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Review

Composting: An opportunity in a carbon conscious world for combating climate change

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Increase of greenhouse gas (GHG) emissions is an ever challenging concern to mitigate global climate change. Governments and corporations across the world have introduced innovative strategies to reduce steadily rising GHG emissions. Some of these strategies are carbon taxes, energy efficiency strategies, command and control policies and market-based pollution trading mechanisms. This review highlighted the concept of carbon cap and trade program, GHG emission from compost, mitigation strategies, and carbon credit opportunities in the developing countries.

Key words: Compost, carbon credits, greenhouse gas (GHG), waste management.

INTRODUCTION

As the debate over global climate change shifts from “is it happening” to “what do we do about it”, composting, like all other waste management activities, is being reviewed through the greenhouse gas (GHG) lens. However, in order to make fair comparisons, we have to compare different activities as both possible sources of GHG and also as possible sinks. Composting would be beneficial if, when compared to alternatives, it either puts less GHG into the atmosphere (avoidance) or takes more CO_2 out of the atmosphere (sequestration). The net benefit can be turned into cash through the sale of “carbon credits” on the emerging carbon trading mark. One of the principal ways of attaining higher productivity and environmental standards are identification and adoption of beneficial management practices (BMP) by reviewing the conventional agricultural activities (Okkan and Fistikoglu, 2013). The BMP are agricultural practices that promote sustainable land stewardship and maintain or increase profitability of farms. The BMP are from both crop and animal production systems and tradeoffs between the two systems could provide several opportunities in reducing, removing and/or avoiding of GHG emission (Asgedom and Kebreab, 2011).

This review article highlights the relevance of composting, and strategies to mitigate global climate change and possibility for carbon credit with following key objectives:

1) What is the basic concept of carbon crediting?
2) Relevance of composting,
3) GHG emission scenarios from the compost,
4) GHG mitigation strategies from compost through alternative management approaches, and
5) Defining the limit of carbon credit through different composting technologies.

We have taken the issues and possibilities of utilizing municipal wastes as composting material in the

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developing countries taking into account of global relevance in waste management.

COMPOSTING IN THE CAP-AND-TRADE PROGRAM

Cap-and-trade regulations limit the quantities of pollutants, (in this case GHG) that entities can emit into the atmosphere, and can provide economic incentives for reducing emissions even further (below the cap). The "cap" sets a limit on GHG emissions, while the "trade" creates a market for carbon allowances. Regulated entities (for example, a coal burning power plant) can either reduce emissions from their own facilities, or can purchase “emission reductions” from other regulated entities that have reduced their emissions below their cap (and therefore have some left over). The major components involved in a cap-and-trade program are caps, coverage, and monitoring. Limit (cap) of GHG emission for any company is set up by international, federal, or local governing body. The government then decides on coverage, or the sectors and sources of carbon that must comply with this limit. To ensure compliance with this cap, systems must also exist to monitor sources, checking and verifying each source’s reporting of carbon output. Sources, however, may go beyond their allowances, or over the cap, if they have traded with another source.

Solid waste management practices practiced in many developing countries release high quantities of GHG in the atmosphere. High GHG emission is mainly due to land filling; thus, solid waste composting sector creates significant opportunities for carbon mitigation, which could eventually become tradable carbon credits. Emission reductions can also be created voluntarily by non-regulated entities (such as a compost facility) to be used by regulated entities to offset their own emissions. The 1992 UN Framework Convention on climate change created that the Kyoto Protocol, was the basis for initial carbon cap-and-trade programs. As of mid 2007, there were 165 pieces of legislation introduced to the 110th congress, of which at least were related to cap-and-trade programs (Kapoor and Ambrosi, 2007). The primary instrument being traded in these programs are “carbon credits”

CARBON CREDITS AND MARKETING OPPORTUNITIES

Carbon credits or carbon offsets usually referred to as certified, tradable GHG emission reductions, used within a cap-and-trade program. Reducing emissions does not automatically create carbon credits - results from a formal process or “protocol” that quantifies, verifies, and certifies qualifying emission reductions from eligible projects. Credible carbon credits as a whole represent real, permanent, quantifiable, verifiable, and enforceable emission reductions. Often carbon credits are formally issued or registered by a carbon “registry” or exchange to facilitate market trading and ensure that the same credits are not sold more than once. Carbon credits are usually quantified in units of metric tons of carbon dioxide equivalents (CO_2 e).

Every tons of CO_2 not emitted is considered as one credit and every carbon credit fetches the firm around $3-6. In Europe it is €5 per tons of CO_2, but is expected to rise to €7.50 during the course of the year 2014. The value will potentially reach to a new high of €180 bn by the year 2016. The carbon credit remuneration continues year after year. And the best part is that it is quite easy to implement technologies known to reduce emissions provided the project meets certain criteria. The firms trading credits have two options to choose from depending on the life of the project - fixed crediting period of 10 years or first period of 7 years extendable twice for a total period of 21 years. Advantage of implanting cleaner and sustainable technologies is the ability to avail funding from prototype carbon fund which is under the Aegis of the World Bank. The fund is formed by contributions from many developed nations. Indian firms may well take the lead to use cleaner technologies to earn credits and secure funds. From 2005 to 2006, the value of the total world market of carbon credits tripled. In 2006, over 1 billion tons of credits, with a market value of about $20 billion, were traded through the European Trading System (by countries that have adopted the Kyoto Protocol) (Kapoor and Ambrosi, 2007). In the U.S., which is not participating in the Kyoto cap-and-trade system, the market is much smaller, but still significant: in 2006 over 10 million tons of carbon traded on the Chicago Climate Exchange (CCX) with a value of over $40 million. Since 2003 CCX prices have ranged from less than a dollar per metric ton to almost $5. Due to international agreements and action on climate change, the carbon market is one of the fastest growing markets for financial commodities.

Amidst growing concern and increasing awareness on the need for pollution control, the concept of carbon credit came into vogue as part of an international agreement, popularly known as the Kyoto Protocol. Carbon credits are certificates issued to countries that reduce their emission of GHG, which causes global warming. It is estimated that 60 to 70% of GHG emission is through fuel combustion in industries like cement, steel, textiles and fertilizers.

IMPORTANCE OF COMPOSTING

With emergence of municipal solid waste (MSW) as a big problem for municipal authorities here in India and abroad, companies introduced indigenously developed equipment to process mixed MSW. Aerobic composting

Table 1. Prevented methane emission (CO_2 equivalent) which otherwise could be claimed as emission reductions (ER) through composting in different places of the world (Gentil et al., 2009).

Name of the country	ER tons CO_2 e year $^{-1}$	Tons per day
Bangladesh (Dhaka)	6814	100
China (Wuzhou)	7022	93
Ivory Coast (Abidjen)	7212	219
Columbia	5570	500
Indonesia (Bali)	27020	700
Delhi (Okhla)	73202	1950

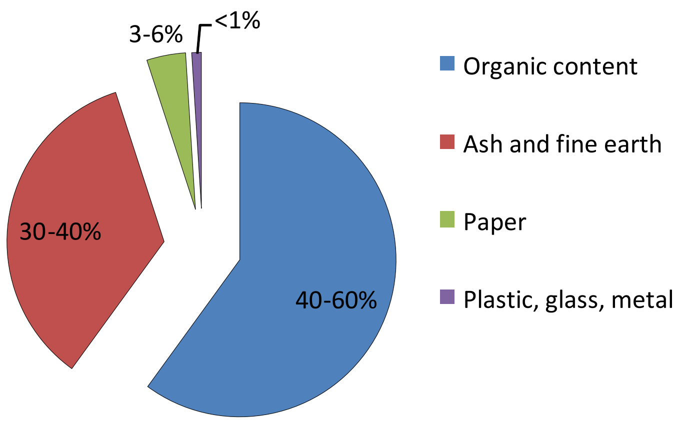

Figure 1. Distribution of waste materials in the municipal solid waste (MSW) source in India (Sharholy et al., 2008).

is one of such technology and it is considered to be one of the cheapest solutions to mixed MSW. Methane emission mitigation potential of compost in different places of the world is given in Table 1. All biodegradable material available in waste is converted into valuable organic manure. Aerobic composting is a process involving bio-chemical conversion of organic matter into humus lignopoteins by mesophilic and thermophilic organisms. A composting process seeks to harness the natural forces of decomposition to secure the conversion of organic waste into organic manure. This process is done under controlled conditions in order to make it aesthetically acceptable, minimize the production of offensive odours, avoid the propagation of insects, destroy pathogenic organisms present in the original waste, destroy weed seeds, retain the maximum nutrient content NPK, minimize the time required to complete the process, and minimize the land area required for the process. Compost serves as an ultimate solution for organic waste disposal, value addition to the project by means of fertilizer generation, easy handling and simple procedure, totally eco-friendly process, support to the green cover in the city, and up-gradation of the natural resources by completing the cycle of nature.

CARBON CREDITS THROUGH COMPOSTING

Carbon credit facilities works with direction of low emissions of GHG or less carbon intensive approaches. Since GHG mitigation projects generate credits, this approach can be used to finance carbon reduction schemes between trading partners around the world. The types of feedstocks, and where they were going before the new composting project, are also important since credits are only valid where real emission reductions (relative to a baseline scenario) occur. In other words, we do not get credit just for composting, but for composting those feedstocks that would otherwise be emitting methane or nitrous oxide into the atmosphere. Formal protocols for quantifying compost-related emission reductions have been developed by the Intergovernmental Panel on Climate Change (IPCC) and are already being used for offset projects within the Kyoto Protocol framework. In the U.S., protocols for the CCX and other programs are being developed. Trading carbon credits between developing and developed nations will soon become a reality. Companies in India will gain monetarily and be able to put up projects that are eco-friendly. The latest comes from quite unconventional quarters - trading of carbon credits or more specifically carbon dioxide credits between developing and developed nations. When global warming is the watchword and reducing carbon dioxide emission is the buzzword, can trade be far behind?

There is close to 5100 odd municipalities across India wherein the problem of MSW management has reached critical dimensions (Figure 1). It is estimated that 377 million urban populations in India (≈31% of the total population) is generating almost 194,000 MT/d of MSW (Sharholy et al., 2008). State-wise solid waste production in India is given in Table 2. The urban local bodies (ULBs) in their efforts to safeguard public health are incurring between Rs. 800-1500/MT of solid waste for collection, treatment and disposal and this activity alone accounts for almost 30 to 50% of a typical municipal budget. There are significant issues related to primary collection, transportation, treatment and safe disposal which impact sustainability and viability of the entire chain

Table 2. Municipal solid waste (MSW) generated from different cities in India (Sharholy et al., 2008).

Name of the state	MSW (tones per day)
Andhra Pradesh	3943
Assam	196
Bihar	1479
Gujarat	3805
Haryana	623
Himachal Pradesh	35
Karnataka	3118
Kerala	1220
Madhya Pradesh	2286
Maharashtra	8589
Manipur	40
Meghalaya	35
Mizoram	46
Orissa	646
Punjab	1001
Rajasthan	1768
Tamilnadu	5021
Tripura	33
Uttar Pradesh	5515
West Bengal	4475
Chandigarh	200
Delhi	4000
Pondicherry	60

of operations. GHG (CH_4 and NO_X) emission from the solid wastes during different year is given in Table 3. A number of ULBs have gone about setting up treatment plants under the paradigm of 'waste to energy' and 'waste to wealth' with the presumption of that being an end in itself. The paradigm of 'safeguarding environment and public health' is often found to be relegated to a secondary level. In most cases, decisions to set up a particular technology solution also appear to have been influenced by other factors. The technologies that have been attempted in India during last 3 decades are windrow composting, mass burn, combustion of refuse derived fuel, bio-methanation, and at a small scale numerous vermicomposting initiatives. However, time and again it is seen that the technology driven initiatives run into rough terrain and perforce do not bring the desired environmental and public health benefits, least of all the financial benefits. A number of institutional, technical and financial risk factors are associated with almost all the resource recovery technologies mentioned above which lead to closure of the facilities within a rather short period after commission.

Okhla composting plant near Delhi, India converts approximately 73,000 tones of MSW into compost every year. This is equivalent to 200 tons of MSW per day. Compost is utilized as organic fertilizer for agricultural purpose. Around 1,600 tons of CH_4 are avoided on average per year. CH_4 has global warming potential; this is equivalent to 34000 tons of CO_2 e year. Not only avoidance of CH_4 emission from composting plant project, the project avoids emission of CH_4 that would be produced by land fill air, and water pollution is also prevented. Therefore, total emission reduction would be 235,000 tons of CO_2 e in the crediting period. And Okhla became the first in India to receive the carbon credits from the United Nations Framework Convention on Climate Change (UNFCCC). The plant received financial assistance in advance against the carbon emission reduction (CER) earnings from this plant.

Composts are rich in long-term carbon in the form of fulvic and humic acids carbon compounds. Compost product is estimated to contain 100 to 150 kg of carbon per cubic meter of product and in the order of 10% or more of this is in non labile/long form such as humic compounds. When this is converted to CO_2-e, the stored carbon benefit of compost is in the order of at least 37 to 55 kg m^{-3} of product. Trading of carbon and NOx emission reduction is an attractive approach to implement cleaner treatment technologies to replace current anaerobic approaches for solid waste management. Kottayam a town in Kerala, India generates 52.6 tons per day as MSW, which would result in 5380 TCO_2 e $year^{-1}$ of GHG emission if dumped. If the same waste was composted aerobically, it may generate 200 t CO_2 $year^{-1}$; hence, a reduction of 5166 t CO_2 e $year^{-1}$. This reduction can lead to the monetary gain for the town on the market price of carbon credit.

The rate of solid waste generation and the corresponding CH_4 emission have increased to an exponential rate since 2001. By the year 2041, the waste will generate about 32 million tons of CH_4 and this waste will require about 1100 km^2 of land for disposal. As composition of MSW in India differs from city to city on wet weight basis the average India MSW consists of organic content, ash and fine earth, paper, glass, metal in different ratios (Figure 1). The calorific value of the Indian MSW is low due to the high inert matter and moisture content and is in the range of 800 to 1000 K Cal Kg^{-1} (Sharholy et al., 2008). The total waste generated in urban India is estimated to be 188,500 tons per day (TPD) or 68.8 million tons per year (TPY). A total of 366 cities in India which represent 70% of India's urban population generate 47.2 million TPY per capita waste generation rates of 500 g/day. At this rate the urban MSW generated in 2041 would be 230 million TPY and would occupy an area equivalent to that Mumbai, Chennai and Hyderabad.

Bangladesh is getting involved in carbon credit trading with the certification of a recycling plant that converts organic waste into compost. Plant collects some 100 tons of vegetable waste from two city markets daily and recycles it through composting. If that waste were dumped in the landfill it could have emitted huge

Table 3. Estimate of annual methane (CH_4) and nitrous oxide (NOx) emission from India 1990 - 2020.

Year	CH_4 emission from land fill (Gg)	NOx emission from manure management (Gg)
1990	334	17
1995	382	18
2000	436	19
2005	498	20
2010	569	20
2015	650	21
2020	743	22

(amounts of) methane gas. The plant currently produces 15,000 tons of compost annually, which is sold inexpensively to rural farmers. The Kyoto Protocol commits most industrialized nations to efforts to reduce GHG emissions that contribute to climate change, in part by investing in emissions-reduction projects in developing countries. The projects received credits that could be traded with industrialized countries, giving the richer countries credit toward their own emissions reduction goals and poorer countries cash. The Asian development bank plans to replicate the organic waste composting model in four other cities in Bangladesh, and the department of the environment is developing five similar projects in cities and municipalities. Waste concern is developing strategies for MSW management in several other Asian countries, including Nepal, Pakistan, Sri Lanka, Cambodia and Vietnam, as well as in Africa.

GREEN HOUSE GAS EMISSION FORM COMPOST

Some GHG emission during composting is unavoidable; however, management practices can reduce those emissions. Manure properties can be modified, e.g., by using bulking material to adjust the C/N ratio and moisture content (Shi et al., 1999), using proper windrow pile dimensions to manage aeration (Fukumoto et al., 2003) and using amendments to change manure pH, available C and N. Adding straw or woodchips (C-rich amendments) will increase the C/N ratio and reduce CH_4 (Yamulki, 2006) and N_2O emission (Mahimairaja et al., 1995; Yamulki, 2006). Adding phosphogypsum (PG), a P fertilizer industry by-product, reduced CH_4 emission (Hao et al., 2005) mainly due to sulfur-reducing bacteria out-competing the methanogens as CH_4 emission decreased exponentially with the total S content in manure. Although the N_2O emission increased with the manure pH decreased from 8.0 to 7.4 by PG addition as N_2O emission is generally greatest around neutral pH, the increases were not significant compared to no amended manure composting (Hao et al., 2005). Adding mature compost as a source of nitrite-oxidizing bacteria reduces N_2O emission when solid swine manure was composted in a pilot scale forced-aeration (Fukumoto et al., 2006). However, when this was done with solid cattle feedlot manure in open windrow composting, no effect on N_2O emission was observed (Hao et al., 2005).

Emissions may come from the composting process itself and from the equipment used to manage the process. Carbon dioxide released during composting is considered biogenic, so does not count in GHG calculations. While it is theoretically possible for CH_4 to be generated in a poorly managed compost pile, the Environmental Protection Agency (EPA) has concluded that there is little evidence that this actually happens, so considers any releases negligible (EPA, 2002). On the other hand, the fuel and electricity used to operate the equipment and buildings result in anthropogenic releases. Methane is formed as a by-product of microbial respiration in severely anaerobic environments when carbon is the only electron acceptor available. Carbon is used as an electron acceptor when other, more energetically favorable electron acceptors, including oxygen, nitrogen, iron, manganese, and sulfur, have been exhausted. Because the environments in a waste storage lagoon, landfill, or compost pile are not uniform, it is also possible that different electron acceptors can be used simultaneously. For example, when sulfur is used as an electron acceptor, highly odorous compounds, including dimethyl disulfide and methyl mercaptan, are formed. The presence of these compounds can be indicative of the presence of CH_4. A compost or waste pile that exhibits minimal odors is more likely to have aerobic conditions throughout than a malodorous pile of processed feedstocks.

Nitrous oxide is a potent GHG, with the global worming potential of 298 over 100 years (IPCC, 2007). Even though many authors agree that compost management is decisive to determinate the amount of emission (Hao, 2007; Szanto et al., 2007; Hellebrand and Kalk, 2000) there is a difficulty to establish the variables that will be influencing the emissions the most. For instance, during the initial phase of composting oxygen limitation plays a big role (Jarvis et al., 2009). In compost nitrous oxide peaks after 9 and 21 days of composting and are attributed to nitrification and denitrification processes, respectively (Jarvis et al., 2009). During the mesophilic temperature the initial phase of composting is beneficial for nitrous oxide formation and when thermophilic conditions are reached, the production decreases (Beck-Friis et al., 2003). In denitrification process, nitrous oxide is an intermediate product, which can be transformed to N_2 if the N_2O reductase is present in the microbial community and the pH levels are beneficial (pH 6.5 to 7) for its assembly and functioning (Bergaust et al., 2010). A substantial release of N_2O happens after the turning operations due to the transfer of NO_2^-/NO_3^- from aerobic portion into the anoxic portion (Jiang et al., 2011). Higher aeration rates increases the nitrification rate, producing both N_2O and higher concentrations of NO_2^-, NO_3^- in the material. Nitrous oxide in maturation phase of composting can be expected due to both nitrification and denitrification processes, which is especially relevant for larger composts as oxygen gradient is formed within the material (Beck-Friis et al., 2001) temperatures in mesophilic range and natural aeration is reducing. These conditions allow both nitrification and denitrification activities to continue.

Reduction of GHG emission from compost

GHG emissions from the agricultural sector can be reduced through implementation of improved management practices. For example, the choice of manure storage method should be based on environmental decision criteria, as well as production capacity. By composting all the cattle manure stored as slurry and stockpile, a reduction of 0.70 Tg CO_2-e year^{-1} would be achieved. Similarly, by collecting and burning CH_4 emissions from existing slurry facilities, a reduction of 0.76 Tg CO_2-e year^{-1} would be achieved. New CH_4 emission factors were estimated based on these results and incorporated into the IPCC methodology. For North-America under cool conditions, the CH_4 emission factors would be 45 kg CH_4 ha^{-1} year^{-1} for dairy cattle manure rather than 36 kg CH_4 ha^{-1} year^{-1}, and 3 kg CH_4 ha^{-1} year^{-1} for beef cattle manure rather than 1 kg CH_4 ha^{-1} year (Pattey et al., 2005) contribution that manure management makes to total national agricultural emissions of N_2O and CH_4 vary, but can exceed 50% in countries reporting to the UNFCCC in 2009. On farm management decisions interact with environmental controls such as temperature and water availability of key microbial processes (that is, nitrification, denitrification, methanogenesis, CH_4 oxidation), affecting the magnitude of emissions from each stage of the manure management continuum. We review the current understanding of how manure management influences direct and indirect N_2O emissions and CH_4 emissions, introduce new data comparing direct N_2O emissions following spreading of a range of manure types by different methods, and highlight some of the mitigations being considered by researchers and policy makers in developed and developing countries (Chadwick et al., 2011).

GHG emission could be reduced by managing compost pile size as larger piles increase CH_4 and N_2O emissions due to poor aeration (Fukumoto et al., 2003). Forced aeration and turning generally reduces CH_4 emission (Lopez-Real and Baptista, 1996), while increasing compost pile porosity could reduce N_2O emission (Møller et al., 2000). Bedding material used in cattle feedlots not only affects NH_3 emission in the feedlot pen, but also GHG emission during composting. However, in open windrow composting, straw or woodchip bedding made no difference to GHG emissions from cattle feedlot manure (Hao et al., 2004).

The effects of diet manipulation on manure properties can also carryover to affect GHG emission from manure composting. When an 85% barley grain finishing diet was replaced with 60% dried distilled grains (DDGS) and only 25% barley grain, N_2O emissions from composting cattle manure were higher but CH_4 emissions were not affected (Hao et al., 2011). The greater N_2O emission can be attributed to the higher N content in DDGS.

Separation of MSW followed by recycling (for paper, metals, textiles and plastics) and composting/anaerobic digestion (for putrescible wastes) gives the lowest net flux of GHGes, compared to other options for the treatment of municiipal solid waste. In comparison with landfilling untreated waste, composting/anaerobic digestion of putrescible wastes and recycling of paper produce the overall greatest reduction in net flux of greenhouse of gases

BIOCHAR (BC) GHG ACCOUNTING AND EMISSION TRADING

It is possible to combat GHG emissions and reinvigorate rural and agricultural communities simultaneously through the use of BC. BC is the name given to charcoal produced for agronomic and other ecosystem applications (Gaunt and Cowie, 2009). It is produced by heating biomass in the absence of oxygen, a process known as pyrolysis. In addition to stably sequestering the carbon in the BC for periods of time estimated to be several hundred to several thousand years (Lehmann and Joseph, 2009) BC can be applied to cropland to increase crop yields, decrease runoff, decrease fertilizer and lime use, increase soil fertility and minimize nitrous oxide (N_2O) and methane (CH_4) emissions, which are also potent GHGs (Sohi et al., 2009). Stored solid manure heaps can be a significant source of N_2O and CH_4 emissions. The manure characteristics influence emissions and solid manure heaps can be managed to promote aerobic decomposition during storage. Increasing the carbon content of the manure heap with high-C additives, such as straw, may provide the opportunity for N_2O and CH_4 emission reduction (Yamulki, 2006). Adding high-C additives, such as straw could be a promising strategy for reducing GHG emissions because it influences the dry matter content, C:N ratio and aeration of the manure. The small-scale farmyard manure (FYM) storage method were shown to be a reliable and an easy method to quantify emissions under a range of environmental conditions and manure manipulations and so develop effective manure management practices to reduce GHG emissions (Yamulki, 2006). BC has been shown to act as an absorber of NH_3 and water-soluble NH_4^+ and might therefore reduce losses of N during composting of manure (Steiner et al., 2010).

BC's porous structure allows oxygen to move through the material, and maintaining these air passageways enhances microbial activity and provides for a faster and odor-free decomposition. Studies have also shown a significant reduction in N-P-K loss during the decomposition process as nutrients and minerals bond to the BC. In using BC, commercial composters find the reduction in GHG emissions and ability to sell their compost as an enhanced N-P-K fertilizer quite significant.

TURNING, COMPACTING AND THE ADDITION OF WATER TO MINIMIZE GASEOUS EMISSIONS FROM COMPOST

Composting allows simple management of animal manure but excessive aeration can increase emissions of polluting gases such as ammonia or nitrous oxide. In an experiment the effect of three techniques - turning, compacting and the addition of water - on gaseous emissions was studied. One ton of cattle manure and 3 tons of turkey manure were composted in two and four cells for 46 and 51 days, respectively. The manure was either turned, wetted, or compacted. Emissions of carbon dioxide, water vapor, ammonia and nitrous oxide were monitored. The results show that turning did not alter the free air space. Compacting can be used specifically to reduce the water loss. A reduction of free air space by 20 to 60%, either by compacting or adding water (or both), reduced the ammonia and nitrous oxide emissions by 30 to 70% (El Kader et al., 2007).

GHG BALANCE FOR COMPOSTING OPERATIONS

The primary carbon credits associated with composting are through CH_4 avoidance when feedstocks are composted instead of land filled (MSW and biosolids) or lagooned (animal manures). Methane generation potential is given based on total volatile solids, expected volatile solids destruction, and CH_4 generation from lab and field incubations. For example, a facility that composts an equal mixture of manure, newsprint, and food waste could conserve the equivalent of 3.1 Mg CO_2 per 1 dry Mg of feedstocks composted if feedstocks were diverted from anaerobic storage lagoons and landfills with no gas collection mechanisms. The composting process is a source of GHG emissions from the use of electricity and fossil fuels and through GHG emissions during composting. GHG emissions during composting are highest for high-nitrogen materials with high moisture contents. These debits are minimal in comparison to avoidance credits and can be further minimized through the use of higher C:N feedstock mixtures and lower-moisture-content mixtures. Compost end use has the potential to generate carbon credits through avoidance and sequestration of carbon; however, these are highly project specific and need to be quantified on an individual project basis (Brown et al., 2008).

Additional credits could be available from the compost use. 14,800 tons of food scraps might result in 2100 tons of finished compost (wet weight at 30% moisture). According to EPA, 0.05 metric tons of carbon equivalents per wet ton of finished compost are sequestered after 10 years. This would add an additional 105 tons of credit to the methane avoidance credit. The Recycled Organics Unit (ROU) study noted that this is a conservative estimate, as it does not include multiplier effects that might accrue from increased yield due to higher organic matter content. In the life cycle analysis performed by the ROU, the reduction in crop inputs such as fertilizer, herbicides and irrigation water coupled with the carbon sequestration more than made up for the emissions stemming from compost production and production transportation. They concluded that there is a net reduction in global warming potential from the windrow composting of yard debris. This was true even if the compost was transported over 400 miles and the trucks returned empty. As can be seen in this example, the primary benefit of composting from a climate change perspective is in the avoidance of methane generation. Sending organics to an anaerobic digester for methane production and use as energy would likewise avoid the GHG release with the additional benefits of replacing non-renewable energy. Some additional credits may come from the use of compost, via carbon sequestration and via reduction of GHG by displacing other inputs. The specific benefits of any composting venture will have to be figured on a case-by-case basis.

The benefits associated with compost use, in relation to GHG emissions were considered by the USEPA (2002), recycled organics unit (Unit, 2006), and (Smith et al., 2001) in their calculations. The EPA estimate and recycled organics unit based their calculations on specific end-use cases. Smith et al. (2001) based their calculations on more general properties of compost and the potential for compost to replace peat for a range of end uses. For their estimate, the recycled organics unit modeled two types of end use for compost as a soil conditioner for cotton with an application rate of 12 Mg ha^{-1} and as mulch for grapes with an application of 75 Mg ha^{-1} every 3 years.

Factors that were considered included increased soil carbon, reduced water usage, fertilizer value, and reduced use of herbicides. The soil conditioner is a nutrient-rich product with total nitrogen of 1 to 2% and a water-holding capacity of 50 to 60%. It contains 55 to 75% organic matter (Brown et al., 2008). As a soil conditioner, the potential carbon credits or benefits associated with compost use were (a) Increased soil water-holding capacity of 2.4 to 3%, resulting in reduced irrigation of 0.13 to 0.16 ml H_2O ha^{-1} in irrigated cotton (reduced energy requirements for irrigation), (b) Fertilizer equivalent of 34 to 68 kg N, 29 to 57 kg P, and 24 to 48 kg K ha^{-1} for the first year (reduced energy from avoidance of synthetic fertilizers). (c) Sequestering 2.9 to 5.9 Mg C ha^{-1} after 10 years. Mulch is categorized as a low-nutrient mixture made from garden wastes with 75 to 95% organic matter and total nitrogen of 0.2 to 0.4%. The water-holding capacity of the mulch is 10 to 20%. The benefits associated with use of compost and using mulch are multifold. It increases soil water-holding capacity of soils by 9.8%, with total savings of 0.95 ml H_2O ha^{-1} for irrigated viticulture. It replaces herbicide from 2 to 6 L ha^{-1}. It also facilitates carbon sequestration of 11.6 Mg C ha^{-1} after 10 years, a potential opportunity for carbon credit.

CONCLUSION

The carbon farming initiative (CFI) has been introduced in many countries to allow landholders to generate offset credits from activities that reduce emissions or sequester carbon, including BC application. This scheme will provide confidence to those purchasing offsets, and regulate those making claims of “carbon neutrality”. Eligible activities that can earn offset credits include a range of land management, agricultural practices, composting. Under the CFI, building soil carbon, reforestation, and reducing livestock emissions are some of the activities that could generate carbon credits. Application of BC to soil and compost can be listed as an eligible activity. Strategies for offsetting current emissions by carbon sequestration and composting are the only viable way to slow the effects of climate change and provide an additional time frame for the development and implementation of new technologies for an attainable sink of GHG.

Conflict of interests

The author(s) have not declared any conflict of interests

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