Poll Res. 41 (3) : 953-959 (2022)

ISSN 0257–8050
DOI No.: http://doi.org/10.53550/PR.2022.v41i03.027

CARBON CREDITS FROM WINDROW COMPOSTING OF MUNICIPAL SOLID WASTE TO COMBAT CLIMATE CHANGE: A CASE STUDY OF CHANDIGARH, INDIA

VISHAL SHARMA

Department of Botany, Post Graduate Government College for Girls, Sector-11, Chandigarh, India

(Received 29 October, 2021; Accepted 15 December, 2021)

ABSTRACT

High greenhouse gases (GHGs) emission is mainly due to landfilling, thus solid waste composting sector creates significant opportunities for carbon mitigation which could eventually become tradable carbon credits. The paradigm of 'waste to energy, mitigation of carbon and its sequestration is relegated to a secondary level which conversely results in India discarding 68.8 million tonnes in landfills and comes third after China and US in total GHGs emission. Food, Fruit and Green waste constitute a copious and ubiquitous waste stream of municipal solid waste globally in escalating population and erratic urbanisation. The present study is a case study initiated in Chandigarh to high light the concept of carbon credit opportunities and to discuss the adept schemes for successful co-composting of green waste and kitchen waste with a mechanism to mitigate carbon leakage in the developing countries. The study credited with 346 carbon credits and 564 quintals organic compost worth 8.71 and 16 lakhs respectively.

KEY WORDS: Windrow composting, Carbon credits, Food waste, Bioreactor, Aerobic, Two-stage composting (TSC)

INTRODUCTION

Windrow composting is a dual nature phenomenon, which creates income generating opportunity in beginning by covering disposal cost and bio-stable compost sale at the end. However, in the carbon conscious world, the third facet of windrow composting is carbon credits, which are generated due to net benefit of carbon avoidance and sequestration. Hence, solid waste management (SWM) is a massive global challenge in developing countries mainly due to indiscriminate population growth and exponentially increased green waste and the food demand. Carbon credits fetches the study around $33.6 and expected to rise to $50-100 per tons by 2030, in order to meet the goals of the Paris agreement (Thube *et al.,* 2021). The composting systems come in different modes but the three commonly used are through aerobic bioreactor, windrow composting and traditional anaerobic pit composting. Till now composting is conventionally carried out by either one of the methods (Al-Alawi *et al.,* 2020; Ajmal *et al.,* 2020; Chaher *et al.,* 2020; Oviedo-Ocaña, 2021). Presently, the two stage composting system (TSC) evaluated, is a pioneer attempt to monitor the physico-chemical parameters (temperature, moisture content, pH, electrical conductivity, C:N ratio), to prevent the landfills interruption of the carbon cycle. The objective of the present study was to produce bio-stable, organoleptic and compatible compost in 110 days in TSC, an operational modifications of single stage composting (SSC), a prototype of composting facility to achieve sustainable zero waste future.

MATERIALS AND METHODS

The present study is set up to evaluate and access the pilot scale composting experiment using two-stage composting strategy. The treatment has the same mixture of materials: 50% green waste (60% leaves, 35% grass clippings and 5% tree branches)

25% food waste and 25% fruit waste of total 100 kg municipal solid waste (MSW).

Site location

The open site windrow composting plant (30.7583° N,76.7841° E) of 0.5 TPD capacity, situated in the campus of Post Graduate Government College for Girls, Sector-11, Chandigarh is the source of the present study. The windrow plant and bioreactor consists of screening facilities, solid waste separator, charging and composting units. The plant converts 135 kg organic waste into compost and if that waste is dumped in the landfill it emitted 40 kg carbon dioxide per day for 100 kg waste, however, the stored carbon benefit of windrow composting is in order of 40%, hence producing 16 kg CO_2 per day (Nordahl *et al.,* 2020). The major success of any study falls in its scalability and reproducibility at different sites and area. In this parameter, the present study is replicated at two places: The Judicial Academy, generates 30 kg municipal solid waste per day and Post Graduate Government College, Sector-1, Panchkula has 0.4 TPD (135 kg/day; Figs. 5-6), hence the total solid waste to energy study is 300 kg.

Study Material

The green waste is obtained from the maintenance of green areas of an institute campus which predominantly consists of grass clippings and leaves. The green waste is stored for one week in 3x4 mlinear rows as an open space piles The food waste and kitchen waste are procured from campus food preparation services (canteen, mess, juice corner; Fig. 7).

Bulking agent

The perusal of literature reveals that variable form of bulking agents (Biochar, rice husk, saw dust, wood chips, wheat straw (Li *et al.*, 2017; Chaher *et al.*, 2020). However, the research to access the cumulative effect of green waste as bulking agent is elusive. The integration of cheap eco-friendly grass clippings in two stage composting (TSC) in the present study solved the global problem of green waste accumulation and also improves the final compost quality and makes TSC technology cost effective. The main pre-requisite of the TCS strategy is a bioreactor and a windrow plant:

Bioreactor, a mechanical way

In the first stage, a bioreactor 'FOODIE' is used for the composting process. The bioreactor is rectangular with a height of 150 cm and diameter of 226 cm. The metal bioreactor consists of mixing blades (ss202) and shaft (ss401) arranged in alternate manner in 930 litres in vessel drum lined with nichrome element (N8020) as heating equipment in basal layer. While on one side, there is a small hollow hole for circulating air inlet, whereas opposite to it is a 4 inch PVC exhaust pipe connected to drainage. The reactor scheme shown in Figure1A. During this process, the waste material is removed from the bioreactor on the 7th day to start the second stage of the process. The bioreactor reduces the waste volume to one tenth on 7th day and the semi-digested organic cake is procured and transferred to windrow composting plant.

Windrow composting plant, a manual way

This study is conducted in the square 64 m^2 open site windrow composting plant. It consists of two charging units (3x4 m) and two windrows; windrow Run1 with measurement of 5x3 m and windrow Run 2 of 3x3 m. The bulking agent (grass clippings) is added as basal layer on brick lined windrows, which was sequentially alternate with food and kitchen waste (30cm) in three different layers. The repetition of the layers is done till the cumulative pile reached 1.5 m high (Fig. 4). The piles in windrows which areturned manually to make the organic waste bio-stable, organoleptic and compatible with sustainable agriculture and floriculture operations. However, the membrane covered windrows (CM) groups with basal layer bulking agent (grass clippings) generate bottom up ventilation system, results in micro-positive pressure, decreasing the anaerobic zone in compost pile and GHGs emissions (Li *et al.,* 2017; Jalalipour *et al.,* 2020; Fang *et al.,* 2021; Wang and Sun, 2021), compared to control group (CG) without covered membrane and the carbon dioxide emission in CM groups was reduced by 74% and 88% respectively in SSC and TSC.

Carbon footprints and Credit

The carbon emission through default emission method is 40 kg CO_2 released per 100 kg solids treated (Singh *et al.,* 2017; Nordahl *et al.,* 2020). The amount of total carbon dioxide generated annually in two stage composting (TSC) is 5280 kg CO_2 annually with carbon footprint benefit of 88% (38,520 kg CO_2 annually) in comparison to landfill generation (Table 1). The bio-conversion of heterogeneous solid waste using cover membrane with a bottom up aeration system generates micro-positive pressure, which hastens decomposition and dropped the carbon emission by 40% (Sun *et al.*, 2018; Al-Alawi *et al*., 2020; Chaher *et al.*, 2020; Ma *et al*., 2020). The carbon foot print benefit till the inception of study (2019-2021) is 346,680 kg CO_2. The present study evaluated the impacts of the three amendments types on the carbon credit which represent all CO_2 emissions, sinks and offsets. The carbon credits are usually quantified in units of metric tons of carbon dioxide equivalents (CO_2e).

Carbon credit=$CO_{2\ emission}$-$CO_{2\ sinks}$-$CO_{2\ offsets}$

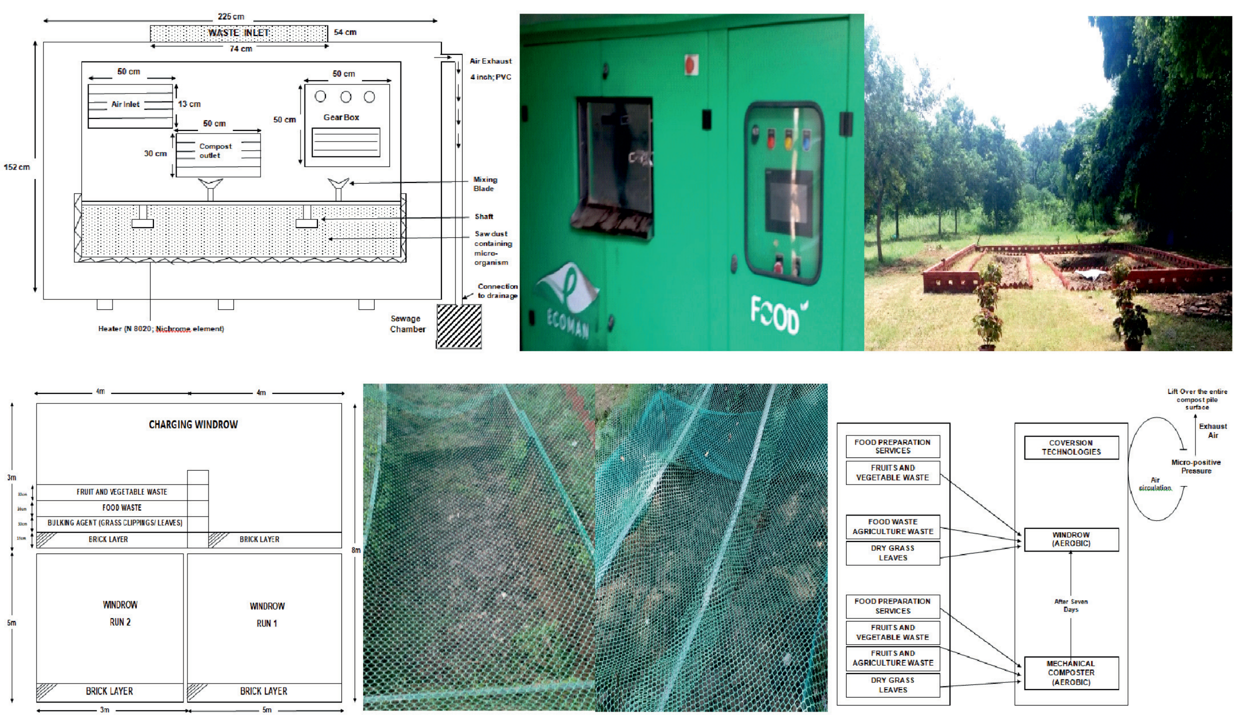
Every ton of carbon not emitted is considered one credit, hence total of 346 carbon credits gained. Each credit in global market costs $33.6, therefore around 8.71 lakhs are gained through the study. Besides this, 564 quintals organic compost is generated worth 16 lakhs, hence in total the study amounted nearly 25 lakhs rupees and provide environment sustainability to the area with the moderation on micro-climatic temperature.

Analytical techniques

The parameters evaluated during two stage composting are temperature, pH, moisture content, electrical conductivity and C/N ratio. These parameters are observed twice a week for the first three weeks and then once a week until the end of the composting. About 200 g of samples are collected on weekly interval from windrows and analysed for physico-chemical parameters (Temperature, pH, moisture content and C/N ratio). For measuring compost pH, raw samples are mixed with de-ionized water at a weight ratio1:10. The mixture is shaken for 1 hour, allowed to settle and

Table 1. Carbon foot prints and Credit in Two stage composting (TSC)

Types of Disposal	Cycle	Total amount of carbon dioxide (kg) generated for 300 kg municipal solid waste	Gestation period (days)	Total amount of carbon dioxide (kg) generated	Carbon foot print benefit annually	Carbon credits Till inception
Landfill	01	120 kg CO_2 per day	365	43,800 kg CO_2	-	-
Two stage Composting (TSC)	03	48 kg CO_2 per day	110	5280 kg CO_2	38,520 kg CO_2 (88%)	346



Figs.1-6: Figs. 1-2-Outlay of Bioreactor 'Foodie'; Figs.3-4-Layout of windrow composting plant; Fig.5-6-Membrane Covered windrows: Fig.7-Composting material

pH of the clear supernatant is measured with digital pH meter. The collected samples are oven dried at 105 °C for 24hrs and loss of weight is taken as the moisture content. The 'ReoTemp' compost thermometer is used to weekly record the temperature data at four cardinal points of the windrows, over the period of 110 days. The sample from organic compost is taken and heated at 70 °C for 24 hours and subsequently cooled and powdered. The 2 g sample taken from blended mixture is placed in a small Al^{+3} cone and a CNHS-O analyzer is used to determine C/N ratio.

RESULTS AND DISCUSSION

The present study aims to optimization techniques to elevate composting efficiency and reduce composting time to produce stable compost with carbon credits, a buzzword of carbon conscious world. The operational modifications to the single stage composting is the integrated waste management strategy, the two-stage composting (TSC) , which is used to reduce the volume and mass of solid organic wastes to one tenth ratio. This reduction in volume increases the vase life of the windrow plant by ten folds and this prototype of composting facility helped to achieve sustainability in the management of the kitchen waste (food, fruit waste) with grass clippings to establish the relationship between physico-chemical parameters (temperature, pH, moisture content, electrical conductivity and C:N ratio). The forced bulking layer bottom up ventilation and cover membrane, generate micro-positive pressure making windrows organoleptic with prolonged the thermophilic phase, and carbon benefit in order of 40% (González *et al*., 2016; Sun *et al*., 2018; Al-Alawi *et al.*, 2020; Chaher *et al*., 2020; Ma *et al*. 2020).

Temperature

The composting process being a biological phenomenon depends highly on temperature fluctuations within bioreactor and windrows. In bioreactor, day first there is the start of intensive phase and temperature began to rise rapidly from 35 °C reaching a peak temperature of 74 °C in three days. After reaching the peak, the temperature of the composting bioreactor shows reduction in temperature on the fourth day onwards and reached to 68 °C on 7th day, when the organic material is de-confined from bioreactor and arranged into the windrow pilesfor further decomposition. The windrows temperature profile showed that initially temperature of organic waste dipped to 66 °C in charging windrow, however, within week the temperature reached 76.2 °C. As a consequence, two thermophilic peaks in the composting temperature observed in two stage composting (TSC), first one during the first seven days in bioreactor and the other during the windrow composting in second week (Fig. 2A). The persistence of thermophilic temperature above 55 °C for 80 days with pre-dominant thermophilic microorganisms enabling rapid decomposition of carbohydrates, proteins and lignocelluloses, resulted in the formation of humus precursors which indicate an efficient composting process. After peaking, the temperature decrease in mesophilic range (40 °C) due to exhaustion of initial simpler molecules and development of conditions hostile for microbial activity. TSC shortened the composting time and produced bio-stable, organoleptic and compatible compost in 110 daysdue to two thermophilic peaks (Al-Alawi *et al.*, 2020; Ajmal *et al.*, 2020; Ayilara *et al*., 2020; Pena *et al.*, 2020; Oviedo-Ocaña, 2021).

pH

The pH value of the compost used to access compost maturity, therefore the changes in pH are monitored during the two stage composting of organic waste mixture. At the beginning of the mechanical composting process in bioreactor the initial pH is slightly acidic, i.e. 5.2 attributed to production of organic acids. However, in bioreactor, pH increased rapidly to 7.8 on 7th day and after being transferred to windrows, the pH value decreased to 7.2 and then after 20 days of addition to windrows increased from 7.2 to 8.05 and subsequently to 9.06 due to intense thermophilic microbial activity. After 40 days, the pH value declined from 9.06 to 8.5 due to volatization of ammonia under prolonged thermophilic temperature as two thermophilic peaks is observed in TSC in comparison to one in single stage composting, which results in decomposition of lignocellulose in the green waste (Fig. 2A). The declining trend continues till the 90th day of composting and afterwards there is marginal increase in pH value and the final pH value of mature compost after 110 days is 7.6 (Al-Alawi *et al.*, 2020; Jalalipour *et al*., 2020; Pena *et al.,* 2020; Rastogi *et al*., 2020; Voberkova *et al.,* 2020; Oviedo-Ocana *et al*., 2021).

Moisture Content

Among these factors, moisture has critical attention during the decomposition of organic matter in the present study, as the main ingredients are food and kitchen waste, which on chopped using mixing blades and shaft produced 68% moisture on day 1 and continuous mixing and thermophilc temperature increase the moisture content to 72% on day 5. The elevated moisture content >60%), generate water logs with prevalent anaerobic conditions that halt the decomposition process and unpleasant odor. After 7 days, the organic waste is de-confined to windrows and the reduction in moisture content is recorded on the tenth day. Subsequently the moisture content increased to 76% on 20^{th} day as food waste has high water content, it is necessary to add bulking agents (grass clippings/ leaves) and moisture content profile shows reducing trend attributed to porous nature of bulking agent and after ninety days the water content of mixture is 50% (Fig. 2B). The moisture content in the present study shows inverse relation with the time interval and the decreased water content is a positive sign of decomposition and it gives more stable and mature compost. The final moisture content of 42% after 110 days is in optimum range of mature compost in compliance to earlier reports (Chaher *et al.*, 2020; Jalalipour *et al*., 2020; Pena *et al.*, 2020; Rastogi *et al.*, 2020; Voberkova *et al*., 2020; Oviedo-Ocana *et al.*, 2021)

Electrical conductivity (EC)

The Electrical conductivity (EC) indicates potential phytotoxicity on plant growth and an important parameter which reflects the degree of compost salinity. Initially, when the organic waste is de-confined from bioreactor after seven days shows EC value of 2.36 ds/m (stage 1) and then after 30 days of addition to charging windrow increased to 2.58 ds/m (stage 2; 50 days), the EC value during TSC process shows elevation from 2.58 ds/m to 3.18 ds/ m in the next 80 days in windrow run1 due to the release of mineral salts and water stress conditions in the compost, however, the EC value of the final compost is 3.36 ds/m after 110 days, which fall in the limit (below 4 ds/m) for safely used in floriculture and agronomic practices (Al-Alawi *et al*., 2020; Jalalipour *et al*., 2020; Pena *et al.*, 2020; Oviedo-Ocana *et al*., 2021).

Carbon/Nitrogen (C/N) ratio

The Carbon to Nitrogen (C/N) ratio, an important parameter provides an optimal conditions for composting process. C/N ratio in the range of 25-30 has been found to be optimum for windrow composting process. However, in the present study, the co-composting of green waste and kitchen waste in two stage composting (TSC) shows two thermophilic peaks in the composting temperature profile and this prolonged thermophilic phase resulted in the lower C/N ratio which enhanced the nitrogen leaching and nitrate mobilization making the windrows anaerobic and end product organoleptic and compatible with sustainable agriculture and floriculture operations with the C/N ratio of compost reached a value of 25 after 110 days. (Al-Alawi *et al.,* 2020; Jalalipour *et al.,* 2020; Pena *et al.,* 2020; Rastogi *et al.*, 2020; Voberkova *et al.*, 2020; Oviedo-Ocana *et al.,* 2021; Wang and Sun, 2021).

Carbon credits

Waste to energy system plays an important role in diverting organic waste from landfills. The baseline solid waste when added to landfilling emitting nearly 40 kg CO_2 per day for 100 kg of organic waste, hence in landfills in solid waste produces 14,600 kg CO_2 annually, however, the windrow composting releases 40% less GHGs emission (16 kgCO_2). In two-stage composting (TSC), the mature organic compost formation process completed in 110 days, 1760 kg CO_2 released per cycle. The inference from the present study is that in TSC, the carbon foot print reduction is observed to level of 88% in compliance to earlier reports (present study; Sun *et al.,* 2018; Ma *et al.,* 2020; Nordah *et al.,* 2021; Fang *et al.,* 2021). The windrows with forced aeration and basal line bulking agent attributed to micro-positive pressure which makes the piles aerobic and results in less carbon dioxide leakage (avoidance) and sequestration. This carbon mitigation would eventually become tradable carbon credits with carbon conscious projects (present study; Kollah *et al.,* 2014). The project prevented 346.7 million tons of carbon dioxide emissions and generated 346 carbon credits since its inception. Each credit in global market costs $33.6, therefore, around 8.71 lakhs are gained through the study. Besides this, 564 quintals organic compost is generated worth 16 lakhs, hence in total the study amounted nearly 25 lakhs rupee and provide environment sustainability to the area with the moderation on micro-climatic temperature. The present study agrees that carbon footprint of landfilling organic waste is higher relative to windrow composting by factor 8.3 in compliance to earlier reports (DeLonge *et al.*, 2013; Morris *et al.*, 2013; Kollah *et al.*, 2014; Thube *et al.*, 2021).

CONCLUSION

The two-stage windrow composting (TSC) is used as an alternative process in solid waste management and this new technology can reduce the composting time, land area and carbon dioxide leakage. The present investigation provide better insight on the feasibility, applicability and reproducibility of the compost potential to generate carbon credits through avoidance and sequestration of carbon dioxide. Carbon pricing and carbon market, an efficient climate strategy to slow decarbonisation scenario and mitigates the environmental crisis. India does not have an explicit carbon price based mechanism, hence the further studies are required on these aspects to have zero waste sustainable future.

ACKNOWLEDGEMENT

The author gratefully acknowledge Prof.(Dr.) Anita Kaushal, Principal, PGGCG-11, Chandigarh, for providing necessary infrastructure for the research work.

REFERENCES

Al-Alawi, M., ElFels, L., Benjreid, R., Szegi, T., Hafidi M., Simon, B. and Gulyas, M. 2020. Evaluation of the performance of encapsulated lifting system composting technology with a GORE(R) cover membrane:Physico-chemical properties and spectroscopic analysis. *Environmental Engineering Research.* 253: 299-308.

Ayilara, M.S., Olanrewaju, O.S., Babalola, O.O. and Odeyem, O. 2020. Waste Management through Composting: Challenges and Potentials. *Sustainability.* 12: 4456; https://doi:10.3390/su12114456

Ajmal, M., Aipinga, S., Awais, S.M. and Ullahc, M.S. 2020. Optimization of pilot-scale in-vessel composting process for various agricultural wastes on elevated temperature by using Taguchi technique and compost quality assessment. *Process Safety and Environmental Protection* 140: 34-44. https://doi.org/10.1016/j.psep.2020.05.0015.

Chaher, N. E. H., Chakchou, M., Engler, N., Nassour, A., Nelles, M. and Hamdi, M. 2020. Optimization of Food Waste and Biochar In-Vessel Co-Composting. *Sustainability.* 12:1-20. https://doi.org/10.3390/su12041356.

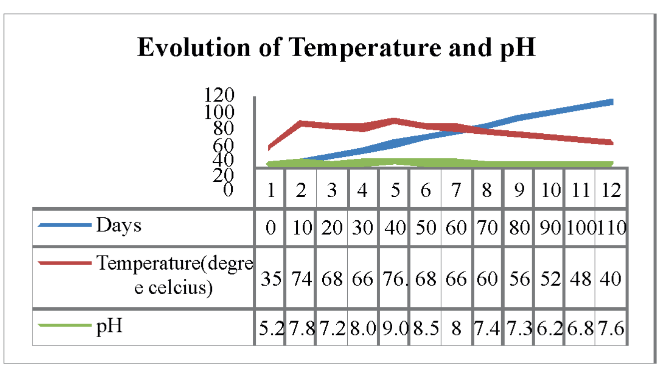
DeLonge, M.S., Ryals, R. and Whendee, L.S. 2013. A lifecycle model to evaluate carbon sequestration potential and Greenhouse Gas dynamics of managed Grasslands. *Ecosystem.* 16: 962-979.

Fang, C., Hongje,Y., Lujia, H., Shuangshuang, M., Xuegin, He and Guanggum, H. 2021. Effects of semi-permeable membrane covering coupled with intermittent aeration on gas emissions during aerobic composting from the solid fraction of dairy manure at industrial scale. *Waste Management.* 131: 1-9.

González, I., Robledo-Mahón, T., Silva-Castro, G.A., Rodríguez-Calv, A., Gutiérrez M.C., \Martín, M.Á., Chica A.F. and Calvo, C. 2016. Evolution of the composting process with semi-permeable film technology at industrial scale. *J Clean Prod.* 115:245-254. https://doi. org/10.1016/j.jclepro. 2015.12.033

Jalalipour, H., Jaofarzadeh, N., Morscheck, G., Narra, S. and Nelles, M. 2020. Potential of producing compost from source separated Municipal Organic waste (A case study in Shiraz, Iran). *Sustainability.*12: 9904; https://doi.org/10.3390/su12229704

Kollah, B., Duber, G., Saha, J.K. and Mohanty, S. 2014. Composting: Anopportunity in a carbon conscious



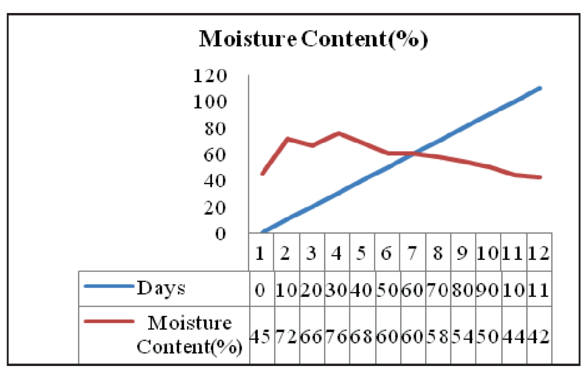


Fig. 2A-B: Fig. A-Evolution of Temperature and pH during two stage composting (TSC) depicting two thermophilic peaks; Fig.B- Moisture content profile during TSC

world for combating climate change. *Scientific Research and Essays.* 9(13): 598-606.

Li Yee Lim, L.Y., Bong, C.P.C, Chew, Tin Lee, C. T., Klemes, J. J., Sarmidi, M.R. and Lim, J. S. 2017. Review on the Current Composting Practices and the Potential of Improvement using Two-Stage Composting. *Chemical Engineering Transactions.* 61: 1051-1056; https://DOI:10.3303/CET1761173.

Ma, S., Xiang, J., Cui, R. and Sun, X. 2020. Effects of intermittent aeration on greenhouse gas emission and bacteria community succession during large-scale membrane covered aerobic composting. *J. of Cleaner Production.* 266: 121551.

Morris, J., Scott Matthews, H. and Morawski, C. 2013. Review and metaanalysis of 82 studies on end-of-life management methods for source separated organics. *Waste Manage.* 33: 545–551.

Nordahl, S.L., Sarah, I., Devkota, J.P., Amirebrahimi, J. and Smith, J.S. 2021. Life-Cycle Greenhouse Gas Emissions and Human Health Trade-Offs of Organic Waste Management Strategies. *Environ. Sci.Technol.* 54: 9200–9209.

Oviedo-Ocaña, E.R., A. María, H-Gómez and M. Ríos 2021. A Comparison of Two-Stage and Traditional Co-Composting of Green Wasteand Food Waste Amended with Phosphate Rockand Sawdust. *Sustainability.* 13:1109, https://doi.org/10.3390/su13031109

Pena, H., Mendoza, H., Dianez, F. and Santos, M. 2020. Parameter selection for evaluation of compost quality. *Agronomy.* 10: 1567.

Rastogi, M., Nandal, M. and Khosla, B. 2020. Microbes as vital additives for solid waste composting. *Heliyon.* 6(2):03343:https://doi.org/10.1016/j.heliyon.2020.e03343.

Singh, C.K., Kumar, K. and Roy, S.S. 2018. Quantative analysis of the methane gas emissions from municipal solid waste in India, *Scientific Reports.* 8: 2913.

Sun, X., Ma, S., Han, L. and Huang, G. 2016. Design and test on lab-scale intelligent membrane-covered aerobic composting reactor. *Trans Chin Soc. Agric. Mach.* 47: 240-245.

Sun, X., Ma, S., Han, L., Li, R., Schlick, U., Chen, P. and Huang, G. 2018. The effect of a semi-permeable membrane-covered composting system on greenhouse gas and ammonia emissions in the Tibetan Plateau. *J Clean Prod.* 204: 778-787.

Thube, S., Peterson, S., Nachtigall, D. and Ellis, J. 2021. The economic and environment benefits from international co-ordination of carbon pricing: a revenue of economic modelling studies. *Environmental Res. Lett.* 16: 113002.

Voberkova, S., Maxianova, A., Schlosserova, N., Adamcova, D. and Vosanska, M. 2020. Food waste composting-Is it really so simple as stated in scientific literature/-A case study. Science of the Total Environment 723:138202; DOI: 10.1016/j.scitotenv.2020.138202

Wang, W., Zhang, L. and Sun, X. 2021. Improvement of two-stage composting of green waste by addition of eggshell waste and rice husks. *Bioresour.Technol.* 20: 124388; https://doi.org/10.1016/j.biortech.2020.124388