Waste Recycling for the Eco-friendly Input Use Efficiency in Agriculture and Livestock Feeding

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Abstract

The increasing competition for available resources and inefficient use of those limited resources necessitates the need to improve the use of available resources. If these inefficacies are not corrected, the resource-poor farmers, mainly living in developing countries will be most affected. Yet these resource farmers contribute immensely for food production in developing countries. Smallholder farmers must be proactive and learn to adopt new strategies that can assist them in continuing farming with maximum use of limited agricultural resources and even wastes in agriculture. Several methods are available to improve the use of agricultural wastes, including non-agronomic benefits. Furthermore, we suggest the integration of waste resources, such as from both the trilogy of human–animal–crop wastes. Similarly, inexpensive techniques are encouraged among the farmers, including composting and vermicomposting of human–crop–animal wastes and/or slaughterhouse/abattoir wastes, biocharing of crop and animal wastes as various means of recycling/recovering nutrients in the soil system. Furthermore, the deployment of fungi could also improve the resource use efficiency through mushroom growth and sales, crop residue fermentation to enhance its feed value. Livestock farmers facing nutritional problems can apply microbes through fermentation to reduce antinutritional factors (lignin, tannins) in plants, and improve the safety of kitchen and dairy waste before feeding. Alternatively, farmers are encouraged to raise micro livestock (rabbits, snails, and grasscutters) on their farm to improve the use of resources. On a large scale, nitrogen and phosphorus recovery from cow urine, slurry, human feces, and fermentation of phytate rich plants with phytate on industrial scales is recommended. This chapter aims to provide insight into the methods by which farmers and industries, especially those in developing countries, can improve their available resources for agricuture and as livestock feeds.

Keywords

Biochar · Biogas · Microlivestock · Nutrient recovery · Resource use efficiency · Smallholders · Waste recycling

Abbreviations

C	Carbon
Ca	Calcium
CEC	Cation exchange capacity
CH_4	Methane
CN	Carbon nitrogen
CO_2	Carbon dioxide
Fe	Iron
GHGs	Greenhouse gases
ha	Hectare
K	Potassium
kg	Kilogram
mg g^{-1}	Milligram per gram
mg l^{-1}	Milligram per liter
Mg	Magnesium
Mn	Manganese
N	Nitrogen/nitrogenous
N_2O	Nitrous oxide
NH_3	Ammonia
NUE	Nutrient use efficiency
P	Phosphorus
RUE	Resource use efficiency
t ha^{-1}	Tonne per hectare
Tg	Teragrams
TKN	Kjeldahl N
Zn	Zinc

1.1 Introduction

Globally, the livelihood of billions of people depends on the agricultural industry. It employs over 1.3 billion people worldwide and contributes to the lives of 0.6 billion smallholder farmers (Thornton 2010). This indicates that it is an industry that arguably generates more means of livelihood and services to humanity than any other industry worldwide. In the agricultural sector (crop, livestock, forestry, processing, and packaging industries), smallholder farmers are key players in food availability and security. Over 0.57 billion farms are available universally, and most of them are small and family-operated, often having less than 2 ha (hectare) producing about 75% of world's agricultural lands (Lowder et al. 2016). About 2.5 billion smallholder farmers depend on natural resources to contribute to food availability and security (Rockstrom et al. 2017). These smallholder farmers, in hundreds of millions, primarily feed more than a billion world's poor people, mainly residing in Africa and Asia (Herrero et al. 2009; Kumar et al. 2017). Due to negative environmental impacts (from nitrogenous (N) and phosphatic (P) fertilizers), water scarcity, depletion of some nonrenewable inputs, slowness in land expansion, and competition from other industries, agriculture systems are confronted with the problem of produce from available resource bases without encroaching into new ones. This calls for the need to change strategies from current farming practice, such that there is an improvement in practices and total efficiency of resources employed in agriculture-based industry (Adegbeye et al. 2020).

Land, water, and nutrients are essential resources on which agriculture owes its function and existence. Efficient use of these resources while providing access to food produced characterizes a good agricultural system. Resource(s) use efficiency (RUE) may be referred to as benefits/improved benefits that could be derived from each unit of input. Inefficiency in resource utilization occurs in the livestock and agro-food processing industry through excessive usage and wastage. To improve the efficiency of available resources, there is a need to improve nutrient use efficiency (NUE) by reducing the excessive use of synthetic fertilizer and improving the fertilizing value of animal manure. Furthermore, there is a need to recover and recycle N and P from wastewater, human and animal waste, as well as improve the quality of wastewater to improve its irrigation value.

Since the 1990s, increasing productivity has been associated with improved input use efficiency (Ramankutty et al. 2018). Additionally, overall global increases in agricultural output have shifted towards enhanced efficiency-based improvement from the previous input-based increment (Fuglie and Wang 2012). Improving the use of available resources by resource-poor farmers could increase the output per input. As such, a multi-user system that allows a circular use of resources for crop and livestock production will ensure that agricultural resources are judiciously used. However, for quick and permanent adoption, such a system should not be alien to the farmer in developing countries; rather, it should improve their current practices. This "indigenous-knowledge upgrading" approach will be farmer-friendly and afford them the privilege of relating to the system. An alteration in management may seek to integrate crop and livestock production systems, etc. Similarly, other processes such as product processing, anaerobic fermentation, composting, vermicomposting, irrigating with wastewater, upgrading manure fertilizing value, and insect farming can be associated. The overview of resource improving techniques for resource-poor farmers to enhance agricultural efficiency through reuse and recycling of nutrients of farming systems is presented in Fig. 1.1.

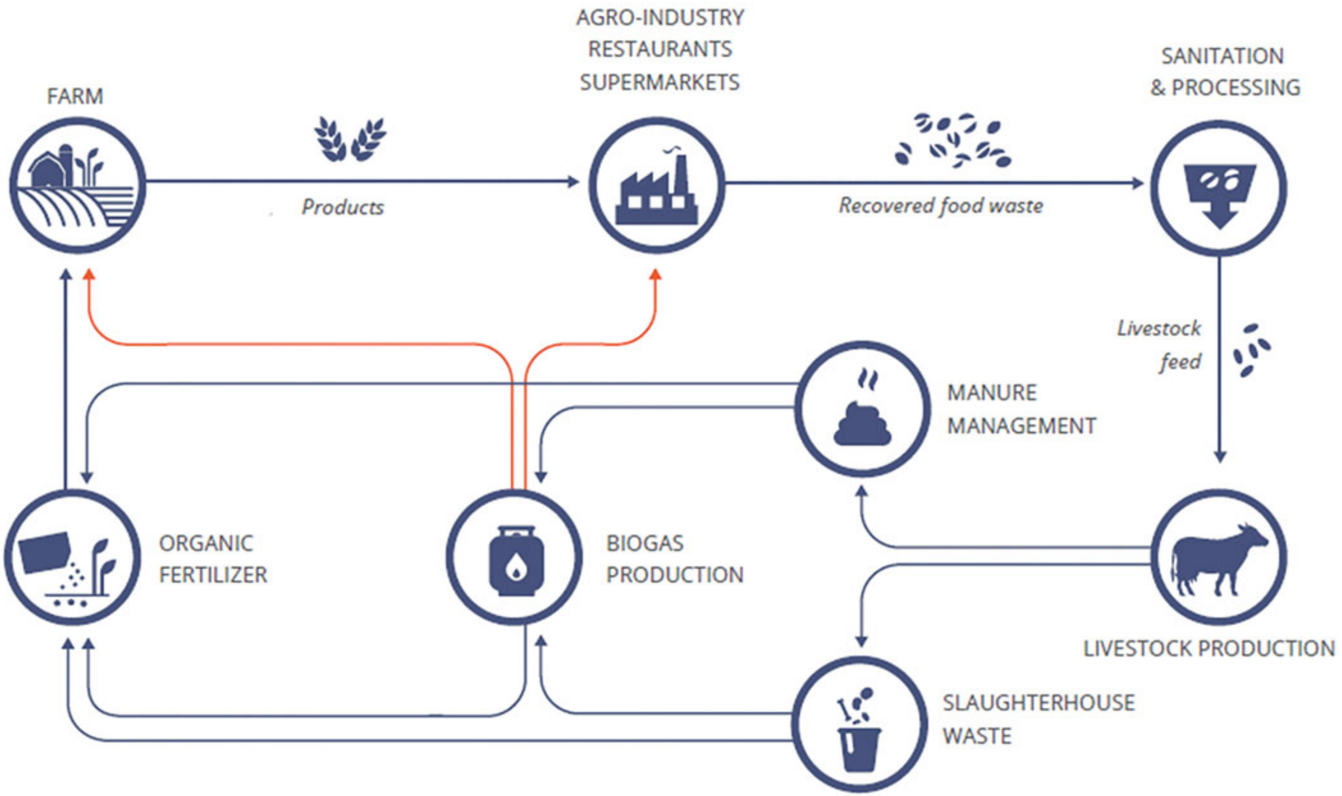

Fig. 1.1 Overview of improving the resource use efficiency (Adopted from FAO 2019)

1.2 Waste Resources Integration

Modern-day farming system models emphasize specializing agriculture such as livestock or cropping alone. This has led to uncoupling of nutrient cycle flow between both systems resulting in increasing waste in the agricultural system (Varma et al. 2017; Kakraliya et al. 2017a, b). Wastes in agrarian systems and agri-food industries are becoming valuable resources due to the essential elements in them that are important to crop and livestock. Integrating the farming system with livestock system is a crucial solution, with low nutrient input and efficiency (Sutton et al. 2013). Such crop–livestock integration signifies practical step in improving resource use (Rufino et al. 2009). It represents a means to increase output for every used input and potential to derive maximum economic yield per unit of water applied or crop planted (Singh et al. 2011). Assimilating livestock, crop, and agri-food industry wastes offer the opportunity to circulate the nutrients that could lead to a more efficient farming system.

1.2.1 Crop–Livestock System

Integrating diverse nutrient flows by linking animal wastes with cropping systems could be a means to achieve NUE (Adegbeye et al. 2020). Increasing the use of these waste resources is advantageous for resource-poor farmers, whose access to inputs such as inorganic fertilizer, feed, and large land size is limited (Thornton et al. 2018). The livestock system represents a means of gathering nutrients from the surroundings and agronomic-agroforestry systems and converting them to milk, meat, and manure (Meena et al. 2020a, b). The milk, meat, and egg represent how nutrients are "pulled" out of the agricultural system, while manure and wastewater represent the means of returning nutrients to the cropping system and the pathways for coupling/integrating livestock and crop system. Livestock offers multi-benefits to crop system such that instead of conserving crop residues for soil fertility, it could be fed to livestock consequently adding more fertilizer value to the crop residue in the form of feces/manure. Integrating agricultural farm systems is more resource-based than location-based. It connects agronomic and agroindustry associated resources like wastewater, manure, and crop residue with crop and livestock systems, to ensure exchanges even when they are spatially separated (Adegbeye et al. 2020).

1.2.2 Human Wastes

The human need to return part of the nutrients pulled from the agronomic and livestock systems. This is because many of the nutrients mined through agronomic and livestock systems are primarily by humans. Therefore, integrating crop–livestock systems and human wastes such as human excreta, kitchen, restaurant, and grocery waste can improve NUE. Yearly, many teragrams (Tg) of N and P are lost in human wastes, and many find their ways into the water bodies. Most of these nutrients lost are obtained from crop and livestock products consumed by humans. Consequently, linking the agricultural system with human waste resources could result in improved crop–livestock–human nutrient recycling. Coupling crop–livestock–human ensures that wastes such as manure, wastewater, kitchen waste, and human feces are recycled to valuable non-edible quality products such as organic fertilizer and bioenergy used to generate cooking fuel and electricity for humans and livestock.

1.2.3 Rural/Peri-urban Approach

Intensifying crop–livestock integration flows and practices outside the rural setting can bring about system efficiency and resilience (Stark et al. 2018). Specialization and intensification occur in peri-urban areas. Linking animal farmers with crop farmers can ensure that animal feces are disposed of as manure, and this will ensure cleaner and environment-friendly agriculture waste disposal method (Roessler et al. 2016; Yadav et al. 2020). For instance, biocharing, composting, vermicomposting, processing of livestock and microlivestock manure, biodigester output, and other agroindustry wastes can allow agriculture to achieve higher RUE in rural and peri-urban areas from both input and output sides. On the input end, higher output is obtained per input, and on the output end, nutrients in waste from other agricultural production systems are recycled and used on crop fields. Therefore, by modifying agricultural production and management systems through integration of livestock system with the agronomic system, on-farm interaction of crop residues and manure could bring about more efficiency by exploiting nutrient resources (Fig. 1.2) (Notenbaert et al. 2009).

1.3 Improving the Use of Agricultural Wastes

1.3.1 Insect

Insects are economically important biological resources in agriculture. They can function as producers (honey), pollinators, and pests. As a matter of interest, these insects can grow on dead woods, manure or feces, and many organic materials, which suggest that they are excellent decomposers. Due to this ability, the insect is playing and will increasingly play a key role in high-quality waste recycling. Insects can convert high energy and fibrous wastes to high-quality protein, making it a promising protein alternative in livestock production. They have a high feed conversion efficiency of waste to animal protein (Looy et al. 2013) and could produce 1 kg (kilogram) insect biomass from 2 kg substrate (Collavo et al. 2005) at low cost and breeding space (Makkar et al. 2014), with lower emissions compared to composting methods (Mertenat et al. 2019). The role of an insect in RUE is based on its ability to use inedible human waste to produce organic material of high-value protein and energy within small confinement. Insects could turn part of the roughly 1.6 billion

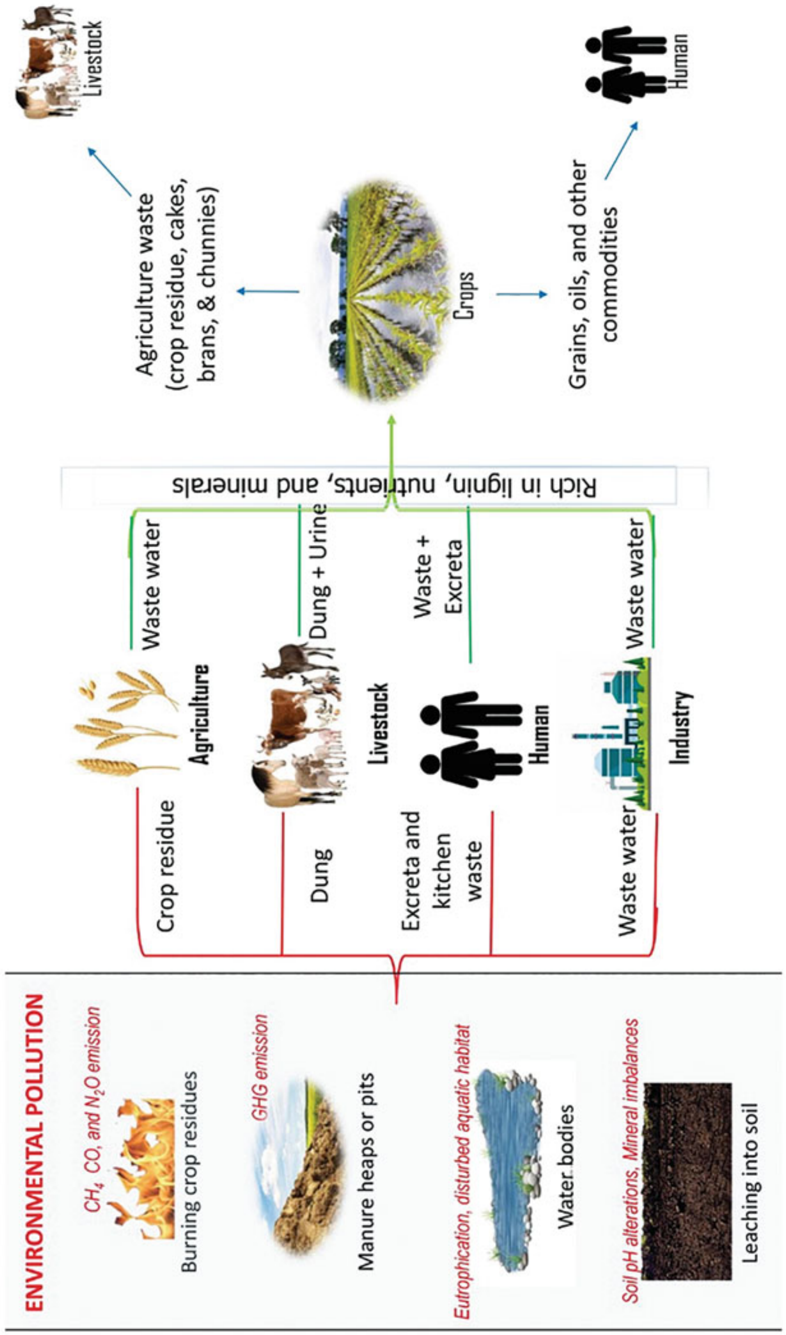

Fig. 1.2 Integration of waste resources

tons of agricultural produce being wasted yearly to high-quality protein (FAO 2013). The aim of using insects to recycle agricultural, kitchen waste and manure is to breakdown organic matter for the growth of insect larvae or fly, while the remaining may be used as organic fertilizer.

Several insects such as mealworms (*Tenebrio molitor*), house fly (*Musca domestica*), and black soldier fly (*Hermetia illucens*) are being grown on agricultural wastes; with a biodegradation potential in a range of 54–81% (Nyakeri et al. 2016). Insect larvae can be grown on brewer's waste, the solid phase of pig manure, semi-digested grass (Liu et al. 2018), and fecal sludge (Nyakeri et al. 2016). Besides, they can survive on abattoir waste, food waste, human feces, fruits and vegetables (Lalander et al. 2019; Cappellozza et al. 2019), and waragi waste (Dobermann et al. 2019). Furthermore, due to the presence of volatile solids and N content, insects can proliferate on grape (*Vitis vinifera*) and potato (*Solanum tuberosum*) peels (Barragán-Fonseca et al. 2018), rice (*Oryza sativa*) and wheat (*Triticum aestivum*) straw (Manurung et al. 2016; Gao et al. 2019), cassava (*Manihot esculenta*) peels (Supriyatna et al. 2016), mushroom waste (Cai et al. 2019), and coconut (*Cocos nucifera*) endosperm waste with soybean (*Glycine max*) curd residue (Mohd-Noor et al. 2016).

These cultivated insects are rich in unsaturated fatty acids and essential amino acids like methionine (17.62 mg g^{-1}) (milligram per gram) and lysine (19.78 mg g^{-1}) content sufficient to meet human and animal needs, but are missing in many kinds of cereal and plant-based protein sources (Azagoh et al. 2016; Cappellozza et al. 2019). Maize (*Zea mays*) straw is typically low in protein and fat, but is high in fiber, which is mostly indigestible for livestock. However, black solider fly grown on *Aspergillus oryzae* fermented maize straws yielded insect protein that is low in saturated fatty acid, high in mono and unsaturated fatty acid, and having 41.76, 30.55, and 8.24% crude protein, crude fiber, and crude ash, respectively (Gao et al. 2019). Various studies on the use of insects in livestock have shown positive results. The replacement of fishmeal with 60–100% black soldier larvae in the diet of guinea fowl improved its juiciness, texture, flavor, and acceptability (Wallace et al. 2018). Also, yellow mealworm larvae added at 50 and 100 g kg^{-1} improved feed intake, weight gain, body weight and had a positive effect on carcass traits (Biasato et al. 2017), while defatted black soldier flies added at 5 and 10% of soybean meal improved live weight, an average daily gain of broilers (Dabbou et al. 2018). This shows that biodegrading crop residue with insect leads to the production of high valued protein, which is a means of increasing the nutrient usage in agriculture.

Apart from the potential for animal protein, the remaining biodegraded and bio converted inedible human waste can be used as organic fertilizer. For instance, the biodegraded substrate left after the growth of larvae of the house fly and black soldier fly was found to be rich in NPK with similarity to China-based standard organic fertilizer (NY525-2012) (Bloukounon-Goubalan et al. 2019; Gao et al. 2019). Other studies showed that when such substrate leftover is used as fertilizer, they improved the germination index of Chinese cabbage by 65.7% (Cai et al. 2019). This implies that the insect leftover is usually rich in a nutrient that could be used as an alternative soil improver. For other uses, the biodegraded waste produced from insect farming can be anaerobically digested for biogas to generate electrical or cooking energy. Thus, food waste could first be converted to food and feed by the insect before being used for biogas production and the biodigester waste used for organic fertilizer.

1.3.2 Biogas

Biogas production from wastes can play a vital role in the waste management system. It could serve as the value addition wing of the waste management sector. Agricultural wastes are used as landfills and for mulching or manure, which sometimes trigger greenhouse gases (GHGs) and non-GHGs emission in both aerobic and anaerobic conditions. Biogas production represents an anaerobic microbial bioconversion of organic material into energy that could be used for cooking or electricity. During anaerobic digestion, biogases contain methane (CH_4) gas, which could have various fuel applications. Generating energy from wastes offers the opportunity to improve the efficiency of organic matters in the agricultural system. For example, a 20–100 kg of dairy cattle feces in a biodigester system can power biogas stove for up to 3.5–10 h and biogas lamp for10–25 h (National Biogas Program 2008). Apart from the benefit of renewable energy, biogas, the solid digestate from biogas plants could be used as fertilizer due to its nutrient enrichment. Adding the anaerobic digestate as 60% of total fertilizer used on maize plot had an NUE similar to 60% of inorganic fertilizer and higher than 100% inorganic fertilizer (Moya et al. 2019). Similarly, instead of using manure directly as fertilizer, the farmer can first bio-digest to reduce the nutrient load in feces and the resulting residue could be used as organic fertilizer. One tonne of manure could be used to produce an energy value of 100 to 125-kWh (Burton and Turner 2003). Therefore, on large farms, such manure could generate electricity or heat energy for brooding. Furthermore, it will reduce the cost of running the generator and decrease the bills paid to electrical companies. If legally permitted in the country, individuals can be selling biomethane gas on a small-scale if they could successfully compress the gas under pressure. For instance, biogas plants existing in Indian and Pakistan can produce CH_4 gases that are 98% pure, store them in cylinders, which is then used to fuel gasoline-based auto-rickshaws and diesel engines (Ilyas 2006; Kapdi et al. 2006). Biogas could also be used as a renewable fuel instead of nonrenewable fluid, commonly used in rural areas. Farmers from countries in Asia and Africa operating crop–livestock systems can use their waste resources to generate energy for cooking instead of firewood.

The potential of energy in crop residues is enormous. From the annual agricultural residues and livestock manure, up to 3,30,000 tons of fertilizers and 1.97×10^9 m^3 $year^{-1}$ CH_4 can be produced, which has the electrical energy capable of replacing 39% of annual energy consumption in Greece (Vlyssides et al. 2015). Besides animal manure, human waste can also be used to generate biogas, and the digestate can be used as organic fertilizer. The digestate of human feces subjected to anaerobic digestion had 877-milligram (mg) liter (l)$^{-1}$ total N and 42 mg l^{-1} total

P. This indicates that anaerobic digestion could be used to recover nutrient from human feces and the digestate could be used for planting to enhance NUE.

To enhance biogas yield from lignocellulolytic wastes, fungal, chemical, thermal, and mechanical pretreatment of biogas substrate has shown positive results (Olugbemide et al. 2019; Abudi et al. 2019). For example, seven days substrate pretreatment with 2% sodium hydroxide (NaOH) decreased lignin by 48.2% and increased CH_4 yield by 407.1%, and the biogas production was completed in 24 h compared to untreated materials that required 168 h for its biogas production (Shah and Ullah 2019). This implies that pretreatment of lignocellulolytic material and crop waste before digestion could lead to increased biogas production and decreased production time (Fig. 1.3).

1.4 Wastewater

Water supply will increasingly become a global issue with the possibility of about three and a half billion humans experiencing a different form of water scarcity that could be economic or physical (WRI World Resources Institute 2019). This will be particularly challenging for agriculture as agriculture is the biggest user of freshwater and contributes significantly to freshwater eutrophication globally (Nasr et al. 2015). Treating and recycling wastewater are some ways by which agricultural water scarcity can be managed. Enormous potential exists in deriving more value per unit of water through integrated and higher value production systems (CAWMA 2007). The need to improve water use is high in the tropics due to its dependence on green water as its primary source is agricultural water (Rockström et al. 1999). It is foreseen that only 5% of future grains increase will come from rain-based farming areas, while the majority will be from irrigation-based farming areas (Taimeh 2013). Therefore, in such a condition, irrigation with wastewater could be valuable for developing countries facing one or more forms of water scarcity.

Wastewater consists of nutrients that cause environmental pollution or enter into different water bodies, reducing the quality of available and accessible water. Agroindustry/processing companies are the main culprits in wastewater generation and livestock production systems characterized by low water productivity (Blümmel et al. 2015). Water management could be used for preserving, restoring the ecosystem through integrating livestock and aquaculture systems (CAWMA 2007). Managing wastewater can get more products and value from the same water, and with this, the resource-poor can benefit from the water through the crop, aquaculture, livestock, and mixed systems, improving water productivity (CAWMA 2007).

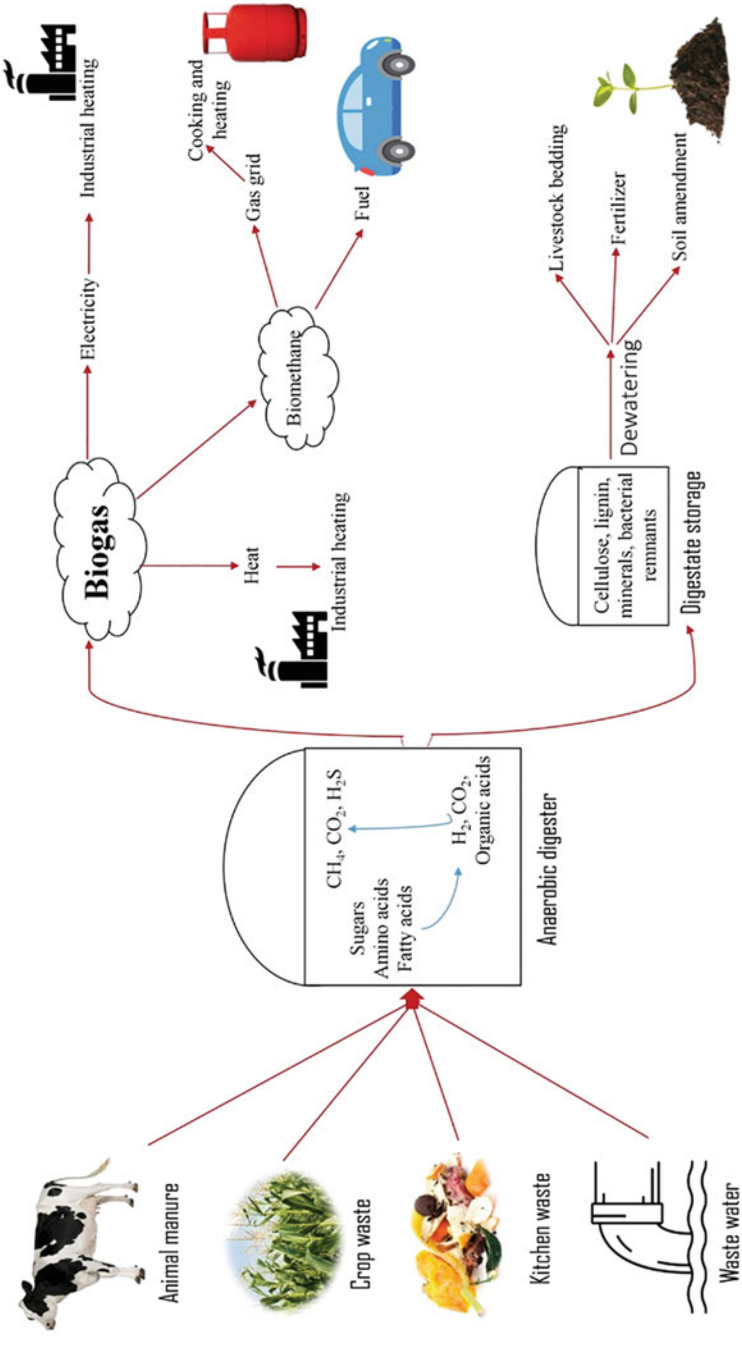

Fig. 1.3 Biogas production to improve the resource use efficiency

1.4.1 Productive Use of Wastewater from the Cassava Processing Industry

Water demand is outstripping water supply in low- to middle-income countries with fast population growth. Competition for water in agriculture and other sectors is leads to environmental stress and socio-economic tension (FAO 2011). Wastewater of such industries can be reused instead of disposing into rivers to pollute the hydrosphere and aquatic habitats. Wastewater from starch industry contains quite a large amount of nutrients; as such, microorganisms can recover part of the nutrients in the starch for protein-rich microbial biomass that can be used to feed livestock. Cassava processing industries produce a large amount of nutrient-rich water. Storing this cassava flour processing or cassava starch extract in large tank permit sedimentations of high-starch paste known as cassava dregs. Such dregs can be fed to ruminants as corn replacements. A report showed that the replacement of corn with cassava dreg increased the concentration of eicosenoic and α-linolenic acids and had a positive effect on the unsaturated fatty acid and flavor (Cardoso et al. 2019). These cassava dregs could be stored during the season of abundance and kept for dry season when forages are scare and could be used during fattening. Another way of improving wastewater use is through microbial growth. Cultivating edible fungi (*A. oryzae* CBS 819.72 and *Rhizopus oryzae* CCUG 28958) on wastewater recovered 48–77% of the nutrients, generated protein-rich biomass at a rate of 7.83–49.13 g l^{-1} of starch wastewater (Souza Filho et al. 2019). The remaining wastewater could be used in aquaculture, piggery, or irrigating field crops.

1.4.2 Wastewater from the Livestock

The piggery production system in the tropics requires the use of large volumes of water. This is because of the relatively high temperature in the tropics, which requires that pigs find means of cooling their temperature. However, pigs do not have sweat glands; therefore, wallows are provided for cooling. An expensive alternative to wallows will be the use of the air conditioner in the piggery. Also, the pigpen must be washed daily to maintain hygiene, which requires a large volume of water. This wastewater could ideally be used for irrigation. However, the risk of contaminating crop yield with food-borne pathogens during irrigation means that efforts should be made to reduce the pathogenic contamination level of livestock wastewater before it is used for irrigation. In Brazil, swine production takes about 15-l water animal^{-1} day^{-1} (Velho et al. 2012), which infer that thousands of liters of water will be wasted on large farms daily. Creating a synergy between pig farmers and crop farmers can improve water reusability, especially in the dry season, where water is scarce and could encourage all-year-round farming. Although wastewater contains high organic matter concentration and nutrients, it contains a lot of pathogenic microbes. Management practices could improve the microbial quality and decrease the nutrient content in the wastewater before reuse. Velho et al. (2012) reported that piggery water collected from maturation pond and kept in a stabilization reservoir for about 320 days showed that the total P, total Kjeldahl N (TKN), biochemical oxygen demand, and *Escherichia coli* decreased by 68, 77, 85, and 99%, respectively. The reduction may be associated with the proliferation of flora–fauna community (microbes and algae), decreasing the available substrate or precipitation of P into calcium (Ca)-phosphate complex. Partial water treatment through the method before it applies to irrigation could improve water use efficiency. However, care must be taken while using only wastewater as the source of water for crop irrigation to avoid soil salinity and oil solidity. Therefore, recovered wastewater could be mixed with fresh water from rivers or streams. This will place less demand for clean water, and less agroindustry related wastewater will be pushed into water bodies.

1.5 Nutrient Recovery/Recycling Methods

About 5–30% of livestock's total nutrient intake is retained, while others are excreted, resulting in low efficiency of nutrients, primarily N and P (Teenstra et al. 2015). These excretions have implications on surface and underground water, aquatic organisms, air quality, global warming, etc.; therefore, recovering these nutrients is essential. Low and declining soil fertility is one of the agricultural intensification challenges in Africa (Vanlauwe et al. 2017). This results in soil nutrient mining and land expansion by farmers that cannot afford inorganic fertilizer. In contrast, livestock intensification increases the quantity of manure produced, resulting in excess N, P, and K balances in agriculture (Vu et al. 2012; Abdulkadir et al. 2013).

Manure use has not been optimally exploited as a local nutrient source among resource-poor farmers (Sutton et al. 2013; Meena et al. 2018). Applying manure for soil amendment rather than indiscriminate disposal is a way to ensure nutrient cycling and soil fertility. This practice helps to return up to 80% of the nutrients extracted by crops back into the soil system in sub-Saharan Africa (Stangel 1995). However, the manure's direct use leads to nutrient losses (ammonization, leaching, runoffs etc.). Developing a closed nutrient cycling system in agriculture through the efficient use of stored manure could increase crop yields (consequently their by-products—as feed) and farm output (Thornton et al. 2018; Meena et al. 2019). Improving manure processing will lead to optimal nutrient benefits derivable from manure and increase the fertilizer equivalence value. Vermicomposting, composting, and anaerobic digestion represent one of the ways to utilize nutrient in the manure properly. Soil nutrient amendment with manure contributes to greater fertilizer use efficiency (Fig. 1.4) (Nigussie et al. 2015).

1.5.1 Composting and Vermicomposting

Direct application of manure on the field causes nutrient losses and pathogenic contaminations. Pathogenic contamination like *Salmonella* spp. and *Escherichia*

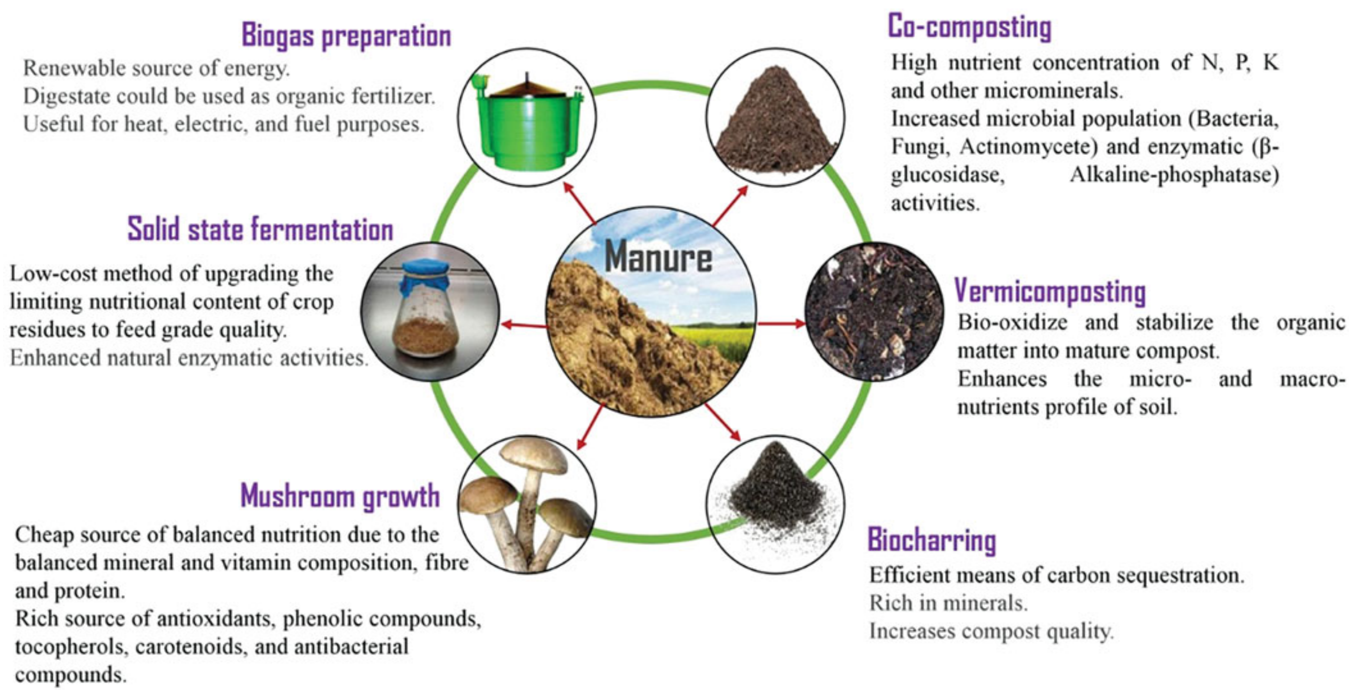

Fig. 1.4 Nutrient recycling from manure

coli has been reported for Niamey in Niger (Diogo et al. 2010). To reduce the problems, composting or vermicomposting could be used. Composting and vermicomposting are efficient processes for recycling manure because they bring stabilized and sanitized biodegraded end product for agriculture (Nasiru et al. 2014; Meena et al. 2020a). It can be used to convert substrate or waste from livestock or insect farming to organic fertilizer. Composting and vermicomposting processes represent a medium of making cheaper, locally, and readily available natural mineral through the decomposition of organic matter (Jangir et al. 2017, 2019; Kumar et al. 2020). Composting technique requires low investment in transforming fresh organic matter into fertilizer valuable organic matter by the microorganism. However, vermicomposting turns fresh organic matter into compost by joint activity of earthworms and microorganisms, which help in bio-oxidizing and stabilizing the organic matter into mature compost, thereby enhancing the micro- and macronutrients profile of soil (Nasiru et al. 2014; Mushtaq et al. 2019). The earthworm works by modifying the decomposing organic matter during their passage through the earthworms in a gut-associated process (Dominguez and Edwards 2011). These processes reduce N losses when fresh manure is applied, reduce odor, eliminate or reduce pathogens spreading and reduce the volume and weight of biomass (Peigne and Girardin 2004; Gomez-Brandon et al. 2008; Hristov et al. 2011).

1.5.1.1 Use of Human Feces Through Composting and Vermicomposting

Human feces are richly embedded with N and P because they consume crop and animal products. Efficient use of human feces could improve nutrient circulation in crop productivity. Yearly, about 3 of 3–5 Tg P that humans excrete spreads to the water bodies through the sewage system (Van Vuuren et al. 2010). Vermicomposting and composting represent good ways to recover nutrients from human feces and turn them to manure. Breakdown of organic matter during composting is due to the enzymes that hydrolyze complex macromolecules present in the decomposing materials (Delgado et al. 2004). Vermicomposting processes and composting process have a different effect on the nutrient profile of compost. Moya et al. (2019) showed vermicomposting of human feces resulted in higher nutrient availability than human feces composted. The composting process can save up to 42% of N, which varies with the type of procedures involved (Gomez-Brandon et al. 2008). Total N was 23 and 11 g kg^{-1} in compost and vermicompost prepared from human feces, respectively. Available N (ammonium and nitrate) in the feces vermicompost was 346% higher, i.e., 1009 vs. 217 mg kg^{-1}, organic carbon (g kg^{-1}) was 125% lower, i.e., 175 vs. 393 g kg^{-1}, P availability was ten times higher than in composted feces. In contrast, available potassium (K) of composted human feces was five times higher than vermicompost prepared from human feces. The CN (carbon/nitrogen) ratio of the compost and vermicompost feces was 17 and 16, respectively. This suggests that composting of human feces represents an excellent carbon (C) sequestration method compared to vermicomposting. Nevertheless, vermicomposting is a right method of increasing the N availability, thus decreasing its loss and environmental pollution. The P increase may be attributed to the digestion process of worms, which transformed the P from an organically bound to a soluble and available form. Other minor elements like zinc (Zn), magnesium (Mg), manganese (Mn), and Ca available in compost and vermicompost range from 3.5–349 and 0.9–946 mg kg^{-1}, respectively. This shows that they can be used as an alternative to mineral fertilizer. Inclusion of vermicompost and compost at 20% and 40% levels, maintained NUE at levels delivered by 40% inorganic fertilizer inclusion. Lesser quantity of vermicompost was needed to produce a similar efficiency to inorganic fertilizer.

1.5.1.2 Vermicomposting of Agricultural Waste

Vermicomposting processes help to stabilize and promote mineralization of organic matter and could be used as a soil health promoter or organic fertilizer. Earthworm (*Eisenia fetida*) is widely known for its ability to make compost out of agricultural wastes and animal manures (Edwards et al. 1998). Vermicomposting of cow dung and biogas plant waste having 70% moisture content increased cation exchange capacity (CEC) and mineral content (Ca, K, and P) by 25–104%. It increased N by 237–382% and decreased total C by 22–35% resulting in 80.9–83.9% decrease in CN ratio, which is below 15. The increase in the amount of P may be attributed to the conversion of P from organic matter into available form by enzymes present in earthworm gut such as acid phosphatases and alkaline phosphatases (Le Bayon and Binet 2006). Sharma and Garg (2017) reported that compost produced from sheep (*Ovis aries*), cow (*Bos taurus*), buffalo (*Bubalus bubalis*), and goat (*Capra aegagrus hircus*) manure with earthworm had higher N, P, and K values, produced odor free and homogenous vermicompost, while the CN ratio ranged from 15 to 38%. High biomass gains of earthworm were observed under buffalo manure, which indicates the richness of nutrients in the manure. As such, vermicomposting could improve the fertilizer value of ruminant manure such as cattle, buffalo, etc., in a country like India, where it is reared extensively in the dairy industry.

1.5.1.3 Enrichment of Manure through Co-Composting

Continuous use of manure as fertilizer represents a way to improve nutrient use in the agricultural system. To encourage manure use, there is a need to upgrade the nutrient profile of manure to the fertilizer equivalence of inorganic fertilizer. The poultry industry is the fastest meat-producing industry in the livestock sector. Presently, there are over 22 billion poultry population globally (FAOSTAT 2017), the highest for any livestock. This represents a tremendous amount of nutrient concentration of N, P, K, and other microminerals (Christensen and Sommer 2013). The manure is nutrient-rich because broiler diet is nutrient-dense due to short fattening days. Compost made from co-composting of 70% poultry waste, 30% rice husk, and 2% rock phosphate was found to have improved the CEC and decreased CN ratio of composted manure (10.8) compared to unenriched compost (24.83) (Mushtaq et al. 2019). Application of about 100 kg-N ha^{-1} of such compost improved growth and nutritional value of okra (*Abelmoschus esculentus*). The rock phosphate bio-oxidate the C into carbon dioxide (CO_2) thereby reducing the CN ratio. Similarly, co-composting of poultry or cattle manure alongside organic waste with non-reactive ground phosphate rock at 8:2 ratio increased organic P availability in the poultry manure compost than cattle manure compost. Furthermore, microbial population (bacteria, fungi, actinomycete) and enzymatic (β-glucosidase, alkaline phosphatase) activity in cattle manure compost were significantly ($p < 0.05$) higher than poultry manure compost (Kutu et al. 2019). This shows that P content and the fertilizer value of manure could be improved by co-composting with phosphate rock.

Fecal and crop waste recycling involves collecting crop–livestock waste and reducing their volume by composting. The organic matter from pineapple (*Ananas comosus*) leaves, and chicken slurry is rich in C, N, P, K, Ca, Mg, sodium (Na), Zn, copper (Cu), iron (Fe), and Mn in a range of 13.4–127,600 mg l^{-1} (Ch'ng et al. 2013). Co-composting of pineapple leaves with chicken slurry increased CEC by 108%, N by 40%, and P by 59%; whereas, C content was reduced throughout the co-composting resulting in decreased CN ratio (Ch'ng et al. 2013). The combined role of bacteria and fungi decomposed available cellulose, hemicellulose, lignin, and some resistant material. Also, the combination of heat, switching from mesophilic to thermophilic and microbial increase aid the breakdown of recalcitrant substances and set loose the polymers and linkages holding the nutrient and minerals. This compost can be used in vegetable and fruit production or garden plantation in urban and peri-urban areas, and to encourage back-yard farming.

1.5.2 Soil Amendment with Abattoir and Slaughterhouse Waste

In slaughterhouses, blood and rumen digesta are waste that is human inedible, and they contain part of the nutrient flow in agriculture. Despite nutrient content in blood, the use of blood to feed livestock is not encouraged due to zoonotic diseases. However, because the nutrient load is high, applying them to the soil could be a way to recover the nutrient. In a study, 2:1 and 3:1 mixture of waste blood and rumen digesta applied at 5 g kg^{-1} soil increased concentrations of C, N, and P and soil microbial population higher than diammonium phosphate (Roy et al. 2013). Besides, they also reported an increased number of tomato (*Lycopersicon esculentum*) fruit and weight by 90–110, and 113–130% respectively, whereas chili (*Capsicum frutescens*) fruit number by 39–100% and fruit weight by 129–258%. Furthermore, sensory evaluation such as sourness, sweetness, and hotness of the grown chili and tomato was identical to usual tomato and chili. This method could be used to improve soil value in back-yard farming or to cultivate this crop.

1.5.3 Biochar

Biochar is an organic material produced by subjecting biomass such as agricultural and agroindustry waste products and animal wastes to pyrolysis in heat between 300 and 700 °C with limited oxygen (Lehmann 2009; Bajiya et al. 2017). Biochar represents a means of concentrating nutrients in large biomass into a char form. Pyrolyzing animal waste and crop residues instead of disposing-off could result in nutrient recovery and recycling (Adegbeye et al. 2020). During pyrolysis, carboxyl and phenolic groups are decomposed, and properties like surface area, porosity, labile, or recalcitrance of chemical elements are altered. Biochar can be made from several sources such as husks, manures, crop shells, and sawmill residue (Speratti et al. 2018; Mirheidari et al. 2019). Biochar nutrients could be less volatile, stable, and compact, which give room for its use as organic fertilizer. Biochar represents a means of C sequestration in agriculture through which agriculture can be eco-friendly. Therefore, it could improve soil C storage better than those directly from animal manure, crop wastes, and composts (Fig. 1.5) (Kimetu and Lehmann 2010).

1.5.3.1 Biochar from Animal Manure

Biochar could be included as additives in feed to improve livestock productivity. Mirheidari et al. (2019) reported that adding biochar prepared from walnut shell and chicken manure at the rate of 1 and 1.5% of the diet, respectively, improved milk yield, milk composition and fiber digestibility. The increasing demand for pork and other animal products could increase animal density, potentially resulting in an unprecedented increase in ammonia (NH_3) and nitrous oxide (N_2O) emissions coming from swine houses and litter if swine production continues in its business as usual manner (Adegbeye et al. 2019). Co-composting of animal manure rich in N could reduce its losses and increase nitrogen use efficiency. Compost made from a mixture of pig manure and biochar–microbial inoculant powder [made from rice straw and $>1 \times 10^8$ CFU (colony-forming units) g^{-1} facultative microbes (consisting *Lactobacillus*, *Flavobacterium*, *Candida*, *Bacillus*, and *Actinomadura*, etc.)] for 42 days increased the compost pH by 3.10%, decreased TKN, CN ratio, and cumulative NH_3 emissions, degraded organic matter, and detoxified the compost (Tu et al. 2019). The decrease in NH_3 is because biochar is efficient at its adsorption during the composting process (Steiner et al. 2010). Therefore, co-composting with biochar and microbial inoculants will help improve compost quality, and reduce NH_3 and N_2O released during composting.

1.5.3.2 Biochar from Crop Waste

Subsistence and medium-scale farmers are affected by limits in their access to inorganic P fertilizers (FAO 2005; Bationo et al. 2006). This results in an inability to fill the crop yield's potential, leading to increased yield gaps and food crop imports. Biochar of some crop–livestock waste could improve the reuse of minerals. The relatively small pool of native soil P causes phosphorous deficiency in soils globally (Vance et al. 2003). Using manure alone result in low to a suboptimal level of soil P (Kutu 2012). In an era challenged with P pollution and depletion in phosphate rocks, biochar could be an alternative source of organic P, resulting in decreased use of inorganic P.

Biochar from sawdust, corn cob, rice husk, coffee (*Coffea* spp.) husk, and groundnut (*Arachis hypogaea*) husk had 10.61, 10.68, 12.26, 15.83, and 20.50 mg kg^{-1} available P, respectively. Similarly, N and K range from 4.17–11.34 g kg^{-1} and 2.16–5.43 c mol kg^{-1}, respectively (Billa et al. 2019).

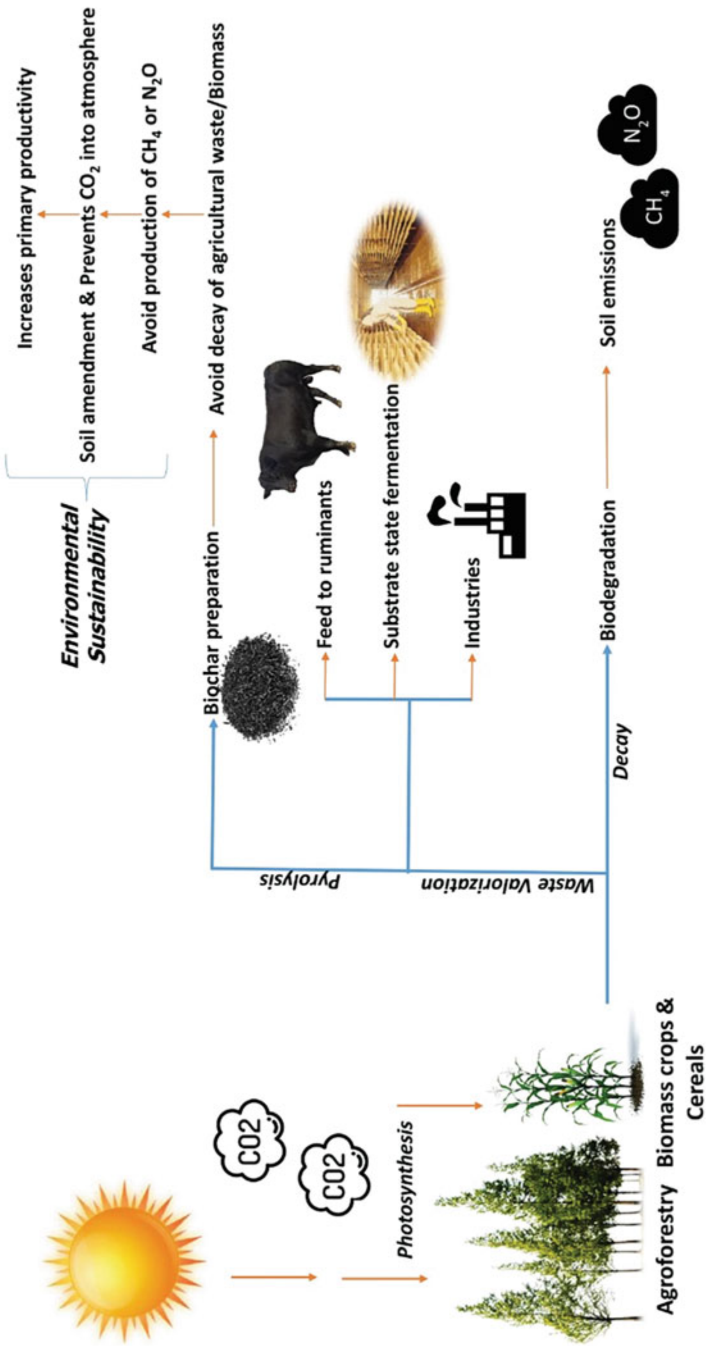

Fig. 1.5 Biochar use in agricultural production (Adapted Adegbeye et al. 2020)

Surprisingly, sawdust had low available P despite containing higher P (86 mg kg^{-1}) in its raw form (Adamu et al. 2014). This could be because wood-based biochar minerals tend to be more recalcitrant (Wang et al. 2016). Presently in Nigeria, sawdust is burnt because it has no commercial use, yet it is being produced in large quantities in sawmills. Biochar could serve as a source of recovering some nutrients in the sawdust. Biochar of poultry manure at 350–450 °C had 14.9–19.5 g kg^{-1} dry matter P and 10–14.8 labile P g kg^{-1} feedstock, respectively, and the N and K contents of poultry manure biochar increased (Keskinen et al. 2019). This could constitute a significant source of both macro and micronutrients for crop production. Alternatively, such biochar could be used as a source of organic P in livestock. Pyrolyzing at a lower temperature may increase mineral availability, which could be used as a supplement in livestock farming. A study found a higher N and P in biochar made from poultry litter at 350 °C compared to 700 °C (UC Davis Biochar Database 2019). This variation is because incomplete pyrolysis occurs at a lower temperature and this results in a higher mineral element in labile forms. The complete pyrolysis of biochar occurring at high temperature leads to the recalcitrance of the mineral element. This suggests that pyrolyzing at a lower temperature could increase the available P and other minerals. The use of labile biochar has been able to improve soil microbial activity (Ameloot et al. 2013). This increase could be due to better soil structure, moisture, and enhanced nutrient availability, which can be linked with NUE. Therefore, the biochar could be applied in livestock feeding as a partial substitute for inorganic P source.

1.5.3.3 Biochar on Plant Performance

Biochar has beneficial effects on crop and animal production systems and even reduced CH_4 emission in ruminants (Leng et al. 2012: Thuy Hang et al. 2019). Further, it has improved soil microbial community structure, soil enzyme activities, soil respiration, and C mineralization (Palansooriya et al. 2019). Also, its augmented soil pH increases microbial population and community structure (Kolton et al. 2016), soil moisture content, water retention capacity, water use efficiency, and, ultimately, crop yield (Fischer et al. 2019). Biochar applied at the rate of 1%, or 16 t ha^{-1} (tonne per hectare) equivalent was able to improve crop productivity and soil nutrient status (Speratti et al. 2018). Similarly, biochar of rice husk and straw compost (straw husk ash, sawdust, water hyacinth, and prebiotic decomposers) improved the rice straw's growth, i.e., plant height and the number of tillers with higher yields (Nisa et al. 2019). Furthermore, *Tibouchina* biochar elevated soil mineral concentration (Mg, K, Ca, and Zn), decreased soil acidity, increased soil microbiome species richness, and improved cassava growth (von Gunten et al. 2019). Biochar improves soil structure, soil moisture content, while inorganic fertilizer adds value to a nutrient-deficient soil. Co-application of biochar and inorganic fertilizer could work in a synergistic relationship. A two-year study on an intensive rice–wheat cropping system showed that co-application of 25 t ha^{-1} biochar plus 270 kg urea ha^{-1} increased rice yield, N uptake, and NUE (Wang et al. 2019). Likewise, Brazil nut husk biochar (1 ton ha^{-1}) or biochar plus fertilizer improved seedling survival and growth of some tropical trees (Lefebvre et al. 2019). Thus, biochar could be valuable in returning nutrients to the agronomic and agroforestry system.

1.6 Fungi as a Source for Improving the Resource Use Efficiency of Crop Residue

Fungi represent a vital source of improving the supply of nutrients through the use of fermentation technology from available alternative feed resources. Several fungi such as *Phlebia brevispora*, *P. fascicularia*, *P. floridensis*, and *P. radiata* (Sharma and Arora 2011), *Aspergillus terreus* (Jahromi et al. 2011), *Pleurotus florida* and *Pleurotus eous* (Sivagurunathan and Sivasankari 2015), and *Pleurotus pulmonarius (*Ariff et al. 2019) have produced valuable materials or improved the nutritional quality, digestibility and decreased the lignin content of crop residues. Therefore, fungi could play a crucial role in enhancing the output derivable from crop wastes.

1.6.1 Fungi on Crop Residue Quality

Fungi grow on plant materials rich in cellulose and lignin because they can synthesize multiple enzymes such as ferulic acid, cellulase, lignases, amylase, glucoamylase, esterases, and peptidases. These enzymes have fiber degrading properties capable of effectively biodegrading feed materials. Solid-state fermentation of crop residues with filamentous fungi represents a low-cost method of upgrading the limiting nutritional content to feed grade quality by taking advantage of natural enzymatic secretions. In practice, exogenous enzymes from *Aspergillus* spp. and *Trichoderma* spp. improve feed digestibility, yet, they could be expensive and inaccessible to farmers in many countries. Fungal inoculation and fermentation could enhance the protein content and digestibility of low-quality crop residue. Fermenting cassava residue for 7, 14, and 21 days with fungi *Aspergillus oryzae* increased the protein content by 104, 140, and 246.6%, respectively (Hong and Ca 2013). The crude protein also increased as the fermentation days increased. This affords farmers the choice of increasing the protein content of crop residue as desired. Likewise, fermentation with *A. oryzae* FK-923 and *A. awamori* F-524 decreased acid detergent fiber, neutral detergent fiber, phenol, and lignin, and improved the amino acid microbial protein. Also, the enzyme activity such as cellulase, xylanase, amylase, glucoamylase, laccase, and phytase increased during digestion (Fadel and El-Ghonemy 2015). Further, the enhanced enzymatic activities broke down cell linkages, and the phytase increased the availability of P. The increase phytase activity will release available P that is chelated with phytic acid thereby preventing P pollution (Konietzny and Greiner 2002).

Lignin remains a significant deterrent to effective digestibility of crop residues. It limits the impacts of gut microbes and their enzymatic activity/secretion on the lignocellulolytic materials. Many crop residues are lignocellulosic at harvest time, which reduces ruminants' ability to derive nutrients efficiently. Corn straw inoculated with *Pleurotus ostreatus* increased crude protein, soluble protein, and carbohydrate and decreased neutral detergent fiber. In vivo trial increased average daily gain and decreased feed conversion ratio by 31.05 and 13.35%, respectively, in Pelibuey lamb (Ramírez-Bribiesca et al. 2010).

White-rot fungus (*Phanerochaete chrysosporium*) produces a strong ligninolytic enzyme with energetic oxidative efficiency (Liang et al. 2010) and can efficiently degrade lignin into CO_2 (Hofrichter 2002). The use of 0.007% di-rhamnolipid biosurfactant alongside white-rot fungus decreased lignin content in rice straw by 54%. The degradation was as a result of the establishment of terrace-like fragments separated from the inner cellular fibers and the release of simple compounds (Liang et al. 2010). The biosurfactant improves the spread of water into rice straw pores, enhancing mass oxygen transfer into large areas (Van der Meer et al. 1992: Fu et al. 2007). Therefore, as oxygen level increases, there is a production of hydrogen peroxide and this induces lignocellulolytic activity (Sanchez 2009).

1.6.2 Fungi on Greenhouse Gases Mitigation

There is a positive correction between high fibrous diet, and GHGs production. Therefore, there is a need to develop and implement feeding and management strategies that reduce GHGs and subsequently increase feed digestibility (Faniyi et al. 2019). Several herbs like neem (*Azadirachta indica*), garlic (*Allium sativum)*, moringa (*Moringa oleifera)*, weeping willow (*Salix babylonica*) and exogenous enzyme have been used as additives in either or both *in vitro* and *in vivo* studies to reduce CH_4 production. Despite the relationship between high fibrous diet and CH_4 emission, fungi fermentation of fibrous materials could play a central role in improving digestibility and mitigating CH_4 emission. For example, fermentation with *A. terreus* can produce anti-methanogenic metabolites known as Lovastatin (Jahromi et al. 2013).

Mohd Azlan et al. (2018) reported that rice straw fermented with *A. terreus* for 14 days decreased methanogens due to the lovastatin, decreased fiber fraction and improved the dry matter digestibility. *Aspergillus terreus* fermentation offers farmers the ability to produce an animal protein with a less environmental footprint, increase degradability of crop residues and the manure obtained can be used for making vermicomposting or biochar for further nutrients recovery. Also, brown rot (*Serpula lacrymans*) produced reducing sugar when used for fermenting cacao pod, rice straw, corn cobs and leaves, and sugarcane (*Saccharum officinarum*) bagasse (Nurika et al. 2019). This indicates multiple substrate metabolism, tolerance to phenol, and ability to break up lignin structures.

1.6.3 Edible Fungi (Mushroom)

Fungi improve the nutrient content and digestibility of human-inedible plant biomass. The growing edible mushroom provides farmers with the option of meeting human nutritional needs from human inedible. Edible mushrooms are an option to reduce waste and generate valuable materials in agriculture. Mushroom farming is an efficient way of converting low-quality organic materials to quality food with higher nutritional and economic value. Mushroom is a cheap source of balanced nutrition due to the stable mineral and vitamin composition, fiber and protein. The amino acid profile is better than potatoes and carrots (*Daucus carota*) (Mattila et al. 2002). Furthermore, it contains antioxidants, phenol, and antibacterial compounds that can enhance the immune system and reduce stress (Borchers et al. 2008; Zhou et al. 2010). Mushrooms market represents a multi-billion-dollar industry, and its consumption has increased by a minimum of 3.7 kg per capital post-millennium (Royse et al. 2017). The substrate left after mushroom harvest can be anaerobically digested for bioenergy, fed to livestock, or burnt for ash. Farmers can use different substrates such as palm oil bunch and sawdust, etc., to grow mushroom.

1.6.3.1 Mushroom Growth/Fortification with Animal Waste/By-Product

Improving the biological efficiency and quality of the mushroom depends largely on the nutritional balance of the substrate (Rizki and Tamai 2011). Edible mushrooms can be grown on human-inedible organic resources. Furthermore, edible fungi's nutritional value can be improved in the growth phase by biofortification with organic minerals. Biofortification of white-rot fungi and *Lentinus squarrosulus* has grown on either coconut husk or palm kernel fiber and fortified with Ca-rich animal waste (eggshell of chicken, snail shell, and the bone shaft of the cow) or Ca salts produced Ca-enriched mushroom with adequate K, protein, and dietary fibers with low fat (Ogidi et al. 2019). The calcium compounds in the organic substrate influenced the growth and development of mushroom by stimulating the hyphal apices (Royse and Sanchez-Vazquez 2003). Similarly, chicken manure alongside paddy straw increased (*Pleurotus florida* and *Pleurotus eous*) growth by 100–105 g 500 g^{-1}, biological efficiency by 20–21%, and the nutritional content (carbohydrate and protein) of mushroom (Sivagurunathan and Sivasankari 2015). This shows that chicken manure can be a source of N in mushroom farming. However, the pathogenic load must be reduced.

1.6.3.2 Mushroom Waste and Spent Substrates

Spent mushroom substrates could be used as livestock feed because they have high cellulose and smaller particles. The delignification caused by ligninolytic enzymes like crude laccase and manganese peroxidase is also advantageous (Ariff et al. 2019). One percent oyster mushroom added as a substitute for maize in broiler diet increased final body weight, feed intake and had humoral immunity similar to the control (Fard et al. 2014). About 1–2 tons of the highly degradable spent mushroom substrate are produced from every 1 ton of mushroom harvested (Vijay 2005). These spent substrates are rich in C and other nutrients, and the multi-enzyme mushroom residue makes them rapidly digestible. They could be used as materials during anaerobic digestion for rural energy needs. The co-digestion of cattle dung with 2% spent mushroom waste increased biogas production up to 30% (Malik et al. 2014). This increment in gas production might be due to the activities of dehydrogenase, which increased by 12.8%. Likewise, the enzyme residue naturally present in mushroom may have enhanced the degradation of organic matter in cow dung, giving access to more surface area for an anaerobic microbial breakdown.

1.7 Waste and Their Use in Livestock Feeding

Increasing NUE from existing feed resources or tapping new non-conventional feed resources represents a way to bridge the gap between the demand and supply of feedstuff (Wadhwa and Bakshi 2016). Agroindustry and agri-food processing wastes, kitchen and restaurant waste are common resources available in crop–livestock–industrial–human interactions. Agricultural waste streams are not to be considered nutrient debiting/loss, rather valuable resources (Grimm and Wösten 2018). Therefore, diverting food waste into feed can replace the cereal-based diet of livestock with human-inedible resources (NAS 2019). The use of these inedible human waste and human-edible-but-wasted products as livestock feed may be an efficient way to recycle nutrient to produce high-value consumable livestock products. However, using the kitchen, agronomic and agri-food wastes alone in monogastric diet represents a threat to protein and micronutrient security. Feeding livestock with only human-inedible feedstuffs will reduce global livestock meat from poultry and swine by 53 and 91%, respectively, and egg production by 90% (Schader et al. 2015).

1.7.1 Cassava and Fruit Waste

Inedible human materials constitute over 80% of global livestock feed (Mottet et al. 2017). Despite environmental issues, ruminant farming permits incorporation of human-inedible wastes into livestock diet without adverse effect on global beef and milk production. Cassava (*Manihot esculentus*) is widely grown in the tropics and is a source of different product such as starch, fuel, and flour products. In cassava processing industries, there are bioethanol cassava wastes—a lignocellulolytic material containing some dissolved solids (mainly starch and minerals) are available at low cost. The nutrient in it shows that it has the potentials to be used in livestock feed as a substitute to established materials. Partial replacement of a conventional protein source Holstein-Friesian calves' ration with yeast (*Saccharomyces cerevisiae*) fermented cassava bioethanol wastes at the rate of 5–20% did not negatively affect nutrient intake, nutrient digestibility, rumen fermentation characteristic (rumen pH, rumen microbes, and total volatile fatty acids) (Cherdthong and Supapong 2019). Similarly, fermented cassava bioethanol waste added to duck diet at the rate of 5% improved the average daily gain and reduced the feed conversion ratio (Lei et al. 2019). Therefore, incorporating fermented cassava bioethanol into livestock diet may reduce environmental pollution from cassava industry and improve values derivable from cassava.

Pineapple fruit residue can be a treasured local resource alternative or a complement to green fodder as livestock feed. Adding 62% ensiled pineapple fruit residue to cattle diet improved the final body weight, digestibility, increased total average milk yield and milk fat, and decreased feed cost per kg gain by 24.19% compared to maize green fodder silage (Gowda et al. 2015).

1.7.2 Antinutritional Factor/Plant Metabolite Removal

Tannins could have both positive and negative impact on livestock. Tannins could be an antinutritional factor and it could be a phytochemical additive that manipulates the rumen ecosystem, mitigates CH_4 emission, and reduces fecal egg count, etc. Many non-conventional feed ingredients that are rich in protein have limited use because of secondary plant metabolites. Therefore, there is a need for processes that will reduce the antinutritional metabolites. The treatment of wheat straw with tannase reduced tannin content by 49.7–91.1% and further fermentation of wheat straw with white-rot fungi (*Ganoderma* spp.) plus 0.1% tannase increased crude protein, acid detergent fiber, and lignin degradation by 28, 17, and 57%, respectively (Raghuwanshi et al. 2014). The acid detergent fiber (ADF) and lignin degradation may be attributed to the increase in laccase and xylanase enzymatic activity during fermentation. Therefore, pretreatment of tannin-rich unconventional ingredient with *Penicillium charlesii*—a tannase producing enzyme—could be used to decrease tannin. Further fermentation with well-established fungus species such as *Aspergillus* spp., *Pleurotus* spp., and *Trichoderma* spp., etc., could improve the crude protein and decrease the fiber fraction components. Such fermentation process could help to improve the use of ingredients within the "unconventional" categories.

1.7.3 Kitchen and Dairy Waste

Kitchen, restaurant, and party wastes are valuable feedstuff for animal nutrition. They are available at little to no cost depending on the location of acquisition. They consist of bones, pepper, and other food ingredients which qualify them as "a junk of nutrients." However, before use, there is a need to improve the nutritional quality and microbial safety of these wastes. Probiotics can be used to advance food processing and quality, and amino acid utilization by lowering protein degradation (Mikulec et al. 1999). Application of *Lactobacilli* group (*L. acidophilus*, *L. casei*, *L. plantarum*, and *L. reuteri*) in fermenting restaurant waste increased the gross energy (1.55–8.1%), crude protein (3.39–11.97%), as well as increased dry matter content of restaurant waste (Saray et al. 2014). The proliferation of *Lactobacilli* using the carbohydrate and N compound in the trash as a source of protein could have increased the microbial protein resulting in an increased crude protein of the material. Besides, *Lactobacilli* can produce metabolites such as bacteriocin hydrogen peroxide, lactacins, and reuterin (b-hydroxy-propionaldehyde) (Avall-Jaaskelainen and Palva 2005; Parvez et al. 2006; Takahashi 2013). These compounds have vast antimicrobial activity against pathogenic microbes and could inhibit the growth of competing microorganisms, leaving available free N for microbial growth. This processed restaurant waste could be fed to pigs and poultry.

Dairy production is one of the most valuable agricultural products sector that resource-poor farmers can participate without much capital. Milk is a readily available animal protein source to smallholder farmers that are into ruminant farming. During processing, milk liquid (whey) is produced due to the coagulation of total solids in milk, and it is eliminated in both formal and informal cheese-making industry. However, in Nigeria's informal market, whey is sold together with the raw cheese "wàrà." Whey is rich in proteins, mineral elements (Ca, P, and sulfur), vitamins, and sugars, including lactose). Therefore, the use of whey in livestock diet is a means of recovering P, protein, and other minerals. Application of dried whey powder as replacements for soybean at the rate of 25–100% in lamb's diet improved total body weight gain by 17.65–56.87% and decreased feed conversion ratio (Kareem et al. 2018). Therefore, whey could be added as protein alternatives in fish, poultry, pig, and ruminant diet. It could be used to wet swine feed or mixed with fish feed before pelleting.

1.8 Nitrogen and Phosphorus Recovery and Release

A system that allows increased output compared to input and at the same time provides an opportunity for the reuse of the output within the producing system increases nutrient use efficiency (Rufino et al. 2006). The amount of N and P lost in crop and livestock production systems indicate poor NUE in the agricultural production systems (Adegbeye et al. 2020). An oversupply of nutrients especially overfeeding in intensive systems, or imbalance between nutrients (Sutton et al. 2013) causes these. Nitrogen utilization efficiency in livestock is low and it is usually in the range of 5–45% depending on animal species, system, and management (Oenema 2006), while the rest are passed out in feces and urine. Over 80% of N and 25–75% of P used, if not stored in the soil, gets lost to the environment (Sutton et al. 2013), indicating low NUE in agricultural systems. To improve the NUE in agrarian operations, there is a need for precise application of minerals tailored towards crop and animal needs, and recovery and recycling of nutrients from livestock manure and human feces.

If human excreta were collected over the globe, it would consist about one-third of the current N, P, and K consumption (Ellen MacArthur Foundation 2013). Human urine consists of 13% C, 14–18% N, 3.7% P, and 3.7% K, whereas the feces consist of >50% C, 5–7% N, 3–5.4% P, and 1–2.5% K (Vassilev et al. 2010; Rose et al. 2015). Furthermore, about 3 Tg P out of 3–5 Tg P in human excreta annually seeps into the river through sewage leaks (Van Vuuren et al. 2010). It is also projected that N (6.4 Tg) and P (1.6 Tg) emission at the beginning of the millennium would have increased by 87.5–150 and 85–139.5%, respectively, in 2050 (Van Drecht et al. 2009). This will be due to increased human population and improved economic state of developing countries of Africa, Asia, and the Middle East, resulting in a transition from cereals-based diets to animal protein, fruit, and vegetables rich diets. This necessitates the need to turn human excreta to organic fertilizer and recover some nutrients from it. In many countries of Africa under energy deficit, the recovery of nutrient from human excreta and manure could be a source of energy and biofertilizer. Similarly, biochar of human feces could be a means of recovering N, P, and other micro-elements (Adegbeye et al. 2020). It will help to reduce the quantity of any nutrient that could be lost and increase the value derivable from organic resources. This biochar of human excreta should be incompletely pyrolyzed to enhance available N, P, and K to ensure maximum nutrient recovery before its use as a soil conditioner.

1.8.1 Phosphorus Use: Recovery and Release

Direct application of urine or manure slurries to soil decreases N-fixing ability of soil (Di et al. 2002) and it causes overapplication of P than is needed by crop (Burns and Moody 2002). Furthermore, the nonrenewable of rock phosphate, and the possibility of P shortage in the future call for the need to get P from another source, which might include the recovery from wastewater and manure. To reduce P pollution, precipitation of struvite could be a medium of recovering P from animal manure (Burns and Moody 2002).

Struvite is a mineral substance that contains an equimolar amount of Mg, ammonium, and phosphate ions, and is measured as a good P source (Barak and Stafford 2006). Precipitation of struvite occurs during supersaturation—where over three ions in wastewater exceed struvite solubility (0.2 g l^{-1}) (Barak and Stafford 2006) or at a pH between 8.5 and 9.5 (Uysal et al. 2010). A 1 to 0.5 ratio of cow urine to brine (inexpensive source of Mg) produced the best struvite, and the struvite was added at up to 2 g kg^{-1} of soil, it resulted in optimal growth of green gram (*Vigna radiata*) (Prabhu and Mutnuri 2014). If up to 40 g struvite is produced per liter of urine, up to 12,176 t of struvite could be produced in a day. This has the potential to be used as a good source of phosphate fertilizer. Similarly, application of nitric acid to dairy cattle slurry allows the recovery of P content in 2.5 h and anaerobic digesta in 48 hours by 100 and 90%, respectively, and further precipitation with Mg:N:P in ratio 1:1:1 at pH 8.0 resulted in the formation of—amorous Ca-phosphates—a potential fertilizer (Oliveira et al. 2016).

The use of phytase—a hydrolytic enzyme—to initiate the dephosphorylation of phytate (Abdel-Megeed and Tahir 2015) or decreasing the phytic acid in feed ingredient could be an effective way to reduce inorganic P excretion and accumulation on livestock farms. Therefore, as phytic acid decreases, an increase in phytase indicates improved availability of imbedded or inherent organic P. Wheat straw fermented with fungal *Aspergillus ficuum* at 30 °C increased phytase production by 22-folds and decreased phytic acid by 57.4% after 144 h of incubation (Shahryari et al. 2018). Thus, fermenting wheat straw or crop residues abundant in phytate before feeding them to livestock could increase the availability of organic P and decrease P excretion to the environment.

1.8.2 Controlled Release of Nitrogen

Controlled release of urea with the barrier to decrease its dissolution rate represents a way to minimize N losses from the field (Shavit et al. 2003). Low cost, nontoxic, and biodegradable suitable coating barrier could improve nutrient efficiency and, reduce the environmental risks (Tomaszewska et al. 2002). Application of bio-polymeric materials, such as lignin from waste lignin controlling N released from urea. The waste lignin modified by acetylation reaction—acetylated kraft lignin and sulfite lignin slowed the release of N by enhancing its hydrophobicity (Behin and Sadeghi 2016). This delayed water permeability and mineral release. Furthermore, the dissolution rate of urea decreased by 25–45% as coating material increased from 5 to 15%. This could be applied in coating other mineral compounds to control its release in livestock. For example, coated urea in the ruminant feed caused the controlled release of N in the rumen, thereby decreasing the N_2O emission and total GHGs emission potentiality (Reddy et al. 2019a, b).

1.9 Microlivestock Farming

Bushmeat (meat from animals in the wild) from a giant rat, antelope, cane rat, deer, monkey, and snails have always served as an alternative source of animal protein among rural dwellers. This contradicts the public opinion that rural dwellers lack animal protein. However, recent endemic diseases such as Ebola, Lassa fever, and Monkeypox in Nigeria were linked with consumption of bushmeat. As alternatives, domestication of some microlivestock in developing countries can serve as a means of improving protein security. Examples of microlivestock that could be reared are snails, grasscutter, and rabbit, etc. Rearing these animals requires fewer resources such as land, water, and feed. Sales of unprocessed or processed bushmeat empower women because it provides financial leverage and security. Meat from microlivestock such as grasscutter, snail, and rabbit commands premium price than beef, chevon, mutton, milk, and egg in Nigeria, etc. Therefore, rearing these animals could improve the use of land as agricultural resources (Fig. 1.6).

1.9.1 Snail Farming

Snail farming is also known as heliculture. The meat of snail is high in protein, Fe, Ca, Mg, and low in fat. Breeds of snail such as *Archachatina marginata* and *Achatina achatina* can be reared and fed with fruit waste and leaves, as well as other household and food processing by-product. However, they must not contain salt. Snails can be fed with concentrate, pawpaw (*Asimina triloba*) fruit, eggplant (*Solanum melongena*), banana (*Musa* spp.), plantain (*Plantago major*), tomatoes, cucumber (*Cucumis sativus*), palm fruits, maize chaff—a by-product of *ogi* extract, and potato peel, etc. This provides a means of improving the use of space on the farms by producing a high-quality protein that could be sold at a premium price, both

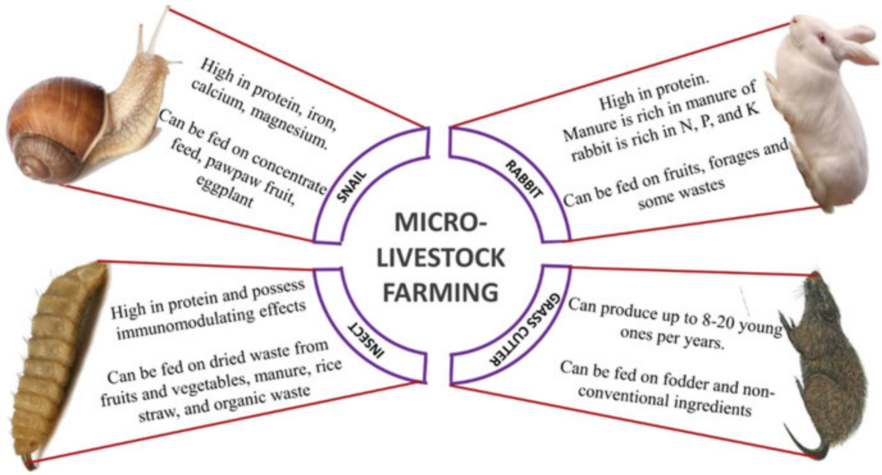

Fig. 1.6 Microlivestock farming

in Nigeria and West African regions. Their hermaphrodite nature permits them to reproduce quickly, laying up to 400 hatchable eggs. Setting up a snail farm is cheap; it could be raised in vehicle tire, drum, pots, old tanks, baskets, and cages.

1.9.2 Rabbits Farming

Domestication of rabbits is well documented. Rabbit production empowers women and children (El-Adawy et al. 2019). It offers smallholder farmer who cannot afford large livestock the chance to produce animal protein, as well as provide a source of fertilizer. The gestation period of a rabbit is short about 31 days and they are a highly prolific animal that can produce up to 5–10 bunnies per kindling. Rabbit can be fed fruits, forages, and some wastes that are not stale. Anecdotal observation indicates that it tastes better than chicken. Besides, the manure of rabbit is rich in N, P, and K so that it could be used as fertilizer. The N, P, and K in rabbit feces are 140, 75, and 53% higher than chicken manure, respectively (Lebas et al. 1996). Furthermore, Tabaro et al. (2012) reported that rabbit farming could be integrated with aquaculture reared in an earthen pond and the pond fertilized with rabbit feces produced higher fish mass and fish-net production.

1.9.3 Grasscutter

Grasscutter (*Thryonomys swinderianus)* farming is highly profitable. The grasscutter reproduces quickly and in good numbers. Grasscutter has a gestation period of 140–150 days and can produce up to 8–20 young ones/years, and an adult, it can reach up to 3–6 kg. They are herbivores, as such; they can be maintained on cheap materials such as elephant grass (*Pennisetum purpureum*), guinea grass (*Megathyrsus maximus*), sugarcane, gamba grass (*Andropogon gayanus*), root and pitch of oil and coconut palm, pawpaw, groundnut, cassava, etc. Financially, grasscutter commands a premium price in a big restaurant. Other non-conventional ingredients can be used to formulate the diet of grasscutter. Edoror and Okoruwa (2017) fed grasscutter with cocoa bean (*Theobroma cacao*) shell and cocoyam (*Colocasia esculenta*) peel as a replacement for grass, i.e., CS30 (30% cocoa beans shell + 40% cocoyam peel and 30% concentrate diet) and CS40 (40% cocoa bean shell + 30% cocoyam peel and 30% concentrate diet). The CS30 and CS40 had final bodyweight that is 6 and 24.81% higher than control diet and lower feed conversion ratio.

1.10 Phytotherapy

Phytotherapy is the application of the phytochemical's existent in the plant for health benefits in animals. Phytotherapy provides a means of improving the health and growth performance of livestock among farmers that cannot afford drugs and veterinary services. Furthermore, the use of phytogenic feed additives to improve growth performance and feed digestibility also plays a part in RUE. For resource-poor farmers, the use of herbs from local plant serves as alternatives to expensive and inaccessible commercial anthelmintic. These plants may be referred to as nutraceuticals based on health benefit derived from them rather than a direct contribution to animal nutrition (Waller and Thamsborg 2004). Frequent applications and improper dosage result in the ineffectiveness of acaricidal and antihelminth. Furthermore, the interest of consumers to go "green" in most of their consumables has drawn attention to the agelong but abandoned practices of using herbs for animal's health benefit. This practice known as ethnoveterinary medicine draws inspiration from traditional practices where the range of plant(s) or plant extract suitable for treating almost every parasitic disease of livestock is used (International Institute of Rural Reconstruction 1994). Diseases that phytochemicals seek to address are both internal and external parasites such as helminths, mange, ringworms, mastitis, foot rot, etc. (Table 1.1).

Several plants from both agronomic, botanical and agroforestry system in the form of herbs, seeds, root, and barks have been used in treating livestock. Neem and pawpaw seed were able to decrease the population of parasitic egg in poultry chicken (Feroza et al. 2017). In Nigeria, Usman (2016) reported that nomadic farmers use herbs, stems, seeds, leaf extract to control diarrhea, fever, ringworm, mastitis, mange, poor milk let down, foot and mouth disease through topical, oral, or feeding to animals. In small ruminants, intestinal worms such as *Haemonchus contortus*, *Strongyloides* spp., and *Trichostrongylus* spp. are prevalent parasites, and herbs can control them. Ameen et al. (2010) reported that both aqueous extract and the dry seed of pawpaw decreased *Haemonchus contortus*, *Trichostrongylus* spp., *Strongyloides* spp., and *Ostertagia* spp. population in West African Dwarf sheep. Adebayo et al. (2019) report that 10% inclusion of scent leaf (*Ocimum gratissimum)* in the diet

Table 1.1 Summary of plants influence on pathogens

Pathogen	Animal species	Plant parts	Form	Quantity	Effects	Reference
Not specified	Zebu cattle (*Bos taurus indicus*)	Neem leaf and Ata leaf (*Annona reticulata*)	Powder	200 mg kg^{-1}	84–95% decrease in fecal egg count in 28 days	Sarker (2014)
Haemonchus contortus	Sheep	Neem, Tobacco (*Nicotiana* spp.), *Calotropis procera* flower, and *Trachyspermum ammi* seed	Aqueous herbal formulations	2 g and 4 g kg^{-1} body weight	Decreased fecal egg count by 91.6 and 96.2% after 15 days	Zaman et al. (2012)
Mixed nematode (*Haemonchus contortus*, *Trichostrongylus* spp., *Oesophagostomum columbianum*, and *Trichuris ovis*)	Sheep	*Trianthema portulacastrum* whole plant and leaves of *Musa paradiasiaca*	Crude aqueous methanolic extract	8 g kg^{-1}	Decreased the fecal egg by 85.6 and 80.7%, respectively, on 15 days post-partum	Hussain et al. (2011)
Gastrointestinal nematode	Goats	Neem, pineapple, bitter gourd (*Momordica charantia*), and clove (*Syzygium aromaticum*)	Ethanol extract	100 mg kg^{-1}	73–83% decrease against gastrointestinal nematodes in goats within 9 days	Sujon et al. (2008)
Eimeria spp., *Trichostrongylus* spp., and *Strongyloides* spp.	Grazing goat	Neem seed extract and garlic extract	Extract mixed with feed bock	1.5–3 and 2%, respectively	Decreased Eimeria spp., by 51–93%, *Trichostrongylus* spp. by 3.8–35%, and *Strongyloides* spp. by 54–73% in 60 days	Sales et al. (2016)
Rhipicephalus (*Boophilus*) *microplus*	In vitro	A methanol extract of pawpaw seeds		100 mg ml^{-1}	Killed over 80% of their larvae and over 90% adults in 15 days, inhibited egg mass per replicate	Shyma et al. (2014)

reduced fecal worm egg count in west African dwarf goat. The reduction in the counts of goat fed scent leaf diets could be attributed to the presence of antinutritional factors especially tannin and phenols—which can control some endoparasites in animals (Butter et al. 2001).

Grazing animals and those in an extensive system of ruminant production are mainly affected by worm and other parasitic infestation. To control this parasitic infection requires regular treatment with anthelmintic. Applying herbs in block licks could help reduce the population of these endoparasites. In application, herbal extracts with anthelmintic potential could be added during mineral and salt lick production as a means to control internal parasites (Sales et al. 2016).

Ticks are economically significant parasites in the tropics and subtropics and are prevalent in wet seasons (Bram 1983). Besides their potential to cause anemia, their sites of binding could cause injury to animals and be a source of secondary infections. However, prolonged use and overuse of chemical ectoparasites resulted in the large-scale development of resistance in these parasites (Adenubi et al. 2016). Extract of pawpaw seeds inhibits egg mass per replicate and oviposition, prevents the reproduction of tick (*Rhipicephalus* (*Boophilus*) *microplus*) and killed over 80% of larvae (Shyma et al. 2014). This shows that topical application of such extract could be used to control tick both in the rainy and dry season in tropical regions where nomadic farming is still in practice.

1.11 Conclusions

The sustainable practices in agriculture of today will be essential for food security. To ensure food security in developing countries of the world, smallholder farmer must be given feasible options that would help them in providing nutrient from their soil and ensure that nutrient in the agricultural system continues to flow in circular manure through the coupling of crop and livestock system even if they are spatially apart. In the agricultural industry, nutrient recovery and recycling remain the feasible option than is economical, eco-friendly, easily adoptable, and multi-beneficial to farmers and livestock feeding. Insect farming, anaerobic digestion, wastewater reuse, composting, vermicomposting, biochar, fungal intervention, and microlivestock farming are options that could aid the reuse and even add values to waste generated in the agricultural system. Tremendous cooperation will play an imperative role in developing the recovery of phosphate from urine and also the development of portable or fixed biogas chamber for anaerobic digestion. These options will ensure that smallholder farmers can increase the efficiency of essential agricultural resources—land, water, and nutrients.

1.12 Future Perspectives

Resources distribution/availability towards agriculture will continue to shrink as other industries compete for the same agriculture related bio-resources for agriculture and livestock feeding. This chapter provides insight into the enormous benefits that could be derived from recycling waste. Wastes in agriculture may not be a “bad” thing but rather, an opportunity to convert organic materials to other forms. We reckon that through the transformation of wastes or linkage of wastes from one agricultural system to the other, nothing will be termed as waste. Smallholder/resource-constrained farmers will find great potential in collaborating on the use of by-products as rich resources. Large-/medium-scale farmers can turn waste to economically valuable resources through biochar, water recycling, composting, mushroom production, and nutrient recovery. Due to the scarcity of water resources in regions, agriculture-industry wastewater can be redistributed after applying minimal treatment to convert it into valuable irrigation resources in the future. Similar, human and animal wastes could be a source of fertilizer and raw materials for mining nitrogen and phosphorus. The nitrogen and phosphorus obtained from it may not be as the common inorganic fertilizer as we know it today, but if these minerals are mined from both human and animal feces, they could reduce environmental pollution. Besides, vermicomposting and composting processes can serve as an alternative to inorganic fertilizer or can work in synergy with inorganic fertilizer thereby reducing the quantity of inorganic fertilizer used. Furthermore, microlivestock is of great potential as it will bring “the wild” nearer to consumers and help to reduce encroachment into the wild thereby reducing the dangerous wildlife are exposed to in the hand of a poacher. Similarly, due to the controlled condition of rearing it will reduce the chance of zoonotic diseases. Finally, microbes especially fungi have an enormous role in ensuring resource use efficiency. The roles range from enhancing rumen degradation, food production in mushroom, greenhouse gas mitigation, increasing the nutritional value of food by decreasing common antinutritional factors in plants. Increasing the reuse or recycling of agricultural system wastes through redistribution, recovery, value addition, etc., will improve nutrient use efficiency. However, nothing is a waste in agriculture.

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