

Technological breakthrough for large scale bioconversion of coir pith towards sustainable soil health management and development of source point Methane Abatement Model

ABSTRACT

Coir pith, a byproduct of coir industry, continues to be dumped as a waste in India, because despite its utility being claimed in different applications, an efficient and adoptable technology for its safe utilization is yet unavailable. Due to high lignin content and high C:N ratio, coir pith when left untreated can take decades to decompose, which not only leads to environmental pollution but most importantly methane emission, thereby contributing to climate change. However, once composted, coir pith can transform into an effective soil rejuvenator, considering its utility towards amelioration of especially marginal/ agriculturally degraded soil and improvement of soil productivity. But so far, there is no available composting technology in this respect which is practically feasible, economically viable and socially acceptable.

Under IBM-IORF Sustainability project (2022-23) at Mandya, Karnataka, an effort was initiated utilizing Novcom Composting Technology, towards bioconversion of coir pith into safe and quality compost for sustainable soil management, especially looking at the stony red soils of the area which are erosion prone, and have a poor productive potential.

Periodical study of Novcom coir pith compost samples on 0, 10, 20 and 30 days confirmed effective degradation as demonstrated by the rapid decline of C:N ratio from 1:100 to < 1:25, appreciation of total nitrogen by 98 percent and 60 % degradation of lignin within a 30 days' time period. The facts are corroborated by the respective very high (*in the order of 10^{16} c.f.u.*) population of bacteria, fungi and actinomycetes. Phytotoxicity Bioassay test values confirmed not only the absence of phytotoxic elements in compost, but also indicated that this compost can actually accelerate seed germination and root growth process. Estimation of methane mitigation potential under this technology utilizing the carbon assessment tool - Agriculture Carbon Footprint Assessor (ACFA, version : 1.0) indicated that untreated coir pith can potentially emit methane in the range of 5897 – 6025 kg CO₂ equivalent (taking GWP₂₄ years of methane: 75).

GHG emission during biodegradation of coir pith utilizing Novcom Composting Technology, was found to be about 31 times lower (6.47 kg CO₂ equivalent/ ton treated waste) than the reference values recorded in respect of any other standard biodegradation process. Especially in terms of methane the negligible emission under this composting technology is the highlight, as corroborated by the documented value of 0.61 kg CO₂ equivalent/ ton treated waste. The evaluation confirmed that bioconversion of coir pith utilizing Novcom Composting Technology can enable methane mitigation of about 6000 ton CO₂ equivalent per 1000 ton waste, directly from the source point.

The study indicated that Novcom Composting Technology can transform not only a potential pollutant to a quality organic soil amendment, the process also etches out an effective pathway for methane abatement directly from the source point that has crucial impact not only in respect of Sustainable Development Goal (SDG) 13, but also SDG 15, SDG-3 and most importantly SDG-2. Hence, bioconversion of coir-pith utilizing this technology can also facilitate an effective model towards the Net Zero commitment with significant social and environmental impacts.

Key Words : Coir Pith, lignin, Novcom composting technology, methane abatement, ACFA, (version : 1.0), Sustainable Developmental Goals (SDG)

1. INTRODUCTION

“Coir pith is a biomass residue generated during the extraction of coir fiber from coconut husk and is a byproduct of the coir manufacturing industry. It is a ligno-cellulosic material forming about 70% of the coconut husk” [1]. “When husk of 10,000 coconuts are utilized for coir extraction, 1.6 ton of coir pith is obtained as a byproduct. If all the coconut husks available in India are processed, it is estimated that about 2.25 million tons of coir pith could be obtained annually” [2].

“The coir pith is finding new applications, as a soil conditioner and is being used as a soil-less medium for agri-horticultural purposes. With its moisture retention qualities, the coir pith is ideal for growing anthuriums and orchids. Moreover, this lignin content can be utilized for high-value applications, but has remained a challenge” [3, 4]. “The lignin part contains aromatic and aliphatic components and various functional groups, including phenolic, hydroxyl, carboxyl, benzyl alcohol, methoxy, and aldehyde groups [4], which can cause phytotoxicity when applied untreated in agricultural soil. Moreover, the high salt content [5], and high lignin in coir pith cause very slow degradability, which offer little scope for its use in crop production”.

“Hence, most of the coir pith is dumped as waste and accumulates as a waste product in the form of heaps of coarse and fine dust. The coir pith poses fire hazard, space problem, health hazard and disposal problem if an appropriate solution is not found” [6]. “Traditionally, these agricultural wastes are disposed off by burning, which results in various environmental problems, including carbon deposits as well as the warming of the atmosphere. During the rainy season, the tannins and phenols of the coir pith leach out into the soil and the irrigation canals, thereby making agricultural lands unproductive. Moreover, the water pollution caused by such leaching is harmful to the aquatic and soil biological life” [7]. “Present forms of management or utilization are not sufficient enough to totally consume the waste generated and it continues to be a perennial problem to the nearby aquatic and terrestrial environments” [8]. But most importantly as a result of dumping, methane, a potent greenhouse gas is generated which contributes to climate change.

Lack of effective technologies is a major challenge towards bio- conversion of coir pith considering that windrow composting requires relatively large areas, is extremely sensitive to ambient temperatures and weather conditions and odour control is a common problem. In-vessel reactors have limited flexibility to handle changing conditions and are maintenance intensive. Moreover, the long time period of composting under all the presently available methods, can form a potent source of greenhouse gases especially for a complex raw material like coir pith. Finally the safety and stability/ maturity of the end product from these composting processes are often questionable. Hence, people continue to face tough challenges towards bioconversion of coir pith into quality manure for soil application.



Pic. 1 : Piling up of coconut husk in coir factory for extraction of coir fibre.



Pic. 2 : Coir factory for extracting coir fibre and coir husk.

However, coir pith in the presence of an effective bioconversion technology, can serve as an excellent resource for compost generation considering its high water holding capacity, nutrient retention capacity as well as large scale availability. Such a 'Waste to Wealth Program can ensure economic sustainability of the coir industry as well, which is facing tough challenges in respect of labour productivity, finances, finished product marketing, etc. Hence, this environment polluting agent and a high GHG emitter can serve as an excellent resource for quality compost production looking at the existential requirement for sustainable agriculture, for reclamation of degraded soil as well as for sustenance of crop productivity.

Novcom Composting Technology developed by Dr. P Das Biswas, an Indian scientist and pioneer of Ecologically and Economically Sustainable Organic Tea Cultivation in India; has shown its potential as a speedy, effective and economic pathway for quality compost generation [9]. This technology was utilized for bioconversion of coir pith and the GHG offsetting potential under this composting method was evaluated using ACFA (Version 1.0) – Agriculture Carbon Assessment Tool developed by Inhana Organic Research Foundation (IORF) as per Intergovernmental Panel on Climate Change (IPCC) guidelines [10].



Pic. 3 : Toxic leachate containing high salt and phenolic content from coir pith dumps in and around coir factories

2.MATERIALS AND METHODS

2.1 Study Area : Village: Kalenahalli, Hobli: Kikkeri, Taluk: Krishnarajpet, District: Mandya, Karnataka, India

The study was initiated under IBM-IORF Sustainability Project during 2022-23 for establishment of the Clean Food 'Net Zero' Model. The quest for quality compost for towards sustainable soil health management led to coir-pith; a waste of coir industry, with an abundant supply of 5.0 – 6.0 lakh metric ton yearly in Karnataka alone and an economic source. 1000 ton coir pith was sourced and Novcom coir pith compost was produced towards attending the objective of eliminating N- fertilizer through sustainable soil health management.

2.2 Method of compost preparation

2.2.1 Raw materials used : Coir pith and cow dung in 80 : 20 ratio was used for making compost.

2.2.2 Novcom solution : It is the biologically activated and potentized extract of Doob grass (*Cynodon dactylon*), Bel (*Sida cordifolia* L) and common Basil (*Ocimum basilicum*). Detail of the solution is given by Seal *et al.* [11] who worked on the biodegradation pathway of Novcom Composting Technology.

2.2.3 Working Mechanism of Novcom Solution under Element Energy Activation (E.E.A.) Principle.

Novcom Composting Technology is a unique biodegradation system that can convert any type of biodegradable material including toxic and hard to biodegrade materials into quality

compost. Through the erection of Novcom composting heap, we tried to create an environment for self-generation of diversified microflora. The application of Novcom solution (Fig 1) served to provide the desired energy sources in the most pure and subtle form for speedy multiplication of microflora and higher activity efficiency. This energy management is based on the 'Element Energy Activation' (E.E.A.) Principle, inspired by the Vedic philosophy.

An effective biodegradation process is usually guided by the mesophilic- thermophilic – mesophilic stages, where one stage comes only when the previous one completes. Novcom solution along with heap construction just speeds up this orchestra, **especially the attainment of thermophilic stage in the initial phase of composting**; in a very organized and synchronized manner. This method provides just the necessary environment for completion of each step so that the next step can take over ultimately culminating into a stable, mature and non- phytotoxic compost, within the shortest time period. Here no specific input or agent that is known to have influence in the breaking down of the organic material is added because these have their own limitations either singly or in combination.

If the mechanism of Novcom Composting Technology is interpreted under the Element Energy Activation Principle, it manifests as a unique, novel but the most convenient system for generation of quality compost. It is known that all objects of Earth are composed of five elements. Hence, in the first stage of degradation under Novcom Composting Technology, the elements are broken into their individual identity. Then, the temperature rises up to 65-70°C by activating the fire element with the help of Apana Prana. In this stage the unfriendly bacteria, fungi or the seeds of unwanted plants are destroyed and thermophilic bacteria start growing up. After a span of time the actinomycete group of micro-organisms come and breaks the degraded material into smaller particles. This function is facilitated by the Space element utilizing Vyana Prana. The process continues at various levels with the help of Fire element and finally the stage of lignin degradation comes. In the complete process Air element plays a very important role by providing the oxygen for respiration of the numerous micro-organisms engaged in the conversion process. The entire process is so rapid, intense and programmed that it finishes within the shortest period of three weeks.

The technology promises to provide solution irrespective of the type or nature of raw material or the agro climatic situations. The process does not require any microbial inoculation because the necessary microbes are generated naturally due to set up of an ideal environment. Moreover, microbial inoculation is an unscientific process because strains are first experimented individually but in the practice is given in combination. Since, each microbe has individual biological cycle and behavior that can never match when applied in combination with other microbes, hence, very naturally the process does not complete in less than three-four months. Moreover, biodegradation is a natural process where one stage only comes when the previous one is completed. Hence, any effort for pre-poning any stage will always make the process a complex one. The compost developed with Novcom Composting Technology provides the energized environment for regeneration of soil fauna. Hence, application of even a small quantity of the compost brings about a noticeable change in the soil in the shortest possible time. Finally, one thing is to be remembered that microbes also

need an adequate environment to grow and function. Hence, to provide the environment is more necessary than to inoculate them directly into the soil. The effectiveness of Novcom Composting Technology is defined by its mechanism to create the required environment.

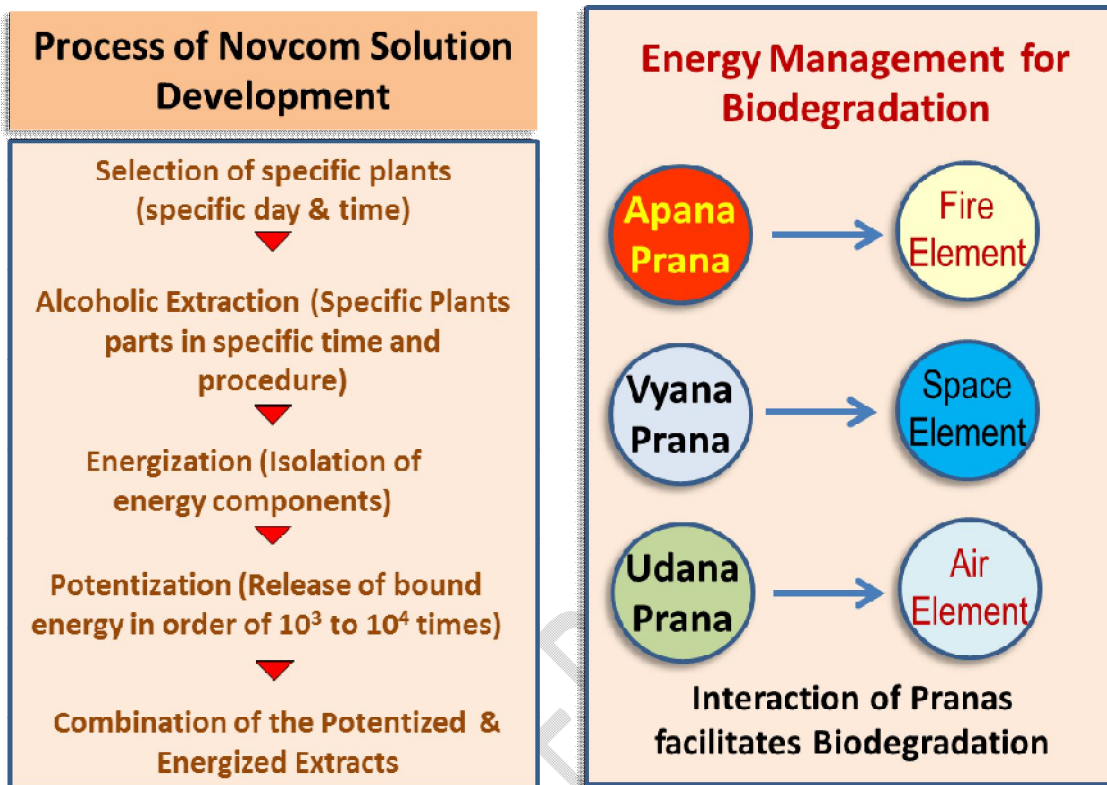


Fig 1: Process of Novcom solution development and interaction of Pranas facilitates biodegradation.

2.2.4 Preparation of Novcom coir pith compost

At a selected upland and flat area, a 10 ft. x 8ft. x 6ft. support structure was made with bamboo strips and coconut leaves for erecting the coir pith compost heap. A layer of cow dung slurry was put as the bottom layer and the same was sprayed on the inside walls of the support structure. Coir pith was mixed with cow dung slurry at 80:20 ratio (coir pith and cowdung on weight basis) and spread layer wise (each layer being approximately 0.5 ft. thick.) till it reached to the top of the structure. About 60 ml Novcom solution (diluted 25 ml in 5 liter water) was sprayed on each layer. Total 16 layers were required to reach a height of 6ft., because the heap height gradually reduced with compression and hence, total 2000 ml of Novcom solution was required for this heap.



Pic. 4 : Support structure for erecting Novcom coir pith compost heap at Mandya, Karnataka.



Pic. 5 : Transport of coir pith for making Novcom coir compost at model farm, Mandya, Karnataka.

The heap was covered with coconut leaves and left in this manner for 9 days. On 10th day, one side of the heap structure was opened and the material was altered and mixed properly with JCB. The material was put back in the structure, repeating the previous process. Once again 2000 ml of Novcom solution was used. The process was again repeated on 20th day and the compost was ready on 30th day.



Pic. 6A & 6B : Preparation of cow dung slurry and mixing of cow dung slurry with raw coir pith in 80 : 20 ratio (coir pith and cow dung on weight basis) at Model farm, Mandya, Karnataka under IBM-IORF Sustainability Project.

2.3 Research methodology

2.3.1 Analysis of compost samples : “Physicochemical properties of compost, *viz.* moisture content, pH, electrical conductivity and organic carbon were analyzed according to the procedure of Trautmann and Krasny” [12]. “The total N, P and K in the compost were determined using acid digestion method of Jackson” [13]. “Estimation of bacteria, fungi and actinomycetes was performed using Thornton’s media, Martin’s media and Jensen’s media respectively, according to procedure outlined by Black” [14].” Stability tests for the compost (CO₂ evolution rate, phytotoxicity bioassay test/ germination index) were performed according to the procedure suggested by Trautmann and Krasny” [12]. Cucumber (*Cucumis*

sativus) seeds were used for phytotoxicity bioassay test. Lignin percentage was analyzed as per methodology of Nandhini *et al.* [1]. Statistical Analysis in terms of standard error was performed with SPSS software.



Pic. 7 : Mixing of raw coir pith with cow dung slurry at Mandya, Karnataka



Pic. 8 : Transfer of cow dung slurry mixed Coir pith by JCB for erection of Novcom heap at model farm, Mandya, Karnataka.

2.3.2 Protocol for greenhouse – gas measurement

For measurement of different greenhouse gas (GHG) viz. CO₂, N₂O, CH₄ and NH₃, five Novcom coir pith compost heaps were made during 2022 - 2023. Details of designing of compost heaps are described in the research work done by Bera *et al* [15]. Day wise evaluation of Nitrous oxide (N₂O), Carbon-di-oxide (CO₂) and Ammonia gas (NH₃) was done as per standard chemical trapping method [15] while methane (CH₄) was estimated using an open bottom chamber to measure gas fluxes as per standard method [16].

3. RESULTS AND DISCUSSION

3.1 Analysis of compost quality : To evaluate the composting process and end product quality under Novcom Composting Technology, raw coir pith, samples from 1st turning (10th day), 2nd turning (20th Day) and final Novcom coir pith compost (30th day) were evaluated for 19 different quality parameters as per National and International standards. The samples were analyzed for physicochemical properties, microbial population, maturity and phytotoxicity parameters (Table 1 and 2).



Pic. 9A & 9B : Addition of Novcom solution in water and spraying of Novcom solution on coirpith at model farm, Mandya, Karnataka.

3.1.1 Changes of organic carbon, nitrogen and C:N ratio with transformation of coir pith to mature compost

“Changes of organic carbon and C:N ratio is the most important indicator of compost maturity and stability. Microorganisms break down the chemical bonds of organic materials in the presence of oxygen and moisture and the rate of decrease in carbon content of waste over time indicates the speed of biodegradation during composting” [17, 18]. “In case of Novcom coir pith compost, organic carbon decreased from 52.10 % in raw material to 31.28 % in the final compost (i.e. on day 30 of composting), which indicated faster biodegradation and simultaneously compost maturity (as organic carbon varied within 16 to 38 % in mature compost) within a short time frame” [11]. “The change in C:N ratio of the composting material was also considered in terms of stability, because as the readily available- C in the organic matter is oxidized and released as carbon dioxide, there is a general reduction in carbon content over time” [19]. “The C:N ratio of 30 day compost sample was 24.9:1 indicating maturity as a ratio of 20–30 results in an equilibrium state between mineralization and immobilization [20] and is considered good for soil application. This is because, soil microorganisms have a C:N ratio of around 8.0 and they must acquire enough carbon and some nitrogen from the soil to maintain that ratio in their cells and have been found to do best on a “diet” having a C:N ratio of 24.0” [21, 22]. According to USDA Natural Resources Conservation Services (NRCS) soil microorganisms use 16 units of carbon for energy and the other eight parts for maintenance [23]. “Under these optimum conditions, soil microbes can spur release of nutrients and this ratio influences the amount of soil-protecting residue cover that remains on the soil” [24]. Novcom coir pith compost also met the additional criteria for compost stability, i.e. $C:N_{\text{final}}/C:N_{\text{initial}}$ ratio <0.75 [25], confirming that it attained maturity within 30 days. So this compost might be proven as an ideal soil energy enhancer for soil microbial rejuvenation resulting in sustenance of soil productivity.

“The total nitrogen content in the compost sample increased from 0.59 to 0.76 % during the first phase of composting (days 0 to 20) which might be due to a concentration effect following a decrease in substrate carbon [26] during the degradation of non-nitrogenous organic matter” [27]. Evaluation of the graph

showing the decrease in organic carbon and increase in total N value revealed that the trend lines (Fig. 2) of organic carbon degradation and lowering of C:N ratio gradually separated from each other over time (as the shaded area widens). This indicated that there was a relatively greater increase in total N compared with the decrease in the organic carbon content. The finding might provide an indirect indication of the fixation of atmospheric- N within the compost heap by the autotrophic microorganisms generated during the composting process. According to de Bertoldi *et al.* [28, 29], “an increase in the population of N-fixing bacteria in the later phase of composting, can be attributed to the increase in the value of total- N in compost, despite volatilization (primarily) losses from compost heap during biodegradation” [11].

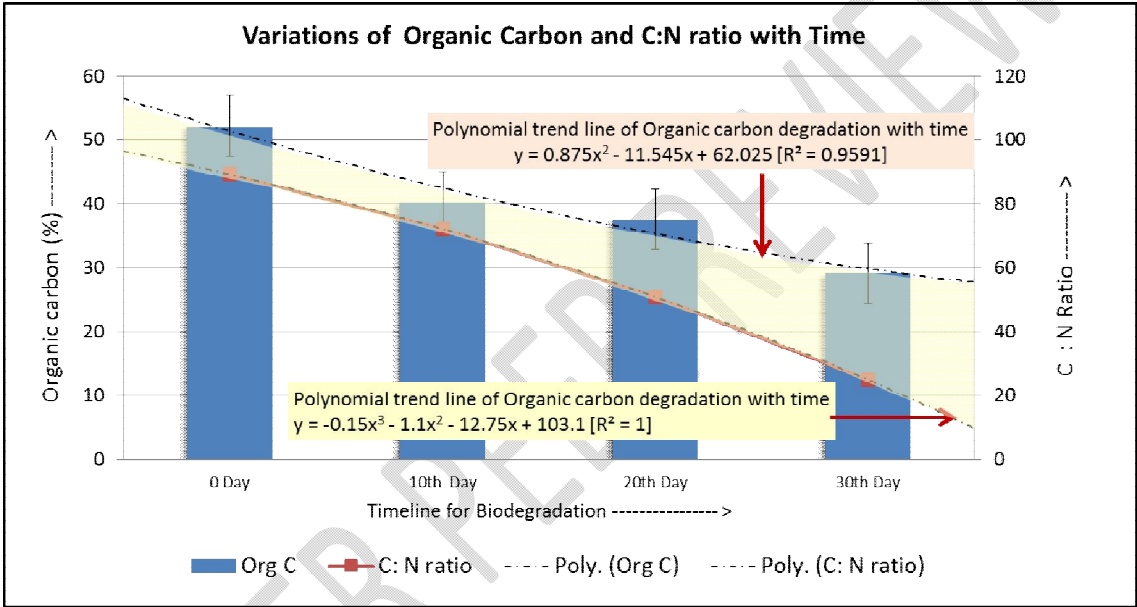


Fig. 2 : Variations in the organic carbon content and C:N ratio of coir pith during biodegradation under Novcom Composting Technology

3.1.2 Degradation of Lignin under Novcom Composting Technology

“Raw coir pith contains the highest percentage of lignin, hemicelluloses, and wax and the lowest percentage of α -cellulose. The percentage of α -cellulose, hemicelluloses, lignin, and wax present in raw coir pith is 27.41%, 14.63%, 42.0%, and 10.16% respectively” [30]. “Especially the degradation of lignin in coir pith is problematic due to its complex structures. According to studies in natural condition, when dumped in open environment, lignin content in coir pith takes decades to decompose. It only begins to break down when it is 10 years old as the pentosan/lignin ratio of pith is 1:0.30 while the minimum value required for moderately fast decomposition in the soil is 1:0.50” [30]. In the case of Novcom Composting Technology, >60% of lignin is degraded within 30 days of composting. This was primarily influenced through energy infusion, brought about by the application of Novcom solution that enabled self- generation of a huge population of microflora within Novcom heap during the process of composting (Fig. 3).

3.1.3 Quality of Novcom Coir- pith Compost

Qualitative evaluation of Novcom coir pith compost (as per 19 different analytical parameters) was carried out to assess the potential of this composting method towards production of high-quality mature compost. In this study, samples collected on the 10th, 20th and 30th day of composting were analyzed for physicochemical, microbial, stability and maturity/phytotoxicity parameters (Table 1 and 2).

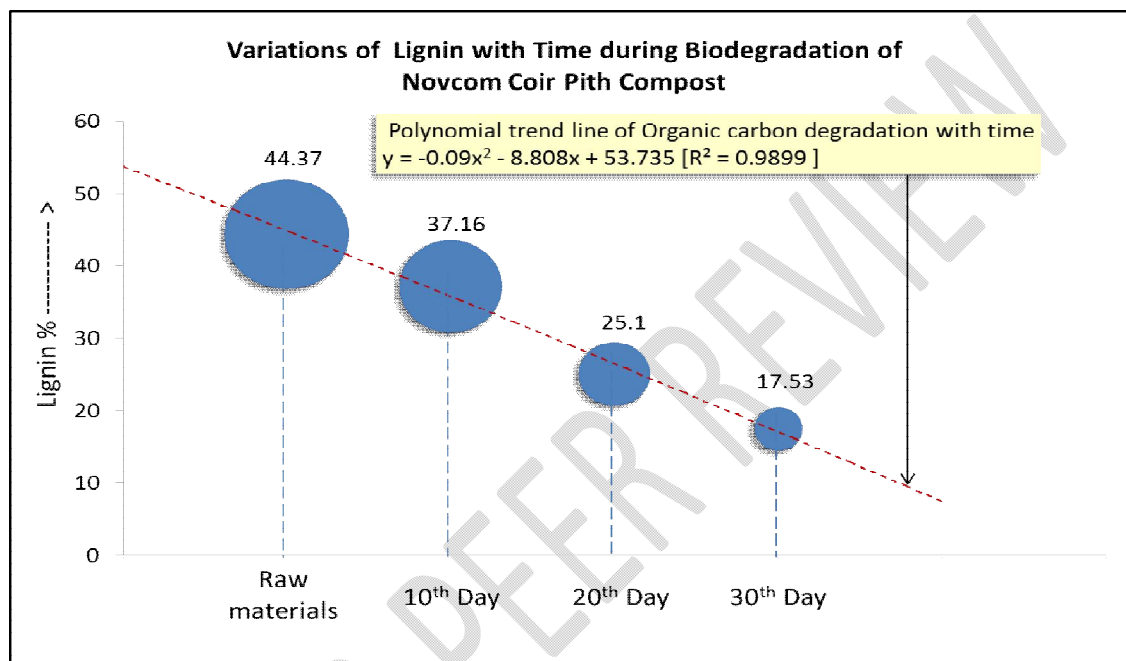


Fig. 3 : Degradation of lignin content in coir pith under Novcom Composting Technology, at Mandya, Karnataka under IBM-IORF Sustainability Project.

3.1.4 Physicochemical parameters of Novcom coir pith compost

“The predominant use of compost is to mix it with soil to form a good growing medium for plants, for which pH forms an important criteria of consideration” [31]. “The pH value of the compost samples ranged between 6.29 and 7.35, with a mean of 7.32, which was well within the stipulated range for good quality and mature compost” [25]. Electrical conductivity of the compost samples ranged between 1.83 and 1.96 with a mean of 1.89 dSm⁻¹, indicating the absence of any saline toxicity effect [32].

Table 1 : Variation of physicochemical properties, fertility parameters and lignin content during bioconversion of coir pith utilizing Novcom Composting Technology.

SI No	Quality Parameters	Raw Coir pith		10 th day Sample		20 th day Sample		30 th day Sample	
		Range Value	Mean Value	Range Value	Mean Value	Range Value	Mean Value	Range Value	Mean Value
1	Moisture (%)	47.00 – 55.4	50.76 ± 0.71	68.50 - 75.0	72.50 ± 0.69	64.96 - 72.50	69.2 ± 0.66	66.0 - 72.0	69.6 ± 0.45
2	pH	5.90 - 6.73	6.15 ± 0.07	6.53 - 6.86	6.70 ± 0.03	6.13 - 6.85	6.60 ± 0.07	7.29 - 7.35	7.32 ± 0.01
3	EC (dSm ⁻¹)	2.69 - 3.24	3.11 ± 0.05	1.95 - 2.65	2.43 ± 0.08	1.96 - 2.30	2.14 ± 0.04	1.83 - 1.96	1.89 ± 0.01
4	Ash Content (%)	3.00 - 11.11	4.83 ± 0.73	21.09 - 41.09	27.65 ± 2.17	19.2 - 39.7	32.4 ± 2.17	42.11 – 51.75	47.6 ± 0.81
5	Total Vol. Solids (%)	88.89 - 97.00	95.17 ± 0.73	58.91 - 78.96	72.35 ± 2.17	60.3 - 80.8	67.6 ± 2.17	50.4 – 57.89	52.4 ± 0.81
6	Org. Carbon (%)	49.38 - 53.89	52.87 ± 0.41	32.73 - 43.87	40.20 ± 1.20	33.5 - 44.9	37.5 ± 1.21	26.81 – 32.16	29.11 ± 0.45
7	Total N (%)	0.53 - 0.67	0.59 ± 0.01	0.47 - 0.62	0.56 ± 0.01	0.58 - 1.18	0.76 ± 0.06	1.12 - 1.20	1.17 ± 0.01
8	Total P ₂ O ₅ (%)	0.08 - 0.21	0.16 ± 0.01	0.12 - 0.26	0.17 ± 0.01	0.12 – 0.24	0.17 ± 0.01	0.18 - 0.22	0.20 ± 0.01
9	Total K ₂ O (%)	1.38 - 1.61	1.48 ± 0.02	1.60 - 1.81	1.72 ± 0.02	2.10 - 2.74	2.48 ± 0.06	2.67 - 2.87	2.80 ± 0.02
10	C:N ratio	89:1 - 99:1	89.9 :1	69 : 1 – 81 : 1	72 : 1	38:1 - 62:1	50.9 : 1	23 : 1 - 27 : 1	24.9 : 1
11	CMI	–	–	0.48 – 1.26	0.71 ± 0.08	0.43 - 1.19	0.89 ± 0.08	1.31 - 1.93	1.64 ± 0.05
12	Total lignin %	40.2 – 47.4	44.37±0.79	33.6 - 41.9	37.16 ± 0.81	18.7 - 30.5	25.1 ± 1.11	15.40 - 20.5	17.53 ± 0.54



Pic. 10A & 10B : Inspection of the on-going large scale Novcom Composting program utilizing Coir pith by Dr. P Das Biswas, Developer of this Method; at Model farm, Mandya, Karnataka under IBM-IORF Sustainability Project.

Composting transforms raw organic residues into humus-like material through the activity of soil microorganisms. The organic matter content of compost is a necessity for determining the compost application rate to obtain sustainable agricultural production [33]. By increasing soil organic matter content, which fuels microbial activity and nutrient cycling, compost applications can increase the overall soil fertility. Organic carbon content in the compost samples ranged between 26.8 and 32.1%, with a mean value of 29.1%, which met the standard value of >19.4% suggested by Australian Standard 4454 [34] for nursery application.



Pic. 11 : Preparation of Novcom coir pith compost at Model farm, Mandya, Karnataka under IBM-IORF Sustainability Project.

3.1.5 Fertility and microbial parameters of Novcom coir pith compost

“Although 36 different nutrients are required for plant growth, the macronutrient (N, P, and K) contribution of compost is usually of major interest” [35]. “The total nitrogen content in the compost samples ranged between 1.12 and 1.20 %, which was well above the Indian standard [36] of 0.5% and the range of 1–2%” suggested by Alexander [37] and Watson [31]. Total phosphorus (0.18–0.20%) was around the minimum suggested standard of 0.22% [36], whereas the values

obtained for total potassium (2.67–2.87%) were much higher than the range (0.2–0.5%) suggested by Alexander [37] and Watson [31], on dry matter basis.



Pic. 12A & 12B : Novcom Coir pith compost ready in 30 days, confirmed by Stability, Maturity and Phytotoxicity Test.

Microbial Status of compost is one of the most important parameter for judging compost quality because microbes are the driving force behind soil rejuvenation and maintenance of soil – plant – nutrient dynamics that is crucial for crop sustenance [7]. The huge population of microflora (in the order of 10^{16} cfu/gram moist compost for total bacteria, fungi and actinomycetes) in Novcom compost, corroborated the uniqueness of this composting technology in respect of faster bio- conversion and high nutrient content, as also found by other research workers in respect of Novcom Composting Technology [38, 39].



Pic. 13 A & 13 B : Analysis of compost fertility parameters and microbial properties in IORF laboratory, Kolkata; under IBM-IORF Sustainability Project.

3.1.6 Evaluation of stability, maturity and phytotoxicity of Novcom coir pith compost

“Compost stability, maturity and phytotoxicity rating are the most important criteria because immature compost may contain high level of free ammonia, organic acids or other water-soluble compounds, which can limit seed germination and root development” [33]. “The stability of given compost is important in determining the potential impact of the material on nitrogen availability in soil or growth media, and maintaining consistent volume and porosity in container growth media. Most uses of compost require a stable to very stable product that will prevent nutrient tie up and maintain or enhance oxygen availability in soil or growth media” [40]. Hence, microbial respiration formed an important parameter for determination

of compost stability [41]. Mean respiration or CO₂ evolution rate of all compost samples (1.74 to 1.89 mgCO₂-C/g OM/day) was more or less within the stipulated range (2.0 - 5.0 mgCO₂-C/g OM/day) for stable compost proposed by Trautmann and Krasny [12] and Bartha and Pramer [42].

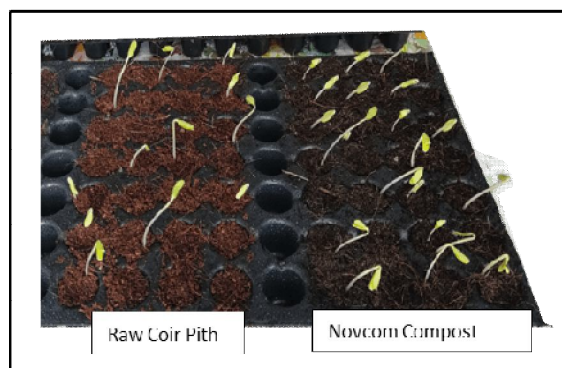


Pic. 14 A & 14 B : Phytotoxicity bioassay test of mature Novcom coir pith samples in IORF laboratory, Kolkata under IBM-IORF Sustainability Project.

The phytotoxicity bioassay test, as represented by the germination index, provided a means of measuring the combined toxicity of whatever contaminants may be present [43]. Phytotoxicity is also a significant indicator of final compost product maturity and is assessed through germination bioassays using a variety of crop seeds [44]. It is known that immature compost introduce phytotoxic compounds such as heavy metals [45], phenolic compounds [46], ethylene and ammonia [45], excess accumulation of salts [45] and organic acids [47] which could retard seed germination and plant growth [48]. The mean germination index value (1.23) of Novcom compost was well above the highest order of rating (1.0). The value indicated the absence of phytotoxicity in the compost [49] and also confirmed that the compost enhanced rather than impaired germination and radicle growth [12].



Pic. 15 : Transformation of raw coir pith to mature compost in 30 days under Novcom Composting Technology.



Pic. 16 : Comparative evaluation of seed germination under raw coir pith and Novcom Coir pith Compost

Table 2: Variation of microbial, stability, maturity and phytotoxicity parameters during during bioconversion of coir pith utilizing Novcom Composting Technology.

SI No	Quality Parameters	Raw Coir pith		10 th day Sample		20 th day Sample		30 th day Sample	
		Range Value	Mean Value	Range Value	Mean Value	Range Value	Mean Value	Range Value	Mean Value
13	Bacteria (c.f.u. per gm moist compost)	–	–	(22-51) x 10 ¹⁴	38 x 10 ¹⁴	(67-176) x 10 ¹⁶	115 x 10 ¹⁶	(127-168) x 10 ¹⁶	142 x 10 ¹⁶
14	Fungi (c.f.u. per gm moist compost)	–	–	(2-7) x 10 ¹²	5 x 10 ¹²	(4-11) x 10 ¹⁴	6x 10 ¹⁴	(12-22) x 10 ¹⁶	17 x 10 ¹⁶
15	Actinomycetes (c.f.u. per gm moist compost)	–	–	(9-15) x 10 ¹⁰	11 x 10 ¹⁰	(1-5) x 10 ¹⁴	3x10 ¹⁴	(9-18) x 10 ¹⁶	12 x 10 ¹⁶
16	CO ₂ evolution rate (mg CO ₂ -C/g/OM/day)	–	–	2.68 - 3.70	3.1 ± 0.13	1.96 - 3.60	2.63 ±0.14	1.74 -1.89	1.82 ±
17	Seedling emergence (% over control)	–	–	79.1 - 87.1	81.2 ± 0.95	78.6 - 102.7	92.85 ± 2.09	92.4 -102.0	98.3 ±0.8
18	Root elongation (% over control)	–	–	73.1 - 85.8	82.6 ± 1.21	82.5 -102.8	94.32 ± 1.85	119.5 - 138.5	130.5 ±1.84
19	Germination Index	–	–	0.58 - 0.75	0.67 ± 0.02	0.68 – 0.96	0.88 ± 0.03	1.18 - 1.37	1.28 ±0.02

3.2 Assessment of GHG emission potential of coir pith from landfill

Coir pith is a lignocellulosic agro residue from coir industry of India. Though utility of coir pith has been claimed in different applications, an efficient and accepted technology for its maximum utilization is not yet available [8]. Coir pith is generally dumped in the environment around the extraction units and form huge hillocks which occupy large land space, create pollution [2] and form potential source for GHG emission. As per scientific literature, whenever any biodegradable waste is disposed in waste dumps and landfills, most of the organic material will be degraded over a period and mostly CH₄ is produced and released to the atmosphere contributing to global warming [50].

Scientists used satellite data from four major cities worldwide — Delhi and Mumbai in India, Lahore in Pakistan and Buenos Aires in Argentina — and found that emissions from landfills in 2018 and 2019 were 1.4 to 2.6 times higher than earlier estimates. Although methane only accounts for about 11% of greenhouse gas emissions and lasts about a dozen years in the air, it traps 80 times more heat in the atmosphere than carbon dioxide does [51] over the first 20 years after it reaches the atmosphere. And most importantly though CO₂ has a longer-lasting effect, methane sets the pace for warming in the near term [52] as methane has a radiative forcing approximately 120 times more than CO₂ immediately after it is emitted [53]. At the same time, methane is an important precursor for tropospheric ozone contributing in both global warming and causing damage to human health and plants [54].



Pic. 17 : Utilization of coir pith to develop quality compost using Novcom Composting Technology and application of Novcom Coir pith Compost in soil for development of Clean Food 'Net Zero' – a practical demonstration of GHG Mitigation in the Agriculture Sector under IBM-IORF Sustainability Project at Model Farm, Mandya, Karnataka.

3.3 Methane Abatement : The most effective pathway for climate action

There has been a worldwide focus on curtailing carbon dioxide emission resultant from burning of fossil fuels, but it is also critical to cut methane emissions—not least because methane has a more powerful near-term warming effect than CO₂, but also because cutting methane emissions would have a more immediate impact on the climate [55]. A recent assessment from the United Nations Environment Programme (UNEP) and the Climate and

Clean Air Coalition found that cutting farming-related methane emissions would be the key in the battle against climate change [56].

Methane mitigation is most important as it is the primary contributor to the formation of ground-level ozone, a hazardous air pollutant and greenhouse gas, exposure to which causes 1 million premature deaths every year. Methane has accounted for roughly 30 per cent of global warming since pre-industrial times and is proliferating faster than at any other time since record keeping began in the 1980s. According to data from the United States National Oceanic and Atmospheric Administration, even as carbon dioxide emissions decelerated during the pandemic-related lockdowns of 2020, atmospheric methane shot up [56].

Methane mitigation is more important because carbon dioxide remains in the atmosphere for hundreds to thousands of years. This means that even if emissions were immediately and dramatically reduced it would not have an effect on the climate until later in the century. But it takes only about a decade for methane to break down. So, reducing methane emissions now would have an impact in the near term and is critical for helping keep the world on a path to 1.5°C. Thus, methane anthropogenic reduction goals are between 44% and 67% to the 2010 level to achieve the maximum 1.5°C global temperature increase by 2050 whereas anthropogenic CO₂ reduction goals are nearer 100% (IPCC 1.5° target) [57].

3.4 Debate on GWP of methane on 100 years basis or on a shorter scale

For many years, methane was overlooked in the climate change conversation. But scientists and policymakers are increasingly recognizing that methane reductions are crucial [15]. Atmospheric concentration of methane is increasing faster now than at any time since the 1980s. At the same time though, annual emissions are only 3% w/w of those associated with CO₂ (0.56 GtCH₄/year vs. 14.5 GtCO₂/year for methane and CO₂ respectively) [58,59] but methane has a radiative forcing approximately 120 times more than CO₂ immediately after it is emitted [53], which means that now is the methane moment.

Acting now to reduce methane emissions will have immediate benefits to the climate that reductions in carbon dioxide cannot provide on their own [52]. But there is an emerging debate whether, GWP of methane will be taken on 100 years basis (as IPCC recommended) or on a shorter scale. Because, GWP hides trade-offs between short- and long-term policy objectives inside a single time scale of 100 or 20 years [60]. Increasingly there are calls for the use of different time horizons (e.g. 20 years) or even different metrics that better reflect climate change or align with climate targets (e.g. the global temperature change potential as described in the IPCC AR5 [53, 61]).

The most common form, GWP₁₀₀, focuses on the climate impact of a pulse emission over 100 years, diluting near-term effects and misleadingly implying that short-lived climate pollutants exert forcing in the long-term, long after they are removed from the atmosphere [62]. Meanwhile, GWP₂₀ ignores climate effects after 20 years [63]. Now, the challenge is majorly related to methane, which is a powerful greenhouse gas with a 100-year global warming potential 28-34 times that of CO₂. Measured over a 20-year period, that ratio grows 84-86

times. Despite methane's short residence time, the fact that it has a much higher warming potential than CO₂ and that its atmospheric volumes are continuously replenished make effective methane management a potentially important element in countries' climate change mitigation strategies [64].

According to J. Trancik, an MIT associate professor at the Institute for Data, Systems, and Society, more scientists are beginning to model the warming effects that today's methane emissions will have over the next 20 or 30 years, in order to predict more accurately whether humanity can avoid overshooting targets such as stopping global warming at 1.5 degrees Celsius [65].

Pérez-Domínguez *et al.* [66] also indicated that methane's short atmospheric life has important implications for the design of global climate change mitigation policies in agriculture. Results also showed that the choice of a particular metric for methane's warming potential is the key to determine optimal mitigation options, with metrics based on shorter-term impacts leading to greater overall emission reduction. Most importantly, when the ambition is to reduce warming in the next few decades, a shorter time horizon might be applied in comparing the effects of CO₂ and CH₄. Thus a two-value approach, which indicates the effect over two different time horizons, is suggested by a number of studies [63].



Fig 4: Field visit of IBM Representatives Mr. Manoj Balachandran, Mrs. Shobha V. Mani, Ms. Nisha Anil & Ms. Usha in the Project Area at Mandya, Karnataka.

In the Sixth Assessment Report of IPCC (AR6) [67], there is discussion regarding the use of a range of emission metrics, including GWP₂₀ and GWP₁₀₀ and how they perform, using methane as an example and explores how cumulative CO₂ equivalent emissions estimated for methane vary under different emission metric choices and how estimates of the global surface air temperature (GSAT) change deduced from these cumulative emissions compare to the actual temperature response computed with the two-layer emulator [68]. GSAT changes estimated with cumulative CO₂ equivalent emissions computed with GWP₂₀ matches the warming trend for comparatively shorter time scale (a few decades) but quickly overestimates the response, whereas estimating emissions using GWP₁₀₀ underestimate the warming potential [67].

Hence, the moot point is that we do not have another 100 years to achieve our 2050 climate neutrality and net zero targets and whatever we need to change, have to be done now. So though under UNFCCC, GWP₁₀₀ remains the standard: according to the Paris “rulebook,” [69] people can use other metrics to provide information; this comes with the requirement to provide supporting documentation [70].

Howarth [71] suggested that the 20-year period is more appropriate for evaluation of GHG emissions since there is an urgent need to mitigate them in the next 15–35 years. Additionally, AR6, published in 2021, raised the GWP of methane to 29.8 over a 100-year horizon but seems to have reduced the 20-year horizon factor to 82.5.16 With the adoption of COP 21 (Paris), and particularly of net zero targets for 2050 there is a convincing case for taking a 20–30-year, rather than a 100-year horizon [72].

In the latest IPCC report [73], it has been clearly maintained that, IPCC does not recommend an emissions metric because the appropriateness of the choice depends on the purposes for which gases or forcing agents are being compared. Emissions metrics can facilitate the comparison of effects of emissions in support of policy goals. They do not define policy goals or targets but can support the evaluation and implementation of choices within multi-component policies (e.g., they can help prioritize which emissions to abate). The choice of metric will depend on which aspects of climate change are most important to a particular application or stakeholder and over which time horizons. Different international and national climate policy goals may lead to different conclusions about what is the most suitable emissions metric [74].

Now, according to Abernethy and Jackson, Emission metrics, a crucial tool in setting effective exchange rates between greenhouse gases, currently require an arbitrary choice of time horizon. So they propose a novel framework to calculate the time horizon that aligns with scenarios achieving a specific temperature goal and to best align emission metrics with the Paris Agreement 1.5 °C goal. They recommend a 24 year time horizon, using 2045 as the endpoint time, with its associated GWP_{1.50C} = 75 [75].

In this study, assessment was done through Carbon assessment Tool (ACFA- Version 1.0) which is based on guideline prepared for the IPCC National Greenhouse Gas Inventories Program to support the development of *Good Practice Guidelines* for estimation of greenhouse gas emissions from the waste sector and to manage the associated uncertainties

[76]. Under this evaluation the default IPCC methodology that is based on the theoretical gas yield (a mass balance equation) was followed, to calculate total methane emission (at a time), assuming that all potential methane is released in the same year when the solid waste is disposed.

3.5 Calculation of GHG emission potential from biowaste (primarily landfill materials) as per IPCC guideline (utilizing Carbon Assessment Tool : ACFA- Version 1.0)

GHG emission (MT in CO₂ equivalent) =

$$[(LM_T \times LF_F \times MC_F \times DOC \times DOC_F \times F \times 16/12 - R) \times (1 - OX)] \times GWP_{CH_4}$$

LM_T : Total Landfill Material(MT)

LF_F : Fraction of Landfill Material disposed at site (if 100 % landfill material which is generated is deposited at site, then LF_F value will be 1.0, default value)

MC_F : Methane correction factor (fraction) (IPCC default value is 0.6, when there is no specific information)

DOC : Degradable organic carbon (fraction) (kg C/ kg landfill material)

DOC_F : Fraction DOC dissimilated (IPCC default is 0.77)

F : Fraction of CH₄ in landfill gas (IPCC default is 0.5)

16/12 : conversion of C to CH₄

R : Recovered CH₄ (MT) (in general value is 0 if not any specific treatment plants in disposal sites to recover methane)

OX : oxidation factor (fraction – IPCC default is 0)

GWP_{CH₄} : 75 (based on 24 year time horizon)

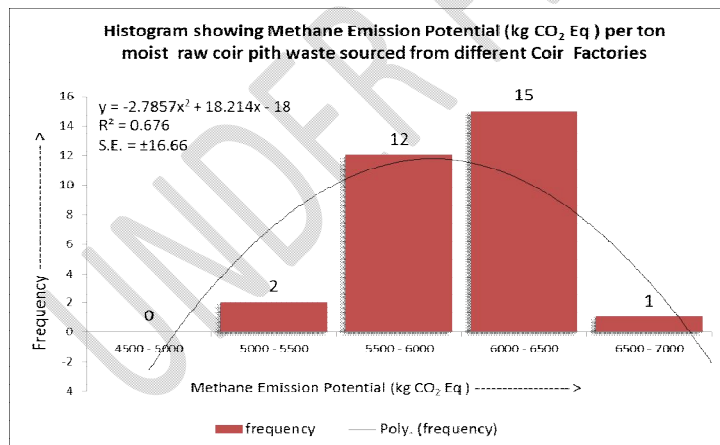


Fig. 5: Histogram showing Methane Emission Potential (kgCO₂ eq) per ton moist raw coir pith, as per IPCC guideline.

Pic. 18: Utilization of coir pith as organic manure post bioconversion under Novcom Composting Technology for developing Clean Food ‘Net Zero’ Model, under IBM-IORF Sustainability Project.

Thirty samples of raw coir pith were collected from different coir factories at Karnataka and analyzed to generate the required database for calculation of the methane emission potential (kg CO₂-eq) per ton moist raw coir pith waste, as per IPCC guideline. The GHG emission (kg CO₂-eq) per ton moist raw coir pith based on 24 years' time horizon varied from 5446 to 6963 kg CO₂-eq with a mean value of 6013.7 kg CO₂-eq. The histogram represents the distribution of numerical data in specific range, which showed that GHG emission potential of raw coir pith is mostly in the range of 6000 – 6500 kg CO₂-eq/ ton wet raw coir pith followed by 5500 – 6000 kg CO₂ eq/ ton wet raw coir pith (Fig 4).

3.6 Study of GHG Emission in Novcom coir pith compost

Ten Novcom coir pith compost heaps were selected to study the emission of CO₂, CH₄, N₂O and NH₃ during biodegradation period under IBM-IORF Sustainability project.

3.6.1 Study of carbon dioxide (CO₂) emission under Novcom coir pith composting process :

The CO₂ released during composting is considered biogenic, not anthropogenic, so it is not considered in greenhouse gas calculation [76]. CO₂ emission measured on day basis during the Novcom composting process showed higher values in the 1st week which gradually decreased with progression in the composting period and became minimum after 30 days indicating completion of the biodegradation process. Total CO₂ emission during entire biodegradation period was 1.848 kg CO₂/ ton raw material.

3.6.2 Emission of Methane (CH₄) under Novcom Composting Technology:

Methane is one of the contributors to non-biogenic greenhouse gas emissions from composting, and the majority of that CH₄ is emitted early in the composting process [77]. In the case of Novcom coir pith composting process methane emission was found to be negligible (0.61 kg CO₂ equivalent per ton wet coir pith) as compared to that documented by several research workers [78,79,80] in respect of other standard biodegradation processes (2.25 – 600 kg CO₂ equivalent per ton wet waste, considering GWP_{24years} of CH₄ : 75) [81]. The primary reason behind negligible methane emission under Novcom Composting process is the aerobic process of composting that minimize the anaerobic pockets (which nullifies the proliferation of methane producing bacteria), controls the O₂ solubility and balances the redox potential. Moreover the enhanced microbiological activity in the composting also means higher storage of the carbon from the decomposed organic matter into the microbial biomass, which lowers the escape potential of C as a potent GHG from the composting heap. This intense microbial activity within the Novcom Composting heap on the other hand is accelerated by the creation of favourable environment due to the application of subtle energy forms through Novcom solution [15].

3.6.3 Emission of Nitrous oxide (N₂O) under Novcom Composting Technology :

Nitrous oxide (N₂O) emission during composting is an important issue. It not only leads to nitrogen (N) loss from compost, but also exacerbates the greenhouse effect [82, 83]. In case of Novcom coir pith composting, emission of nitrous oxide (N₂O) was about 5.86 kg CO₂

equivalent/ ton wet coir pith w.r.to reference range of 16.38 – 163.8 kg CO₂ equivalent/ ton wet waste (considering GWP_{100years} of N₂O : 273) [82]. The lower values under Novcom coir pith composting might be due to initial lower value of N in the raw material as well as higher speed of biodegradation under this method that is induced by the self- generated diversified microbial pool (in order of 10¹⁶ c.f.u. per gm moist compost) and not through any mechanization or artificial induction. The speedy nitrification process as well as faster immobilization of the nitrogen released due to organic matter breakdown by the high microbial pool; reduces the escaping chances of N₂O from Novcom Composting heap during the process of organic matter breakdown [15].

3.6.4 Emission of Ammonia (NH₃) under Novcom Composting Technology: Ammonia is one of the main compounds responsible for generation of offensive odours and atmospheric pollution when composting organic wastes with high nitrogen content [83]. In case of Novcom coir pith composting, NH₃ emission (0.03g CO₂ equivalent/ ton wet coir pith) decreased with progression of composting indicating intense microbial activity within compost heap that reduced the escaping chances of NH₃ during the biodegradation process [15]. However, due its very low CO₂ equivalency, NH₃ is generally not considered under the GHG calculation methodology, though it has a negative impact on environment and reduces the nutrient quality of compost.

3.6.5 Total GHG emission during biodegradation of Novcom coir pith compost

To calculate the total GHG emission during biodegradation of Novcom coir pith compost we took the total emission value of methane (CH₄) and nitrous oxide (N₂O) in terms of CO₂ equivalent as per IPCC guideline. It was found that a total 6.47 kg CO₂ eq was emitted per ton of raw coir pith during the entire biodegradation period of 30 days. Now, considering the reference value of 200 kg GHG emission per tonne treated wet waste during composting [78,79,80, 84, 85, 86], Novcom coir pith composting would be about 31 times more efficient in terms of GHG mitigation; which might be due to the prolific self- generated population of native microflora within the compost heap, that speeded up the biodegradation process and alternately shortened the biodegradation period to under 30 days.

3.7 Case Study of GHG emission from 1000 ton landfill material (Coir pith) bio-converted utilizing Novcom Composting Technology under IBM–IORF Sustainability project at Mandya, Karnataka; during 2022 – 23.

Clean Food ‘Net Zero’ program was taken up under the IBM-IORF Sustainability Project, to establish the ‘Net Zero’ Model in Agriculture towards impactful climate action (especially in respect of methane mitigation), degraded soil reclamation as well as to showcase the relevance of safe and sustainable agriculture in respect of crop yield improvement *vis-à-vis* farmers’ empowerment. About 1000 ton of coir pith was bio-converted utilizing Novcom Composting Technology. The total GHG emission/ mitigation was evaluated through ACFA (version 1.0) – a carbon assessment tool for agriculture, developed by IORF as per IPCC

guideline; which uses an empirical equation to calculate total GHG emission from raw material under Novcom Composting Technology with inputs of moisture, carbon and nitrogen value from initial and final stages.

As per ACFA (version 1.0), calculation of GHG emission from composting activity (E_{CA}) is as follows :

$$E_{CA} \text{ (Kg CO}_2 \text{ equivalent/ MT Raw Materials)} = E_T + E_{CM} + E_{CB}$$

Where,

E_T : Total GHG Emission from Raw Material Transport (kg CO₂ equivalent/MT Raw materials)

E_{CM} : Total GHG Emission from Composting Activity (kg CO₂ equivalent/MT Raw materials)

E_{CB} : Total GHG Emission during Compost Biodegradation

Total GHG Emission from Raw Material Transport (E_T)

$$E_T : [2 \times D_{LS} \times FE_V \times E_F] / V_{CC} + (E_{EI} \times V_w \times T_O) / V_{CC}$$

$$= [2 \times 10 \times 0.224 \times 2.644] / 5 + [0.0975 \times 12 \times 2.5] / 5 \text{ kg CO}_2 \text{ Equivalent / MT Raw material}$$

$$= 2.954 \text{ kg CO}_2 \text{ Equivalent MT Raw material}$$

So, GHG emission for 1000 MT coir pith transport = 2954 kg CO₂ equivalent

Where,

D_{LS} : Total distance (in km) from composting unit to disposal site from where raw materials are collected (Default value 10 km up to 5,000 ton and 0.003 km / ton when value is > 5000 ton)

FE_V : Fuel Efficiency of the vehicle carrying the landfill material (i.e. litre of diesel / petrol / gasoline used to carry the vehicle 1 km) (Default value 0.224 litre diesel/km)[87]

E_F : Reference GHG emission value of the fuel used by the vehicle (Default value 2.653 kg CO₂equ / litre).

V_{CC} : Carrying Capacity of the vehicle carrying the landfill material (i.e. total amount of landfill material can be carried (in MT) in single trip). (Default value 5 MT).

E_{EI} : Embodied emissions factor for the vehicle per hour (Default value 0.0975 kg CO₂equ / hour/ ton)[88]

V_w : Total weight of the empty vehicle (Default value 12 MT)

T_O : Total Time of Operation (i.e. time (in hour) required to carry single trip landfill material from disposal site to composting unit) (Default value 2.5 hour upto 5000 ton and (1.5 +0.1 x Km) hour for < 5000 ton)

Total GHG Emission from Composting Activity (E_{CM})

$$= [(T_{CM} \times F_M \times E_F) + (T_{ECM} \times E_M \times E_{CE})] + [(E_{E2} \times M_w \times T_{CM}) + (E_{E2} \times M_{Ew} \times T_{ECM})]$$

$$= [(0.2 \times 5 \times 2.644) + (0 \times 0.0 \times 0.236)] + [(0.0975 \times 10 \times 0.2) + (0.0975 \times 0 \times 0)] \text{ kg CO}_2 \text{ equ}$$

$$= 2.839 \text{ kg CO}_2 \text{ equivalent}$$

So, GHG emission for 1000 MT coir pith preparation = 2839 kg CO₂ equivalent

Where,

T_{CM} : Total machine operating time for compost making (in hour) (Default value 0.2 hour / MT raw materials).

T_{ECM} : Total electric machine operating time for compost making (in hour) (Default value 0.0 hour / MT raw materials).

F_M : Total Fuel used per hour (in ltr) for compost making (Default value 5 ltr / hr)

E_F : Emission factor (kg CO₂ equivalent) per liter Fuel used (Default value 2.653 kg CO₂equ / litre)

E_M : Total Electricity used by machinery (in MJ) per hour for compost making (Default value 0 MJ)

EC_E : Emission factor (kg CO₂ equivalent) per MJ electricity used. (Default value 0.236 kg CO₂/ MJ)

E_{E2} : Embodied emissions factor per hour for the machinery used (Default value 0.0975 kg CO₂equ/ hour/ ton). (for both electric and diesel operated machinery) [89]

M_w : Total Weight of the general machines used for compost preparation (Default value 10).

M_{Ew} : Total Weight of the electric machines used for compost preparation (Default value 0).

TL_C : Total Raw material used for compost making

Total GHG Emission during Compost Biodegradation (E_{CB})

To evaluate the total GHG emission during biodegradation of Novcom coir pith composting, we took the help of hypothetical equation developed by Bera *et al* [15] which was used by the carbon assessment toll ACFA (version 1.0).

Now total GHG emission during biodegradation of Novcom coir pith composting

$$= E_{N_2O} \text{ (kg CO}_2 \text{ equivalent / MT waste)} + E_{CH_4} \text{ (kg CO}_2 \text{ equivalent / MT waste)}$$

Now in case of Novcom compost

$$E_{N_2O} \text{ (kg CO}_2 \text{ Equivalent / MT waste)} = [39.31 \times TNL_{20 \text{ Days}} \text{ (kg/ton waste)} + 0.6338] \times 1/1000 \times 273 \text{ ----- (i) (Where } TNL_{20 \text{ Days}} \text{ : Total Nitrogen Loss in first 20 days)}$$

Calculation of $TNL_{20 \text{ Days}}$ from the analytical value

$$TNL_{20 \text{ Days}} \text{ (kg/ton waste)} = [(100 - M_{0 \text{ Day}}) \times (TN_{0 \text{ Day}}/100) - (100 - M_{20 \text{ Day}}) \times (TN_{20 \text{ Day}}/100)] \times 10$$

$$= [(100 - 50.76) \times (0.59/100) - (100 - 69.20) \times (0.76/100)] \times 10 \text{ kg/ton waste}$$

$$= 0.6 \text{ kg/ton waste}$$

$$\text{So, } E_{N_2O} = [39.31 \times 0.6 + 0.6338] \times 1/1000 \times 273 \text{ kg CO}_2 \text{ Equivalent / MT waste}$$

$$= 6.44 \text{ kg CO}_2 \text{ Equivalent / MT waste}$$

$$E_{CH_4} \text{ (kg CO}_2 \text{ Equivalent / MT waste)} = [0.06399 \times TCL_{30 \text{ days}} \text{ (kg/ton waste)} - 0.2498] \times$$

$$1/1000 \times 75 \text{ (Where } TCL_{30 \text{ days}} \text{ : Total Carbon Loss in first 30 days)}$$

Calculation of $TCL_{30 \text{ days}}$ from the analytical value

$$\text{TCL}_{30 \text{ days}} (\text{kg/ton waste}) = [(100 - M_{0 \text{ Day}}) \times (\text{TOC}_{0 \text{ Day}}/100) - (100 - M_{30 \text{ Day}}) \times (\text{TOC}_{30 \text{ Day}}/100)] \times 10 = [(100-50.76) \times (52.87/100) - (100-69.6) \times (37.53/100)] \times 10 \text{ kg/ton waste}$$

$$= 146.2 \text{ kg/ton waste}$$

$$\text{So, } E_{\text{CH}_4} (\text{kg CO}_2 \text{ Equivalent / MT waste}) = [0.06399 \times 146.2 - 0.2498] \times 1/1000 \times 75$$

$$= [9.355 - 0.2498] \times 1/1000 \times 75 \text{ kg CO}_2 \text{ Equivalent / MT waste (Considering GWP}_{24} \text{ of Methane} = 75 \text{ for which detail discussion was done in earlier part of the paper)}$$

$$= 0.68 \text{ kg CO}_2 \text{ Equivalent / MT waste}$$

So, GHG emission during biodegradation for 1000 MT coir pith was 7120 kg CO₂ equivalent

So total GHG emission from 1000 ton Novcom coir pith composting is as follows

$$E_{\text{CA}} = E_{\text{T}} + E_{\text{CM}} + E_{\text{CB}} (\text{kg CO}_2 \text{ equivalent/ 1000 MT raw coir pith})$$

$$= 2954 + 2839 + 7120 \text{ kg CO}_2 \text{ equivalent / 1000 MT raw coir pith}$$

$$= 12.913 \text{ ton CO}_2 \text{ Equivalent /1000 MT coir pith}$$

Total GHG Offsetting with bio-conversion of coir pith into Novcom coir pith compost

GHG Offsetting with bio-conversion of coir pith to Novcom coir pith compost

GHG Offsetting with conversion of landfill materials to compost = GHG Emission from untreated waste - GHG Emission during composting

$$= (6013.7 - 12.91) \text{ MT CO}_2 \text{ equivalent /1000 MT coir pith}$$

$$= 6000.79 \text{ ton CO}_2 \text{ equivalent /1000 MT coir pith}$$

3.8 Comparison of the measured GHG emission from actual study with the calculated value utilizing the empirical equation from AFCA (version 1.0)

In the following study we compared GHG emission from actual study and from empirical equation under AFCA (version 1.0) to evaluate how much the data sets are correlated and whether this tool can be used in any practical projects; as actual field study for every case might not be practically feasible and economically viable. Pearson correlation coefficient (r) value (r = 0.9863) indicated that there was high degree of positive correlation between the measured and calculated GHG values and thus AFCA (version 1.0) can be utilized for GHG evaluation specially where Novcom composting technology is adopted.

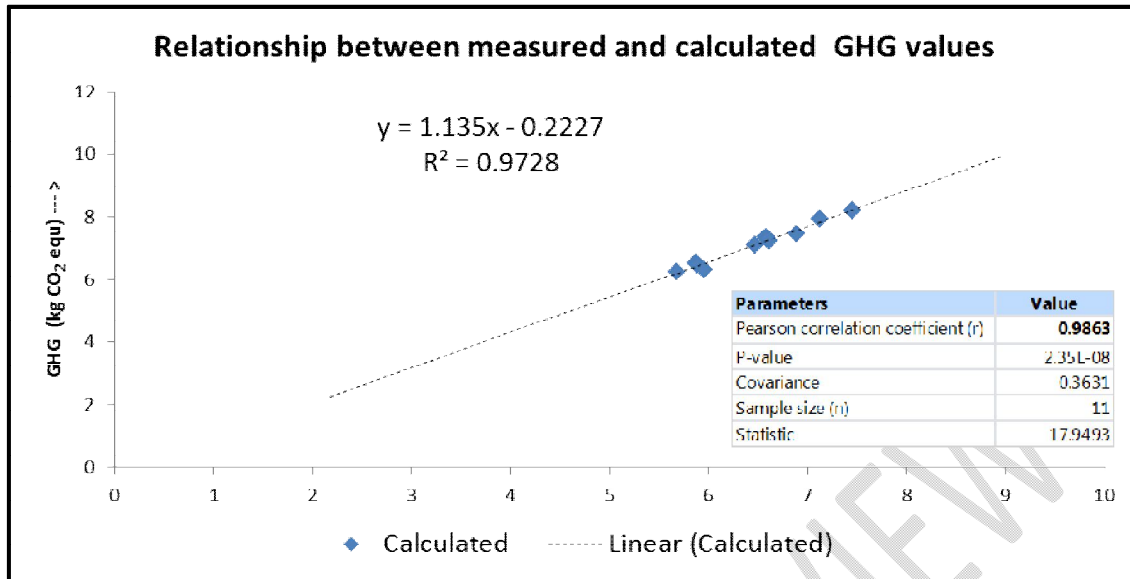


Fig 6: Relationship between the measured and calculated GHG values (kg CO₂ equivalent / MT wet raw coir pith) under IBM-IORF Sustainability Project at Mandya, Karnataka.

4. CONCLUSION

Study of the biodegradation pathway under Novcom Composting Technology, and evaluation of the end product (Novcom Coir- pith Compost) quality, indicated that the process can provide an excellent solution towards production of stable, mature and non-phytotoxic compost using any type of biodegradable material, especially toxic, hard to biodegrade and methane emitting waste, including landfill materials.

The results indicated that, this Composting Technology can help out not only in transforming coir pith – a high GHG emitter, toxic and hard to biodegrade waste, with no effective technology for effective bio-conversion, into a safe and quality amendment for soil health management. Moreover, the bio-conversion actually demonstrates a First of a Kind Model in Agriculture for methane abatement, directly from source point.

In respect of climate action, composting activity has been referred as one of the most effective and economic option towards GHG abatement. And this study specifically indicates the very high GHG offsetting potential under Novcom Composting Technology; as reflected by more than 99% Omission of GHG from source point during the process of coir pith bioconversion.

Finally, the safe, quality and microflora rich (one trillion billion c.f.u. of self-generated microflora per ton moist compost) coir pith compost, generated through Novcom Composting Technology within a short time frame of 30 days validates its potential as an effective tool that can successfully drive the Net Zero Goal, enable successful reclamation of degraded lands and improve crop productivity; while also generating additional mandays and options for income generation; that can empower farmers' livelihood.

Acknowledgement

The authors are thankful to IBM Sustainability Platform for facilitating this study.

COMPETING INTERESTS:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

REFERENCE

1. Nandhini PR, Kalaiselvi G, Saravanan N, Ramesh babu NG. Chemical analysis of agro-pollutant coir pith- a byproduct of coir industry, *International Journal of Environmental & Agriculture Research (IJOEAR)*, 2016; 2(11) : 13 – 20.
2. Coir Board. Coir Pith – Wealth from waste – a reference, Ministry of MS&ME, Govt. of India, Published on the occasion of the India International Coir Fair 2016; Coimbatore, Available on <http://coirboard.gov.in/wp-content/uploads/2016/07/Coir-Pith.pdf> (Accessed on 30.10.22)
3. Gao WJ and Fatehi P. Lignin for polymer and nanoparticle production: Current status and challenges, *Can. J. Chem. Eng.*, 2019; **97**: 2827.
4. Azimvand J, Didehban K, Mirshokraie S. Safranin-O removal from aqueous solutions using lignin nanoparticle-g-polyacrylic acid adsorbent: Synthesis, properties, and application. *Adsorption Science & Technology*. 2018; 36(7-8):1422-1440.
5. Cresswell CG. A Comparison of the Chemical and Physical Properties of Coir Dust with Sphagnum and Sedge Peats: Laboratory and Glasshouse Studies, Biological and Chemical Research Institute, Australia. 1992
6. Thenmozhi P. Studies on ion exchange capacity in coir pith, *St. Joseph's Journal of Humanities and Science*, 2014; Page 124 – 126. Available at <https://sjctnc.edu.in/wp-content/uploads/2014/08/paperS11.pdf>
7. Seal A, Bera R, Datta A, Saha S, Chatterjee AK, Barik AK, Nath R and Mazumdar D. Successful Biodegradation of coir pith waste using Novcom Composting Method : A Case Study from Vaniampara Rubber Estate, India. *Journal of Pharmaceutical and Scientific Innovation*, 2015; 4(1) : 73-77.
8. Kunchikannan LKNV, Mande SP, Kishore VVN and Jain KL. Coir Pith: A Potential Agro Residue for Anaerobic Digestion, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2017; 29:4, 293-301
9. Barik AK, Chatterjee AK, Datta A, Saha S, Nath R, Bera R, and Seal A. Evaluation of Inhana Rational Farming (IRF) Technology as an Effective Organic

- Option for Large Scale Paddy Cultivation in Farmer's Field- A Case Study from Kowgachi-II Gram Panchayat, North 24 Parganas, West Bengal. *The International Journal of Science and Technoledge*. 2014; 2(5):183-197.
10. IPCC. IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories 5.1, 2018; Available at https://www.ipcc.ch/site/assets/uploads/2018/03/5_Waste-1.pdf
 11. Seal A, Bera R, Chatterjee AK and Dolui AK. Evaluation of a new composting method in terms of its biodegradation pathway and assessment of the compost quality, maturity and stability. *Archives of Agronomy and Soil Science*, 2012; 58(9):995-1012.
 12. Trautmann NM and Krasny ME. Composting in the classroom. 1997; Available from: <http://www.cfe.cornell.edu/compost/schools.html>
 13. Jackson, ML. Soil chemical analysis. 1973; Prentice Hall of India Pvt. Ltd., New Delhi.
 14. Black CA. Methods of soil analysis, 1965; Part 1 and 2. Madison (WI): American Society of Agronomy.
 15. Bera R, Datta A, Bose S, Dutta S, Mukhopadhyay K, Goswami KK, Debnath M, Barik AK, Ganguli M, Narasimhan VL, Quah E, Bhattacharya P and Seal A. Recycling of Waste Utilizing Novcom Composting Technology towards GHG Abatement from Source, *International Journal of Environment and Climate Change*, 2022, 12 (12): 1605 – 1629.
 16. Andersen JK, Boldrin A, Samuelsson J, Christensen TH and Scheutz, C. Quantification of greenhouse gas emissions from windrow composting of garden waste. *Journal of Environmental Quality*. 2010; 39(2):713-724.
 17. Dell'Abate M, Benedetti A and Sequi P. Thermal methods of organic matter maturation monitoring during a composting process. *J. Therm. Anal. Calorimetry*. 2000; 61(2): 389–396.
 18. Mondini C, Sa´nchez-Monedero MA, Sinicco T and Leita L. Evaluation of extracted organic carbon and microbial biomass as stability parameters in ligno-cellulosic waste composts. *J. Environ. Qual.* 2006;35: 2313–2320.
 19. Bishop PL, Godfrey C. Nitrogen transformation during sludge composting. *BioCycle*. 1983; 24:122–127.
 20. Brust GE. Management Strategies for Organic Vegetable Fertility, in *Safety and Practice for Organic Food*, Chapter 9, Editor(s): Debabrata Biswas, Shirley A. Micallef,; Academic Press, 2019;Pages 193-212.
 21. Howell J. Organic Matter: Key to Soil Management.2005; Available at http://www.hort.uconn.edu/ipm/veg/croptalk/croptalk1_4/page8.html. [cross reference].
 22. USDA. Carbon to Nitrogen Ratios in Cropping Systems, USDA Natural Resources Conservation Service,2011; Available at https://www.hamiltonswcd.org/uploads/3/7/2/3/37236909/nrcs_carbon_nitrogen.pdf (accessed on 30.10.22)

23. Begemann S. Understand Carbon to Nitrogen Ratios before Buying Cover Crop Seed, Henry Ag News, The OHIO State University, USA, 2018; Available at <https://u.osu.edu/henryag/2018/05/14/understand-carbon-to-nitrogen-ratios-before-buying-cover-crop-seed/> (accessed on 30.10.22).
24. Gullickson G. Here's Why The Carbon-Nitrogen Ratio Matters, Successful Farming, 2015; Available at https://www.agriculture.com/crops/cover-crops/heres-why-carbonnitrogen-ratio-matters_568-ar48014 (accessed on 30.10.22).
25. Jimenez IE and Garcia PV. Evaluation of city refuse compost maturity: a review. *Biological Wastes*.1989; 27: 115-42.
26. Kapetanios EG, Ioizidon M, Volkanas G. Compost production from Greek domestic refuse. *Bioresource Technol*. 1993; 44:13-16.
27. Rekha P, Suman-Raj DS, Aparna C, Hima-Bindu V and Anjaneyulu Y. Bioremediation of contaminated lake sediments and evaluation of maturity indices as indicators of compost stability. *Int. J. Environ. Res. Public Health*,2005; 2(2): 251-262.
28. de Bertoldi M, Vallini G and Pera A. The biology of composting: a review. *Waste Manage Res*.1983; 1: 157-176.
29. de Bertoldi M, Vallini G, Pera A and Zucconi F. Comparison of three windrow compost systems. *BioCycle*. 1982; 23(2): 45-50.
30. Narendar R, Priya DK. Chemical treatments of coir pith: Morphology, chemical composition, thermal and water retention behavior, *Composites Part B: Engineering*, 2014; 56: 770-779.
31. Watson ME. Extension Fact sheet. Ohio State University. 2003; <http://ohioline.osu.edu>.
32. Evanylo G. Compost maturity and indicators of quality: laboratory analyses and on farm tests. 2006; http://www.mawaterquality.org/industry_change/compost_school/Compost%20quality_Evanylo.pdf
33. US Composting Council. 2002; Available from <http://www.compostingcouncil.org>
34. Australian Standards. 1999. 4454: (1999). Composts, soil conditioners and mulches. Standards Association of Australia, Homebush, NSW.
35. Tisdale SL, Nelson WL, Beaton JD. Soil fertility and fertilizers. 4th edn. New York:Macmillan.1985
36. Fertiliser Association of India (FAI). The Fertilizer (Control) Order 1985. New Delhi (India): FAI.2007.
37. Alexander RA. Standards and guidelines for compost use. *BioCycle*. 1994; 35(12):37-41.
38. Dolui AK, Som A, Mukhopadhyay K, Mukherjee S, Bera R and Seal A. Evaluation of a Novcom Composting Method towards Speedy Biodegradation of Water Hyacinth for Effective Bio-resource Utilization in Farmers Level. *Journal of Natural Product and Plant Resource*, 2014;4(3):44-47.

39. Mukhopadhyay K, Mukherjee S, Seal A, Bera R and Dolui AK. Effective soil resource recycling with a new biodegradation method towards organic soil management – A case study from Howrah Krishi Vigyan Kendra, ICAR. *Central European Journal of Experimental Biology*, 2015; 4 (2):17-23.
40. USCC. Compost – Characteristics and Why it Matters, 2022; Available at <https://www.compostingcouncil.org/page/CompostCharacteristics> (Accessed on 27.10.22)
41. Gómez RB, Lima FV and Ferrer A S. The use of respiration indices in the composting process: a review. *Waste Management Research*. 2006;24: 37 – 47.
42. Bartha R and Pramer D. Features of a flask and methods of measuring the persistence and biological effects of pesticides in soil. *Soil Science*. 1965; 100:68–70.
43. Zucconi F, Fera A, Forte M and de Bertoldi M. Evaluating toxicity of immature compost. *Biocycle*. 1981; 54-57.
44. Milon AR, Chang SW, Ravindran B. Biochar amended compost maturity evaluation using commercial vegetable crops seedlings through phytotoxicity germination bioassay, *Journal of King Saud University - Science*, 2022; 34(2):101770
45. Tam NFY and Tiquia SM. Assessing toxicity of spent sawdust pig-litter using seed germination technique. *Resources, Conservation and Recycling*, 1994;11: 261-274.
46. Wong MH. Phytotoxicity of refuse compost during the process of maturation. *Environmental Pollution*, 1985; 37: 159-174.
47. Manios VI, Tsikalas PE and Siminis HI Phytotoxicity of olive tree in relation to organic acid concentration. *Biological Waste*, 1989; 27: 307- 317.
48. Selim, Sh & Zayed, Mona & Atta, Houssam. (2011). Evaluation of phytotoxicity of compost during composting process. *Nature and Science*. 10. 469-475.
49. Tiquia SM, Tam NFY, Hodgkiss, IJ. Effects of composting on phytotoxicity of spent pig manure sawdust litter. *Environ Pollut*. 1996; 93:249–296.
50. Singh CK, Kumar A and Roy SS. Quantitative analysis of the methane gas emissions from municipal solid waste in India. *Sci Rep*, 2018; 8: 2913
51. The Associated Press. Scientists say landfills release more planet-warming methane than previously thought. 2022; Available at <https://www.npr.org/2022/08/11/1116874946/scientists-say-landfills-release-more-planet-warming-methane-than-previously-tho> (Accessed on 27.10.22)
52. EDF. Methane: A crucial opportunity in the climate fight, *Environmental Defense Fund*. 2022. Available at <https://www.edf.org/climate/methane-crucial-opportunity-climate-fight> (Accessed on 30.10.22)
53. Balcombe P, Speirs JF, Brandon NP and Hawkes AD. Methane emissions: choosing the right climate metric and time horizon, *Environ. Sci.: Processes Impacts*, 2018; 20: 1323-1339

54. Acid News Cut methane to reduce ozone, Acid News, 2018; Available at <https://www.airclim.org/acidnews/cut-methane-reduce-ozone>(Accessed on 30.10.22)
55. Black S, Parry I, Vernon N. Methane Emissions Must Fall for World to Hit Temperature Targets, IMF Blog, 2022; Available at <https://www.imf.org/en/Blogs/Articles/2022/11/02/methane-emissions-must-fall-for-world-to-hit-temperature-targets>
56. UNEP Methane emissions are driving climate change. 2021; Here's how to reduce them. Available at <https://www.unep.org/news-and-stories/story/methane-emissions-are-driving-climate-change-heres-how-reduce-them>
57. Cady RA. A Review of GWP*: A proposed method for estimating global warming potential (GWP*) of short-lived climate pollutants like methane, Global Dairy Platform, 2020; Available at https://www.globaldairyplatform.com/wp-content/uploads/2020/11/literature-review-of-gwp-nov_20.pdf
58. Saunio M, Bousquet P, Poulter B, Peregon A, Ciais P, Canadell JG, Dlugokencky EJ, Etiope G, Bastviken D, Houweling S, Janssens-Maenhout G, Tubiello FN, Castaldi S, Jackson RB, Alexe M, Arora VK, Beerling DJ, Bergamaschi P, Blake DR, Brailsford G, Brovkin V, Bruhwiler L, Crevoisier C, Crill P, Covey K, Curry C, Frankenberg C, Gedney N, Höglund-Isaksson L, Ishizawa M, Ito A, Joos F, Kim HS, Kleinen T, Krummel P, Lamarque JF, Langenfelds R, Locatelli R, Machida T, Maksyutov S, McDonald KC, Marshall J, Melton JR., Morino I, Naik V, O'Doherty S., Parmentier FJW, Patra PK, Peng C, Peng S, Peters GP, Pison I, Prigent C, Prinn R, Ramonet M., Riley WJ, Saito M, Santini M, Schroeder R, Simpson IJ, Spahni R, Steele P, Takizawa A, Thornton BF, Tian H, Tohjima Y, Viovy N, Voulgarakis A, van Weele M, van der Werf GR, Weiss R, Wiedinmyer C, Wilton DJ, Wiltshire A, Worthy D, Wunch D, Xu X, Yoshida Y, Zhang B., Zhang Z and Zhu Q, Earth System Science Data, 2016; 8: 697–751
59. Quéré C. Le, Andrew RM, Canadell JG, Sitch S, Korsbakken JI, Peters GP, Manning AC, Boden TA, Tans PP, Houghton RA, Keeling RF, Alin S, Andrews OD, Anthoni P, Barbero L, Bopp L, Chevallier F, Chini LP, Ciais P, Currie K, Delire C, Doney SC, Friedlingstein P, Gkritzalis T, Harris I, Hauck J, Haverd V, Hoppema M, Klein Goldewijk K, Jain AK, Kato E, Körtzinger A, Landschützer P, Lefèvre N, Lenton A, Lienert S, Lombardozzi D, Melton JR, Metzl N, Millero F, Monteiro PMS, Munro DR, Nabel JEMS, Nakaoka SI, O'Brien K, Olsen A, Omar AM, Ono T, Pierrot D, Poulter B, Rödenbeck C, Salisbury J, Schuster U, Schwinger J, Séférian R, Skjelvan I, Stocker BD, Sutton AJ, Takahashi T, Tian H, Tilbrook B, van der Laan-Luijkx IT, van der Werf GR, Viovy N, Walker AP, Wiltshire AJ and Zaehle S, Earth System Science Data, 2016, 8, 605–649
60. Plattner GK, Stocker T, Midgley P and Tignor M.. "IPCC expert meeting on the science of alternative metrics: Meeting report," Oslo, 18 to 20 March 2009 (IPCC Working Group I, Technical Support Unit, Bern, Switzerland, 2009).

61. Myhre G, Shindell D, Bréon FM, Collins W, Fuglestedt J, Huang J, Koch D, Lamarque JF, Lee D, Mendoza B, Nakajima T, Robock A, Stephens G, Takemura T and Zhang H, in *Climate Change. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 2013; ed. T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013
62. Allen M, Fuglestedt J, Shine K, Reisinger A, Pierrehumbert RT, Forster PM. New use of global warming potentials to compare cumulative and short-lived climate pollutants. *Nature Climate Change*; 2016; 6:773–776.
63. Ocko IB, Hamburg SP, Jacob DJ, Keith DW, Keohane NO, Oppenheimer M, Roy-Mayhew JD, Schrag DP and Pacala SW. Unmask temporal trade-offs in climate policy debates, *Science*, 2017; 356 (6337), 492-493.
64. UNECE Methane Management - The Challenge, The United Nations Economic Commission for Europe (UNECE), 2022; Available at <https://unece.org/challenge> (Accessed on 28.10.22)
65. Moseman A and Trancik J Why do we compare methane to carbon dioxide over a 100-year timeframe? Are we underrating the importance of methane emissions? 2021; Available at <https://climate.mit.edu/ask-mit/why-do-we-compare-methane-carbon-dioxide-over-100-year-timeframe-are-we-underrating> (Accessed on 27.10.22).
66. Pérez-Domínguez I, del Prado A, Mittenzwei K, Hristov J, Frank S, Tabeau A, Witzke P, Havlik P, van Meijl H, Lynch J, Stehfest E, Pardo G, Barreiro-Hurle J, Koopman JFL and Sanz-Sánchez MJ. Short- and long-term warming effects of methane may affect the cost-effectiveness of mitigation policies and benefits of low-meat diets. *Nature Food*, 2021; 2:970–980.
67. IPCC AR6 WGI Chapter 7: The Earth's energy budget, climate feedbacks, and climate sensitivity, 2021; Available at https://report.ipcc.ch/ar6wg1/pdf/IPCC_AR6_WGI_Chapter_07.pdf
68. EFCTC. IPCC AR6 Discusses the use of 100-Year and 20-Year GWPs and Other Emission Metrics, European FluoroCarbons Technical Committee, 2021; Available at <https://www.fluorocarbons.org/news/ipcc-ar6-discusses-the-use-of-100-year-and-20-year-gwps-and-other-emission-metrics/> (Accessed on 28.10.22)
69. Mar KA, Charlotte U, Walderdorff L, Butler T. Beyond CO₂ equivalence: The impacts of methane on climate, ecosystems, and health, *Environmental Science & Policy*, 2022; Volume 134, Pages 127-136,
70. UNFCCC. Decisions adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement. In Decision 18/CMA1, 2018.

71. Howarth, R. W., R. Santoro, and A. Ingraffea. Methane and the greenhouse gas footprint of natural gas from shale formations. *Clim. Change Lett.* 2011; **106**: 679–690.
72. Stern J.. Measurement, Reporting, and Verification of Methane Emissions from Natural Gas and LNG Trade: creating transparent and credible frameworks, Oxford Institute for Energy Studies, 2022; Page 1-55, available at <https://www.oxfordenergy.org/wpcms/wp-content/uploads/2022/01/Measurement-Reporting-and-Verification-of-Methane-Emissions-from-Natural-Gas-and-LNG-Trade-ET06.pdf>
73. IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfeld, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391pp.
74. Myhre, G. et al.,: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013; pp. 659–740.
75. Abernethy S and Jackson RB. Global temperature goals should determine the time horizons for greenhouse gas emission metrics , *Environ. Res. Lett.* 2022; 17: 024019
76. USCC Greenhouse Gases and the Role of Composting: A Primer for Compost Producers, USCC Factsheet; 2008. Available: <https://www.sanjoseca.gov/home/showpublisheddocument?id=198> (Accessed on 28.10.22)
77. Vergara S E and Silver WL 2019 *Environ. Res. Lett.* 14 124027
78. Hermann BG, Debeer L, De Wilde B, Blok K., Patel MK. To compost or not to compost: carbon and energy footprints of biodegradable materials' waste treatment. *Polymer Degradation and Stability* 2011; 96: 1159-1171.
79. Lou XF and Nair J. The impact of landfilling and composting on greenhouse gas emissions e a review. *Bioresource Technology*, 2009;100: 3792-3798.
80. IPCC. IPCC Guidelines for National Greenhouse Gas Inventories. In: Waste. Intergovernmental Panel on Climate Change, vol. 5. 2006; Available at www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html (18.05.11.)
81. Adhikari BK, Trémier A, Barrington S, Martinez J and Daumoin M. Gas emissions as influenced by home composting system configuration. *Journal of Environmental Management.* 2013;116:163 -171

82. Tang, Xiang Li, Peng Cui, Jiayang Lin, Raymond Jianxiong Zeng, Hao Lin, Shungui Zhou. Nitrification plays a key role in N₂O emission in electric-field assisted aerobic composting, *Bioresource Technology*, 2020;Volume 297,
83. Bong CPC, Lim LY, Ho WS, Lim JS, Klemeš JJ, Towprayoon S, Ho CS, Lee CT. A review on the global warming potential of cleaner composting and mitigation strategies, *Journal of Cleaner Production*, 2017;Volume 146, Pages 149-157.
84. Pagans E, Barrena R, Font X, Sa´nchez A. (2006). Ammonia emissions from the composting of different organic wastes. Dependency on process temperature, *Chemosphere* 62 : 1534–1542.
85. Friedrich E and Trois C. Quantification of greenhouse gas emissions from waste management processes for municipalities - a comparative review focusing on Africa. *Waste Management*, 2011; 31: 1585-1596.
86. Rogger C, Beaurain F, Schmidt TS. Composting projects under the Clean Development Mechanism: sustainable contribution to mitigate climate change. *Waste Management*, 2011;31: 138-146
87. Mart´ınez-Blanco J, Col´on J, Gabarrell X, Fon, X, S´anchez A, Artola A, Rieradevall J. The use of life cycle assessment for the comparison of biowaste composting at home and full scale. *Waste Management*, 2010; 30: 983-994.
88. India Specific Road Transport Emission Factors, India GHG Program, 2015; <https://indiaghgp.org/sites/default/files/Road%20Transport%20Technical%20Paper.pdf>
89. Wells, C., Total Energy Indicators of Agricultural Sustainability: Dairy Farming Case Study. 2001. Technical Paper 2001/3, Page 1 -90.