers performing post-treatment would be exposed to pathogens in the compost. There are several groups of pathogens, but the pathogens of considerable interest in the study area are *Ascaris* eggs, viral infections (norovirus) and *Salmonella* because *Ascaris* and norovirus are also known to be the most resistant to treatment processes [11, 12]. Burkina Faso recorded 32.8% of bacteraemia among febrile children admitted to hospital (non-typhoid *Salmonella*) between 2012 and 2013 [2] and it is also reported that the carrier state of *Salmonella* typhi is defined as persistent shedding in faeces for greater than 12 months [2]. Accidental ingestion of a small dose consequently implies a high risk of infection compared to many other pathogens [10].

2.1.3. Dose-response assessment

The QMRA-MC was used to estimate risks of *Ascaris* and norovirus and *Salmonella* infections. The study by Navarro et al. [13] found that *Ascaris* infection data best fitted the β-Poisson dose-response equation [13]:

$$P_I(d) = 1 - \left[1 + (d/N_{50})(2^{1/\alpha} - 1)\right]^{-\alpha} \tag{1}$$

where P_I (d) is the probability of infection in an individual (infection/event), d is the ingested number of *Ascaris* eggs on one occasion (eggs/event), N_{50} is the mean infective dose number of *Ascaris* eggs (eggs), I means considerable spice for calculation of probability (−) and α is an infectivity constant of *Ascaris* (−). They found the values of N_{50} and α to be 859 and 0.104, respectively. Since they were working with epidemiological data on *Ascaris* prevalence rather than conducting human *Ascaris* dose-challenge studies, the value found for N_{50} is not a measure of the actual median *Ascaris* infective dose, but rather an empirical value arising from their statistical analyses [14].

The annual probability of infection, $P_{I(A)}(d)$ (pppy), is given by:

$$P_{I(A)}(d) = 1 - [1 - P_I(d)]^n \tag{2}$$

Where n is number of events per year to the single *Ascaris* dose (−) [14]. For norovirus, the dose response data set of Teunis et al. [1] was used in place of the β-Poisson equation [14]. The β-Poisson equation was used to assess the dose response of salmonellosis. The N_{50} and α used are 17,700 and 0.23475 respectively.

2.1.4. Exposure assessment

The human exposure assumed to take place is an event when farmers work on compost. Practically, one egg is enough to cause an infection. Norovirus has an extremely low infectious dose [9] and salmonellosis is a public health concern in Burkina Faso [2].

2.1.5. Risk characterisation

The Monte Carlo technique has been used to evaluate the infection risk. The random number is applied for estimation of variables with distributions for simulation of Eqs. (1) and (2). The simulation was repeated 10,000 times [14]. Then, 95 percentile of the probability was estimated as the infection risk.

3. Results and discussion

The temperature variation for 1 week was measured during February, 2015 in the post-treatment unit with the aid of ThermoManager sensors in Ouagadougou, Burkina Faso. The sensors recorded temperature data every five mins during the week. **Figure 3** shows the temperature pattern in the post-treatment unit. The maximum and minimum temperatures recorded from the bottom were 51.0 and 10.5°C. The middle recorded 50.0 and 9.5°C for maximum and minimum temperatures while the top recorded maximum of 78.5°C and a minimum of 6.5°C. Obviously, the lower temperatures were recorded in the night and high temperature during the day.

The estimated changes in concentration of *Ascaris* for the scenarios S1–4 are shown in **Figure 4**. The concentrations declined from the initial value of 336 eggs/g dry-compost. S1 with high temperature gave high decline rate of the concentration due to high inactivation rate coefficient. Each scenario showed high and low reduction rates, because high temperature at day time and low temperature at night respectively. All scenarios for *Ascaris* obtained reduction

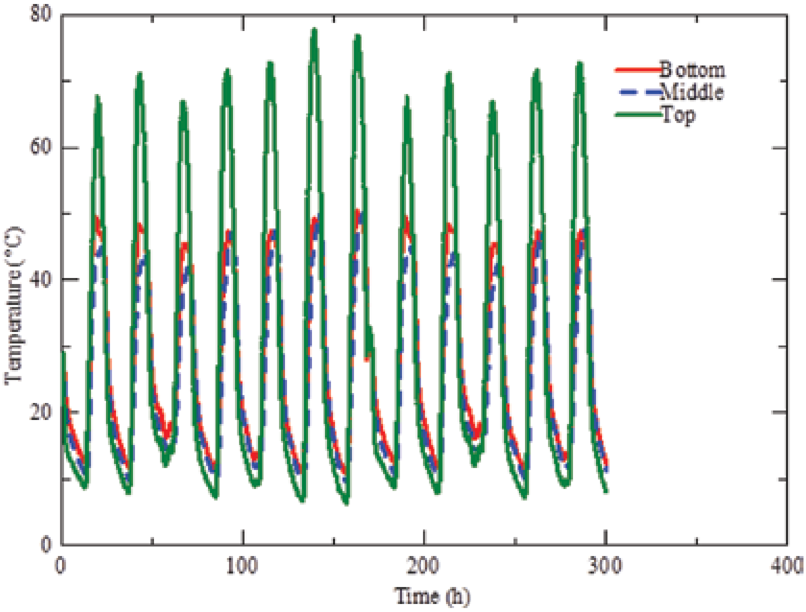


Figure 3. Temperature distribution assumed in the risk estimation.

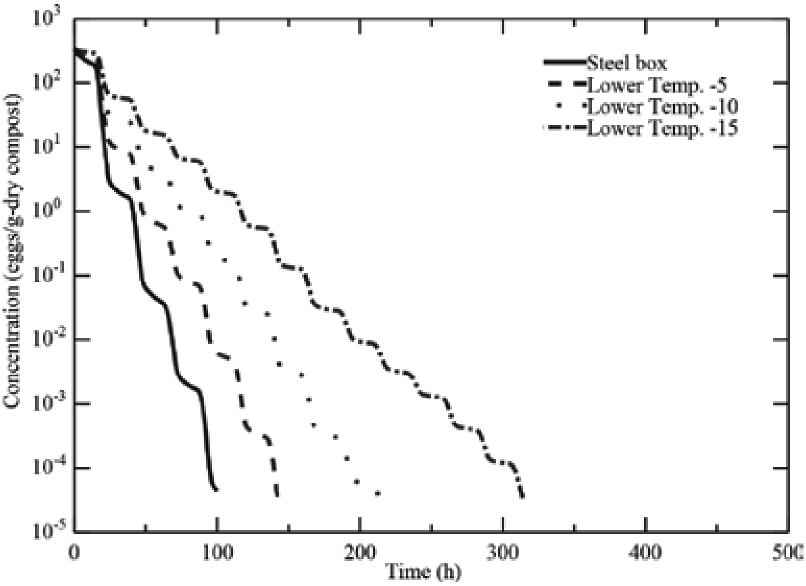


Figure 4. Change in *Ascaris* eggs concentration for the post-treatment.

of eggs in 295 h and the differences of the temperature resulted in the differences in concentrations. The changes in concentration of norovirus with elapsed of time under all scenarios are shown in **Figure 5**. The concentration declined from the initial of 6.72×10^8 copies/g-dry

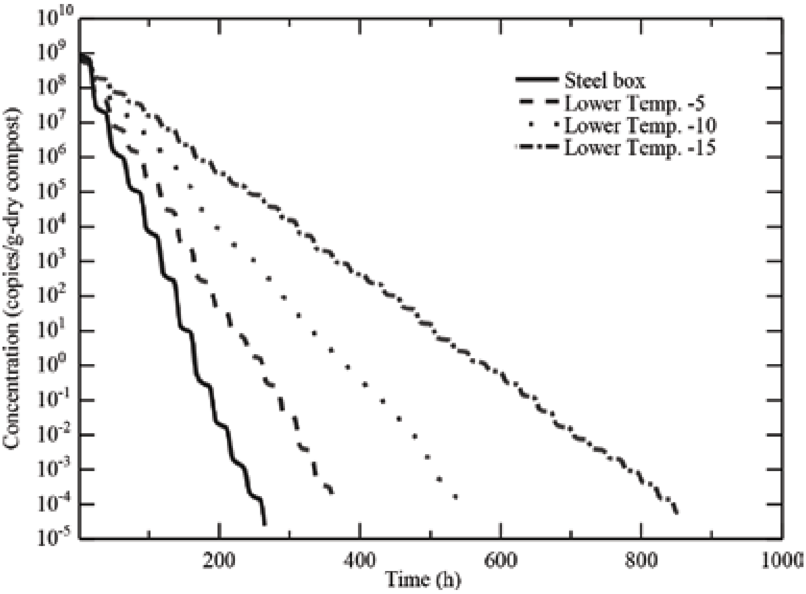


Figure 5. Change in norovirus concentration for post-treatment.

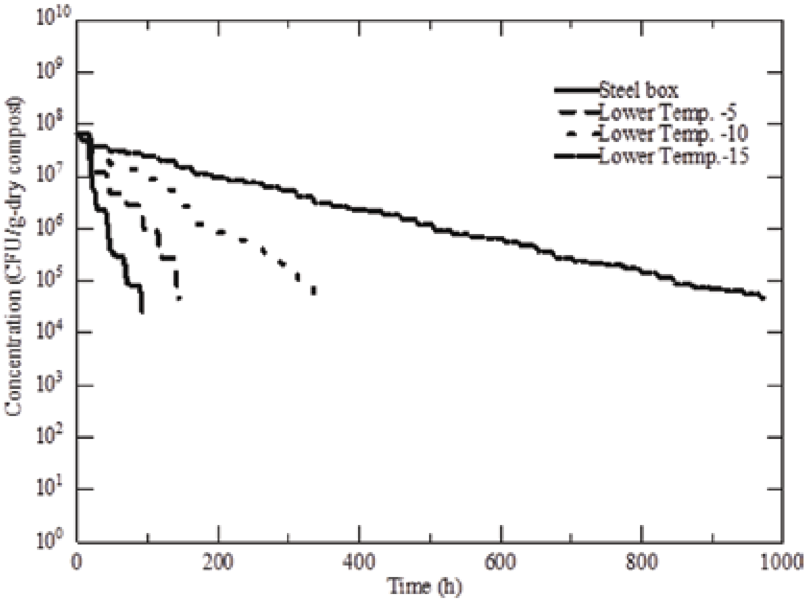


Figure 6. Change in *Salmonella* concentration.

compost. Higher temperature condition also gives higher decline rate. The reduction rate of norovirus concentration had difference among four scenarios like the *Ascaris* case. The concentration varied due to the varied temperature especially at night. As expected, the day time recorded higher temperatures and lower temperatures were recorded at night. All the scenarios achieved safe level at 845 h.

The change in concentration of *Salmonella* with elapse time under all scenarios are shown in **Figure 6**. The concentration declined from the initial of 6.72×10^7 CFU/g dry-compost. Higher temperature condition also gave higher decline rate. The reduction rate of *Salmonella* concentration had difference among four scenarios like the *Ascaris* and norovirus case. All scenarios achieved safe level at 969.5 h.

The 95-percentile annual risk of *Ascaris,* norovirus and *Salmonella* infections for the all scenarios are shown in **Figures 7–9**. The risk of the pathogens are almost 1 at the initial for all scenarios. This means the people who use the compost would be heavily polluted by the pathogens. They would be infected if the composting reactor fails to reduce the pathogen concentration and also if they do not apply the post-treatment. Schönning et al. [15] also reported a 95-percentile risk of rotavirus and *Ascaris* for 0 months' storage in a worst case as 1. The results show the risks for the *Ascaris* for S1 and the low temperatures as S2–4 reduced concentrations and reached a safe level at 97.5, 138, 190 and 295 h respectively.

The volume of the composting reactor is 100 L. Taking account of the temperature distribution with depth of the unit, the top and bottom temperature would achieve a safe level before the middle because that is the lowest temperature zone in the post-treatment unit. It should be noted that about 25% of the volume of the composting reactor was used for the design of the

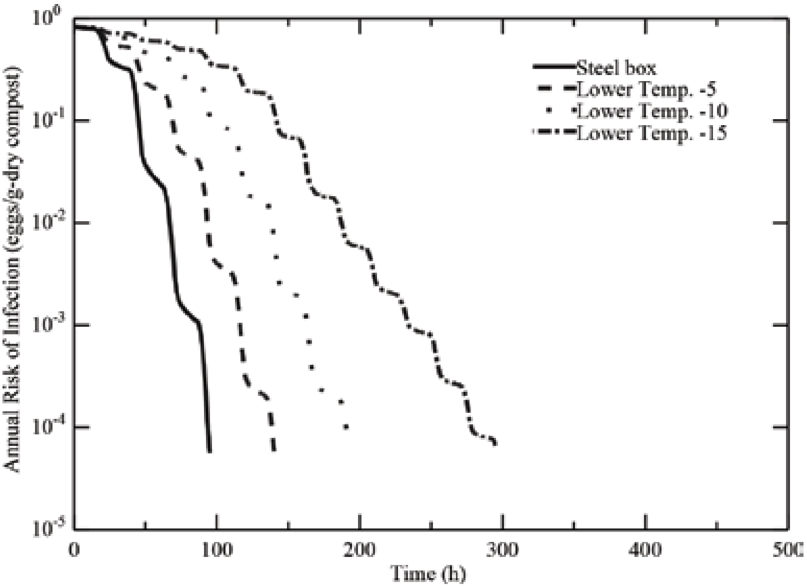


Figure 7. Ascaris annual infection risk associated with post-treatment.

unit. This is to ensure that the unit is not too deep to reduce the efficiency of the unit. The unit is considered as a batch reactor (BR) where concentration of the compost would change with time. The expected concentration can be obtained by adjusting the reaction time. The temperature distributions in S1 recorded a shorter time than the other scenarios. The treatment time can be reduced if the heating process of the unit is improved. During the day, there is a sufficient increase in temperature, but it suddenly decreases towards the evening and at the nights. This phenomenon causes sufficient inactivation by the balance of the high inactivation rate at high temperature and the low inactivation at low temperature. To reduce treatment time, one needs to improve the post-treatment unit increasing the maximum temperature and keeping temperature during the night.

The required times to reach the safe level for norovirus for the scenarios S1–4 were 264, 362.5, 554 and 845 h respectively. And also the required times for *Salmonella* were respectively 90.5, 143, 356.5 and 969.5 h respectively. Comparing *Ascaris*, norovirus and *Salmonella*, *Salmonella* requires more time at lower temperatures than *Ascaris* and norovirus to reach safe level of 10^{-4} per person per year (pppy) [16]. This is probably due to the fact that lower temperature are favourable conditions for bacteria. Therefore, *Salmonella* is more important indicator for the design of the unit, even though *Ascaris* eggs have possibility to survive several months in a soil system [17].

Risk assessments for post-treatment of compost have received very little documentation. Seidu et al. [17] reported increased levels of *Ascaris* and rotavirus infection for farmers due to accidental ingestion of contaminated soils. The estimated median risk values for farmers were 0.99 and 7.2×10^{-2} pppy for Ascariasis and rotavirus. The study indicated that the elevated hazard posed by the soils on the farm could be attributed to the persistence of *Ascaris*

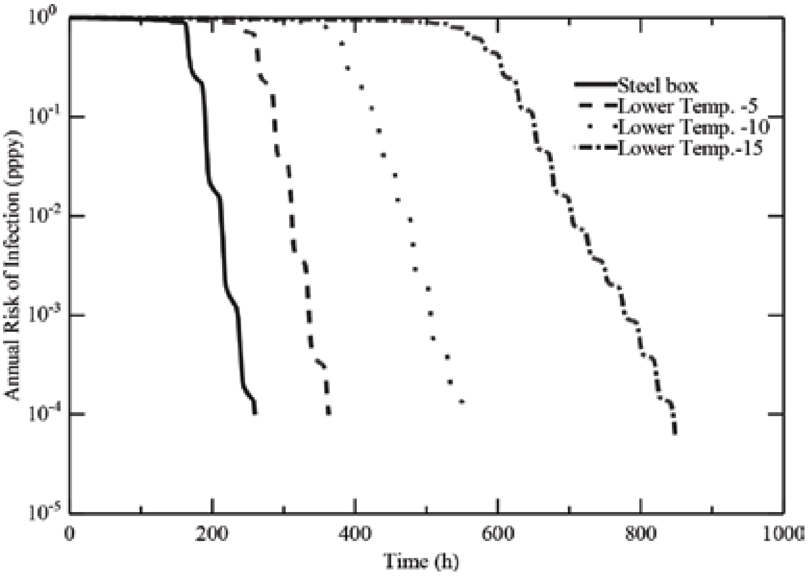


Figure 8. Norovirus annual infection risk with post-treatment.

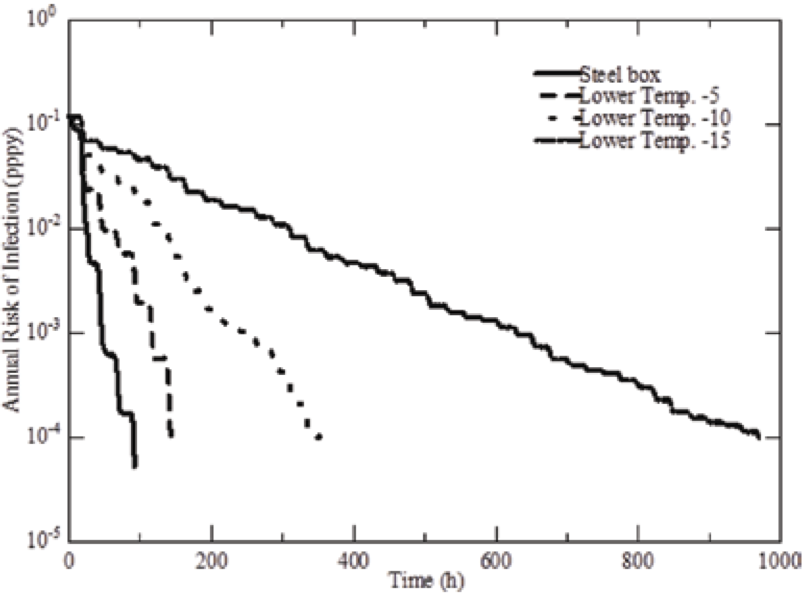


Figure 9. *Salmonella* annual infection risk associated with post-treatment.

in the soils. This implies that compost must be treated properly before reuse as fertiliser so as not to pose even greater risk in the soils. However, in semi-arid regions where the compost is expected to be used, inactivation of *Ascaris* occurs in soils rapidly [9] which indicates that post-treatment in these regions could be feasible. The results of this study indicate that high temperature with prolonged treatment time could reduce the hazard considerably. Mara et al. [14] reported risk of fieldworkers' involuntary ingestion of 100 mg of waste-water contaminated soils. The median of norovirus infection risk for an ingestion of 100–1000 mg, 10–100 mg, 1–10 mg of contaminated soil were 0.98, 0.32, and 3.7×10^{-2} pppy respectively. The study also reported the median *Ascaris* infection risk for ingestion of 100–1000 mg, 10–100 mg, and 1–10 mg of contaminated soils as 0.14, 1.5×10^{-2}, and 1.5×10^{-3} pppy respectively. In this study, the risk associated with the exposure of *Salmonella* at lower temperature was estimated to be the highest, thus, this level of pathogen reduction will provide sufficient protection against *Ascaris* and norovirus infections.

4. Conclusion

The temperature distribution in the steel box and the lower temperatures although reached a safe level, the time required for the safe treatment is too long and hence the steel box needs an improvement. Therefore, to efficiently reduce pathogens during the post-treatment and also reduce the time of treatment, the steel box needs an insulator to maintain the temperature. The guidelines for the design of the post-treatment facility are: For *Ascaris*, the steel box and the lower temperature −5, −10 and −15°C, post-treatment requires temperature between

78°C (maximum temperature during the day) − 6.5°C (min temperature during the night) and approximately time of 295 h to achieve the safe level of 10^{-4} pppy. For norovirus, post-treatment requires temperature from 78 to 6.5° and approximately time of 845 h for all the scenarios to achieve a safe level. *Salmonella* requires temperature range from 78 to 6.5°C and time of 969.5 h, for all scenarios to reach a safe level. The evaluation of the performance of post-treatment unit for risk assessment of the targeted pathogens has been achieved with the developed mathematical model.

Funding

This study was carried out with the grant project of Science and Technology Research Partnership for Sustainable Development (SATREPS) supported by JST (Japan Science and Technology agency) and JICA (Japan International Cooperation Agency).

Author details

Hamidatu S. Darimani[1]* and Ryusei Ito[2]

*Address all correspondence to: hamidnid2012@gmail.com

1 School of Engineering, Wa Polytechnic, Wa, Upper West Region, Ghana

2 Faculty of Engineering, Hokkaido University, Sapporo, Hokkaido, Japan

References

[1] Teunis PF, Moe CL, Liu P. Norwalk virus: How infectious is it? Journal of Medical Virology. 2008;**80**:1468-1476

[2] Berger S. Echinococcosis: Global Status. GIDEON Informatics Inc.; 2015. Available from: https://books.google.bf/books?id=c2QBwAAQBAJ&pg=PA49&lpg=PA49&dq=Prevalence+of+salmonella+in+Burkina+Faso&source [Accessed: 12 June, 2014]

[3] Haas CN, Rose JB, Gerba CP. Quantitative Microbial Risk Assessment. New York: John Wiley and Sons; 1999

[4] Andreev S, Samoil V. Solar thermal sanitisation of human faeces—An affordable solution for ensuring sustainability of EcoSan initiative. 2009. http://www2.gtz.de/Dokumente/oe44/ecosan/en-solar-thermal-sanitisation-of-human-faeces.pdf [Accessed: 18 February, 2014]

[5] Darimani HS, Ito R, Sou M, Funamizu N, Yacouba H, Maiga AH. Design of post-treatment unit for compost from a composting toilet with microbial risk assessment.

Journal of Residual Science & Technology. 2015;**12**(2):43-51 http://www.dpi-journals.com/index.php/JRST/article/view/1213

[6] Darimani HS, Ito R, Maiga Y, Sou M, Funamizu N, Maiga AH. Effect of post-treatment conditions on the inactivation of Helminth eggs (*Ascaris suum*) after the composting process. Environmental Technology. 2015;**37**(8):920-928. DOI: 10.1080/09593330.2015.1092587

[7] Hotez PJ, de Silva N, Brooker S, Bethony J. Soil Transmitted Helminth Infections: The Nature Causes and Burden of the Conditions. DCPP working Paper No. 3. http://www.dcp2.org/file/19/wp3.pdf [Accessed: 15 February 2014]

[8] Aoki Y, Suto A, Mizuta K, Ahiko T, Osaka K, Matsuzaki Y. Duration of norovirus excretion and the longitudinal course of viral load in norovirus-infected elderly patients. The Journal of Hospital Infection. 2010;**75**:42-46

[9] Hall AJ. Noroviruses: The perfect human pathogens? Journal of Infectious Diseases. 2012;**205**(11):1622-1624

[10] Nakata S, Lopez Zavala MA, Funamizu N, Otaki M, Takakuwa T. Temperature effect on pathogens decline in the bio-toilet system. In: Proceedings of the 1st International Dry Toilet Conference. 2003

[11] Feachem FG, Bradley DJ, Garelick J, Mara DD. Sanitation and Disease. Health Aspects of Excreta and Wastewater Management. New York: Wiley, World Bank Publication; 1983

[12] Kazama S, Tameike N, Nakagawa N, Otaki M. A fate model of pathogenic viruses in a composting toilet based on coliphage inactivation. Journal of Environmental Sciences. 2011;**23**(7):1194-1198

[13] Navarro I, Jiménez B, Cifuentes E, Lucario S. Application of helminth ova infection dose curve to estimate the risks associated with bio-solids application on soil. Journal of Water and Health. 2009;**7**(1):31-44

[14] Mara DD, Sleigh PA, Blumenthal UJ, Carr RM. Health risks in wastewater irrigation: Comparing estimates from quantitative microbial risk analyses and epidemiological studies. Journal of Water and Health. 2007;**5**(1):39-50

[15] Schönning C, Westrell T, Stenström TA, Arnbjerg-Nielsen K, Hasling AB, Høibye L, Carlsen A. Microbial risk assessment of local handling and use of human faeces. Journal of Water and Health. 2007;**5**(1):117-128

[16] Regli S, Amirtharajah A, Borup B, Hibler C, Hoff J, Tobin R. Panel discussion on the implications of regulatory changes for water treatment in the United States. In: Walls PM et al. Advances in Giardia Research. Calgary: University of Calgary Press; 1988. pp. 275-286

[17] Seidu R, Heistad A, Amoah P, Drechsel P, Jenssen P, Stenstrom T. Quantification of the health risk associated with wastewater reuse in Accra, Ghana: A contribution toward local guidelines. Journal of Water and Health. 2008;**6**(4):461-471

Sustainable Animal Manure Management Strategies and Practices

Gabriel Adebayo Malomo,
Aliyu Shuaibu Madugu and Stephen Abiodun Bolu

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.78645

Abstract

Animal manure is a valuable resource if handled responsibly but a source of serious challenges and public health concerns if managed inappropriately. Risks associated with animal manure handling could be related to soil, water and air quality. In spite of this, non-sustainable animal manure management practices are still common in some places. Sustainable management of animal manure requires multi-prong approaches and holds several benefits both to the farmers and the general public. The importance attached to the handling and management of manure in several countries has led to the enactment of relevant legislations, regulations, standards and policies to promote sustainable handling of animal manure. Some of these are enacted at community, state, national, regional and international levels. Several techniques ranging from simple, low-cost to complex strategies are available for proper handling of animal manure. The proposed chapter will highlight some unsustainable animal manure handling practices. It will discuss some of the risks associated with irresponsible handling of animal manure as well as some of the measures to promote sustainable animal manure management.

Keywords: animal, manure, sustainable, management techniques, regulations

1. Introduction

Animal agriculture is important to global food, nutrition and economic security. In many countries, domestic animal agriculture consists of mainly ruminants, non-ruminant and aquatic animals. Examples are cattle, swine, poultry and companion animals. Animal agriculture plays a critical role in the economic and social lives of the populace through its contribution to nutritious food supply, job creation, income generation and household earnings, asset saving, economic output and taxes, agricultural diversification, animal traction, soil fertility and transportation [1, 2]. Meeting the food needs of the growing world population which is estimated to be over 9 billion by 2050 is one of the greatest challenges facing animal agriculture the world over. Increasing food production is not as straightforward as simply increasing production capacity. There are constraints such as land and water use, environmental impact of animal agriculture and regulations which may limit the ability of producers to simply add enough animals to meet future demand for foods of animal origin. Therefore, animal agriculture must be carried out in a way that does not jeopardize the future use of natural resources while attempting to meet the food needs of man and animals.

Animals are raised primarily for food and non-food purposes such as companions, leather and even manure in some production systems [3]. By-products, which may constitute wastes if not managed appropriately, are generated in the process of producing, processing, transporting and marketing animals. Some potential wastes generated during animal production operations include waste or left-over feed, wastewater, hatchery wastes, abattoir wastes and manure. Manure from animal production often has external contributor such as beddings, urine, wash water, precipitation, spilled feed and spilled water [4]. Prior to the introduction of organic fertilizers, animal manure played the central role in enhancing soil fertility. In spite of the role of organic fertilizers in agricultural production, manure remains an important fertilizer resource especially in areas where organic fertilizers are not readily available or accessible to farmers.

The intensification of animal operations has led to the production of a considerable amount of manure concentrated in a particular location in excess of the need and may become a liability. The estimated total manure nitrogen production increased from 21.4 TgN/year in 1860 to 131.0 TgN/year in 2014 with an overall significant increasing trend during 1860–2014 (0.7 TgN/year, $p < 0.01$) [5]. Intensive animal production, therefore, can be significantly problematic with respect to waste storage and removal. Air and water pollution associated with animal manure has been at the centre of several regulatory discussions across the world. Animal manure contains a wide range of micro-organisms which could be a source of hazards to humans and animals. These micro-organisms can cause food contaminations and epidemics and therefore dangerous to public health. In fact, several foodborne illnesses around the world have been linked directly or indirectly to manure contamination. To therefore limit some of the challenges associated with animal manure handling, sustainable manure management practices and strategies are advocated. It is critical that manure management plans form an integral part of the animal production strategy. These include legislations and other legal instruments as well as other innovative practices that reduce the risks of exposure. Many manure management strategies and technologies are applicable to a wide range of production environment and scales. The adoption of sustainable manure management technologies holds a lot of direct and indirect benefits to the society. These include contributions to a clean environment, pollution reduction, job creation and the protection of biodiversity. This chapter gives an overview of sustainable animal manure management practices and strategies.

2. Characteristics of animal manure

Manure contains many useful and recyclable components (**Table 1**). The physical and chemical characteristics of animal manure will impact its potential use particularly as a fertilizer and the ease with which it would be handled. Animal manure can be categorized based on their consistency or moisture content into liquid manure (up to 5% solids), slurry and semi-solid manure (between 5 and 25% solids) and solid manure (more than 25% solids) [6]. The general characteristics of manure generated from typical animal production operations are presented (**Table 2**). In view of high variability in consistency, physical structure and chemical composition of animal manure from one location to the other, preference should be given to locally derived manure characteristics.

Manure component	**Beneficial uses**	**Advantages**
Nutrients	Compost, fertilizer, biomass conversion (animal feed, soil amendments, fertilizer, etc.)	Cost savings on fertilizer and income generation from sales of manure
Organic matter	Soil amendments/structuring	Improves soil structure and water holding capacity; impacts on crop yield
Solids	Bedding	Savings on cost of bedding materials, e.g., up to $50/cow/year
Energy	Biogas, bio-oil, and syngas	Supplementary energy for farm use; reduced reliance on fossil fuels; income generation from sales of energy
Fiber	Peat substitute, paper, and building materials	Potential environmental liability turned into useful commodities

Source: Adapted from [7].

Table 1. Beneficial uses of manure.

Category of animal	**Weight (lb)**	**Moisture (%)**	**Total solids (lb)**	**Volatile solid (lb)**	**Biological oxygen demand (lb)**	**Nitrogen (lb)**	**Phosphorus (lb)**	**Potassium (lb)**
Dairy manure								
Lactating cow	97–130	87	12–17	9.2–13	2.1	0.66	0.11–0.15	0.30–0.38
Calf	83	83	9.2	7.7	—	0.42	0.05	0.11
Heifer	56	83	8.5	7.3	1.2	0.27	0.05	0.12
Dry cow	51	87	6.6	5.6	0.84	0.30	0.042	0.10
Beef manure								
Beef cow in confinement	104	88	13	11	2.5	0.35	0.08	0.25
Growing calf in confinement	77	88	9.2	7.7	1.7	0.45	0.08	0.29

Category of animal	Weight (lb)	Moisture (%)	Total solids (lb)	Volatile solid (lb)	Biological oxygen demand (lb)	Nitrogen (lb)	Phosphorus (lb)	Potassium (lb)
Finishing cattle	65	92	5.2	4.3	1.0	0.36–0.50	0.044–0.076	0.25
Swine manure								
Gestating sow	25	90	2.5	2.3	0.84	0.16	0.05	0.11
Lactating sow	59	90	5.9	5.4	2.0	0.45	0.13	0.28
Boar	19	90	1.9	1.7	0.66	0.14	0.05	0.09
Poultry manure								
Layers	57	75	15	11	3.3	1.1	0.33	0.39
Broiler	88	74	22	17	5.3	0.96	0.28	0.54
Turkey toms	34	74	8.8	7.1	2.3	0.53	0.16	0.25
Turkey hen	48	74	12	9.8	3.0	0.72	0.20	0.31
Duck	102	74	27	16	4.5	1.0	0.35	0.50

Source: ASABE [8]; Barth et al. [9].

Table 2. Characteristics of manure of farm animals (per 1000 lb. animal unit per day).

3. Animal manure management systems

The animal waste management system can be described as a planned system with relevant components installed and managed to control and use by-products of animal production in a way that sustains and enhances the quality of air, water, soil, plant and animal resources (adapted from [10]). Animal manure management system is an integral part of the agricultural waste management system. Animals are raised under different systems of production and this influences the manure management systems and strategies adopted. Manure produced by animals managed in range and pasture lands is usually managed using strategies that are different from those employed for animals raised in confinement. Manure management is important because it significantly reduces the risks associated with manure handling and utilization. An efficient manure management system will limit or prevent manure or its constituents from gaining undesirable access to the larger environment. Sound manure management contributes to health and environmental, economic and social benefits (**Table 3**). A resource-efficient, socially inclusive and low-carbon economy is achieved by tapping into waste as a resource, extending the life cycle of valuable materials and increasing the use of secondary materials [11].

Establishing the goals of animal manure management systems is critical to its successful planning and implementation. The objectives of a manure management system could range from limiting the environmental impacts of manure handling, limiting manure nutrient losses and promoting its efficient use to regulatory compliance, regulating the timing of use in sync with the other uses of the manure resources and the generation of income.

Sustainable development pillar	Associated benefit of sound manure management
Environment	• Prevents the environmental impacts on air, water, soil, wildlife and the marine • Protects human health in communities and at waste management facilities • Minimizes the risks associated with the waste • Improves occupational health • Reduces greenhouse gas emissions from waste • Reduces litter and odor • Prevents the risks of flood
Economy	• Increases business opportunities • Contributes to GDP • Provides savings to businesses, especially in resource extraction and use, by waste prevention actions, recovery and/or recycling activities • Achieves economic savings by improvements in human health and the environment, leading to higher productivity, lower medical costs, better environmental quality and the maintenance of ecosystem services.
Social	• Creates employment, including low, medium, and high-skilled jobs • Integrates and professionalizes employment in the informal sector (the route to addressing equity and poverty issues) • Delivers more attractive and pleasant human settlements and better social amenity • Encourages changes in community attitudes and behaviors.

Source: Adapted from [11].

Table 3. Environmental, economic and social benefits of sound manure manage management.

Several methods of manure management systems have been identified. Each system of manure management also has its own challenges particularly with the nutrient management (**Table 4**). The primary nutrients of concern as it affects animal manure are nitrogen, phosphorus and potassium largely due to their importance in soil application. The concerns are associated with potential nutrient losses in storage and during handling as well as potential nutrient overload during land application. Due to limited land availability and lack of nutrient test to determine requirements before applications, soils applied with manure tend to have excess nitrogen and phosphorus [12]. The evidence of considerable losses of manure nutrients in storage is abundant [13] (**Table 5**). The basic functions of production, collection, storage, treatment, transfer and utilization associated with manure management systems must, therefore, be managed holistically to minimize nutrient losses, prevent pollution and other potential risks [10].

In view of the variation in the situations in which the waste management system is incorporated, as a guide, the decision-makers' concerns, needs and objectives must be considered in planning the animal waste management system; the characteristics and annual production of the waste that would require management as well as potential future changes in the size of operation must be determined; the alternatives the decision-maker is willing to consider for utilization must be determined; the landowner's preference for equipment and location of the facility must be determined; and the design of the system should cover from the production to the utilization function level and must be put in place [9]. These considerations are germane to planning and designing the waste management systems for dairy, beef, swine, poultry and other animals.

Type of system	Description	Associated nutrient loss challenges
Grazing	Animals deposit manure directly on the field during grazing	Substantial nutrient losses especially nitrogen occur through leaching and volatilization
Kraals	Animals are kept in enclosed land area to be used for cropping in the future on rotational basis.	High losses of nutrients through leaching.
Dry lot storage	Manure and urine are captured using bedding materials	Substantial losses of nutrient could occur, particularly through urine. Leaching and surface run-off can also occur
Slurry storage	Urine and feces are stored together and the manure is usually in semi-liquid form	Volatilization losses are dependent on ventilation, depth of storage tanks and length of storage
Lagoon	Liquid manure are treated in anaerobic lagoon with or without the solids separated	Leaching through lagoon bottom, discharge into water surface and odor. High ammonia, and some methane and nitrous oxide emissions may occur
Fuel	Manure are either burnt directly as fuel or handled anaerobically for biogas production	Nitrogen, carbon and sulfur losses as a result of burning. High water content of slurry makes it difficult to handle
Others	These could include plastering for house construction and use as animal feed. These forms of uses are limited and the use of manure as animal feed is not encouraged	Manure used for construction is totally lost to agriculture.

Source: Adapted from [14].

Table 4. Examples of manure management systems.

Manure management system	Beef			Dairy			Swine			Poultry		
	N	P	K	N	P	K	N	P	K	N	P	K
Manure stored in open lot, cool, humid region	30–45	20–30	30–45	15–30	5–15	5–15	30–45	20–35	30–45	—	—	—
Manure stored in open lot, hot arid region	40–60	20–30	30–45	30–45	5–15	5–15	—	—	—	—	—	—
Manure liquid and solids in a covered, watertight structure	15–30	5–15	5–15	15–30	5–15	5–15	25–30	5–15	5–15	—	—	—
Manure liquid and solids in an uncovered watertight structure	25–40	10–20	10–20	25–35	10–20	10–20	25–30	10–20	10–20	—	—	—
Manure liquid and solids (diluted less than 50%) held in waste storage pond	—	—	—	20–35	5–20	5–20	—	—	—	—	—	—
Manure and bedding held in roofed storage	—	—	—	20–35	5–20	5–20	—	—	—	30–45	5–20	5–20
Manure and bedding held in unroofed storage, leachet lost	—	—	—	25–45	15–25	15–25	—	—	—	—	—	—
Manure stored in pits beneath slated floor	15–30	5–15	5–15	15–30	5–10	5–10	15–30	5–10	5–10	10–20	5–10	5–10

Manure management system	**Beef**			**Dairy**			**Swine**			**Poultry**		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
Manure treated in anaerobic lagoon or stored in waste storage pond after being diluted more than 50%	65–80	50–65	35–50	65–80	50–65	35–50	70–80	50–65	40–50	70–80	50–65	40–50

Source: Adapted from [15].

Table 5. Nutrient losses in various manure management systems (%).

Waste Management Hierarchy	**Attribute**	**Applicability in animal manure management**
Avoidance	Most preferred option. Preventive. Use of less hazardous materials in the design and manufacture of products. Develop strategies for cleaner and environmentally friendly production	While the production of wastes cannot be completely eliminated in animal production, the production can be made cleaner and environmentally friendly
Reduction of wastes	Second most preferred option. Preventive. Actions to make changes in the type of materials being used for specific products. This approach contributes to effective savings of natural resources	Applicable
Reuse	Predominantly ameliorative and partly preventive. The waste is collected during the production phase and fed back into the production process. Reduce the amount of wastes generated and the cost of production. Desirable.	Applicable
Recycle	Predominantly ameliorative and partly preventive. The waste materials are collected and processed, and used in the production of new products. The process prevents pollution. Desirable.	Applicable
Energy recovery	Predominantly assimilative and partly ameliorative. This is also called waste to energy conversion. Wastes are converted to usable energy forms such as heat, light, electricity, etc. Desirable.	Applicable
Treatment	Predominantly assimilative and partly ameliorative. Desirable.	Applicable
Sustainable disposal	Disposal is the least preferred option in the waste management hierarchy and should be avoided.	Possible but not preferred

Source: Adapted from [16].

Table 6. Waste management hierarchy and animal manure management.

The concept of waste management hierarchy can serve as a guide in the choice of the appropriate waste management strategy, policy or options for adoption on the farm. The hierarchy is from the most preferred (avoidance of waste generation) to the least preferred (disposal) waste management options. The waste management hierarchy can be applied to animal manure management as shown in **Table 6**.

4. Some principles associated with manure management

There are several principles which are associated with waste management [11] and by extension, manure management. It is important to take these principles into account when formulating manure management strategies and interventions. Some of the principles are as follows:

- Proximity principle: The principle of proximity indicates that as practicable as possible, wastes should be managed close to where they are produced.
- Self-sufficiency principle: The principle of self-sufficiency indicates that each country, and potentially each state, region and city, should manage its own wastes wherever possible. If applied to animal production facilities, this means farms should manage the wastes that they generate. However, this principle does not foreclose regional cooperation, which may be the most efficient and environmentally sound way of waste management.
- The polluter-pays principle: This principle indicates that those who cause or generate pollution should bear its cost. In this context, those who generate manure should bear the cost of managing it to prevent the potential risks to human health and the environment.
- Precautionary principle: This principle is applied according to the capabilities of the affected states. According to the principle of precaution, the absence of scientific certainty shall not be used as the reason for postponing cost-effective measures to prevent environment degradation, particularly where substantial threats of serious or irreversible damage exist [11].
- Sustainable development: The principle indicates that development activities geared towards meeting the needs of the present must not compromise the ability of the future generations to meet their own needs. Thus, manure should be handled and managed in such a way that will not negatively affect the environment.
- Principle of intergenerational equity: The principle of intergenerational equity indicates that waste should not be managed in such a way that will leave the responsibility for the problems to the subsequent generations.

5. Challenges associated with manure handling

Animal manure can be a challenge when produced in excess of requirements. Unsustainable manure management practices, which consist of various disposal approaches, are still prevalent in some places (**Table 7**). This is particularly the situation in some intensive animal operations. For example, costs associated with manure storage and disposal can contribute to unsustainable practices in handling manure. This is possible especially when the alternatives to sustainable management are considered much cheaper, in terms of financial requirement. However, the public health and economic costs in form of disease outbreaks, rejects of products, products recalls and regulatory fines and so on that could be associated with improper disposal of animal manure or manure contaminated foods and food products may far exceed whatever cost-savings are being targeted by the producers who adopt unsustainable manure

Manure management method	Proportion of farms* (%)	Proportion of farms** (%)
Sold	—	20
Buried	—	5
Burnt	26	23.33
Recycled into crop production	—	14.17
Dumped in bushes or farms	37	—
Flushed in pits, streams and rivers	21	21.25
Others (combination of above practices)	16	16.25

*Source: [17].
**Source: [18].

Table 7. Prevalence of unsustainable manure management practices.

management practices. Manure disposal is the most unsustainable and by far the least desirable strategy in the hierarchy of management. Animal manure could be a valuable resource or a waste depending on how it is handled and managed.

Animal manure contains significant amounts of micro-organisms which make it a source of major risk to the public (**Table 8**). Risks of nutrients, organic material and pathogens contaminating water bodies and food products are common with increased manure spread [19]. Nutrient run-off into groundwater can occur from uncovered livestock facilities, from manure

Organism	Type of organism	Illness caused in humans	Route of infection
Escherichia coli	Bacteria	Bloody diarrhea, severe anemia, kidney failure or even death	Direct contact with feces and through water contaminated with feces
Campylobacter	Bacteria	Diarrhea and systemic illness	Fecal contaminated water
Salmonella	Bacteria	Diarrhea, fever, and abdominal cramp	Through fecal contaminated water or food
Leptospira	Bacteria	Leptospirosis with symptoms such as high fever, kidney or liver failure, meningitis, or even death	Directly through animal urine or soil containing animal urine contacting breaks in the eyes, skin, mouth or nose
Listeria	Bacteria	Listeriosis characterized by fever, chills, headache, upset stomach and vomiting, most likely to affect pregnant women and unborn babies	Manure contaminated food
Shigella	Bacteria	Bloody diarrhea	Direct contact with feces
Cryptosporidium	Parasite	Watery diarrhea, may be life-threatening to peoples with poor immune system	Soil, water, food, or surfaces contaminated with feces of infected animal
Hepatitis A	Virus	Viral liver disease causing mild to severe illness, flu-like symptom, diarrhea, fever, discomfort, decreased appetite, tiredness	Fecal, or by indirect contact through contaminated food and water
Rotavirus	Virus	Gastroenteritis. Symptoms include severe diarrhea, vomiting, fever, and dehydration	Contamination of hands, objects, food or water with infected feces

Organism	Type of organism	Illness caused in humans	Route of infection
Nipah virus	Virus	Severe illness in both animal and human. Asymptomatic infection to acute respiratory syndrome and fatal encephalitis	Eating food contaminated by feces of infected animal
Avian Influenza	Virus	Conjunctivitis, fever, cough, sore throat, muscle aches, pneumonia	Contact with contaminated droppings

Source: Adapted from [20].

Table 8. Animal manure, potential pathogens and illnesses caused in humans.

applied to land, from pasture feeding and watering areas or from direct discharge into water bodies which causes water pollution.

Major consequences of manure pollution in water bodies include oxygen depletion due to increased biological oxygen demand and the resultant effect on sustainable fisheries, eutrophication and algae bloom, water taints and odor, nitrate poisoning in humans and animals and water acting as a carrier for several disease pathogens [21]. Gaseous emissions from manure facilities contribute to noxious odor, greenhouse effect and other potential health hazards. Apart from the direct discharge of manure or its constituents, water bodies can absorb airborne manure constituents. Substantial amounts of nutrients, particularly nitrogen, are lost during manure collection, storage and removal. Therefore, animal manure can be a contaminant for food, soil and water. Manure is also a cause of offensive odor. Therefore, manure management systems must integrate appropriate measures for odor control. Reducing the frequency, intensity, duration and offensiveness of the odor is the main goal of effective odor control.

6. Strategies for promoting sustainable manure management

6.1. Policy and legal frameworks for sustainable manure management

In view of the numerous challenges associated with manure handling, relevant policies, legislations, regulations, directives, codes, standards and guidelines have been enacted to promote its sustainable management. The responsibility of setting policies and/or regulations for manure management could rest with the federal, state, local or provincial government. A policy articulates the course of action or principles and associated guidelines adopted to guide decisions and achieve some national outcomes relating to particular issues. Policies should usually have long-term goals. A manure policy is supposed to outline rules, provide principles that guide actions and set roles and responsibilities of waste generators and the public authorities. It also reflects values and beliefs as well as the intention to take action. Legislations and regulations are usually set to give effect to the manure management policy. Guidelines, standards, codes and procedures may also be associated with a policy. Policies may include mandatory or voluntary compliance.

Manure management policies could be a stand-alone policy or a part of another. National Agricultural Policy, Environmental Policy, Climate Change Policy, Energy Policy, Renewable Energy Policy, Livestock Development Policy, Poultry Development Policy, Food Safety Policy, Water Policy, Integrated Waste Management Policy and so on do address some aspects of manure management. A challenge with the policies earlier mentioned in relation to manure issues is that they may not be comprehensive as desirable or adequately cover every important aspect of manure management. This is the situation in several countries. Dedicated manure management policies and legislations may address the gaps associated with the other policies in relation to manure issues. The Integrated Livestock Manure Management Policy of Bangladesh is an example of a stand-alone manure policy [20]. Manure management hierarchy can guide the formulation of manure management policy objectives. To make the manure management policies effective, goals and targets can be set over various time scales. It is essential to involve the stakeholders in the processes of formulating the policies and strategies. The stakeholders should also be adequately sensitized as per their roles and responsibilities relating to sound manure management.

Policy incoherence and weak enforcement due to the lack of coordination among relevant ministries are other major challenges associated with manure policies in several countries [22]. It suffices to note that policy implementation is challenging without accompanying it with enforcement and compliance. Legislations can also contribute to increased litigation associated with manure management. Ref. [23] noted adding incentives in the form of subsidies to mandatory requirements could help to fast-track and enlarge the adoption of sustainable manure management practices such as anaerobic digestion of animal manure.

Dutch manure policy has been reported to have the following impacts: a decreased fraction of phosphate and nitrogen from the synthetic fertilizer and reduced nutrient dispersion in the environment. The success of the policy implementation has been attributed to strict application of standards for agricultural production, more efficient production per animal, low emission from stored and applied manure, manure processing, transportation and export.

6.2. Manure management practices

6.2.1. Nutritional strategies for reducing the environmental impact of animal agriculture

Feeding strategies can also be used to reduce livestock manure yield and potential emissions from manure management. Ref. [24] reported that chickens fed low protein diets had lower manure output and reduced nitrogen output intensity compared to those on higher protein regimes. The studies also found that amino acid supplementation, enzyme supplementation and manure treatments with various types of alum resulted in additional reduction in nitrogen excretion in chickens [24–27]. The implication of the finding is that lower manure and nutrient output reduces their potential environmental impacts.

6.2.2. Manure treatment

Manure treatment can be physical, biological or chemical. The objectives of manure treatment include reduction of manure volume, improvement of its applicability and/or increase in fertilizer value. Forms of treatment include dehydration, solid separation, anaerobic and aerobic lagoons, nutrient fortification, pelletizing, composting, refining and methane digester [22, 28].

Treatment with alum: Alum (aluminum sulphate), sodium bisulphate and mineral or organic acids are some of the materials that could be used for litter or manure amendments for N and NH_3 as well as other benefits [29]. Amendments of manure could be utilized to further control mineral volatilization and other forms of releases from animal manure. Alum, also referred to as filter alum ($Al_2(SO_4)_2$), is used as a flocculating agent in the purification of drinking water and waste-water treatment. Use of alum is an effective method of reducing nitrogen loss due to ammonia volatilization [30]. Use of alum in chicken manure amendment would lead to decreases in animal-house ammonia level, reduction in energy usage, improvement in animal performance, precipitation of soluble phosphorus, reduction of phosphorus and heavy-metals run-off and imposition of drying effect that reduces litter moisture. Manure treated with 1.5% alum inclusion had higher nitrogen content than untreated manure during a week of storage [27]. Nitrogen concentration in alum-treated manure tends to be elevated compared to normal manure. Elevated fecal nitrogen in stored alum-treated manure was attributed to a lower magnitude of nitrogen loss in treated compared with untreated manure and enhances its fertilizer value.

Composting: This is a natural process of aerobic decomposition or fermentation of manure by micro-organisms. Compost is rich in organic matter and has the ability to improve soil health. Compost can be made either through heap/pile or through pit method. Some of the benefits of compost in the soil include improved fertility, water-holding capacity, bulk density and biological properties [31]. A lower number of viable weed seeds in composted manure contributes to the reduction in the use of herbicides or tillage requirements for weed control [32]. Composting could be effective in killing some pathogens in manure. It also leads to up to 50–60% of reduction in the volume and density of manure thereby making its transportation more energy efficient than that of non-composted manure [33].

Anaerobic digestion: Anaerobic digestion of manure is the processing of manure to produce energy, mainly biogas. Anaerobic digestion of manure can be made more efficient through the use of co-products such as water hyacinth, corn silage and so on. Methane yield differs from various animal manure types. Rice straw (550–620 m^3 biogas/tonne DM), maize straw (400–1000 m^3 biogas/tonne DM), vegetable wastes (400 m^3 biogas/tonne DM) and kitchen wastes (400–1000 m^3 biogas/tonne DM) yield relatively more biogas than animal manure with biogas yield of 200–300, 250–500, 310 and 300–400 m^3 biogas/tonne DM for cattle, pig, poultry and sheep manure, respectively [34]. Biogas from manure digester can be used for cooking instead of the direct burning of biomass. It can also be used to power the generator for electricity. The composition of biogas produced for bio-digester is 50–70% methane, 30–45% carbon dioxide, 0–3% nitrogen, 0–3% oxygen, 0–3% hydrogen [22] and the heating value of the gas ranges from 18 to 25 MJ/m^3 [35, 36]. Whereas the biogas market may currently be underdeveloped in several countries of the world, it holds great potentials if rightly channeled to meet some of the national energy targets. The digestate from manure digestion is valuable as a fertilizer and should be used as such. However, this may require additional technologies and costs because of the high moisture content [37]. Sales of bio-energy and compost/manure substrate from biogestion can be economically viable while at the same time contribute to a safe and sane environment [38].

6.3. Strategies for odor control from livestock manure

Manure is one of the most common and main sources of odor in a livestock operation. Ref. [28] provided the following guidance on strategies for odor control from livestock manure:

- Plan, design, construct and manage livestock operations in a way that minimizes the impact of odor on neighbors. This will require reducing the formation of odor-forming gases and reducing their release into the atmosphere.
- The location of livestock operations, particularly outside lot systems, should maintain a safe distance from residents and other odor-sensitive land use. This is because odors may be generated from these systems even with good facilities design and management practices.
- As much as possible, manure storage facilities should not be located close to residential areas.
- Solid manure from farm animals can be stacked on a temporary basis outside the livestock building. Farmstead stockpiled manure should be on a hard surface, preventing direct contact with the soil. Where they are in direct contact with the soil, they should be temporary and removed from time to time. Such grounds should be left vegetated for at least 3 years to allow enough time for the nutrients to be taken up by plants. Stockpiles could also be covered with straw, wood chips and other materials and/or treated with additives such as lime to help reduce odors and pests. Field stockpiles must be temporary and should not be in an area that allows nutrient run-off.
- Manure storage facilities are temporary measures to hold manure-pending soil application. Therefore, where it is economically and technically feasible, covered manure storage facility should be used. This is because uncovered manure storage facilities are more prone to release odor into the atmosphere.
- Manure should be incorporated into the soil almost immediately after application where feasible.
- Odor from manure can also be reduced through treatment. For example, composting manure reduces odor [39].

7. Future of manure management

Manure management is an integral part of the waste management system. Therefore, current trends shaping waste management policies and practices will dictate the direction of future shifts in manure management. Several authors have identified some trends and those expected to influence future animal manure management systems, policies and practices. In a bid to reduce the quantity of wastes generated in the production, multiple industries are now leaning towards sustainable innovations and processes in the sourcing and production of items; the use of renewable resources and environmentally friendly raw materials is being favored, and products and materials that cannot be recycled are being eliminated from the production.

Waste management policies and regulations are also improving speedily globally. The rate of recycling solid wastes is increasing fast in some countries around the world [40].

There is so much going around the world in relation to manure management. The current trends in manure management are expected to further intensify in the nearest future. The future of manure management is expected to be shaped by a number of factors, one of which is regulatory compliance. Compliance with existing international, regional and national policies and laws and regulations on manure management will be a major determinant of future manure management practices. For example in Denmark, it has been noted that the European Union legal framework on manure will influence future actions and priorities in manure management [41].

The factors that will influence the general trends and development in animal agriculture will exert both direct and indirect influence on future manure management practices. In the future, several countries will be seen putting in place relevant laws and taking actions to promote sustainable manure management practices. This is because as animal production increases, measures to reduce and recycle manure are expected to increase as well. For example, the crises associated with the mobile nature of cattle production in some parts of the world have necessitated serious consideration of a shift towards encouraging sedentary production in many countries. The current cattle population needs to develop larger productive breeds, and increased intensification may result in the accumulation of greater volume of manure accumulated in some locations. This is because intensification increases the potential of manure accumulation in the producing areas [42]. Thus, policies promoting intensification of cattle and other livestock must be accompanied with relevant regulations on manure management in those places. This will require strong institutions, relevant infrastructure and sustainable partnerships to be in place to combat unsustainable manure management, particularly in places which currently have a weak regulatory and institutional framework for manure management. Lessons from other nations with successful manure management trends and history will be valuable for countries where manure management is currently emerging.

Trade is another potential driver of future manure management practices. On the one hand, food safety and global health concerns in traded food commodities will play a major role in shaping future manure management practices as it affects international and cross-border trades. On the other hand, increasing opportunities to trade high-quality improved manure products which could be used for several beneficial purposes will stimulate actions.

Availability of cheap, efficient and easy-to-adopt/adapt manure management technologies is expected to play a key role in stimulating actions. Unless environmentally and economically sustainable management technologies are employed, environmental pollution becomes inevitable [43]. Technological innovations are expected to contribute to significant improvement in the efficiency and effectiveness of waste management systems. Innovations in reduction, reuse and recycling of manure are therefore expected to increase in the nearest future. With increased development and dissemination of adaptable technologies, it would become more convenient for industry actors to adopt sustainable manure management practices in the nearest future. For example, innovations in manure nutrient fortification, reducing the variability of manure components, nutrient extraction and purification will remove some of the limitations in the use of manure as a fertilizer. Sustainable manure management can be a veritable income spinner and may also constitute significant savings on farm expenditure or cost of trading. The prospect of some forms of economic benefits from sustainable manure management may promote appropriate actions.

Development, professionalization and popularization of the manure management career will also stimulate positive actions in future manure management practices. Innovations and research in the area of manure management will go a long way in promoting this field of specialization. In view of the need for farmers to comply with more stringent manure management requirements, they may need to employ the services of skilled professionals with specialized knowledge in manure handling. They would partner with the farmers to enable them to better cope with the challenges of managing manure sustainably. This will mean more people will work in this and other areas of solid waste management. There will also be the need to add new competencies due to the need to perform a wide range of environmental-related management activities. The emergence of small businesses that specialize in manure management should be encouraged and promoted to service the industry.

The drive towards ensuring a safe environment in the future will also promote the practice of sustainable manure management. Animal manure disposal is the least preferred option for manure management. The shifting preference from disposal to more sustainable options in manure management hierarchy is expected to continue. Therefore, increased awareness of the advantages of sustainable practices and better alternatives to disposal is expected to play a crucial role in driving future actions in manure management. There are several sustainable development goals that could directly or indirectly influence positive actions in future manure management. These include SDG 1, 2, 3, 6, 7, 8, 10, 11, 12, 13, 14 and 15 [20].

Pressure from sustainable manure management groups and movements is expected to increase and stimulate appropriate actions to promote responsible manure management practices around the globe. The operations of these advocates are expected to produce an increasing number of sustainable manure management champions. Hence the number of initiatives to address manure management-related issues is expected to increase significantly.

8. Conclusion

The importance of sustainable animal manure management cannot be over-emphasized. However, generated on the farm, the impact of manure transcends its source of production. Manure contamination has been implicated in several public health epidemics around the world. Sustainable management of manure requires a multi-pronged approach. These approaches include nutritional strategies, policy and legal framework as well as physical, biological and chemical manure treatment. Effective manure policy, legislation and regulations will promote efficient and sustainable manure management practices, especially, with adequate enforcement and compliance. Manure management strategies adopted should efficiently mitigate the negative impact of manure on the environment and the general public. Several benefits are derivable from sustainable manure management.

Author details

Gabriel Adebayo Malomo[1]*, Aliyu Shuaibu Madugu[1] and Stephen Abiodun Bolu[2]

*Address all correspondence to: digabby1@gmail.com

1 Livestock Research Division, Agricultural Research Council of Nigeria, Abuja, Nigeria

2 Animal Production Department, Faculty of Agriculture, University of Ilorin, Ilorin, Nigeria

References

[1] Moyo S, Swanepoel FJC. Multifunctionality of livestock in developing communities. In: Swanepoel FJC, Stroebel A, Moyo S, editors. The Role of Livestock in Developing Communities: Enhancing Multifunctionality. 1st ed. South Africa and Netherlands: University of Free State (UFS) and the technical Centre for Agricultural and Rural Cooperation (CTA); 2010. Chapter 1; pp. 1-11. ISBN: 978-0-86886-798-4

[2] Magnusson U. Sustainable Global Livestock Development for Food Security and Nutrition Including Roles for Sweden. Stockholm: Ministry of Enterprise and Innovation, Swedish FAO Committee; 2016. 67 pp. Article no: N2016.38

[3] Romney DL, Thorne PJ, Thomas D. Some animal-related factors influencing the cycling of nitrogen in mixed farming systems in sub-Saharan Africa. Agriculture, Ecosystems and Environment. 1994;**49**:163-172

[4] British Colombia Ministry of Agriculture. Summary of manure handling systems in the context of Hullcar. A part of the Hullcar Situation Review: Nutrient Management Practices – Technical Report. File No. 631.700-6; October 2017. 14 p

[5] Zhang B, Tian H, Lu C, Dangal SRS, Yang J, Pan S. Global manure nitrogen production and application in cropland during 1860–2014: A 5 arcmin gridded global dataset for earth system modelling. Earth System Science Data. 2017;**9**:667-678. DOI: 10.5194/essd-9-667-2017

[6] Ogejo JA. Manure Production and Characteristics [Internet]. 2015. Available from: http://articles.extension.org/pages/15375/manure-production-and-characteristics. [Accessed: 2018–05-05]

[7] The Cattle Site. Beneficial Uses of Animal Manure and Environmental Protection. England: 5m Publishing; August 2015. Accessed from: http://www.thecattlesite.com/focus/5m/2311/beneficial-uses-of-manure-and-environmental-protection on 23rd March, 2018

[8] ASABE. Manure production and characteristics. ASABE Standard D384.2. St. Joseph, MI: American Society of Agricultural and Biological Engineers; 2005. Available at: http://www.asabe.org/standards/index.html. [Accessed on 23rd March, 2018]

[9] Barth C, Powers T, Rickman J. Agricultural waste characteristics. In: Herbert N, Stettler D, Zuller C, Hickman D, editors. Agricultural Waste Management Field Handbook, Part 651. Chapter 4. USA: USDA; 2008, 2008. pp. 4-1-4-32

[10] Mac-Safley LM, Boyd WH, Schmidt AR. Agricultural waste management systems. In: Hickman D, Owens L, Pierce W, Self S, editors. Part 651 Agricultural Waste Management Field Handbook, Chapter 9. USA: USDA; 2011. Amend 47, December, 2011. pp. 9-i-9-31

[11] United Nations Environmental Programme. Guidelines for National Waste Management Strategies: Moving from Challenges to Opportunities. Osaka, Japan: UNEP; 2013. 112 p. ISBN: 978-92-807-3333-4

[12] Moreki JC, Chiripasi SC. Poultry waste management in Botswana: A review. Online Journal of Animal and Food Research. 2011;**1**(6):285-292

[13] Rotz CA. Management to reduce nitrogen losses in animal production. Journal of Animal Science. 2004;**82**(E. Suppl):E119-E137

[14] Brandjes PJ, de Wit J, van der Meer HG. Environmental Impact of Manure Management. Rome: FAO; 1996. http://www.fao.org/WAIRDOCS/LEAD/X6113E/x6113e00.htm

[15] USDA. Waste utilization. In: Part 651 Agricultural Waste Management Field Handbook, Chapter 11. USA: USDA; 1996. Rev. 1, July, 1996. pp. 11-i-11-36

[16] Gertsakis J, Lewis H. Sustainability and the Waste Management Hierarchy. A discussion paper on the waste management hierarchy and its relationship to sustainability [Internet]. 2003. Prepared for EcoRecycle Victoria. Available from: http://www.helenlewisresearch.com.au/wp-content/uploads/2014/05/TZW-Sustainability_and_the_Waste_Hierarchy_2003.pdf [Accessed: 2018-03-23]

[17] Olarinmoye AO, Tayo GO, Akinsoyinu AO. An overview of poultry and livestock waste management practices in Ogun state, Nigeria. Journal of Food, Agriculture and Environment. 2011;**9**(3&4):643-645

[18] Akanni KA, Benson OO. Poultry wastes management strategies and environmental implications on human health in Ogun state of Nigeria. Advances in Economics and Business. 2014;**2**(4):164-171

[19] Smith DR, Moore PA Jr, Maxwell CV, Daniel TC. Dietary phytase and aluminium chloride manure amendments to reduce phosphorus and ammonia volatilization from swine manure. In: Addressing Animal Production and Environmental Issues. Research Triangle Park, NC: Sheraton Imperial; 2001. pp. 502-507

[20] Bangladesh Ministry of Fisheries and Livestock. Draft National Integrated Livestock Manure Management (ILMM) Policy. Bangladesh: Ministry of Fisheries and Livestock; 2015. 43 p

[21] Minister of Supply and Services Canada. Canada animal manure guide. Publication 1534. Cat. No. A53-1534/1980. Ottawa, Canada: Information Services, Agriculture Canada; 1980. 39 p. ISBN: 0-662-10604-0

[22] Teenstra E, Vellinga T, Aektasaeng N, Amatayakul W, Ndambi A, Pelster D, Germer L, Jenet A, Opio C, Andeweg K. Global Assessment of Manure Management Policies and Practices. Netherlands: Wageningen, Wageningen UR (University & Research Centre) Livestock Research; 2014. 39 p

[23] Zahariev A, Penkov D, Aladjadjiyan A. Biogas from animal manure–Perspectives and barriers in Bulgaria. Annual Research & Review in Biology. 2014;**4**(5):709-719

[24] Malomo GA. Effects of protein manipulation, enzyme supplementation and faecal treatment on nitrogen emissions in chicken production [thesis]. Ilorin, Nigeria: University of Ilorin; 2016

[25] Malomo GA, Bolu SA, Olutade SG. Effects of dietary crude protein on performance and nitrogen economy of broilers. Sustainable Agricultural Research. 2013;**2**(3):52-57. DOI: 10.5539/sar.v2n3p52

[26] Malomo GA, Bolu SA, Olutade SG, Suleiman ZG. Effects of feeding low protein diets with methionine and lysine supplementation on the performance and nitrogen economy of broilers. Research Opinions in Animal and Veterinary Sciences. 2013;**3**(9):330-334

[27] Malomo GA, Bolu SA, Olutade SG, Suleiman ZG. Effect of alum (aluminium sulphate) of faecal quality of broilers fed low protein diets. Research Opinions in Animal and Veterinary Sciences. 2014;**4**(30):133-137

[28] Michigan Commission of Agriculture & Rural Development. Generally Accepted Agricultural and Management Practices for Manure Management and Utilization. USA: Michigan Department of Agriculture and Rural Development. 49 p

[29] Koelkebech KW, Harrison PC. Evaluation of Aluminium Sulphate Manure Treatment Application on Ammonia Generation Rate and Manure Properties of Laying Hen Manure. Urbana, IL: University of Illinois; 2013

[30] Moore PA Jr, Daniel TC, Edwards DR, Miller DM. Effect of chemical amendments on ammonia volatilization from poultry litter. Journal of Environmental Quality. 1995;**24**: 294-300

[31] Flavel TC, Murphy DV. Carbon and nitrogen mineralization rates after application of organic amendments to soil. Journal of Environmental Quality. 2006;**35**:183-193

[32] Larney FJ, Blackshaw RE. Weed seed viability in composted beef cattle feedlot manure. Journal of Environmental Quality. 2003;**32**(3):1105-1113. DOI: 10.2134/jeq2003.1105

[33] Wiederholt RJ, Rahman S, Ehni A. Calculating energy efficiency of applying and composted manure to soil. In: Clay DE, Shanahan JF, editors. GIS Applications in Agriculture – Volume two: Nutrient Management for Improved Energy Efficiency. USA: CRC Press; 2009, 2011. pp. 265-276

[34] Teenstra E, De Buisonjé F, Ndambi A, Pelster D. Manure Management in the Sub-Tropics; Training Manual for Extension Workers. Wageningen: Wageningen UR (University & Research Centre) Livestock Research; 2015. 56 p

[35] Timbers GE, Downing CGE. Agricultural biomass wastes: Utilization routes. Canadian Agricultural Engineering. 1977;**19**(2):84-87

[36] Obi FO, Ugwuishiwu BO, Nwakaire JN. Agricultural waste concept, generation, utiization and management. Nigerian Journal of Technology (NIJOTECH). 2016;**35**(4):957-964. DOI: 10.4314/njt.v35i4.34

[37] Aladjadjiyan A, Penkov D, Verspecht A, Zahariev A, Kakanakov N. Biobased fertilizers - comparison of nutrient content of digestate/compost. Journal of Agriculture and Ecology Research International. 2016;**8**(1):1-7

[38] Atanasov D, Aladjadjiyan A, Penkov D. Economic efficiency comparison of different installations for bio-energy and compost production. BAOJ Nutrition. 2017;**3**(3):1-045

[39] Larney FJ, Buckley KE, Hao X, McCaughey WP. Fresh, stockpiled, and composted beef cattle feedlot manure: nutrient levels and mass balance estimates in Alberta and Manitoba. Journal of Environmental Quality. 2006;**35**:1844-1854. DOI: 10.2134/jeq2005.0440

[40] The Economist. The Truth about Recycling [Internet]. 2007. Available from: https://www.economist.com/node/9249262?zid=313&ah=fe2aac0b11adef572d67aed9273b6e55. [Accessed: 2018-04-20]

[41] Wageningen UR Livestock Communication Service. Manure: A valuable resource. In: Leenstra F, Vellinga T, Neijenhuis F, de Buisonje F. editors. Wageninigen: Wageningen UR Livestock Research; 2014. 38 p

[42] Monteny GJ, Bannink A, Chadwick D. Greenhouse gas abatement strategies for animal husbandry. Agriculture, Ecosystems and Environment. 2006;**112**:163-170. DOI: 10.1016/j.agee.2005.08.015

[43] Power JF, Dick WA. Land Application of Agricultural, Industrial and Municipal By-Products. Madison, WI, USA: Soil Science Society of America Incorporation; 2000

Edited by Anna Aladjadjiyan

This book is dedicated to the reuse of waste and residues from the agricultural sector. Plant residues, as well as animal manure and residues from animal breeding, contain useful elements that can be processed for production of fertilizers, compost for soil recultivation, and biofuels. The emerging energy and resources crisis calls for development of sustainable reuse of waste and residues. This book contains eight chapters divided into four sections. The first section contains the introductory chapter from the editor. The second section is related to the preparation of fertilizers and compost for soil amelioration from agricultural residues and waste water. The third section considers the use of agricultural waste for solid biofuels and biogas. The fourth section discusses sustainability and risk assessment related to the use of agricultural waste and residues.

Published in London, UK

IntechOpen

ISBN 978-1-83881-793-0
9 781838 817930