Bio-Waste Management in Subtropical Soils of India: Future Challenges and Opportunities in Agriculture

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Abstract

The rapid growth in population, food production, urbanization, and industrialization has accelerated the generation of bio-waste material such as crop residues, animal waste, and municipal solid waste. They wield tremendous impacts on soil health, climate change, and overall environment with pronounced ramifications for developing countries like India. In addition to the previously mentioned challenges, overexploitation of soil is causing the second-generation problems of nutritional disorders, decline in productivity, global warming—driven climate change, pollution, and so on. Therefore scientific and logical recycling of organics is of prime importance to eradicate the huge piles of bio-waste material in agriculture. It will, firstly, be of benefit to minimizing environmental pollution and, secondly, improve crop productivity, soil carbon status, and soil health in general. Contrary to this, unscientific management of organic waste hold disadvantages such as losses of essential plant nutrients, greenhouse gas emissions (GHG), heavy metal contamination and development of sporadic pathogens harmful to animals and plants. The prime focus of this review is to signify the current prospects of organic waste management in India and their potential in agriculture. The article has comprehensively elaborated on GHG, fertilizer consumption, food grain production, nutrient removal by crops, and constraints of waste recycling. This review further emphasizes through future research needs the need to advance our knowledge regarding bio-waste management, so that we better understand and implement efficient waste management. It is also pertinent to develop a sustainable and eco-friendly agricultural practices so that organic resources mainly in the form of crop residues, animal waste, and municipal solid waste are utilized.

1. INTRODUCTION

The burden on climate change such as abrupt rainfall pattern, alteration of maximum and minimum mean annual temperature and inflow of solar radiation are increasing globally; these will inevitably impact on land use patterns. Agriculture is the major use of land throughout the world comprising approximately 1.2–1.5 billion ha cropland and 3.5 billion ha of pasture land (Howden et al., 2007). Agriculture depends heavily on steady water supplies, different land use, and management practices. Nevertheless, climate change is likely to disrupt those supplies through floods and droughts. Increased warming may also have a greater effect on countries whose climate is already near or at a temperature limit over which yields reduce or crops fail in the tropics or subtropics. One of the most critical questions regarding climate change is how it would affect the food supply for a growing global population particularly for developing countries. For example, India's population has remarkably expanded from 369.88 million (in 1947) to 1173.10 million by 2010 and expected to be more than 1460.74 million by 2030 and 1656.6 million by 2050 with the population growth rate of 1.2% in India (Anonymous, 2017, Fig. 1). Similarly, the world's population is expected to reach 9.7 billion by 2050, 34% higher than current population (7.3 billion) as projected by the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (UNDESA, 2015).

It has been suggested that higher latitudes may become productive due to global warming, but the soil in the Arctic region and bordering territories is very poor, and the amount of sunlight reaching the ground in summer will not change because it is governed by the tilt of the earth. Agriculture can also be disrupted by wildfires and changes in seasonal periodicity, which is already taking place, and changes to grasslands and water supplies could impact on grazing and welfare of domestic livestock. Now, researchers have been overlooking the two key human responses to climate changes, specifically (1) how much land people choose to farm and (2) the number of crops that will have an impact on agriculture in the future. Crop yields have already been affected by these changes to some extent, but it is not clear if future changes will be catastrophic or not. It could affect crop growth and quality, livestock health, and pests.

Furthermore, urbanization will continue at an accelerated pace and time. In order to feed this larger, more urban, and richer population, annual food

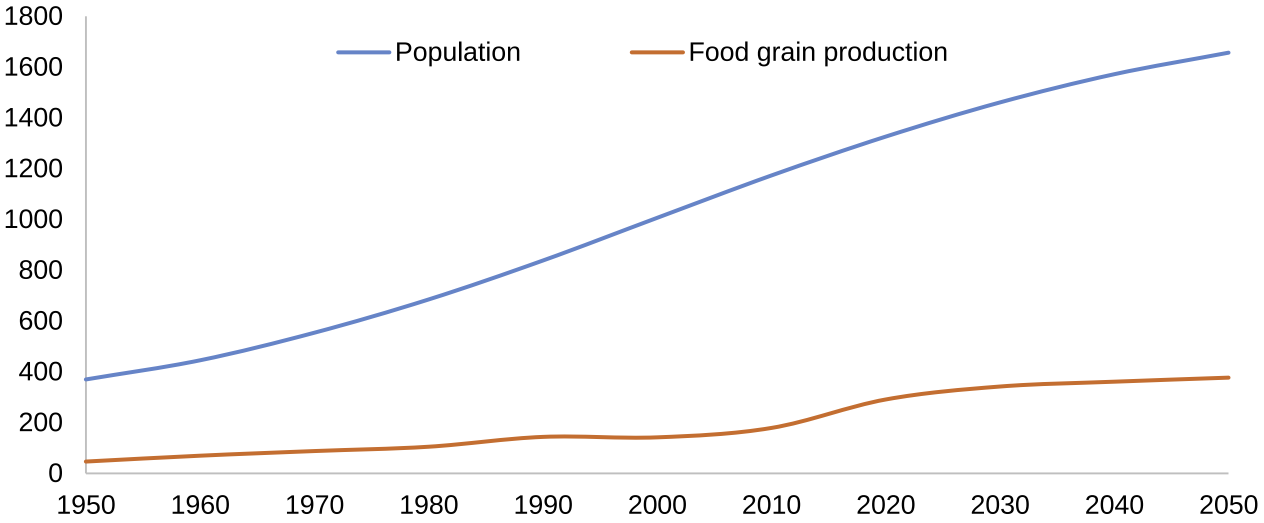

Figure 1 Population (million) and food grain production (million tonnes) in India over year. *Source: Anonymous, 2015. The Projection of World Population by 2050. Department of Economics and Social affairs of the United Nations Secretariat (UN DESA report, 2015); Anonymous, 2017. Population Estimates for India for Each Year from 1950–2050. The mid-year population estimates are from the United States census Bureau, www.bluemarblecitizen.com/worldpopulation/India; Goyal, S.K., Singh, J.P., 2002. Demand versus supply of food grains in India: implications to food security. In: Paper Presented in 13th International Farm Management Congress on "Feed the World- Please the Consumer-maintain the Environment"Wageningen, The Netherlands, pp 1–21; Amarasinghe, U.A., Shah, T., Turral, H., Anand, B.K., 2007. India's Water Future to 2025–2050: Business-as-usual Scenario and Deviations IWMI Research Report 123. International Water Management Institute, Colombo, Sri Lanka, pp. 47.*

grain production will need to rise severalfold than the current one. In fact, India has the second largest amount of agricultural land in the world, and it produced 252.68 million tons of food grain during 2014–15. Moreover, to project the level of future demand, food grains supply and past growth trends have been extrapolated. These are expected to be about 291, 342, and 377 million tons by 2020, 2030, and 2050, respectively (Amarasinghe et al., 2007; Goyal and Singh, 2002). A dramatic improvement has occurred in Indian agriculture during last few decades; its impact has been visible and subsequently documented with reference to national food production where natural resources like land, water, and genetic diversity have been used better. Now, however, we are witnessing the second-generation problems due to intensive cultivation, imbalanced use of fertilizers with rare application of organic manure, emerging soil nutrient depletion, and visible nutrients deficiency symptoms in many crop plants. These are occurring due to disparity between the removal and addition of nutrients to the soil (Manna et al., 2012b; Rao and Reddy, 2005). Moreover, development of soil sickness and disproportionate growth of soil biodiversity (Batra and Manna, 1997) and soil salinity, alkalinity, and acidity are also magnifying the soil health deterioration in the long term. As well, erosion, desertification, lowering of water table, climate change and lack of required genotype, loss of tropical forest, and biodiversity are clear indicators of poor sustainability of the production system (Bhattacharyya et al., 2012; Mandal and Sharda, 2011; Pathak et al., 2010). For these reasons, investments in maintenance of natural resources and rehabilitation are needed to strengthen food security, sustain ecosystem services, and to minimize the alarming rates of the previously mentioned indicators; doing so will holistically help to make use of land, water, and genetic resources more sustainable and productive. The reasons are fairly well known, and the questions are how can we protect, restore, and sustain the natural resources like soil and water in particular for better ecosystems services in the long run.

The key question is whether present average yields can continue to meet the burgeoning food demand and at the same time maintain food security. However, prior experiences indicated nearly stagnant yields for coarse grains including rice and wheat (Ladha et al., 2003; Manna et al., 2005). Similar evidence seems to hold for other major food crops grown in India such as soybean, sugarcane, and so on, whose yields continue to decline according compared with past trends (Manna et al., 2013a,b; Phalke et al., 2014). Consequently, we need to give more prominence to developing best bet management practices that serve to mitigate the greenhouse gas (GHG) emissions, sustain higher production with minimal soil environmental degradation to meet the projected increase in food security prospects, and curb the overwhelming pressure on natural resources (soil, air, and water) over the very long-term (20–50 years).

A crucial challenge is to manage organic matter for protecting the soil. Soil security has been a major concern with respect to maintenance and improvement of the global soil resource to produce food, fiber, and fresh water, contribute to energy, climate sustainability, biodiversity protection, and ecosystem service delivery, in order for the human race and the planet earth to survive well into the future and sustainably (McBratney et al., 2014). In general, organic carbon plays a multifunctional role in soil such as regulating nutrient supplies to plants, buffering, filtering, restoring, and maintaining soil health (Manna et al., 2012a). Their efficient management is indispensable for the sustainability of production in different cropping systems. Considering the global demands and escalating costs of chemical fertilizers: first, the use of biodegradable organic sources including manures, composts, crop residues (CRs), and municipal solid waste (MSW) is rapidly increasing; and secondly, their share in agricultural land use and farms continues to grow in many countries.

Despite all the management strategies attempted to date, a sharp decline in soil organic carbon (SOC) content has been reported mainly in tropical and subtropical climates. This has resulted in a decline in yield and productivity of various cropping systems (Manna et al., 2005, 2013b). The data in Table 1 show a decline in SOC concentration of cultivated soils by 30%–60% compared with the antecedent level in undisturbed ecosystems. The amount of SOC in Indian soils is relatively low, less than 0.5%–1%, cutting-edge on soil fertility, microbial activity, and physical condition (Swarup et al., 2000). The key question is "are organic sources sufficient enough to supply nutrients at desirable levels in Indian agriculture without sacrificing bio-energy production and cultivation of crops?" If the answer is yes, it needs to be ascertained where the available sources are and critically examine their potential, plant nutrient values to sustain soil health for better nutrient supply in the long run.

A major source of the global fluxes of the GHGs including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) is agriculture which contributes up to 10%–20% of total global GHG and organic matter may provide a major source for all these gases (IPCC, 2007). Despite a number of reviews having examined the GHG emission from agricultural soils, no comprehensive reviews have been done on the contribution of organic application from different sources of GHG emissions.

Table 1 Depletion of SOC Concentration of Cultivated Compared With That in Undisturbed Soils of India

	Region SOC Content (%)		
Regions	**Cultivated**	**Undisturbed**	**Percent (%) Reduction**
1. Northwest India			
(a) Indo-Gangetic Plains	0.42 ± 0.09	1.04 ± 0.36	59.6
(b) Northwest Himalaya	2.43 ± 0.87	3.45 ± 1.16	29.6
2. Northeast India	2.32 ± 1.04	3.83 ± 2.33	39.4
3. Southeast India	2.96 ± 3.01	4.37 ± 2.34	32.3
4. West coast	1.32 ± 0.81	1.86 ± 0.21	29.1
5. Deccan Plateau	0.77 ± 0.41	1.79 ± 0.76	57.0

SOC, soil organic carbon.
Source: Manna M.C., Bhattacharyya P., Adhya T.K., Singh M., Wanjari R.H., Ramana S., Tripathi A.K., Singh K.N., Reddy K.S., Rao A.S., Sisodia R.S., Dongre M., Jha P., Neogi S., Roy K.S., Rao K.S., Sawarkar S.D. and Rao V.R., Carbon fractions and productivity under changed climate scenario in soybean—wheat system, Field Crops Res. 145, 2013b, 10—20; Swarup, A., Manna, M.C., Singh, G.B., 2000. Impact of land use and management practices on organic carbon dynamics in soils of India. In: R. Lal et al. (Ed.), Global Climatic Change and Tropical Ecosystems. Adv. Soil Sci. CRC Press, Boca Raton, FL, pp. 261—281; modified from Jenny, H., Raychaudhuri, S.P., 1960. Effect of Climate and Cultivation on Nitrogen and Organic Matter Reserves in Indian Soils. ICAR, New Delhi, pp. 1—126.

Till now, no systematic reviews or meta-analyses have summarized the evidence on availability of bio-organics from CR, animals, and MSW, their nutrient potential for crop production, and organic farming in particular and bioenergy, GHGs emission, and crop production in the Indian context. Keeping the previously discussed facts in view, our objective was to conduct a qualitative systematic review and meta-analyses of the evidence on the relationship between CR, animal waste, and municipal city waste management. Furthermore, local constraints without quantitative pooling of study results and future research priority will be evaluated in this review. The article then aims to highlight the nutrient potential of different sources of organics and factors influencing soil health without minimum environmental degradation (soil, air, and water pollution) and the management practices to mitigate the emissions. The aforementioned discussion may create the impression that there are no land constraints to increasing production because land constraints can be significant at the country or regional level. The review also underlines the strength—weakness—opportunity—threat (SWOT) analysis of organics for use in agriculture and highlights the future research scope for maximizing the benefit of organic matter application to restore soil health and explore the strategies to mitigate GHG emissions from different sources of organic matter.

2. METHODOLOGY

The systematic search and review processes were conducted in accordance with the preferred reporting items such as both research and review articles available on the Web of Science database. The following keywords were used: "crop residue," "animal waste," and "municipal solid waste management," although the quality and quantity evidence on horticultural waste were not evaluated in this search. However, we did search Google Scholar for relevant information from other sources for inclusion in the present review. The search period was between January 1956 and June 2016. There were no language restrictions. In addition, we manually reviewed 419 references listed from original research and review articles, as well as investigators' files. The search strategy in the flowchart describes the selection process summarized in Fig. 2, aiming to identify all studies assessing the following: the potential sources of different bio-waste management in India and their nutrient potential total nitrogen, phosphorus and potassium (NPK) in particular; the relationship between fertilizer consumption, removal of NPK, and food grain production; methods of waste management; SWOT analysis; bio-energy production from waste; and

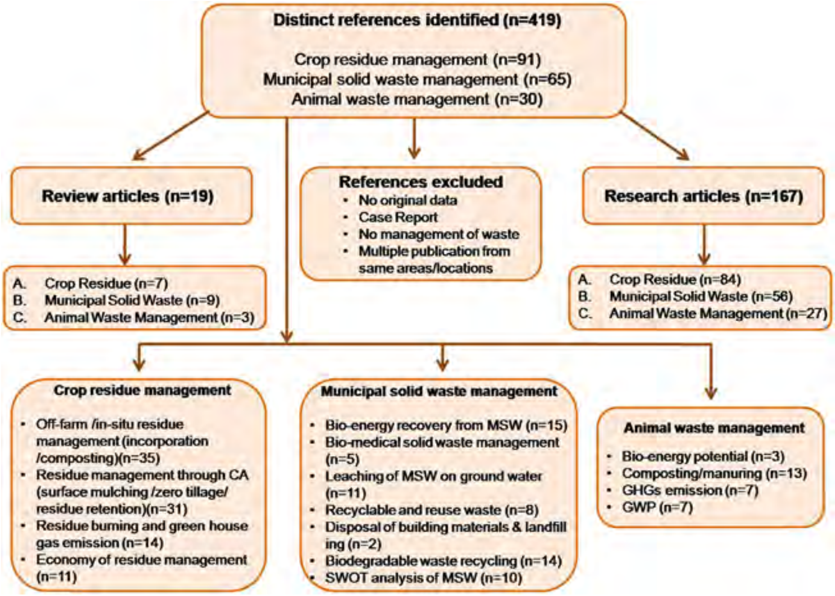

Figure 2 Summarized selection strategy of searched references of Bio-waste management.

waste exposure using environmental measures (including heavy metal contents, GHGs emissions, etc.). Our exclusion criteria were, first, publications containing no original data (abstracts, editorials, and nonresearch letters); second, case reports; third, no management of waste; and fourth, multiple publications from the same areas/locations. While reviewing the relevant studies, horticultural waste management and nutrient potential were not found, and consequently, we presented the data from other sources for descriptive purposes. Considering the importance of CR management, we observed four exposure categories, namely (1) off-farm/in-situ residue management; (2) residue management through conservation agriculture (CA); (3) residue burning and GHGs emission; and (4) economics of residue management.

To assess MSW management, we evaluated the following evidence this being: (1) bio-energy recovery from MSW, (2) bio-medical solid waste management, (3) leaching of MSW on groundwater, (4) recyclable and reuse waste, (5) disposal of building materials and landfilling, (6) biodegradable waste recycling, and (7) SWOT analysis of MSW.

Our inclusion criteria for animal waste management were (1) bio-energy potential, (2) composting/manuring, (3) GHGs emission, and (4) contribution of animal waste to global warming potential (GHG). We reviewed the research articles for each study: authors, journal, year of publication, country, study design, and other critical comments on the subject of more flexible waste management in India.

3. PRESENT SCENARIO OF BIO-WASTE MANAGEMENT IN INDIA

In this section, we look at those studies investigating the unscientific management of major sources of organic waste. These sources mostly occur in the form of CR, livestock, city waste, and horticultural waste.

3.1 Current Prospectives of CR Management

In this section research findings related to residue management are summarized in Fig. 2, which provides the following information with the reference listed in parentheses. A total of 91 published studies (including seven reviews) meeting our inclusion criteria for CR management are all concerned with off-farm/in-situ residue management (direct incorporation/composting). This has an effect on improvements of soil fertility, soil's physical properties, crop yields, and SOC. Furthermore, residue management is an integral aspect of CA, particularly tillage (residue retention [RR], zero tillage [ZT], minimum tillage) and surface mulching. The consequences of tillage and mulching on soil quality, yield improvement, and soil physical properties have been discussed. The effect of burning of residue (cereals, sugarcane trash, cotton stalk, pigeon pea stalk, and so on) on SOC storage, soil quality, crop yields, and GHG emissions (cereals, sugarcane trash, cotton stalk, pigeon pea stalk, etc.), and the economy of residue management have also been examined.

3.1.1 Off-Farm/In-Situ Residue Management (Incorporation/Composting)

The results of the existing studies (Fig. 2), a total of 28 analyses (Aulakh et al., 2001a, 2001b; 2012; Bandyopadhyay et al., 2010; Benbi and Senapati, 2010; Das et al., 2008, 2014b; Davari et al., 2012; Gangwar et al., 2006; Ghosh et al., 2010; Hajra et al., 1992; Jalota et al., 2008; Kuotsu et al., 2014a, 2014b; Manna and Ganguly, 1998; Pandiaraj et al., 2015; Paul et al., 2014a, 2014b; Saha and Ghosh, 2013; Sharma and Behera, 2009; Sharma et al., 2010; Singh et al., 2004, 2007; Surekha et al., 2003; Thuy et al., 2006; Tripathi et al., 2007; Walia et al., 2010; Yadav, 1997) were on direct incorporation of CR management (*in-situ*). Meanwhile seven studies (Arunachalam et al., 2003; Chaudhary et al., 2015; Hajra et al., 1994; Manna et al., 2001a; Maruthi et al., 2008; Sharma et al., 2016; Sodhi et al., 2009) looked at *off-situ* residue management, for example, composting/manuring on SOC and soil chemical and physical properties and crop productivity. Most of the studies were conducted on the Indo-Gangetic Plains (IGP) where the rice—wheat cropping system was operating. It is a major contributor to India's total cereal production, occupying about 10.3 M ha area and accounts for 23% and 40% of the nation's total rice and wheat area, respectively (Ladha et al., 2003).

Studies were also included from the rice—maize, groundnut-rapeseed, rice—potato—sorghum, and sugarcane-fallow system. The agro-eco-regions in these analyses were sub-humid tropical, sub-tropical, semi-arid-subtropical, hot humid-subtropical, and so on. It was concluded that direct incorporation of CR improved SOC and soil quality (Aulakh et al., 2001b; Benbi and Senapati, 2010; Das et al., 2014b; Kuotsu et al., 2014a; Pandiaraj et al., 2015; Saha and Ghosh, 2013; Sharma et al., 2010, 2016; Tripathi et al., 2007). Also, the physical properties of soils were enhanced, for instance, reduced bulk density, improved infiltration rate, water stable aggregates (Bandyopadhyay et al., 2010; Das et al., 2008; Ghosh et al., 2010;

Kuotsu et al., 2014b; Maruthi et al., 2008; Walia et al., 2010). It also improved soil respiration and microbial activities and enhanced biological health of soil (Arunachalam et al., 2003; Aulakh et al., 2012; Chaudhary et al., 2015; Das et al., 2008; Jalota et al., 2008; Phalke et al., 2016; Sharma et al., 2010; Singh et al., 2007; Surekha et al., 2003; Yadav, 1997) with a concomitant increase in crop productivity. Additionally, three studies were conducted in a hot-moist semi-arid region under a finger millet—groundnut, groundnut—castor and rice—fallow system in Alfisols. They concluded that incorporation of residue substantially improved crop yield and soil quality (Pandiaraj et al., 2015; Sharma et al., 2016; Surekha et al., 2003). Three other studies employing internal comparisons in per-humid regions of north-east India (Kuotsu et al., 2014a, 2014b; Ghosh et al., 2010) under the groundnut-rapeseed and rice-vegetables system (Das et al., 2014b), concluded that incorporation of residue is better than ZT in terms of SOC improvement and soil health.

3.1.2 Residue Management Through CA (Surface Mulching/ZT/RR)

Of 31 studies, 21 research articles have been undertaken in a range of agro-ecological regions in India for residue management through CA, for example, minimum tillage/ZT/RR (Bhattacharyya et al., 2009; Blaise and Ravindran, 2003; Das et al., 2014a, 2014b; 2014c; Gathala et al., 2014; Gupta et al., 2014; Hari et al., 2013; Hati et al., 2015; Jat et al., 2014, 2015; Patil et al., 2016; Prasad et al., 2016; Sandeep et al., 2016; Sepat et al., 2015; Sharma et al., 2011; Shekhawata et al., 2016; Singh et al., 2014, 2015a, 2015b; 2016). Four studies compared *in-situ* residue incorporation with RR for SOC storage and crop productivity (Gangwar et al., 2006; Ghosh et al., 2010; Sharma et al., 2016; Tripathi et al., 2007). Another six articles reported the benefits of residue mulching on moisture retention, nutrient transportation, reduced evapotranspiration, and minimizing the weed population (Dahiya et al., 2001; Grace at al., 2013; Laik et al., 2014; Parihar et al., 1996; Singh et al., 2012; Yadav et al., 2009). The main principles of CA are minimal soil disturbance, retention of CR mulch, and a rational use of crops in rotations, along with profitability at the farm level. These principles are increasingly recognized as essential for sustainable agriculture. The common practices are continuous cultivation of rice—wheat in rotation, intensive cultivation, and complete removal of CR for animal consumption, direct burning, and fuel that have reduced the organic matter content and productivity of irrigated semi-arid subtropical soils of India.

The CA-based component technologies such as ZT or reduced tillage (RT), crop RR on the soil surface met our inclusion criteria (Fig. 2). Most of these studies concluded that ZT and RT improved crop yields ranging from 5% to 30% (Jat et al., 2015; Prasad et al., 2016; Shekhawata et al., 2016; Singh et al., 2015a, 2015b; 2016) under maize—pea, caster bean—mustard, pearl millet—mustard, finger millet—pigeon pea, rice—maize, potato—wheat, and cotton—wheat in Vertisols, Alfisols, and Inceptisols. The CA has positive benefits in terms of enhanced productivity and reduced cost, increased physical, chemical, and biological health of soils under different soil types, and climatic conditions (Hati et al., 2015; Hari et al., 2013; Sandeep et al., 2016; Singh et al., 2014). It was concluded that residue management through CA is one of the pathways for improving productivity, income, and food security while at the same time sustaining the natural resources in smallholder production systems (Laik et al., 2014). CRs are an integral part of rural livelihoods. Their utilization provides coherence to the prevailing smallholder crop—livestock systems, being important sources of livestock feed for the dominant species in the region and sometimes having other productive uses such as fuel and construction materials.

3.1.2.1 Residue Burning and GHG Emissions

There is a broad consensus that straw burning should be avoided. However, this practice is common in IGP in many parts of India. One option is recycling in soil, but this will simply increase the workload and lead to imbalanced nutrient inputs. The second most prevalent residue is sugarcane trash which is an important cash crop in Indian agriculture, occupying 2.5% of India's gross cropped area and sharing 7% of total value of agricultural output (Phalke et al., 2016). It is the second largest agro-based industrial sector next to cotton textiles. Currently, sugarcane growers are facing problems such as decline in productivity, soil health deterioration, improper management of farm CRs, and indiscriminate waste disposal in sugar factory. The common practice of farmers is either burning the residues or removal of stubble from the field. Trash is usually burnt which results in potential loss of useful plant nutrients. Of 14 articles, six studies carried out on residue burning and GHG emissions (Gurjar et al., 2015; Lenka et al., 2014; Padre et al., 2016; Pathak and Wassmann, 2007; Paul et al., 2014a; Sapkota et al., 2015), while three studies compared both residue management on CA for improvement of soil health and the consequences of residue burning on GHG emissions (Aulakh et al., 2001a; Kuotsu et al., 2014a; Singh et al., 2012). In 2000

India's total contributions toward the world's total CH_4 and N_2O emissions were ~4.7% and ~2.8%, respectively; of which as much as ~3.2% and ~2.7% were contributed to by the Indian agriculture sector alone (Bhatia et al., 2004). In recent years, residue burning has been calculated from CR, and the conclusion reached was that the emission of 379 Gg C was equivalent for India, and 14 Gg C was equivalent for central India (Lenka et al., 2014). Burning of CR substantially reduced SOC storage and decline in crop yield and soil quality when compared with incorporation (Gangwar et al., 2006; Jalota et al., 2008; Singh et al., 2011a,b; Yadav et al., 2009).

3.1.2.2 Economics of Residue Management for Crop Productivity

About 80% of farmers in India are small landholders where farms are generally <2 ha, yet they contribute more than 50% of total agricultural output in their cultivation of 44% of agricultural land. Consequently, smallholder farmers constitute a key group requiring attention in agriculture so that their productivity and incomes are increased. Some studies evaluated the economics of CR (Aggarwal, 1994; Chhetri et al., 2016; Erenstein, 2011; Ramachandra et al., 2004; Reddy et al., 2003). The econometric analysis indicates that the combination of improved seeds with ZT elevated net return under IGP. It was further concluded that ZT with RR provides tangible and significant yield benefit, saves labor costs, conserves soil moisture, reduces evaporative loss of moisture, and subsequently requires less water than conventionally tilled fields (Singh et al., 2015c). In another study, Keil et al. (2015) assessed that the economic benefit from ZT related yield increase and cost savings in wheat production amounted to 6% of total annual income and offers considerable scope for energy savings and efficiently used irrigation water. Yet, the prevailing scenario under the rice–wheat system implies an intensive collection, trading, and use of wheat straw as basal feed for dairy livestock which differs from the CR management strategy where ZT, RR, and mulching are utilized.

The farmers in the Western regions of IGP do not generally consider rice straw as a suitable animal feed due to the perceived silica content and fear of reduced milk yield (Sidhu et al., 1998). However, in the eastern regions of India, rice straw is intensively used as livestock feed (Erenstein and Thorpe, 2010). Apart from this, farmers also perceive that *in-situ* burning is needed to have clean fields prior to initiating their land preparation. This is because the burning process allows the field to be vacated in little time. In contrast, incorporation collection and composting are perceived to be labor intensive as well as cost-intensive (Singh and Sidhu, 2014). Ramachandra et al. (2004)

surveyed the whole state of Karnataka, which is situated in the Western region of South India. They concluded that the rural bio-energy originates mainly from agriculture residue burning, ranging from 8% to 59% of total energy requirements. To minimize this burning, wasteland development has been recommended as the viable option. Incorporation of CRs improves soil health, SOC, and associated soil physical properties. Often, however, it may not improve crop yields including the costs and benefits from incorporation into the soil (Narayana, 2009).

In India the potential of CR is a serious concern, and more efforts need to be made to estimate food grain production and availability of CR. Over 502 million tons of agricultural residues are produced every year (MNRE, 2009; Table 2). Among the various crops, cereals generate 352 million ton residue followed by fibres (66 million tons), oilseed (29 million tons), pulses (13 million tons), and sugarcane (12 million tons). The cereal crops (rice, wheat, maize, millets) contribute 70% out of which the rice crop alone contributes 34% of CR. Wheat ranks second contributing 22% of total residues, whereas fiber crops contribute 13% of residues generated from all crops. Among fibers, cotton generates maximum of 53 million tons of CR sharing 11% of total CRs. Coconut ranks second among fiber crops with 12 million tons of residue being generated. Sugarcane residues (tops and leaves) account for 12 million tons, that is, 2% of CRs in India. With reference to the various states' contributions, the highest residue is generated from Uttar Pradesh (60 million tons) followed by Punjab (51 million tons) and West Bengal (36 million tons). Maharashtra stood first in sugarcane residue generation, whereas Andhra Pradesh is dominant in fiber CRs. Gujarat and Rajasthan each generate about 6 million tons of residues derived from oilseed crops.

3.2 Animal Waste Management

Numerous studies carried out on the topic of animal waste management in India met our inclusion criteria (Fig. 2). Studies were conducted on conversion of animal waste to bio-energy potential related to cooking gas and generation of electricity, manurial value of manure/compost on crop production and soil health, groundwater pollution through unscientific management of animal waste, and impact of global warming potential from animal waste. A recent survey reported that the total livestock population, except the poultry population, substantially decreased from 529.7 million to 512.1 million during 2007–12 (Anonymous, 2012, Table 3). This reduction has resulted in less potential of animal excreta during

Table 2 Generation and Surplus of CR (in million tons per year) in Various States of India

States	Residue Generation[(a)]	Residue Surplus[(a)]	Residue Burned[(b)]	Residue Burned[(c)]
Andhra Pradesh	43.89	6.96	5.73	2.73
Arunachal Pradesh	0.4	0.07	0.06	0.04
Assam	11.43	2.34	1.42	0.73
Bihar	25.29	5.08	3.77	3.19
Chhattisgarh	11.25	2.12	1.84	0.83
Goa	0.57	0.14	0.08	0.04
Gujarat	28.73	8.9	6.69	3.81
Haryana	27.83	11.22	5.45	9.06
Himachal Pradesh	2.85	1.03	0.20	0.41
Jammu and Kashmir	1.59	0.28	0.35	0.89
Jharkhand	3.61	0.89	1.11	1.10
Karnataka	33.94	8.98	2.85	5.66
Kerala	9.74	5.07	0.40	0.22
Madhya Pradesh	33.18	10.22	3.46	1.91
Maharashtra	46.45	14.67	6.27	7.41
Manipur	0.9	0.11	0.14	0.07
Meghalaya	0.51	0.09	0.10	0.05
Mizoram	0.06	0.01	0.01	0.01
Nagaland	0.49	0.09	0.11	0.08
Orissa	20.07	3.68	2.57	1.34
Punjab	50.75	24.83	8.94	19.62
Rajasthan	29.32	8.52	3.58	1.78
Sikkim	0.15	0.02	0.01	0.01
Tamil Nadu	19.93	7.05	3.55	4.08
Tripura	0.04	0.02	0.22	0.11
Uttarakhand	2.86	0.63	13.34	21.92
Uttar Pradesh	59.97	13.53	0.58	0.78
West Bengal	35.93	4.29	10.82	4.96
India	501.76	140.84	83.66	92.81

CR, crop residue.
Source: (a) MNRE (Ministry of New, Renewable Energy Resources). 2009. Govt. Of India, New Delhi. www.mnre.gov.in/biomassrsources; (b) Based on IPCC coefficients, 2007; (c) Pathak, H., Jain, N., Bhatia, A., Patel, J., Aggarwal, P.K., 2010. Carbon footprints of Indian food items. Agric. Ecosys. Environ. 139, 66—73.

2012. It could be attributed to more emphasis being put on utilization of lands for producing food grains, oilseeds, and pulses instead of growing pasture to support grazing and livestock populations. Furthermore, ever-increasing urban sprawl has also limited the amount of land available for growing the livestock population.

Table 3 Estimated Annual Production of Dung/Excreta by Animals and Poultry

Species	Population (Million)			Production of Dung/ Excreta (Million Tons)[a]		
	2003	2007	2012	2003	2007	2012
Cattle	185.18	199.075	190.904	203.70	218.985	209.996
Buffaloes	97.92	105.342	108.702	132.20	142.220	146.757
Yaks	0.07	0.083	0.077	27.85	0.083	0.077
Mithuns	0.28	0.264	0.298	0.38	0.292	0.330
Sheeps and goats	185.83	212.095	200.242	0.41	31.786	30.010
Horses/ponies	0.75	0.612	0.625	0.51	0.310	0.317
Donkeys and mules	0.83	0.575	0.515	3.38	0.284	0.254
Camels	0.63	0.517	0.4	0.07	0.419	0.324
Pigs	13.52	11.133	10.294	0.31	2.783	2.574
Total (animals)	485.00	529.696	512.057	368.80	402.787	389.374
Poultry	489.01	648.829	729.209	0.69	0.916	1.029
Grand total (Animal + poultry)	974.01	1178.525	1241.266	369.47	447.048	470.848

[a] Excreta/dung by animals and poultry estimated for 2007 and 2012 from the base value of 2003.
Source: Anonymous, 2008. Basic Animal Husbandry Statistics. Ministry of Agriculture, Government of India, New Delhi, 19th Livestock census-2012 All India Report (2012).

3.2.1 *Bioenergy Potential of Animal Waste*

Although biogas technology provides an alternative source of energy for cooking and electricity (Ravindranath and Balachandra, 2009; Suthar, 2009) and is mainly derived from animal organic waste, other sources such as trees, plants, crops residues human excreta, and municipal and industrial wastes have also contributed to bio-energy production for cooking food in rural areas. However, in different regions of India, the agricultural waste is being used as animal feed which is a highly energy inefficient process (Manna et al., 2012b). The biogas technology from animal waste has been widely employed in rural areas for many years for cooking and also for lighting using specially designed mantles. Biogas from animals is primarily in the form of CH_4 and CO_2. In India the estimated production of biogas was approximately 20,757 lakh cubic meters in 2014—15, in which 17,768 lakh cubic meters of biogas was produced in India's major cities (Fig. 3). It appears that the production of biogas in Maharashtra is the highest, followed by Andhra Pradesh, Karnataka, and the lowest is in Odisha. The biogas option uses cattle dung as the feedstock, and India has the highest bovine population that produces total recoverable dung of 458 million tons per year (Ravindranath and Balachandra, 2009).

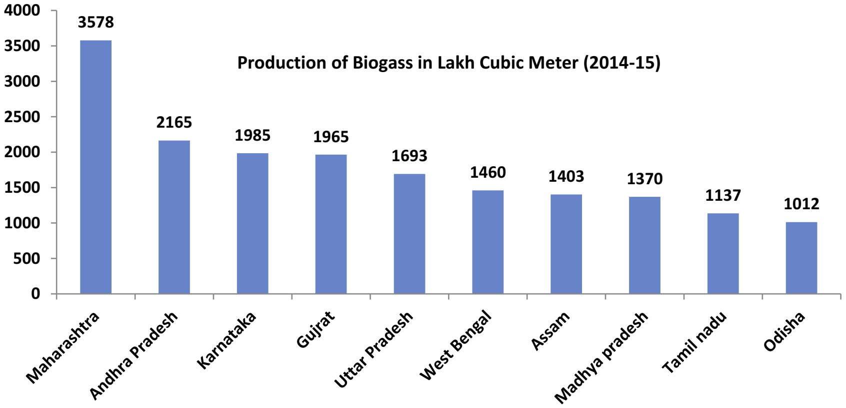

Figure 3 Biogas productions from major cities of India during 2014–15. *Source: Modified from Goyal, P., 2015. Biogas Production in India Is Equivalent to 5% of the Total LPG Consumption. https://www.saddahaq.com/biogas-production-in-india-is-equivalent-to-5-of-the-total*

3.3 Composting/Manuring of Animal Waste

In terms of the nutrient supply potential of animal waste, five studies have been evaluated (Jeyabal and Kuppuswamy, 2001; Manna and Hazra, 1996; Srivastava et al., 2002; Sujatha and Bhat, 2015; Verma et al., 2014), and three articles have been reviewed on animal waste management (Bansal and Kapoor, 2000; Rao, 2006; Singh and Sekhon, 1976). Nutritional enrichment of animal dung has been done by mixing it with rock phosphate, pyrites, and nitrogen (Hajra et al., 1994; Manna et al., 2001a; Manna and Hajra, 1996) in the composting system. Various kinds of animal excreta under aerobic decomposition enhanced plant nutrients, namely N, P, K and Fe, Cu, and Zn (Bansal and Kapoor, 2000; Rao, 2006). The majority of waste in the meat industry is produced during slaughtering. It is estimated that the average solid waste generation from bovine slaughterhouses is 275 kg ton^{-1} of total live weight, equivalent to 27.5% of the animal weight which is more than 2.1 million tons $annum^{-1}$. In India the slaughterhouse waste management system is very poor despite several government regulations put in place to administer the effective management of wastes generated from slaughterhouses. Regulatory requirements are in fact important because many countries restrict the use of meat by-products for food safety and quality reasons. Animal by-products contain a larger amount of proline, hydroxyproline, and glycine, manganese, P and K, and a lower level of tryptophan and tyrosine (Devatkal et al., 2004);

however, unscientific management or simply poor practices are creating groundwater pollution in the long-term. Although reliable data on the annual availability of animal and poultry wastes are not available, based on the average quantity of dung and excreta produced/animal, annual production of dung and other excreta has been estimated as 369.50, 447.04, and 470.85 million tons during 2003, 2007, and 2012, respectively (Anonymous, 2008, 2012).

3.3.1 Contribution of Animal Waste to Groundwater Pollution

It is widely known that livestock production has great potential for water and soil pollution. Effluents and other wastes that originate from animal dairy, poultry farm, wastewater from slaughterhouses, and milk processing units create problems. During the process of decomposition, these waste effluents end up on land, and organic matter percolates into the groundwater or runs off to surface waters causing pollution which leads to health hazards and fish mortality. Nutrient leaching, mainly N and P, ammonia evaporation and pathogen contamination are some of the major threats. Intake of water with a high concentration of nitrate (>45 mg L^{-1}) is a major problem in many countries because it affects people's health. This systematic review of the literature revealed common limitations on groundwater pollution due to animal waste and excessive use of N-fertilizer application in agriculture. However, all together six studies were considered for groundwater contamination from animal waste (Brindha and Elango, 2014; Brindha et al., 2012; Garg et al., 2004; Sankararamakrishnan et al., 2008; Suthar et al., 2009; Swamy and Bhatacharya, 2006). As a result of this activity, a large volume of gases, organic material, bacteria, and other substances are produced, posing a risk factor for groundwater.

These studies reported that animal waste is the major cause of $NO_3{-}N$ pollution in groundwater. Both natural and anthropogenic nitrate pollution in drinking water leads to infant methaemoglobinaemia (blue-baby syndrome), gastric cancer goiter, metabolic disorder, birth malformations, hypertension, and livestock poisoning. Rising concentrations of hydrotoxicants have created socioeconomic problems and seriously affected the livelihoods of inhabitants. The point sources could be attributed to the animal wastes derived from cows and buffaloes, while nonpoint sources could be due to the extensive agricultural activity prevalent in that area. Singh and Sekhon (1976) reported that animal wastes appear to be the major contributor of nitrate content of well water in the village area. In most cases, minimal use of chemical N fertilizer would be the appropriate solution to overcome this situation. The problem is that in India, agricultural and livestock production management is very inefficient, particularly in small rural properties since no adequate animal waste treatment strategy is available. This leads to a growing environmental problem associated with the production process. When the cattle sheds are situated in places where the soil is dominated by clay, the ammonium released from animal excreta and urine is absorbed in clay during dry periods, and this absorbed ammonium releases nitrate when it leaches to groundwater during the rainy season (Brindha and Elango, 2014). In that sense, this work defends the hypothesis that the current model of rural production is not a viable option and should be replaced by an agro-energy strategy in the rural areas so that social and environmental sustainability in India is possible.

3.3.2 Contribution of Animal Waste on GHG Emissions for GWP

The major GHG emissions from the livestock sector are confined to enteric fermentation and manure management. Large amounts of animal manure and slurries produced today by the animal breeding industry and wet organic waste streams represent a constant pollution risk with a potentially disastrous impact on the environment, if they are not well managed. Several studies revealed possible GHG emissions scenarios originating from animal waste in India (Bhattacharyya et al., 1997, 2003; Garg et al., 2004; Pathak et al., 2009, 2010; Sirohi and Michaelowa, 2007; Thangarajan et al., 2013). High levels of effluents flow directly or indirectly into surface waters in open lagoons, also resulting in high CH_4 emissions, and toxic gases can be released upon decomposition of manure, with negative consequences for farmers' fields and livestock farms. However, no study has reported on the direct consequences of this. In general, biological generation of CH_4 in anaerobic environments including enteric fermentation in ruminants and aerobic animal waste processing is the principal source of CH_4.

3.4 Municipal Solid Waste Management

The third largest organic source in India is MSW, which contains enormous amounts of nonbiodegradable hazardous materials. A total of 65 studies carried out on MSW from various cities in India met our inclusion criteria (Fig. 2). Studies were conducted in (1) recovery of bio-energy from MSW, (2) bio-medical solid waste management, (3) leaching of MSW on groundwater pollution, (4) recyclable and reuse waste, (5) disposal of building materials and landfilling, (6) biodegradable waste recycling, and (7)

Table 4 Municipal Solid Waste Generation From Urban Areas in India and Estimated Quantity of Compost Production From It

Year	MSW (Million Tons per Annum)	Compost (Million Tons per Annum)
2005	57.5	8.1
2010	64.8	9.1
2015	73.4	10.3
2020	82.2	11.7
2025	94.4	13.2
2030	107.0	15.0

Source: Sharma, P.D., Singh, M., Ali, M. 2006. Recycling and utilization of urban and rural wastes for the welfare of the society. In: Proceedings of International Conference on Soil, Water and Environmental Quality-issues and Strategies. Indian Society of Soil Science, pp: 387–401.

SWOT analysis of MSW management. In 2012 the annual global generation of MSW was estimated to be 1.3 billion tons, and it is expected to rise to 2.2 billion tons by 2025 (Hoornweg and Tata, 2012). India's cities generated about 73.4 million tons of city refuse during 2015, and it is expected to increase to 107 million tons by 2030 (Table 5). Major cities such as Delhi, Mumbai, and Kolkata with populations greater than 10 million are generating 4000–6000 tons of MSW daily. Other cities such as Bhopal, Nagpur, Chennai, and Bangalore are producing about 1500–3000 tons of MSW day^{-1} (Manna et al., 2017). Although about 40% of matter in MSW is considered to be biodegradable, only 14% (10.3 million tons) of the MSW was composted in 2015. The percentage composted will barely reach 15 million tons by 2030 (Table 4). MSW management in India regularly suffers from the lack of financial and operational autonomy, scientific approach, and adequate levels of resources.

3.4.1 Bio-Energy Recovery From Municipal Solid Waste

Energy recovery from MSW has become an attractive option for an effective waste management solution around the world. Fourteen studies examined the transformation of waste into energy. Many technologies like mass burning or incineration (Saini et al., 2012; Singh et al., 2011a,b; Yap and Nixon, 2015), energy generation from pyrolysis (Nixon et al., 2013; Saini et al., 2012; Singh et al., 2011a,b; Tanigaki et al., 2013, 2015; Yap and Nixon, 2015), conventional gasification process (Nixon et al., 2013; Ojha et al., 2012; Saini et al., 2012; Singh et al., 2011a,b; Tanigaki et al., 2013; Yap and Nixon, 2015), direct recovery of GHGs from landfills (Chakraborty et al., 2011; Jha et al., 2008; Kumar et al., 2004; Thomas et al., 2014;

Table 5 Municipal Solid Waste Generation as a Function of Source

Generation Sources	Composition Types	Techniques to Be Adopted
Residential	Food scraps, food packaging, newspapers, clothing, yard waste	Composting
Commercial	Office paper, corrugated boxes, food waste, disposable tableware, paper napkins, yard waste, wood pallets	Composting
	Construction and demolition waste	Landfilling
	Hospital waste	Incineration
Institutional	Office paper, corrugated boxes, cafeteria waste, restroom waste, classroom waste, yard waste	Composting
Industrial	Office paper, corrugated boxes, wood pallets, cafeteria waste	Composting
	Iron and steel	Remoulding
Municipal	Litter, street sweepings, abandoned automobiles, e-waste	Composting
	Construction, and demolition debris	Landfilling

Source: Manna, M.C., Sahu, A., Singh, A.B., Tripathi, A.K., Bhattacharjya, S., Patra, A.K., Chaudhari, S.K., SubbaRao, A., Khanna, S.S., 2017. Quality Compost Production from Solid Urban Waste for Enhancing Crop Productivity and Soil Health. Bulletin No: 02/IISS/2017. Indian Institute of Soil Science, Bhopal, pp. 1—63.

Yedla and Parikh, 2002), energy recovery from composting (Khaiwal et al., 2015; Unnikrishnan and Singh, 2010), and plasma arc gasification techniques (Saini et al., 2012; Singh et al., 2011a,b; Tanigaki et al., 2015; Yap and Nixon, 2015) can convert waste to electricity, heat, or transport fuels from MSW. The sources for this include medical, industrial, plastic, vegetable market waste, sewage, animal waste, and so on.

Two studies created a mathematical model based on the Hierarchical Analytical Network Process and multicriteria decision-making methodology for energy recovery from MSW in India (Nixon et al., 2013; Yap and Nixon, 2015). It was concluded that while gasification is the preferred technology in other countries, anaerobic digestion is the preferred technology for India. However, they also suggested that it is widely applicable for energy planning where MSW management is considered, opening up the potential involvement of investors, policymakers, researchers, and plant developers in India. Only one study proposed that plasma arc gasification is the best alternative approach for converting waste into energy (Ojha et al., 2012). However, a superheated column of electrically conductive gas production is difficult because such temperatures can destroy any materials found on earth with the exception of nuclear waste.

Limited experiments have been conducted in thermochemically aerobic digested treatment of solid waste converted into energy (Jha et al., 2008; Saini et al., 2012; Singh et al., 2011a,b; Tanigaki et al., 2013). As MSW in India is high in moisture and low biodegradable matter (>40%), it is thus well-suited for anaerobic digestion or composting (Khaiwal et al., 2015; Unnikrishnan and Singh, 2010). However, large-scale aerobic digestion plants in India face difficulties with segregation of MSW, and this problem has contributed toward the failure of a high electricity generation plant in many parts of India. Kalyani and Pandey (2014) have noted the failure of smaller scale aerobic digestion when using waste from restaurants, hotels, and vegetable markets. To strengthen the waste to energy conversion approach, one study appraised the improvement in the quality of MSW at every stage starting from waste generation, collection, transportation, disposal, and treatment inclusion (Khaiwal et al., 2015). To reduce the problem of landfilling, mitigation of CH_4 gas emissions, and energy generating potential from MSW, several studies were conducted using the mass balance approach (Chakraborty et al., 2011; Jha et al., 2008; Thomas et al., 2014; Yedla and Parikh, 2002). The conclusion was reached that the new waste management methodology could solve environmental degradation and depletion of natural resources.

3.4.2 Biomedical Solid Waste Management

Biomedical waste has posed a serious health hazard when MSW is disposed at an open landfill site in India. Indiscriminate disposal of the waste generated from different hospitals, private clinics, and healthcare establishments and research centers contributes to the spread of serious diseases such as hepatitis and AIDS (HIV). Five studies carried out on healthcare waste management met our inclusion criteria (Gupta and Boojh, 2006; Patil and Pokhrel, 2005; Patil and Shekdar, 2001; Ravichandran and Sivasankar, 2010; Ray et al., 2005). All occupational studies reported that most of the hospitals do not have any pretreatment facility for infectious (contaminated, uncontaminated, and surgical) waste before disposal. Laboratory waste materials, which are disposed of directly into the municipal sewer without proper disinfection of pathogens, ultimately reach the sewage canal, rivers, and other water bodies which threaten aquatic species. Open dumping of the waste simply increases the risks of transmitting infections and exposes rag pickers to serious health hazards due to injuries from sharps, needles, and other types of material used for giving injections. They suffered more often from diarrhea, fungal infection and ulceration of the skin, burning sensation in the extremities, tingling or numbness, transient loss of memory, and depression (Ravichandran and Sivasankar, 2010; Ray et al., 2005). Infectious waste includes human tissue, body fluids, excreta, articles such as urine containers, sharp-edged and glass pieces, many of which may be contaminated (Patil and Pokhrel, 2005; Patil and Shekdar, 2001). There is no proper systematic methodology available for the collection and disposal of biomedical waste in many hospitals in India. The infectious and noninfectious wastes are piled into a corner of the hospital and often burned inside the premises, which may pose additional exposure risk to people.

3.4.3 Leaching of MSW and Its Contribution to Groundwater Pollution

Most of the MSW in landfill sites has been identified as one of the major threats to groundwater pollution. Of 11 studies, seven investigated groundwater pollution through leaching due to unscientific dumping of MSW in landfill sites of India (Adhikari et al., 2004; Dhere et al., 2008; Kale et al., 2010; Misra, 2011; Mor et al., 2006; Nagarajan et al., 2012; Venkatesan and Swaminathan, 2009). Meanwhile, four studies have been identified for their investigation of surface pollution in landfill sites (Mondal and Dasgupta, 2010; Gowd et al., 2010; Rawat et al., 2009; Adhikari et al., 2004). More than 90% of the MSW generated in India is directly dumped on land in an unsatisfactory manner (Gowd et al., 2010; Rawat et al., 2009). All these studies concluded that the industrial waste in cities, domestic sewage, and landfill sites constitute the major source of groundwater pollution. During the rainy season, the MSW placed in landfills or open dumps areas receive water and the by-products of its decomposition move into the water through runoff or percolation of water. The liquid containing innumerable organic and inorganic compounds is called “leachate.” This leachate accumulates at the bottom of the landfill and percolates through the soil and reaches the groundwater and thus renders the associated aquifer unreliable for domestic water supply and other uses. The quality of the groundwater was found to improve when the well was deeper and further away from the landfill site. Partial segregation at the disposal site, bioremediation, and phytoremediation by growing certain plants in and around the landfill site should be carried out to minimize the rate of contamination and extent of future pollution problems.

3.4.4 Recyclable and Reused Waste

Most environmentally sound and preventive strategies for MSW management focus on source reduction and reuse potential. The advantages from diverting millions of tons of MSW away from incinerators, landfills, pyrolysis, and combustors to prevent greenhouse gaseous emissions, soil and water pollution will save huge amounts of energy and costs. Of four studies, three (Agarwal et al., 2005; Nandy et al., 2015; Panda et al., 2010) were carried out on recyclable waste including plastic, paper, textiles, leather, glass, metals, combustible household objects, and so on, while the other (Dwivedy and Mittal, 2010) focused on waste in the form of electrical and electronic equipment. The composition of MSW at sources and collection points was determined, and it consists mainly of a large organic fraction (41.8%), ash and fine earth (40.3%), paper (5.7%), plastic (3.9%) glass (2.1%), metals (1.9%), and textiles (3.5%). The C/N ratio ranges between 20 and 30, and the lower calorific value ranges between 800 and 1000 kcal kg^{-1}. In all developed countries, recycling waste is a formal activity with benefits at every level—environmental, financial, and social—through a hierarchy of recycling dealers (Agarwal et al., 2005).

Annually, MSW contributes a huge amounts of recyclable waste, about 1.2–2.4, 2.4–4.3, 6.5–8.5 million tons of newspapers, cardboard, and mixed paper and plastic waste, respectively (Nandy et al., 2015). However, more than1.3 million tons of glass, >2.6 million tons of metal waste, and 4–6.2 million tons of other recyclable materials are generated every year. The most carcinogenic waste is plastic, and by 2010, India had a plastic consumption of 12.5 million tons (Nandy et al., 2015; Panda et al., 2010). Several studies have focused on the environmental problems arising due to uncontrolled waste management, but only a few of them highlighted the conservation of resources and recycling of materials recovered at various stages. During the last two decades, the Indian economy has changed radically as a result of the rate of electronic consumption. It has proved to be significant, and e-waste is becoming an important type of waste in terms of both quality and toxicity which poses grave environmental and health hazards.

A few articles have discussed the problem of e-waste occurring in India (Babu et al., 2007; Dutta et al., 2006; Jain and Sareen, 2006; Sinha et al., 2007). These studies were limited to a few states and selected areas. Dwivedy and Mittal (2010) estimated the e-waste generation and disposition quantities for the whole of India, encompassing a wide variety of items. They concluded that around 2.5 million metric tons of waste electrical and electronic equipment is generated each year. Therefore an appropriate recycling infrastructure must be planned and developed for reselling them or reassigning them to a second user, or a third alternative could be recycling and landfilling.

3.4.5 Disposal of Building Materials and Landfilling

Two studies were conducted on the landfilling of MSW and disposal of building materials (Pappu et al., 2007; Singh and Vidyarthi, 2008). In the construction industry, building materials such as clay, sand, stone, gravels, cement, bricks, blocks, tiles, distemper, paint, timber, and steel are regularly used components. These materials are produced from existing natural resources which in turn leads to the continuous anthropogenic exploitation in urban areas. Eventually and inevitably, this results in damage being done to the environment. In India, about 14.5 million tons of solid wastes are generated annually from construction sites, and various gasses are emitted into the atmosphere from building materials during the manufacturing process. Landfilling is the most commonly used method of disposal of urban solid waste. However, the principles of sanitary landfills through the use of appropriate technology and its implementation through careful supervision are usually conspicuous by their absence.

Solid waste from urban areas is commonly disposed of in the nearest available low-lying areas. Moreover, the garbage is not covered with earth, and compaction is not done. These improperly operated landfills lead to a number of health and environmental problems. Proper use of mechanical equipment to level and compact the wastes and a final covering with earth followed by further compaction will reduce fly, rodent, animal, and human intrusion into the garbage and minimize their environmental and health consequences. It is evident that existing landfill practices are poorly organized, insanitary, cause pollution of groundwater, and if the waste is burnt at these sites, it can cause air pollution.

3.4.6 Biodegradable Waste Recycling

After incineration and landfilling, composting is used for recycling by MSW management. A total of 14 studies met our inclusion criteria on MSW management using the composting process. Generally, biodegradable MSW is generated from vegetable markets, slaughterhouses from cities' peripheries, by-products from agro-based industries and mixed bio-wastes from the cities. The unsegregated bio-waste produced poorer quality compost in terms of organic carbon and low plant nutrient (NPK) content

(Bhattacharyya et al., 2003; Jayathilakan et al., 2012; Kumar and Goel, 2009). Manual composting of MSWs is commonly practiced in small towns.

In the last three decades, technical advances and knowledge on the stabilization of organic matter involved in the composting process have led to one of the most promising technologies for organic waste treatment and its management. In fact, the most attractive aspects of composting are its low environmental impact and cost and its capacity for generating a final valuable product that increases soil fertility or as a growing medium in agriculture (Hajra et al., 1992, 2000; Manna and Sahu, 2012; Manna et al., 1997, 2001b, 2015; Monson and Murugappan, 2010; Narayana, 2009; Pattnaik and Reddy, 2010; Sarkhel et al., 2016). Three different types of composting technologies commonly used in India for MSW management are windrows, aerated static piles, and in-vessel systems (Manna et al., 2017).

These methods differ primarily in the level of technology employed to control the various factors governing the composting process. The moisture content, aeration, C:N ratio of materials, and pore space are some of the factors normally optimized to accelerate the growth and activity of microorganisms during composting. Moreover, due to the absence of any control over the process, the produced compost is often of poor quality. There is a great need to move away from the disposal-centric approach and toward the recovery-centric approach of waste management. This paradigm shift requires some level of public participation by regulating and monitoring waste generation and disposal. However, time, space, and manpower required to carry out these activities are drawbacks of this eco-friendly technology. Table 5 shows the common MSW generation as a function of source.

3.4.7 SWOT Analysis on MSW Management

Many studies have been published on solid waste management. A total of 10 research studies met our inclusion criteria on SWOT analysis based on different case studies (Seth and Kishore, 2015; Singh and Gu, 2010; Srivastava et al., 2005, 2015; Suthar and Sajwan, 2014). A qualitative investigation using strengths, weaknesses, opportunities, and threats analysis has been implemented in a number of community participation–based studies. Most of the weaknesses of MSW management concern the lack of suitable facilities such as equipment and infrastructure, underestimation of waste generation rates, inadequate management and technical skills, improper bin collection, route planning, and so on, which are responsible for collection and transportation of MSW (Chakrabarti et al., 2009; Singh and Gu, 2010; Srivastava et al., 2015; Suthar and Sajwan, 2014).

While comparing developed countries with developing countries, it has been observed that India is not actively involved in the recycling process, recycling plans, and techniques (Chatterjee, 2010). Public community participation took the form of voluntary services provided by the communities, little involvement of private sector agencies, inappropriate choice of methods for waste recycling. The outcome was widespread poor operational efficiency because payments of incentives/subsidies in exchange of rendered services were less than what was desired (Zia and Devadas, 2008; Hazra and Goel, 2009). To achieve better compliance with MSW rules, powers need to be given to the municipal corporation to levy spot fines on polluters (Gupta et al., 1998). In India the collection, transportation, and disposal of MSW are unscientific and ramshackle. Uncontrolled dumping of waste materials on the outskirts of towns and cities has created overflowing landfills, which are not only impossible to reclaim because of the haphazard manner of dumping but also have serious environmental implications in terms of groundwater pollution and contribution to global warming (Singh and Gu, 2010). Unemployment, a serious problem faced by the governments of developing countries like India due to their burgeoning populations, could be solved by getting people without jobs to work in a clean development mechanism program.

In India, many people depend on recycling and sanitary support services for their livelihoods (e.g., rag pickers, scrap dealers, sweepers, etc.). Although informal recyclers face adverse working conditions, it is more important to understand that it allows them to survive and be employed. Due to the continuous increase in solid waste generation, its ever-changing composition, mismanagement, and poor public attitude, people are directly exposed to health risks. In the absence of waste segregation practices, recycling is the only feasible option.

3.5 Horticultural and Fruit Waste

The estimated annual generation of by-products/wastes from the horticultural and plantation sectors is estimated to be 263.4 million tons, out of which 134 million tons is considered to be available for recycling (Table 6). India's agro-industries and food processing units turn a variety of primary crop produce into foodstuffs and products for various markets. The by-products and wastes arising from these operations are available in substantial quantities, often as large as the raw materials or the finished products. It is

Table 6 Estimated Production of Crop Residues From the Horticultural and Plantation Sectors During 2008–09

Crop	Total Production of Main Product in Million Tons	Estimated Production of Byproduct in Million Tons	Estimated Availability of Surplus Byproducts in Million Tons
Fruits	69.45	83.34	41.67
Vegetables	133.07	173.00	86.50
Plantation crops	12.08	7.00	5.48
Others crops/ items	4.25	<1	<1
Total	218.85	263.36	134

Source: Compiled from Anonymous, 2009. Agricultural Statistics at a Glance. Directorate of Economics and Statistics, Ministry of Agriculture, Govt of India, New Delhi. http://www.dacnet.nic.in/eandds.

impossible to quantify exactly the amount of organic wastes generated by this industry due to the involvement of many factors and unorganized nature of operations. The production of agro-industry–based wastes (excluding the wastes generated by processing of horticultural produce) in 2010 was 184.3 million tons, of which 95% originated from sugarcane crushing (114 million tons of bagasse), paddy processing (56.7 million tons of husk + bran although bran is too valuable to be used in composting) and groundnut (4.8 million tons of husk).

4. NUTRIENT POTENTIAL OF BIO-WASTES

In India, three major sources of organics are commonly used in agriculture, namely animal manure, CR, and MSW. However, yard waste compost, blood and bone meal, seaweeds are rarely used. Although a large range of MSW compost is available in the Indian market, the quality of the compost is very poor. In this section, we discuss the nutrient potential of three major organic sources.

4.1 Nutrient Potential of CR

CRs are potential sources of plant nutrients, and their beneficial effects on soil fertility and productivity could be harnessed by recycling them in the soil. Estimates showed that 30%–35% of applied N and P and 70%–80% of K are accumulated in the CRs of food grain crops (Table 7). Moreover, residues are the primary source of organic matter (since C constitutes

Table 7 Total Residue, Nutrient Potential, and Surplus NPK (Million Tons) During 2012

Crops	Total Residue (Million Tons)	Total NPK (Million Tons)	Surplus NPK[a]
Rice	210.48	4.567	1.522
Wheat	140.27	2.553	0.851
Sorghum	15.84	0.331	0.110
Millet	34.96	0.612	0.204
Maize	100.17	2.053	0.684
Bengal gram	11.48	0.305	0.102
Pigeon pea	12.08	0.308	0.103
Lentil	2.26	0.044	0.014
Groundnut	9.40	0.301	0.100
Rap seed	16.06	0.318	0.106
Soybean	14.67	0.519	0.173
Sunflower	1.62	0.042	0.014
Cotton	17.46	0.295	0.098
Sugarcane	102.36	1.904	0.635
Potato	34.91	0.625	0.313
Total	724.02	14.78	5.030

[a] One-third of the total NPK potential assuming that two-thirds of the total residue is used as animal feed or for other uses.

Sources: Compiled from Anonymous, 2009. Agricultural Statistics at a Glance. Directorate of Economics and Statistics. Ministry of Agriculture, Govt of India, New Delhi. http://www.dacnet.nic.in/eandds; Anonymous, 2014. Agricultural Statistics at a Glance.Directorate of Economics and Statistics. Ministry of Agriculture, Govt of India, New Delhi. http://www.dacnet.nic.in/eandds; Manna, M.C., Rao, A.S., Mandal, A., 2012a. Maintenance of soil biological health under different crop production systems. Indian J. Soil Conserv. 41, 127–135.

about 40% of the total dry biomass) which is indispensable for sustainability of agricultural ecosystems. About 40% of the N, 30%–35% of the P, 80%–85% of the K, and 40%–50% of the S taken up by rice remaining in the vegetative parts at maturity (Dobermann and Fairhurst, 2000). Similarly, about 25%–30% of N and P, 35%–40% of S, and 70%–75% of K uptake are retained in wheat residue. Dobermann and White (1999) estimated the typical amounts of nutrients in rice straw at harvest were 5–8 kg N, 0.7–1.2 kg P, 12–17 kg K, 0.5–1 kg S, 3–4 kg Ca, 1–3 kg Mg, and 40–70 kg Si per ton of straw on a dry weight basis. Similarly, Singh and Sidhu (2014) reported that 1 ton of wheat residue contains 4–5 kg N, 0.7–0.9 kg P, and 9–11 kg K. However, soil conditions, crop management, variety, and season determine the nutrient concentration in CRs. The total amount of NPK contained in food grain residues produced (724 million tons) is about 14.78 million tons, and from surplus residue, it is about 5.03 million tons in India (Table 7). At its maximum, cereal residue contributed about 70% of total residue where rice and wheat share 34% and 22% of total cereal residue, respectively. Thus CRs play an important role in the recycling of nutrients in addition to the role of chemical fertilizers in crop production; however, their continuous removal and burning can lead to net losses of nutrients (70% CO_2, 30% N, 20% P, 50% S, and 20% K), which ultimately will lead to higher nutrient cost input in the short-term and reduction in soil quality and productivity in the long-term. Annual nutrient recycling in the plant—soil ecosystem is essential for maintaining a productive agricultural system. Management of CR therefore has important implications for the total amount of nutrients removed from and returned to the soil.

4.2 Nutrient Potential of Animal Waste

As amendments for soils, animal manures have economic value as plant nutrient sources that can improve soil health by adding organic matter. Rising human populations coupled with a decline in availability of land area for crop production as well as farm mechanization have suppressed the population of animals in India. The value of animal manure as fertilizer per metric ton applied is generally inverse to their water and carbon contents. Plant nutrient concentrations in animal manures are highly variable, thereby introducing uncertainty into meeting plant nutrient needs for crop production. Of the total quantity of available cattle manure, about two-thirds are being utilized to produce fuel cake in villages, and only one-third is serving as manure for agricultural land. However, the storage conditions and degree of dilution mainly determine the fertilizer value of liquid manure. One estimate revealed that the annual quantities of manure produced from the livestock cattle, sheep, goats, pigs, and poultry systems are as follows, respectively: 356.76 million tons; 30.1 million tons; 2.57 million tons; and 1.09 million tons (Table 8). It was also noted that these manures could contribute (specifically in the year 2012) a substantial amount of nutrients, about 2.7 million tons of nitrogen, 0.79 million tons of total P, and 1.87 million tons of total K (Table 8).

4.3 Nutrient Potential of MSW

MSW management has become a global issue and is a major concern, particularly in developing countries like India because of various environmental problems such as pollution of air due to GHG emissions during landfills and groundwater pollution caused by leaching (Manna et al., 2017).

Table 8 Total Population of Animals and Poultry Birds, Production of Dung/Excreta, and Nutrient Potential (NPK, Million Tons) During the Year 2012 in India

Species	Population 2012	Production of Dung/ Excreta in Million Tons (DM; 2012)[a]	TOC	TN	TP	TK	NPK
Cattle	190.904	209.996	72.869	0.945	0.321	0.630	1.896
Buffaloes	108.702	146.757	50.925	0.660	0.225	0.440	1.325
∞ Yaks	0.077	0.077	—	—	—	—	—
∞ Mithuns	0.298	0.330	—	—	—	—	—
Sheeps and goats	200.242	30.010	16.160	0.975	0.225	0.750	1.950
Horses/ponies	0.625	0.317	0.131	0.002	0.001	0.002	0.005
∞ Donkeys and mules	0.515	0.254	—	—	—	—	—
∞ Camels	0.4	0.324	—	—	—	—	—
Pigs	10.294	2.574	1.349	0.084	0.023	0.048	0.155
Total (animal)	512.057	389.374	141.434	2.666	0.795	1.870	5.331
Poultry	729.209	1.029	0.331	0.014	0.007	0.007	0.028
Total (animal + poultry)	1241.266	470.848	141.765	2.680	0.802	1.877	5.359

∞ Data not available for NPK estimation.

[a] Production of excreta has been calculated from the base value conversion of animal population to excreta during the year 2003.

Source: Dhama, A.K., 1996. Organic farming for sustainable agriculture. In: TNAU Agritech Portal Organic Farming: Composting, Agro Beneficial Pub. 1—4; Population data has been obtained from 19th census animal population (Anonymous, 2012. 19thLivestock Census-2012 All India Report. Ministry of Agriculture Department of Animal Husbandry, Dairying and Fisheries Krishi Bhawan, New Delhi, pp. 1—130).

Present work highlights the fact that current management practices are insufficient and ineffective. Considering the current state of technological, financial, and institutional factors, a strong conceptual framework is required for fulfilling the complete recycling of waste. Solid wastes collected by local urban bodies are seldom segregated at the point of origin. This heterogeneous and unsegregated waste is a mixture of biodegradable and nonbiodegradable materials consisting of virtually every disposable item which a city generates and is thrown out as garbage. It may consist of about 60% of total mass, and the proportion of biodegradable matter in unsegregated wastes varies widely depending on the location. It contains 35.2%–47.1% compostable materials, 2.1%–5.4% plastics, 0.4%–0.5% rubber and leather, and the remainder is nondegradable (Table 9). However, the inert material (soil, building debris, etc.) is about 30%–43%. Management of such a heterogeneous mixture of biodegradable and nonbiodegradable fractions becomes a problem for the municipalities from the perspectives of collection, safe disposal, and recycling.

Biodegradable MSW is the second largest organic matter available in India. It was estimated that about 14.2 million tons of biodegradable waste was generated in 2011 alone (Table 10). These wastes have the nutrient potential of approximately79.4, 32.2, and 21.1 1000 tons of N, P, and K, respectively, leading to a combined total of 0.1827 million tons of NPK (Table 10). One study found that only 40% of the MSW is biodegradable waste (Manna et al., 2017).

Table 9 Composition of Unsegregated MSW Collected From Different Cities (Average of Six Cities)

	Content (%)	
Fraction	**Range**	**Average**
Plastics	2.1–5.4	4.1
Glassware	3.1–6.5	4.5
Rag	0.3–3.9	2.8
Metals	0.5–4.5	1.7
Stone/soil	24.9–39.7	30.7
Compostable materials	35.2–47.1	39.8
Tyre/tubes	2.3–4	3.3
Others (ceramic, earthen pot, soil etc.)	11.9–18.5	13.2

MSW, municipal solid waste.

Source: Manna, M.C., Sahu, A., Singh, A.B., Tripathi, A.K., Bhattacharjya, S., Patra, A.K., Chaudhari, S.K., SubbaRao, A., Khanna, S.S., 2017. Quality Compost Production from Solid Urban Waste for Enhancing Crop Productivity and Soil Health. Bulletin No: 02/IISS/2017. Indian Institute of Soil Science, Bhopal, pp. 1–63.

Table 10 Total Biodegradable Waste, Nutrient Potential (N, P, and K, in Thousand Tons) From MSW in Different States of India

S. No.	MSW From Different Cities and States	Total Population[a]	Per Capita Waste (kg day) [b]	Total Biodegradable Waste (MT year^{-1}) [c]	Thousand Tons TOC, 000)	(Thousand Tons TN,000)	Thousand Tons TP,000)	(Thousand Tons TK,000)	Total NPK, 000 Tons)
1	Andhra Pradesh (31)	9,590,992	0.364	0.510	85.94	2.85	1.16	2.19	6.203
2	Assam (9)	2,096,405	0.223	0.068	11.51	0.38	0.15	0.29	0.831
3	Bihar (27)	7,180,361	0.28	0.294	49.49	1.64	0.67	1.26	3.572
4	Chhsttisgarh (11)	3,543,583	0.316	0.163	27.56	0.92	0.37	0.70	1.990
5	Gujarat (31)	19,006,271	0.451	1.251	211.00	7.01	2.84	5.38	15.231
6	Haryana (18)	6,315,290	0.276	0.254	42.91	1.43	0.58	1.09	3.097
7	Himachal Pradesh (12)	6,856,509	0.427	0.427	72.07	2.39	0.97	1.84	5.202
8	Karnataka (25)	16,277,359	0.376	0.894	150.65	5.00	2.03	3.84	10.875
9	Kerala (18)	14,935,061	0.393	0.857	144.48	4.80	1.95	3.68	10.429
10	Madhya Pradesh(33)	11,918,474	0.316	0.550	92.71	3.08	1.25	2.36	6.692
11	Maharashtra (33)	37,083,326	0.378	2.047	345.05	11.46	4.65	8.80	24.907
12	Manipur (1)	264,986	0.201	0.008	0.98	0.04	0.02	0.05	0.117
13	Meghalaya (7)	2,966,889	0.157	0.068	11.47	0.38	0.15	0.29	0.828
14	Mizoram (1)	291,972	0.296	0.013	1.59	0.07	0.04	0.08	0.191
15	Orissa (11)	3,526,511	0.366	0.188	31.77	1.06	0.43	0.81	2.293
16	Punjab (19)	6,499,474	0.312	0.296	49.92	1.66	0.67	1.27	3.603
17	Rajasthan (20)	9,519,216	0.355	0.493	83.18	2.76	1.12	2.12	6.004
18	Tamil Nadu (12)	17,557,501	0.467	1.197	201.83	6.70	2.72	5.15	14.569
19	Tripura (1)	399,688	0.21	0.012	1.54	0.07	0.04	0.08	0.185
20	Telengana (12)	11,277,875	0.364	0.599	101.05	3.36	1.36	3.90	8.613
21	Uttar Pradesh (65)	28,918,609	0.381	1.609	271.21	9.01	3.65	10.46	23.116
22	Uttarakhand (7)	1,930,600	0.381	0.107	18.11	0.60	0.24	0.70	1.543

(Continued)

Table 10 Total Biodegradable Waste, Nutrient Potential (N, P, and K, in Thousand Tons) From MSW in Different States of India—cont'd

S. No.	MSW From Different Cities and States	Total Population[a]	Per Capita Waste (kg day) [b]	Total Biodegradable Waste (MT year^{-1}) [c]	Thousand Tons TOC, 000)	(Thousand Tons TN,000)	Thousand Tons TP,000)	(Thousand Tons TK,000)	Total NPK, 000 Tons)
23	West Bengal (29)	21,763,877	0.397	1.261	212.69	7.06	2.86	8.20	18.127
24	Chandigarh (1)	960,787	0.475	0.067	11.23	0.37	0.15	0.43	0.957
25	Jharkhand (11)	5,280,205	0.28	0.216	36.39	1.21	0.49	1.40	3.102
26	Delhi (7)	13,481,997	0.295	0.581	97.90	3.25	1.32	3.77	8.344
27	Pondicherry (1)	541,801	0.376	0.030	5.01	0.17	0.07	0.19	0.427
28	Jammu and Kashmir (3)	1,804,987	0.427	0.113	18.97	0.63	0.26	0.73	1.617
Total	456 cities	261,790,606	0.341	14.173	2388.21	79.37	32.20	71.10	182.665

MSW, municipal solid waste.

€ N, P, and K were computed from Agarwal et al. (2005).

[a] Population data have been obtained from census 2011 (google.com).

[b] Total biodegradable waste was calculated from the conversion of total MSW to biodegradable (Manna et al., 2017) waste calculated.

[c] Per capita waste (kg day^{-1}) was calculated from the report (status of MSW generation, collection, treatment, and disposal class-I cities, CPCB, 2000).

5. IMPACT OF ORGANIC AMENDMENTS ON INDUCED GHG EMISSIONS AND MANAGEMENT PRACTICES FOR MITIGATION

Global warming poses a major threat to the global environment and the major GHGs, which comprise the key contributor to global warming, originate from fossil fuel consumption (IPCC, 2007; Pathak et al., 2009). Increased population and urbanization indicate rising shares of MSW, while rising food grain production generating plenty of CRs and unscientific management of livestock and poultry contribute large amounts of CO_2, CH_4, and N_2O to the atmosphere. In the present study, we have computed GHG emissions from the livestock population census during the year 2012 (Table 11). Normally, this is done at every 5-year interval. We have also computed GHG emissions for MSW from urban populations during the year 2012 and origins of GHG emissions from agricultural residue during 2012 (Table 11). The CO_2 from manures is a part of the short C cycle and therefore not considered a form of GHG emission. The data computed here regarding the quantity of CO_2 equivalent GHG emissions possibly generated during 2011–12 derived from the wastes' decomposition in fields over time. We have also noted a decline in the livestock population during the last two censuses which is possibly attributed to, first, this sector being poorly organized, and second, the low-quality animal feed such as agriculture CRs and common grass. Table 11 summarizes the estimates of CO_2 emissions from this untreated source, and they may account for annual emissions of approximately 5.2 and 155 Tg from MSW and animal waste and 298 Tg from CR manure (Table 12). MSW generated in India is increasing at a rate of 1.33% annually (Pappu et al., 2007; Shekdar, 2009). It is estimated that overall N_2O loss from agriculture, animal, and MSW is about 45.73 Tg. The average per capita solid waste generation has been assessed as 341 g, of which 40% is biodegradable on dry weight basis. The estimates of GHG emissions from MSW were 5198 Gg CO_2, 612 Gg CH_4, and 442.7 Gg N_2O, while GHG emissions from animal wastes in India were 155,765; 39,472; 16,272 Gg of CO_2, CH_4, and N_2O, respectively (Table 11). During the year 2012, the contribution of CRs to GHG emissions were 2896.063, 96.052, and 25.04 Gg of CO_2, CH_4, and N_2O, respectively (Table 12).

Acceptability of mitigation options technologies needs to be increased to reduce the net emissions of CO_2, CH_4, and N_2O. Nonetheless, the real challenge lies in the regional diversity of agricultural management practices

Table 11 Potential of Quantity of Carbon Dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_2O) Emission From Municipal Waste and Animal Waste

Municipal Solid Waste

	Total population ($\times 10^3$)	Total quantity of biosolid produce ($\times 10^3$) (Mg year^{-1})[a]	CO_2-C (Gg year^{-1})[b]	CH_4-CO_2-C eq (Gg year^{-1})[c]	N_2O-CO_2-C eq(Gg year^{-1})[d]
	261,790	12,995	5198	612	442.7

Animal waste

	Total Population ($\times 10^3$)	Total quantity of manure produce ($\times 10^3$) (Mg year^{-1})[e]	CO_2-C (Gg year^{-1})[f]	CH_4-CO_2-C eq (Gg year^{-1})[g]	N_2O-CO_2-C eq(Gg year^{-1})[h]
Cattle	299,606	355,483	142,193	34,452	9,732
Sheep and goat	200,242	30,010	12,004	4,514	5,934
Horse and ponies	625	317	127	37	10
Pig	10,294	2,574	1,030	377	509
Poultry	729,209	1,028	411	92	88
Total animal + poultry	1,239,976	389,411	155,765	39,472	16,272

	Cattle	**Sheep and goat**	**Horse and ponies**	**Pig**	**Poultry**
Manure weight (kg $year^{-1}$)★	1186.5	150	506.7	250.1	1.4
Total C (%)	34.7	53.85	41.4	52.4	32.2
Total *N* (%)	0.5	3.25	0.5	3.3	1.4

All emission factors are adopted from IPCC (1996).

[a] Quantity of biodegradable wastes (BDW) produced = 136 g/person/day calculated from average of 0.341 kg/person/day, whereas 40% is biodegradable.

[b] CO_2–C (Gg $year^{-1}$) = (potential quantity of BDW produced [Mg $year^{-1}$]/potential application rate [50 t ha^{-1}]) × (C to CO_2 emission factor [20 C t/ha/year]/1000). The CO_2 from BDW is part of short C cycle and not considered as greenhouse gas emission. Data only show the quantity of CO_2 possibly generated from the BDW decomposition in a landfill site with time.

[c] CH_4–CO_2–C eqv. (Gt $year^{-1}$) = potential quantity of BDW produced (Mg $year^{-1}$) × %C in BDW × C to CH_4 conversion (1.33) × 21 × C to CH_4 emission factor (1%); C content of BDW = 16.86% and N content 0.56%.

[d] N_2O–CO_2eqv. (Gg $year^{-1}$) = potential quantity of BDW produced (Mg $year^{-1}$) × % N in BDW × N to N_2O conversion (1.57) × 1/1000 × 310 × N to N_2O emission factor (1.25%).

[e] Potential quantity of manure produced (Mg dry weight/year) = calculated from 2012 Life stock census report of India and excreta computed from 2003 as base value × manure weight = (kg/year/1000).

[f] CO_2–C (Gg $year^{-1}$) = (potential quantity of manure produced [Mg/year]/potential application rate [50 t ha^{-1}]) × (C to CO_2 emission factor [20Ct/ha/1000]). The CO_2 from manures is part of short C cycle and not considered as greenhouse gas emission. Data only show the quantity of CO_2 possibly generated from the manure decomposition in a field with time.

[g] CH_4–CO_2–C equivalent (Gg $year^{-1}$) = potential quantity of manure produced (Mg $year^{-1}$) × %C in manure × C to CH_4 conversion (1.33) × 1/1000 × 21 × C to CH_4emission factor (1%).

[h] N_2O–CO_2–C equivalent (Gg $year^{-1}$) = potential quantity of manure produced (Mg $year^{-1}$) × % N in manure × N to N_2O conversion (1.57) × 1/1000 × 310 × N to N_2O emission factor (1.25%).

Table 12 Table Potential of Quantity of Carbon Dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_2O) Emission From Crop Residue

Plant Residue	Net Area ($\times 10^3$) (ha year^{-1})	Potential of Residue ($\times 10^3$) (Mg year^{-1})	TOC (%)	TN (%)	CO_2−C Eq (Gg year^{-1})[a]	CH_4−CO_2−C Eq (Gg year^{-1})[b]	N_2O−CO_2−C Eq (Gg year^{-1})[c]
Rice	42,750	210,480	45.3	0.61	841.9	26.631	7.81
Wheat	30,000	140,265	46.3	0.48	561.1	18.138	4.10
Sorghum	6,210	15,840	44.8	0.52	63.4	1.982	0.50
Millet	7,300	34,960	44.8	0.45	139.8	4.374	0.96
Maize	8,670	100,170	52.5	0.52	400.7	14.688	3.17
Bengal gram	8,520	11,479	47.8	0.8	45.9	1.533	0.56
Pigeon pea	3,890	12,080	48.6	0.87	48.3	1.640	0.64
Lentil	1,420	2,260	45.9	1.21	9.0	0.290	0.17
Groundnut	4,720	9,400	41.9	1.6	37.6	1.100	0.91
Rap seed	6,290	16,060	45.9	0.67	64.2	2.059	0.65
Soybean	10,840	14,670	50.0	0.97	58.7	2.049	0.87
Sunflower	830	1,620	39.7	0.53	6.5	0.180	0.05
Cotton	11,980	17,460	49.8	1	69.8	2.429	1.06
Sugarcane	5,000	102,360	50.7	0.4	409.4	14.495	2.49
Potato	1,990	34,912	45.8	0.52	139.6	4.466	1.10
Total	—	—	—		2896.063	96.052	25.04

Calculation: potential quantity crp residue produced (Mg dry weight year^{-1}) = 2012 calculated from FAI statistics.

[a] CO_2−C (Gg year^{-1}) = (potential quantity of residue produced [Mg year^{-1}]/potential application rate [5 t ha^{-1}]) × (C to CO_2 emission factor [20 Ct/ha/year])/1000). The CO_2 from residues is part of short C cycle and not considered as greenhouse gas emission. Data only show the quantity of CO_2 possibly generated from the manure decomposition in a field with time.

[b] CH_4−CO_2−C equivalent (Gg year^{-1}) = potential quantity of residue produced (Mg year^{-1}) × %C in residue × C to CH_4 conversion (1.33) × 1/1000 × 21 × C to CH_4 emission factor (1%).

[c] N_2O−CO_2−C equivalent (Gg year^{-1}) = potential quantity of residue produced (Mg year^{-1}) × % N in residue × N to N_2O conversion (1.57) × 1/1000 × 310 × N to N_2O emission factor (1.25%).

which controls the rate of potential adoption of mitigation practices to accrue sustainable production and benefit farmers. The major challenge is how GHG emissions can be reduced in the agriculture, animal, and MSW management sectors. Moreover, no quantitative information is yet available on the total potential reduction in CO_2, CH_4, and N_2O emissions from existing croplands offset by biofuel production. Under flooded conditions, CH_4 emissions from wheat and rice straw were significant in the early growth stage of crops as reported by Singh et al. (1998). The emissions of CH_4 from composted farmyard manure and poultry manure-amended soils were very low. The practice of green manure application in rice fields emitted less CH_4 by methanogens than wheat straw. This is because easily biodegradable material provided less activation energy for microbes (Bhat and Beri, 1996). Application of surface mulching of straw during the winter season reduced CH_4 emissions compared with field incorporation. Composts consistently produced less CH_4 emissions than fresh green manures or straws. Aerobic composting reduces readily decomposable carbon to CO_2 instead of CH_4. Low CH_4 production is highly influenced by inflow of oxygen and downward discharge of methanogenic substrate into the soil (Yagi et al., 1996). In rice fields amended with biogas, slurry emitted significantly less CH_4 than manure with wheat straw (Jain et al., 2000). Ishibashi et al. (2001) reported that in high-percolating sites with rice fields, CH_4 emissions were extremely low.

The main reason for low CH_4 emissions from rice fields in India is that the soils have very low organic C or receive very little organic amendments (Jain et al., 2000). Few measurements have been published for N_2O emissions from flooded rice soils amended with organic materials. The existing information indicates that N_2O emissions from flooded soils with organic additions are similar to or less than the soils receiving chemical fertilizers, indicating that organic amendments do not appear to influence N_2O emissions very much. The dominant sources of N_2O in soils are biologically mediated reduction processes of nitrification and denitrification. In rice fields during alternating wet and dry seasons, N_2O occurs as a result of nitrification–denitrification processes. Aulakh et al. (2001a) showed that application of organic amendments such as wheat straw or green manure coupled with nitrogenous fertilizer significantly reduced cumulative gaseous N losses. High livestock density is always accompanied by the production of a surplus of animal manure, representing a considerable pollution threat to the environment. Cayuela et al. (2014) found that soils treated with various organic amendments increased basal respiration and

CO_2 emissions. Biogas is a smokeless fuel offering an excellent mitigation option for GHG emissions from cattle dung cake, agricultural residues, and firewood, which are used as fuel in India (Pathak et al., 2010).

6. ORGANIC AMENDMENTS IMPROVE SOC AND SOIL HEALTH

In earlier times, crops were cultivated in a semi-nomadic style because land was more abundant, so when soil lost its productivity, people abandoned it in favor of new land. Gradually, as land became scarcer and populations exploded, agriculture involved continuous cropping on the same piece of land. The major reasons for poor soil health in tropical soils are (1) wide discrepancy between nutrient demand and supply; (2) high nutrient turnover in soil—plant system coupled with use of low and imbalanced fertilizers; (3) emerging deficiency of secondary and micronutrients due to improper use of inputs such as water, fertilizers, pesticides; (4) insufficient use of organic inputs; (5) acidification and Al toxicity; (6) increasing salinity and alkalinity in soils; (7) development of adverse soil conditions such as heavy metal toxicity; (8) disproportionate growth of microbial populations responsible for soil sickness, and (9) natural and man-made c-alamities such as erosion, and deforestation occurring due to rapid industrialization and urbanization.

It is evident from the literature that soil organic matter is the key to improving almost all soil functions (Lal, 1984; Karlen et al., 1997; Pierce and Larson, 1993; Joshi et al., 2017). In the earlier section we reviewed (Fig. 2) and discussed, the benefits of adding organic amendments to improve soil health by enhancing soil quality parameters. These refer to physical properties (soil aggregation, porosity, bulk density, and water-holding capacity), chemical properties (pH, organic carbon and its associated fractions, electrical conductivity, available nutrients), and biological health (microbial biomass carbon, mineralization potential). This section examines how the organic matter and its associated fractions (active, slow, and passive pools of carbon) are altered due to long-term intensive cultivation, nutrient management, and soil types. Labile fraction**s** or active pools of SOM (microbial biomass C and N, light fraction of organic matter, water-soluble carbon, acid hydrolysable carbohydrates, and potentially mineralizable carbon) are more sensitive to changes in soil management practices compared with total SOM and could be serve as an indicator of change. These pools vary with different sources of amendments. Despite this, little attention has been paid to labile pools of carbon when compared with total organic carbon in most agricultural soils in India.

It was observed that decline in yields is more pronounced with a concomitant decrease in SOC content under imbalanced fertilizer application (N or NP). However, long-term application of fertilizer and manure either maintained or improved SOC and its associated carbon fractions over initial (Manna et al., 2006, 2007a, 2013a). It was therefore concluded that application of fertilizer in combination with repeated applications of manure every year may contribute more labile C, which acts as a source of energy for soil microbes and improves nutrient supply. More precisely, it provides energy and nutrients for soil biota, regulates aggregate stability, water retention, hydraulic properties, resistance or resilience to compaction, buffering capacity, cation exchange capacity, and formation of soluble and insoluble complexes with metals. Particulate organic carbon (size 53 μm) is the slow pool of carbon that is considered to be an intermediate fraction of active and passive fractions of SOC; these change slowly over time due to changes in management practices. It contributes to 20%–45% of total organic carbon (TOC) and 13%–40% of total nitrogen (TN) of the soil. These fractions indicate significant variations with fertilizer treatments (Manna et al., 2005) and are affected by tillage and residue input, whereas other fractions are affected by aggregation and aggregate mineralization.

In Vertisols, passive fractions of carbon were significantly improved after 30 years of cultivation with fertilizer and manure application, yet in Inceptisols, its improvement was negligible. This suggests that more time is required to change this pool even with the application of manure and fertilizer (Manna et al., 2005, 2007b). Scientific research has demonstrated that organic agriculture significantly increases the density and species of a soil's life. In the organic farming system, manure fertilization, manipulation of crop rotations and strip-cropping, green manuring, minimum tillage, and avoidance of pesticides and herbicides will promote environments suitable for soil, fauna, and flora to proliferate. They will also encourage nutrient recycling and soil biological activity. On the other hand, excessive amounts of salts present in the soil will have an adverse impact on soil microbial biomass, soil respiration, and dehydrogenase activity due to exo-osmosis in microbial cells (Batra and Manna, 1997).

After years or even decades of residues' transformation, the original organic materials are converted into chemically complex, relatively stable

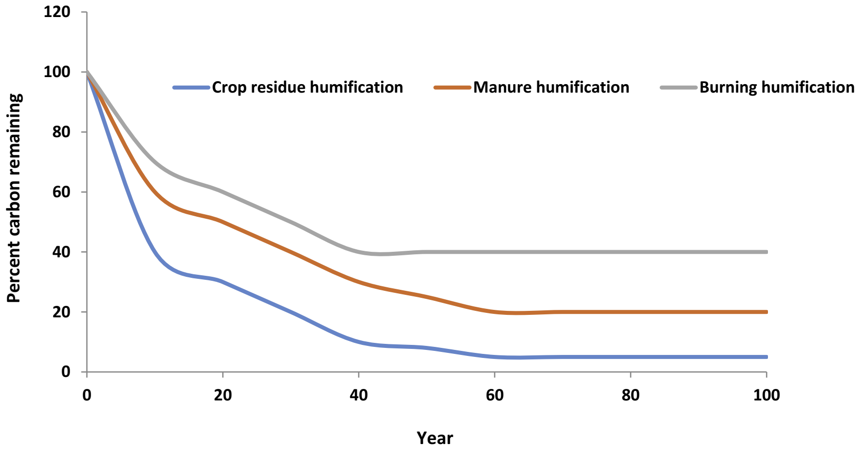

Figure 4 Residue transformation and carbon changes over a period of time from different organic sources.

but nutrient-poor humic substances. If the percentage of carbon remaining in the original organic materials over a period of time is compared, it will be found that the amount of humified materials in the soil is relatively less than that in CR incorporation/retention when compared with manure and burning of CR (Fig. 4). Burning is not a good practice in tropical soil because this fraction does not contain many available nutrients and so is not directly important for soil fertility.

7. COMPARISON BETWEEN: FERTILIZER CONSUMPTION AND FOOD GRAIN PRODUCTION AND FOOD PRODUCTION AND NUTRIENT REMOVAL BY CROPS IN INDIA

At present, India is the world's second largest producer of nitrogen fertilizer and the third largest producer of phosphate fertilizer, whereas all potash fertilizer is imported from overseas. This section will discuss the comparison between fertilizer consumption and food grain production and between food grain production and nutrient removal.

7.1 Fertilizer Consumption *Vis-A-Vis* Food Grain Production

The level of fertilizer consumption in India is quite skewed. The supply of nutrients to plants from chemical fertilizers is the key to increasing

Table 13 Total Food Grain Production and Fertilizer Consumption (Million Tons)

Year	Total NPK Consumption (Mt)	Food Grain Production (Mt)
1950–51	0.06	50.8
1960–61	0.26	82.0
1970–71	1.92	108.4
1980–81	4.73	129.6
1990–91	10.53	176.4
2000–01	14.09	196.8
2010–11	23.04	218.2
2014–15	21.75	252.6

Sources: Compiled from Anonymous, 2014. Agricultural Statistics at a Glance.Directorate of Economics and Statistics. Ministry of Agriculture, Govt of India, New Delhi. http://www.dacnet.nic.in/eandds.

agriculture production and thereby land productivity. However, the demand-supply gap concerning fertilizers in India has increased in recent times, consequently leading to increased dependency on imports. In view of the importance of fertilizers in expanding agriculture and the possibility of an emerging demand–supply gap, it is vital that future demand can be forecast accurately. At the 1950–51 level of productivity, when very little fertilizer was used, the food grain produced was only 50.8 million tons and in more times was 252.6 million times during 2014–15 (Table 13). In fact, 21.75 million tons of fertilizer (NPK) was used in 2014–15 compared to a mere 0.06 million tons in 1950–51. A recent study conducted at the National Centre for Agricultural Economics and Policy Research, New Delhi (Chand and Pandey, 2008), demonstrated that the growth rate of crop output has not kept pace with that in fertilizer consumption and both have declined over the years. This is a matter of great concern, and the causes for this need to be found. Due to the imbalanced use of plant nutrients, mining of nutrients is considered to be the main cause for the decline in crop yield and crop response ratio. India's food and fertilizer needs are expected to go up consistently in the future without a break. The net cropped area is more or less stabilized at 143 Mha. The current population of 1 billion plus is expected to grow by 14–15 million per year. At present, each hectare of net sown area has to support more than seven persons. This pressure will only increase in the coming years. To meet the food grains requirement of 291–300 million tons by 2025, about 30–35 million tons of NPK will be required from various sources (Amarasinghe et al., 2007).

7.2 Food Grain Production *Vis-A-Vis* Nutrient Removal from Soil

At the present level of crop production (i.e., 2014–15), crops remove around 30.43 million tons of NPK, whereas the consumption of fertilizer is around 21.75 million tons which leaves a gap of 8.68 million tons (Fig. 5). It is estimated that from all organic sources which include CRs, livestock dung and human excreta (MSW), 6.84 million tons of N, P, and K could be potentially obtained (Table 14). These estimates exclude secondary and micronutrients added, which are sizeable. Organic manures and CRs can play a major role in recycling K. Although use of organic manure and fertilizer-N can reduce leaching losses of N, the amount of existing surplus waste is very limited. Agricultural residues are mostly burnt out, and cow dung is used for fuel cake. Only MSW, which is steadily increasing in quantity, could serve as a good alternative to bridge the nutrient gap.

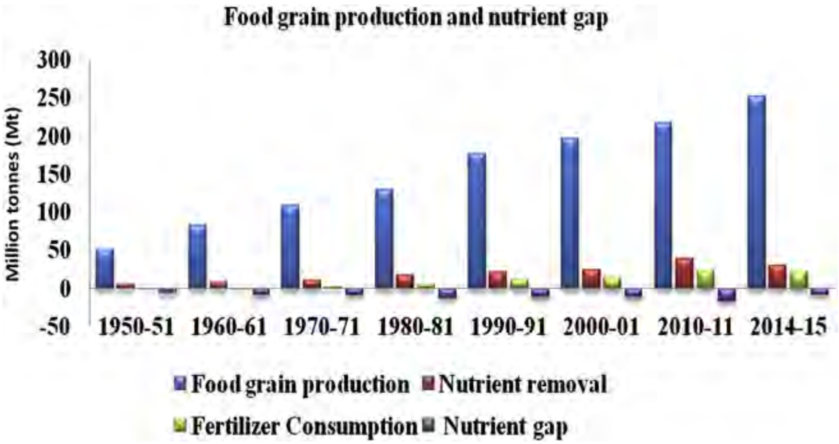

Figure 5 Fertilizer consumption, nutrient removal (NPK), and food grain production (Million tonnes).

Table 14 Nutrient Availability (NPK, Mt) From Three Crop Residue, Animal Dung, and MSW Compost

Sources	Potential Availability	Actual Availability	Nutrient Value (NPK)
Crop residue	724.02	247.16	5.03
Animal dung	470.85	141.26	1.61
MSW compost	35.43	14.17	0.20
Total	–	–	6.84

Overall, a conducive and stable policy environment, availability of raw materials, capital resources, and price incentives will play a critical role in meeting India's fertilizer requirements. This may be a potential threat to the quality of soils and our ability to sustain agriculture, suggesting the need to develop better ways and means to recycle organic wastes generated in municipalities. The total area that is suffering from various kinds of land degradation is estimated to be 120.72 million ha, of which 104.19 million ha falls under arable land, and 16.53 million ha is under open forest. Accelerated soil loss has contributed to substantial yield loss in many crops in India. To restore and maintain the lands suffering from such disorders is a challenge that needs immediate and long-term attention. Deficiency of N is widespread with 89% of soils having low to at best medium N status. The amount of phosphorus is low in 80% of the soils and that of potassium in 50% of the soils. Sulphur, Zn, Mn, and Fe deficiencies are increasing rapidly in several parts of the country. The major threats to soil quality emerge from loss of organic carbon.

8. IS ORGANIC WASTE SUFFICIENT FOR BIO-ENERGY PRODUCTION?

Availability of primary CRs for energy application is usually low since collection is difficult, and the recycling of CRs has the advantage of converting the surplus farm waste into useful products for meeting nutrient requirements of crops and animal feeds (Pandiaraj et al., 2015). The primary or field-based residues include straw and sugarcane tops, whereas those co-produced during processing are called secondary or processing-based residues, including rice husk and bagasse (Singh and Gu, 2010). However, secondary residues are usually available in relatively small quantities at the processing site and may be used as a captive energy source for the same processing plant involving no or little transportation and handling costs (Singh and Gu, 2010). The management of these areas is generally in the hands of poor farmers, rural households, and the tiny agro-based industry sector which is only generating low incomes. About half of the surplus residues are burnt in the fields causing serious air pollution. Some waste effluents have an energy potential such as black liquor from the pulp and paper industry, wastewater from slaughterhouses, milk processing units, breweries, the vegetable packaging industry, and animal manure (Singh and Gu, 2010).

The potential industries producing wastewater for anaerobic digestion and their energy potential can effectively be used as feedstock for the biofuel production (Ravindranath and Balachandra, 2009; Singh and Gu, 2010). Production of energy from cow dung is common in India and usually takes the form of dung cakes, but availability of cow dung is only 30% after being used for fuel cakes. Although biogas is a smokeless fuel offering an excellent substitute for kerosene oil, cattle dung cake, agricultural residues, and firewood continue to be used as sources of fuel in the rural areas of most developing countries, the acceptance of biogas has not gained much momentum. Given the large number of existing and potential biogas plants, India has a good opportunity to solve its energy crisis and can earn substantial revenue under the new regime of carbon marketing. The third largest contributor of organic waste is MSW. The root causes of this are the high inert content (>30%) in the mixed waste (MSW), low energy value (3350–4200 kJ kg^{-1}), and thus it is unsuitable for incineration or gasification for conversion to bio-energy. There is furthermore a problem in marketing the compost product due to low nutrient quality (Manna et al., 2014).

9. CONSTRAINTS ON WASTE RECYCLING IN AGRICULTURAL LAND

Soil dilapidation is a global issue caused by many factors including extensive tillage operation, intensive and inappropriate crop rotations, excessive CR removal, deforestation, mining, construction and urbanization, etc. In India, farmers prefer to burn CR in their fields so that the commencement of the next crop can start almost immediately, reduce weed infestation, and make the mechanization aspects of farming easier to implement. Moreover, either removal or recycling or CR is a labor-intensive process, and in some region of India, they do not prefer to feed it to animals. To stop the residue burning the viable and best alternative management option is either ZT or *in-situ* composting. For example, *in-situ* decomposition takes about 30–45 days for CR recycling, but it is rarely accepted by farmers because the transitional period between postharvest and sowing of the next crop is only 20 days. For this reason, farmers do not want to sacrifice their important crop. However, delaying the crop cultivation reduces the yield.

There is a great challenge to shorten the period of CR decomposition. ZT is another alternative to burning of residue particularly in Indo-Gangetic alluvial soils. It is, however, very difficult to adopt ZT operations in semi-arid-tropic Vertisols due to the abundance of weeds and less moisture content in surface soil of swell-shrink black soil. This affects seed germination during the winter wheat crop. Improper seed germination due to hindrance or encumbrance of seed drill operation is reported to severely reduce the crop yield.

Animal dung is one of the largest energy sources in rural areas. Biogas (generated from animal dung) plants in India have not as yet been extensively adopted as energy sources. Because the government has withdrawn subsidies, and also due to mechanization of agriculture and less availability of pasture/grazing land for animals, farmers have barely adopted livestock rearing on a large scale. The alternative of biogas has not made any substantial impact in India's rural areas. Only one-third of cow dung is being used as an organic source in India.

The vegetable wastes, kitchen and agro-based industrial wastes are regularly accumulating in ever-increasing amounts in city areas. However, all these wastes are unsegregated and deposited in dumping yards. Due to the poor quality of end products, such large-scale examples of bio-waste are hardly used by farmers. The transportation costs are also very high, and they contain several contaminants like pathogens and heavy metals. Nonetheless concerns continue to grow over how to recycle these all wastes which are potential sources of plant nutrients.

10. CONCLUSIONS

The rapid increases in the world's population, food grain production, economic growth, urbanization, and industrialization is coupled with accelerated generation of waste. CR, animal waste, and MSW now constitute national and global problems. The major dilemmas concerning CR burning are soil health, soil biodiversity, crop productivity, and these wastes' heavy contribution to global warming and climate change. Most animal waste is being used as fuel cakes which are a very good source of plant nutrients and soil organic matter. Two of the major problems being encountered are the insufficient collection and inappropriate final disposal of MSW. Various collection systems employed by the municipalities collect less than half of the total waste generated. As a result, wastes are either scattered in urban centers or disposed of in an unplanned or poorly managed ways in low-lying areas or open dumps or burned by residents in their backyards.

The unscientific or unsystematic management of all waste has made the situation worse and led to several environmental and health-related problems simply increasing and not being solved. All these organic sources have great potential for plant nutrient, and particularly SOC in the Indian scenario. Keeping in mind the present situation, the current review examines the opportunities and improvements that could be introduced to CR, animal waste, and MSW management systems.

11. FUTURE RESEARCH ON WASTE MANAGEMENT

Long-term research studies have shown that deficiencies involving micro and secondary nutrients are usually associated with imbalanced use of fertilizer application. Application of organic matter in conjunction with balanced chemical fertilizer will nevertheless remove some deficiency symptoms. Scientific management of all bio-wastes has a tremendous scope not only for productivity, soil health, and improvement of soil biodiversity but also minimizing global warming and climate change.

The use of CRs biomass is a source of plant nutrients, and several scientific approaches have attempted to minimize the outcomes of burning. The practice of burning residues in fields needs to be restricted for all categories of farmers, and the potential of CRs needs to be illustrated to generate sustainable changes in soil health dynamics. For example, direct residue incorporation in the shortest possible time is a great challenge for the rice—wheat system especially. Furthermore, the mechanized postharvest residue accumulation and transportation especially as done by small and medium farmers is a major problem. The lack of equipment for residue accumulation, transportation, and decomposition is a very common problem throughout India. Interest needs to increase in *off-situ* decomposition techniques, especially to improve soil ecosystem functioning and minimize the environmental pollution, as an alternative to burning CRs. Extensive research on ZT is a good practice if the CRs are burned beforehand. However, RR in ZT practice sometimes reduces the crop establishment, while the excessive growth of weed biomass usually suppresses the initial crop growth. Good management practices are required with ZT to sustain better crop yields.

There is a growing interest in alternative energy sources as a result of increased demand for energy coupled with a rise in the cost of available fuels. Slaughterhouses and dairy farms have a tremendous scope. It is clear from our review that there are no governing factors that dictate the suitability of particular reactor design for safe use of wastewater. Reactors' advanced methods should be developed for suitable pretreatment and posttreatment, which can result in complete treatment of waste effluents. Subsequently, digested bio-solids may be suitable for safe use in agriculture.

The liquid wastes originating from a dairy's manufacturing process are spilled milk, spoiled milk, skimmed milk, whey, washed water from milk cans, equipment, bottles, and so on. The treatment of cheese whey wastewater by anaerobic degradation is constrained by the drop in pH which inhibits further conversion of acids into CH_4. There is a need to develop advanced techniques to recycle this wastewater not only for production of energy but also to improve agricultural practices. In rural areas the animal waste is dung and urine that mainly derive from cows, buffalos, poultry but less from sheep, goats, and pigs. The animal dung is being used as fuel cakes for energy sources because farmers rear animals only for milking purposes. There is no governmental compulsion to restrict these practices of dung cake for fuel in rural areas. There is a need for other arrangements concerning energy sources so that all the animal waste will be recycled in agriculture. Biogas is a renewable form of energy that could very well substitute in the rural sector for conventional sources of energy. Despite its numerous advantages, the biogas technology cannot be fully harnessed because of the large hydraulic retention time of 30–50 days, low gas production in winter, and so on. Therefore strategies are needed to remove its various limitations so that this technology becomes more popular in rural areas. The digested cow dung slurry is a good source of plant nutrients.

In urban areas, about 40% of unsegregated city garbage is a bio-waste segment that can be separated for recycling through composting channels in India. A thorough segregation is most vital for achieving pollutant-free, well-decomposed, and high-quality compost. It is a paradox that India has not been able to get each household to separate the biodegradable materials, recyclable materials, civil work materials, hospital waste, and so on, which could be encouraged by the electronic media, social workers, nongovernmental organizations, and others, especially at the generating and collecting stages. Bio-waste should not be allowed to exist in dumping yards or landfill sites because to do so simply promotes groundwater pollution through leaching. There is ample scope of research to reduce contaminants and minimization of pathogens in city waste through advanced knowledge and practice of bioremediation.

There is an urgent need to accelerate the process of decomposition using thermophilic lignocellulolytic microbes for the rapid composting process.

No proper established criteria are available for recommending the optimum loading rates of soils to receive urban solid wastes as a source of organic matter and nutrients. The build-up of soluble salts and heavy metal contents and methods to mitigate this situation need to be worked out. Furthermore, there are two kinds of information that are currently not available in India: first, regarding the relationship between the concentration of metals in soil and uptake by plants and availability of metals in polluted soils over time; and second, the significance of critical concentrations of heavy metals in food plants with reference to suggested dietary limits. More studies wastes, soil, and crop management practices and their role in minimizing the pollution of environment area are urgently needed.

The information on retention mechanisms and factors influencing the form and the long-term behavior of metals in soils is essential to develop practicable recommendations and management techniques for application of MSW to soils. Finally, research is needed to evaluate the effect of organic materials on increasing the efficiency of fertilizers and evaluating crop yield response to various combinations of organic and chemical fertilizers for a sustainable production system.

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