MANAGING BIO-WASTE: A WEALTH FROM WASTE PERSPECTIVE

Sayaji T. Mehetre, Poulomi Mukherjee, Darshana Salaskar and Suvendu Mondal*
Nuclear Agriculture and Biotechnology Division
Bhabha Atomic Research Centre
Mumbai - 400085, India

*Email: suvendu@barc.gov.in

Abstract

Managing bio-waste is the concept of enrichment of natural process of degradation in a more controlled way towards utilization of its resources for mankind. Bhabha Atomic Research Centre has developed a bi-phasic bio-methanation plant (Nisargruna) which uses a thermophilic phase of rapid degradation of complex biomolecules into simple organic acids and successive generation of methane in a completely anaerobic environment. The product methane is used directly for cooking or in generating electricity. The byproduct manure is a good source of soil conditioner and improves soil health. This process needs complete segregation of biodegradable waste from general waste. Apart from this, BARC has developed a rapid composting technology based on the use of a single cellulolytic fungal strain of *Trichoderma koningiopsis* for aerobic composting. This technology does not require complete segregation and helps in managing waste into a good quality manure. The article discusses in detail both these processes to generate wealth from waste.

1. Significance of Bio-Waste Management

Waste management has assumed global significance as huge amounts of waste is getting piled up every day in major cities of the world. About half of this waste is biodegradable and needs to be processed by different technologies. Bio-methanation process offers an excellent way to convert this waste to a good quality fuel and more importantly bio-manure/slurry which can be used for soil health improvement. This manure/slurry will be a good alternative to cow dung for soil health management. Apart from providing manure, this process also generates energy in a sustainable manner. On the other hand, leaf litter decomposition is a complex and time-consuming process spanning over years, if occurring naturally in a forest floor. Such time scales of degradation cannot be afforded in urban and commercial rural areas, where garden and plantation wastes are generated on a daily basis. Such wastes are most often burnt causing fire and environmental hazards. Currently management of dry leaf waste comprises of dumping in land-fills and burning which liberates smoke and carbon monoxide. If left unattended, they can be a medium for spreading of forest and landfill fires. Residual agricultural biomass in the form of stubble and leaves after harvesting of grains or other useful parts of the plants, are another difficult to degrade organic substrate. These residues are often burnt as a no-cost measure to render the field available for the next cropping cycle. BARC has developed two technologies, Nisargruna and Rapid composting to offer promising solutions to the above problem. A few decades of research efforts were made to develop such processes, validate technologies and deploy them in field and/or society. Overview of the exciting journey of these technology development and important milestones are discussed here.

2. Process of Nisargruna plant

Fig. 1: First Nisargruna plant installed at Nursery (opposite to CFB), BARC during 2001

The first Nisargruna plant was installed at Nursery (Opposite to CFB, BARC), in June 2001. The design of the plant is shown in **Fig. 1**. The capacity of this plant was 500 kg per day. It was the first design with minimum infrastructure. At this initiation stage, this was only an illuminating idea which was put into action. After seeing the success of this idea, more plants were installed at different parts of India. Many changes were made during next design of the plant. The present design of the plant is given in **Fig. 2**. The waste generated in kitchens in the form of vegetable waste, stale cooked and uncooked food, extracted tea powder, waste milk and milk products have been processed in this newer version of plant. In order to accommodate such diverse wastes, two important modifications were made in the conventional design of the biogas plant. First, a mixer/shredder was introduced to process the waste before putting it into the pre-digestor tank. Second, the pre-digestion is accelerated by the addition of hot water and

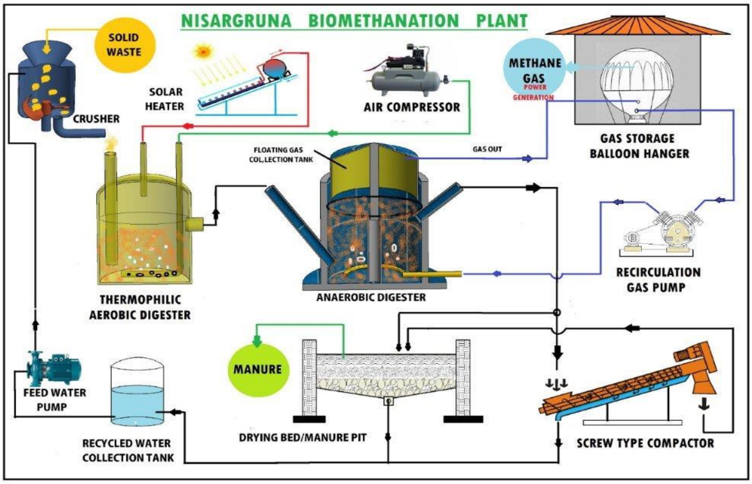


Fig. 2: Design of Nisargruna plant used during recent times with improved parameters

intermittent aeration. The waste is converted into slurry by mixing it with water in a 1:1 ratio. This helps in reduction of substrate size and thereby prevents clogging of the system. In the pre-digester, the slurry is aerobically digested and complex bio macromolecules in food are converted to organic acids. Pre-digestion reactions are exothermic and temperature rises to 40ºC by itself. Hot water obtained using solar energy is added to further raise the temperature to 50ºC. In case of insufficient sunlight during winter, provision is made to use a part of the generated biogas for production of hot water using methane stoves. The high temperature enriches thermophilic microflora present in the waste and helps to achieve faster kinetics in enzymatic degradation of biological macromolecules. The main role of these enriched microflora is to digest fats, proteins and carbohydrates into simple sugars, volatile fatty acids, amino acids and organic acids. The pH of the feed slurry in the pre-digester is around 6.5 to 7.5 and the retention time (often termed as hydraulic time) is 4 days. After the pre-digestion process, the pH reduces to 4.0 - 5.0. The pre-digested slurry is further digested under anaerobic conditions in the main digester for about 25 days by a process called as methanogenesis. The anaerobic bacteria are naturally present in the alimentary canal of ruminant animals (cattle) and such culture is added during the installation of bio-gas plants. The undigested lignocellulosic and hemi-cellulosic materials along with microbial biomass are then passed on to a settling tank. After about a month, good quality manure is obtained from the settling tanks. Introduction of sand filters at this stage also improves the process of easy drying of the manure and allows reuse of the filtered water either for gardening or for processing back to the plant. Methane and carbon dioxide are the terminal products of this process. Methane is produced from two primary substrates namely acetate and 'hydrogen / carbon dioxide' by acetoclastic ($CH_3COOH \rightarrow CH_4 + CO_2$) and hydrogenotrophic ($CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$) methanogenic archaea, respectively. The difference between Nisargruna technology and classical anaerobic digesters are mentioned in Table 1. Overall biochemical and/or microbiological reactions are summarized as follows:

Solubilization: Facultative anaerobic microorganisms hydrolyse complex materials into soluble monomers. The mechanical mixer helps in reducing the particle size of the waste material for better solubilization. Polymeric biomolecules such as lipids, proteins, and carbohydrates are primarily hydrolysed by extracellular hydrolases secreted by these microbes. Hydrolytic enzymes (lipases, proteases, cellulases, amylases, etc.) convert polymers into monomeric units, which are then utilized by another group of microbes.

Non-methanogenic phase (acidification): The dissolved complex organic substrates are reduced to soluble simple organic acids (mainly acetic acid). Obligate H_2-producing acetogenic bacteria produce acetate and H_2 from higher fatty acids. The fermentative products, ethanol and lactate are also converted to acetate and H_2 by other acetogens and anaerobes.

Methanogenic phase (methanogenesis): Methane producing bacteria reduce acetate to methane and carbon dioxide. Some methanogens ferment the acetic acid to methane and carbon dioxide. While, others reduce carbon dioxide to methane by using hydrogen gas or formate. H_2/CO_2-consuming methanogens reduce CO_2 via formyl, methenyl, and methyl containing compounds with the help of unusual coenzymes, to finally produce methane.

3. Advantages of Nisargruna Technology

Environmental Benefits

Waste Management: Nisargruna effectively converts biodegradable waste into valuable resources, eliminating the need for landfills and reducing methane emissions associated with waste decomposition.

Nutrient Cycling: By mimicking natural processes, Nisargruna ensures the recycling of essential elements like nitrogen, carbon, hydrogen, and oxygen, promoting ecosystem health.

Land Conservation: Decentralized waste management significantly reduces the demand for landfill space, conserving land and reducing transportation costs.

Carbon Reduction: Utilizing biogas as a clean energy source displaces fossil fuels, mitigating greenhouse gas emissions and contributing to the reversal of climate change.

Soil Health: The nutrient-rich manure produced by the process enhances soil fertility, promoting sustainable agriculture and food security.

Economic Benefits

Resource Recovery: Nisargruna generates valuable end products such as biogas and manure, creating economic opportunities and reducing waste disposal costs.

Energy Independence: In rural areas, Nisargruna plants can provide a sustainable and affordable energy source, fostering self-reliance and reducing dependency on fossil fuels.

Table 1: Salient differences between Nisargruna technology and the classical anaerobic digesters

Properties	Conventional anaerobic digesters (gobar gas plant)	Nisargruna biogas plant
Type of waste processed	Mainly cow dung (gobar)	All biodegradable wastes, e.g. kitchen waste, food waste, green grass, animal waste, abattoir waste, etc.
Pre-digestor	Not included	Included
Waste feeding	Direct	After making a slurry through a mechanical mixer
Handling of waste	Direct	Needs segregation
Use of hot water	No usage of hot water	Solar heater is used for getting hot water, which is then mixed in predigestor
Types of bacteria	Only methanogenic	Thermophilic bacteria in predigestor and methanogenic bacteria in main digester
Digestion	Single phase, i.e. anaerobic	Biphasic, i.e. aerobic and anaerobic
Type of manure	Manure is more fibrous and less consistent. Loss of nitrogen is more due to open storage	Good quality and odourless Use as soil conditioner
Processing time	About 45-50 days	About 30 days
Gas output	Methane 50-55%	Methane 75-78%
Scope	Only rural area	Urban and rural area both
Design	Small scale	Suitable for scaling up
Recycling water	Not done	Saves 60% water
Advantages/ disadvantages	More retention time Useful for small-scale use	Less retention time Save on transporting cost of waste. Uses in large scale

Technical Advantages

Efficient Processing: Nisargruna offers a continuous and compact solution for treating large volumes of biodegradable waste without requiring additional space.

Versatility: The technology can be adapted to various waste streams and scales, making it applicable to both urban and rural environments.

4. Various major success stories of Nisargruna technology

4.1. Obtaining an ISO certificate for managing waste at Matheran, Maharashtra

Matheran is a small hill station and a popular tourist destination that is 80 km away from Mumbai. This has been declared as a highly eco-sensitive zone and is home to several rare flora and fauna. There are several hotels and restaurants to cater to a large number of tourists and such establishments produce several metric tons of biodegradable kitchen waste. Being a vehicle free town, horse is the main mode of transportation and sometimes the roads are littered with horse dung. Due to its official eco-sensitive status, hoteliers are not allowed to dump their waste in the vicinity of the town. A five-ton capacity Nisargruna project was installed during 2007. All food waste from hotels and a part of the horse dung has been processed in this plant. The biogas generated in the plant is used to run a 30 kVA generator and the eletricity produced from it lights up the town's street lights. This not only shows the utility of the technology in such an eco-sensitive zone with variable weather conditions, but also proves that such projects can be successful even under municipal settings. Successful operation of the Nisargruna plant in such a new environment has led to awarding of an ISO certification for managing waste.

4.2. NISARGRUNA for community kitchen

Kurudampalyam is a small village, 20 km away from Coimbatore, with most of the villagers residing below poverty line. Coimbatore (rural) district authority installed a 2-ton capacity Nisargruna plant during 2014. Biodegradable waste from the adjoining part of Coimbatore city is delivered to the plant every day. The biogas produced at the plant is supplied to a community kitchen across the road. The community kitchen has 12 biogas burners. Villagers come here with their raw ingredients and cook their meals (**Fig. 3**).

Fig. 3: Nisargruna plant for community kitchen installed at Coimbatore village during 2014

4.3. Nisargruna at the doorstep of software techies

Several corporate houses including Tata Consultancy Services (TCS) have adopted this technology to make their corporate campuses and premises zero waste facility. TCS has Nisargruna plants at many of their campuses including their largest campus at Chennai. The Chennai campus has a 3 MTPD (metric ton per day) plant where the gas is converted to electricity using a biogas generator. TCS, Thane plant is working for more than a decade now.

4.4. Handling Abattoir waste - Nisargruna gave a solution

A MoU was signed between BARC and MCGM, Mumbai for processing slaughter house waste (15-ton capacity) by Nisargruna technology. Deonar abattoir being the biggest slaughter house in Mumbai was selected for setting up the plant. Before setting up of the biogas plant, slaughter house waste was discarded in the dumping ground resulting in pollution of the surrounding area. During the working of this plant for three years, a total of 10,000-ton waste was processed resulting in 400 ton manure and about 55,000 units of electricity. This plant has also saved the expenditure of sending this material to the dumping ground and making the environment clean. Subsequently the technology was implemented at different slaughter houses in Chennai, Rajkot and Bengaluru.

4.5. Large scale deployment of Nisargruna technology to the state of Chhattisgarh

The technology was transferred to Chhattisgarh Biofuel Development Authority (CBDA), Government of Chhattisgarh during 2023. During the first phase, biogas plants were installed at seven locations from tribal districts of Chhattisgarh. The first plant at Janapad Panchyat, Jagdalpur was inaugurated by Shri Bhupendra Baghel, Hon. ex-chief minister on 25th Jan 2023. The plant has a capacity of processing 500 kg cow dung per day. The plant has also successfully completed production of 10 KW electricity per day and it is connected to the grid (**Fig. 4**).

Fig. 4: Nisargruna plant installed at Chhattisgarh and inaugurated by Chief Minister during January 2023

4.6. Modernization of the technology and setting up of a new plant at BARC hospital

Nisargruna plant was initially installed at hospital site during 2006. This plant has been further modernized for enhanced performance last year. The newer concepts like spraying water to the main digester slurry through a high pressure nozzle has been introduced for breaking scum formation. Methane recycling grid has been introduced which has helped in improving methane quality by maintaining complete anaerobic environment. Improved water recycling system has been installed by using screw press system. All these modifications have resulted in better performance of the plant.

4.7. Nisargruna for Swachha Bharat Mission

The technology has been recommended by Swachha Bharat mission of Government of India for making cities clean. The technology was installed by many municipal authorities throughout the country. Further the second phase of Swachha Bharat Mission was launched for rural part of country and Nisargruna technology has been introduced for implementation.

5. Nisargruna technology in the context of climate change:

Nisargruna technology offers a two-fold approach towards curtailing CO_2 emissions from fossil fuel combustion. Firstly, biogas produced through this process serves as a direct replacement for gas or coal in cooking, heating, electricity generation, and lighting. Secondly, the high-quality manure generated by Nisargruna plants reduces the dependency on chemical fertilizers, thereby avoiding CO_2 emissions associated with their production. Moreover, by substituting firewood with biogas, Nisargruna mitigates deforestation and land degradation, indirectly functioning as a carbon sink. While methane, a primary component of biogas, is a potent greenhouse gas, its conversion to CO_2 through combustion within the Nisargruna process is a net benefit when compared to the uncontrolled release of methane from anaerobic decomposition. This is analogous to the sustainable use of firewood, where CO_2 emitted is offset by recent carbon absorption through plant growth. Unlike fossil fuels, biogas combustion does not introduce new carbon into the atmosphere. Nisargruna's potential to generate carbon credits through integrated plant systems underscores its significant contribution to carbon reduction and climate change mitigation.

6. Technological improvement/upgradation: Generation of '*Shesha*'

A novel, compact helical shaped digester cum waste converter made of low-cost PVC pipes, has been developed and deployed for kitchen waste processing during 2021. The name Shesha (शेष) has been given on the basis of the serpentine shape of this digester (its resemblance to the snake *Shesha*) as well as Sanskrit word for waste (**Fig. 5**). The system has been patented with Indian Patent No.531960 very recently. The main advantage of this waste converter includes helical shaped digester made from low-cost PVC pipes which saves major cost of civil construction and MS (mild steel) dome required for conventional designs. It is suitable for skid mounting on a vehicle or wheels required for processing waste from smaller societies/residential complexes. Also, the design has inbuilt suitability of biogas recycling for methane enrichment and is suitable for online monitoring of process parameters. The overall process includes converting organically rich bio-degradable portion of solid waste to slurry by mixing equivalent quantity of water and it is almost the same as in Nisargruna except the plug-flow system. The undigested lignocelluloses and hemicelluloses then flow out as high-quality organic manure slurry. The pH of this slurry ranges from 7.5 – 8.0. It has been observed that the waste is converted into good quality manure and the gas generation is substantial. All the microbial and biochemical parameters of the waste is achieved at the end of the process. The know-how of this novel design made of PVC pipes has been transferred to several industries. A higher capacity Shesha plant (50 Kg) has been installed at IGCAR campus for catering biowaste (**Fig. 6**).

Fig. 5: Shesha pilot plant installed at Training School Hostel during 2021

Fig. 6: Shesha plant installed at BARC Facility, Kalpakkam during 2023

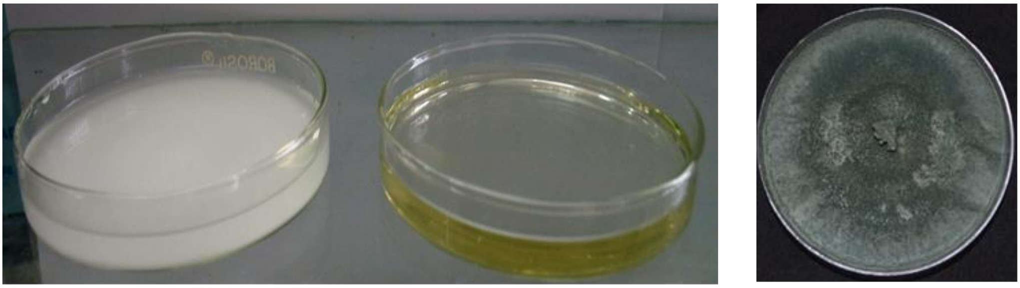
7. Managing solid waste through rapid composting technology

7.1. Genesis of Rapid Composting Technology

Biodegradable organic wastes such as crop residues, agro industrial organic wastes (including animal litter), city garbage and forest litter have wide C/N ratios ranging from 80 to 110, and thus can't be used directly in agricultural soil without converting them into compost. Around 7 to 8 million metric tons of paddy residue are set on fire in open fields between October and November. Thus, air quality in the thickly populated adjoining regions is badly affected. Similar problems are encountered in case of sugarcane and banana plantations where residual biomass poses a problem in disposal. Its treatment in anaerobic digestion (like in bio-methanation plant) as such is not feasible because it requires longer retention period and also forms scum during the initial stages leading to clogging of pipelines. These organic solid wastes generated in different sectors are often indiscriminately dumped on-ground. When organic material such as food and green waste is disposed in landfills, it gets compacted and covered. This cuts off oxygen supply and causes it to break down via an anaerobic process, eventually releasing methane, a greenhouse gas that is 25 times more damaging than carbon dioxide. The implications of such release for global warming and climate change are enormous. Methane is a flammable gas that can cause fire hazards in dumping grounds. This comes with a heavy carbon footprint as well. Composting food scraps and green waste into manure, eliminates many of these problems. Such a process needs effective microbial strains for decomposition.

7.2. Isolation of a cellulolytic fungus, formulation, and its potential use in waste composting

Cellulose is the most abundant natural polymer on the earth and also the structural component of majority of cells. It is also a substrate which is difficult to degrade. Hence it is pertinent to look for an organism that effectively uses cellulose as a carbon source. Tree bark was one such lignocellulose rich niche from where we could isolate at least 10 micro-organisms. However cellulolytic filamentous fungi are the organism of choice given the ease in downstream processing and amenability to solid state fermentation. Considering other criterion for selection like growth under ambient conditions, non-pathogenic to plants/animals and safety in handling at large scales, the genus *Trichoderma* was selected. The cellulose degradation potential of this isolate was checked on 1% cellulose suspension which was solubilized in 10 days under constant shaking (**Fig. 7**). The species was identified as *Trichoderma koningiopsis* by molecular tools. Pilot experiments on leaf degradation were carried out at BARC in drums and further large-scale experiments were managed on diverse substrates at different locations.



CONTROL **TREATED** ***T. koningiopsis***

Fig. 7: Cellulose degradation by rapid composting strain, *Trichoderma koningiopsis*

7.3. Development of culture formulation

The process of formulation development for *Trichoderma koningiopsis* is depicted in the figure below (**Fig. 8**). Briefly, it includes inoculation of pure culture of *T. koningiopsis*, in sorghum seeds, incubation for growth and making a wettable powder (WP) formulation.

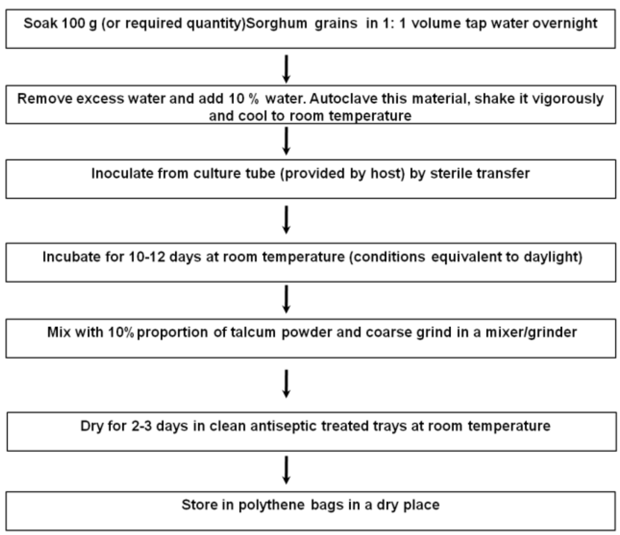


Fig. 8: Flow chart for the development of rapid composting formulation

7.4. Implementation of rapid composting technology and it's success stories

The Rapid Composting Technology (RCT) was implemented for the first time at Kurla Kamgar Society, Mumbai for which the society received the "Clean and Green Society" Award in 2018, organized jointly by Pollution Control Board and Loksatta. At Tata Institute of Fundamental Research (TIFR), Colaba, Mumbai several tons of garden waste comprising of peepul, barrintonia, banyan and almond were processed and the manure obtained was used in the gardens of the same premises. Implementation for kitchen waste was done at Mahindra Nagar colony, Malad and Homi Bhabha Centre for Science Education and Research (HBCSE, TIFR). The introduction of this technology was particularly useful after the imposition of strict guidelines by Brihanmumbai Municipal Corporation banning collection of biodegradable garbage from institutions and housing societies, thus forcing them to process their waste *in-situ*. Even sending waste out of the premises by private agencies for processing incurred good amount of expenditure. HBCSE has successfully implemented RCT from last five years and composting kitchen waste in–house, till date. This technology has been implemented at DAE colony in Mandala and Electron Beam Centre at Kharghar. Agricultural residues like sugarcane leaves were composted at farmer's fields in Ahmednagar district, Maharashtra. Whole geranium plants after extraction of oil were processed to yield manure at Sangamner. Farmers at Nandurbar district of Maharashtra have adopted RCT for in-situ decomposition of whole banana plants after harvesting of fruits. **Fig. 9** represents a collage of various wastes processed and its implementation at several areas.

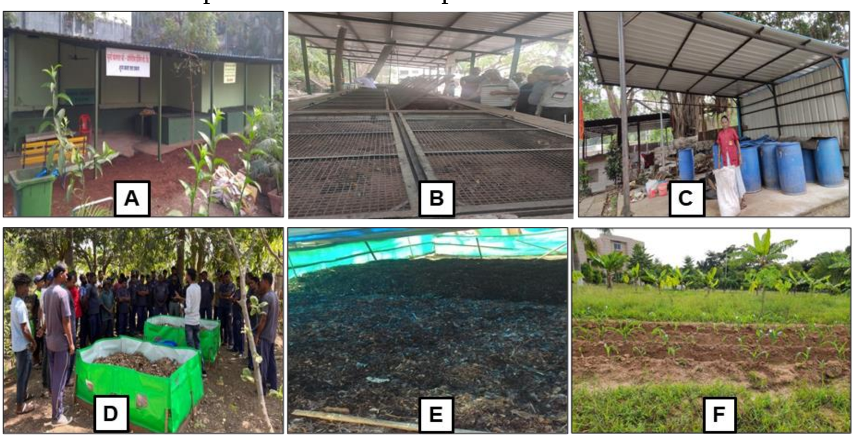


Fig. 9: Collage of different composting sites and different wastes processed

7.5. Technology transfer and Implementation under AKRUTI scheme of BARC

This technology has been transferred to more than 65 agencies including biotechnology and agricultural businesses, institutions, housing societies, non-governmental organizations and agencies working in the field of environment and agriculture. Agri business start-ups have also taken up this process and are establishing themselves in this venture. A list of products launched in the market is depicted in **Fig. 10**. AKRUTI training centre at Tarapur Atomic Power Station (TAPS), Maharashtra has successfully implemented preparation of microbial formulation in-house as well as setting up of facilities for composting of kitchen waste and dry garden leaf waste. AKRUTI centre conducted training programs to create awareness about Rapid Composting Technology amongst local villagers in and around Tarapur as well as employees of TAPS, workers, gardeners, cleaners and other staffs. As a result of this, many residents have started composting at their house hold levels. Many youngsters have also come forward to take up the license of this technology and become an entrepreneur. A glimpse of the deployment of this technology is narrated in Table 2.

Fig. 10: Various products marketed using BARC-Rapid Composting Technology

Table 2: Implementation of Rapid Composting Technology to process diverse bio-substrates

Substrate	Location	Scale of processing
Whole Coconut leaves (after shredding)	Kurla Kamgar Society, Mumbai	200 kg/month in pits
Peepul, Barrintonia, Almond and banyan leaves	Tata Institute of Fundamental Research	500 kg/month in heaps on the ground
Kitchen waste	Mahindra Nagar Colony	400 kg/day, in pits on the ground
Kitchen waste	DAE Mandala Colony, Trombay	100 kg/day in plastic drums
Kitchen waste	Homi Bhabha Centre for Science Education and Research, TIFR, Mumbai	100 kg/day in plastic drums
Paddy straw	GCNEP, Bahadurgarh	Demonstration in 100 kg heaps
Spent mushroom straw	GCNEP, Bahadurgarh	100 kg in waste collection bins
Whole banana plants	Nandurbar, Maharashtra	Farmers field (*in situ*)
Sugarcane leaves	Ahmednagar, Maharashtra	Farmers field (*in situ*)
Whole geranium plants after extraction of oil	Ahmednagar, Maharashtra	Farmers field (*in situ*)
Mahua Cake	Nandurbar, Maharashtra	In pits
Nirmalya or Floral waste	Anushaktinagar, Ganeshotsav	In drums at the pandal sites
Canteen waste	Imperial College, Bargarh, Odisha	In drums at the canteen site
Elephant grass	DCSEM, Anushaktinagar	Pits dug on the ground with earth removing machines
Nirmalya	Kumbh Mela 2021, Haridwar	In drums and pits

8. Contributions on soil science related techniques at NA&BTD

Application of isotopic techniques for sustainable agriculture in general and their use for soil health improvement in particular has remained an important mandate of bioscience group since its inception. Different radioisotopes were used for studies of nutrient movement in soil and plants. These isotopes act as tracer tools for unlocking the biochemical pathways in plant and soil.

8.1. Use of radioisotopes for soil fertility management:

Radioisotopes are used as a 'tracer' or 'label', which helps to follow the movement of specific nutrients in different layers of soil. This helps in getting information on fertilizer use efficiency, quantifying losses from soil and biological transformations of mineral nutrients in plants. It allows tracing of the translocation routes in the soil and different plant parts. Soil science section (presently plant pathology and microbiology section) played a pioneering role in studies on movement of nutrients in plethora of soils across the Indian sub-continent by using isotopic techniques. Fertilizers enriched with ^{15}N and ^{54}Fe offer excellent methods of understanding their fractionation among different components while ^{32}P and ^{35}S help in dissecting differential uptake of the nutrients by the plant. Effects of crop residue incorporation on soil stabilization and fertility enhancement is determined by the analysis of stable isotopes like ^{13}C and ^{15}N. Studies on labelled fertilizers provided useful information on nutrient requirements of crops, precise knowledge on the type, amount, method and time of application of fertilizer materials best suited for specific soil-crop combination and quantification of biological nitrogen fixation by leguminous crops.

8.2. Development of improved fertilizer formulations:

Characterization of rock phosphate from all over the world was carried out extensively at NA&BTD, BARC. An improved phosphorus fertilizer formulation (Patent No 238485) was developed and commercialized. A zinc fertilizer formulation (Patent No 239929) was made as an alternative to commonly available micronutrient-fertilizers in the market. Both these inventions were further developed as a technology and transferred to industries through Technology Transfer and Collaboration Division (TT&CD).

8.3. Development of soil organic carbon detection kit and multi-nutrient extractants:

Organic carbon is an important parameter of soil health and indicator element for status of soil productivity. In order to make farmers aware about importance of soil organic carbon, an instant field-testing kit has been developed at BARC. This kit analyses the carbon status of soil in minimum time and therefore the farmer doesn't have to rely on other agencies for results. This ultimately helps farmers to decide the nutrient supply to crop which is very critical for better production. The technology has become very popular amongst farmers. The simplicity of the technology was appreciated by IAEA and an impact story was published on IAEA webpage during April 2021 (**Fig. 11**). Taking this technology further for understanding the status of other nutrients in soil, a universal multi-nutrient soil extractant has been developed. This extractant got Indian Patent (No

358936). This was further developed as a technology and transferred to three industries. One product based on this technology is available in the market (Harit Kranti).

Effect of irradiated sewage sludge obtained from SHRI facility, Baroda was evaluated as part of IAEA project on different soil and plant systems. The study revealed improvement in physicochemical properties and organic carbon content in soil without any significant uptake of heavy metals in plant residues.

Overall, the above studies at NA&BTD have contributed in the development of different strategies towards improving soil health for sustainable agriculture.

IAEA
International Atomic Energy Agency

Living in Harmony with Mother Earth: User-Friendly Instant Tool Kit Helps Indian Farmers Determine Soil Organic Carbon

22 Apr 2021
Carley Willis, IAEA Office of Public Information and Communication

(https://www.iaea.org/sites/default/files/styles/original_image_size/public/soil-india-1140x640.jpg?itok=tS3cDvtJ)

Carbon-rich minerals, organic materials and living organisms – these various components of soil are necessary to absorb water and breakdown pollutants. Having the right balance of organic matter and living organisms, nutrients are released in the soil, allowing healthy crops to grow. (Photo: S. Mehetre/Bhabha Atomic Research Centre)

"To be a successful farmer, one must first know the nature of soil," ancient Greek

Fig. 11: Soil organic carbon kit developed at BARC

9. Way forward: Future direction of managing liquid and solid waste

Nisargruna and Rapid Composting technologies have played a significant role in processing variety of biodegradable waste generated in different parts of the country. These technologies have been transferred to 225 entrepreneurs (till August 2024) and spread across the country for processing variety of wastes. There are more than 360 plants working successfully throughout the country starting from Leh to Kanyakumari, processing different types of waste and utilizing the bio-gas generated therein for diverse applications. The Rapid Composting technology has been transferred to more than 65 agencies so far. Nisargruna is an excellent decentralized sustainable option for processing biodegradable waste materials generated in various parts of the country. The technology has made significant impact on the solid waste management sector for last two decades. It has showed the way forward for successful bio-methanation option from biodegradable waste. The biogas generated is being used for cooking, street light, electricity generation, compression purpose and gas turbine use. In the near future, challenge remains in exploring such technology at house-hold level to combat the effect of climate change and develop a sustainable model for biodegradable waste management.

Conversion of waste biomass to manure for soil application allows effective carbon sequestration which will go a long way in reducing the alarming levels of atmospheric carbon di-oxide concentration that stands at 425 ppm as opposed to 325 ppm of pre-industrial revolution. The USP of the rapid composting technology lies in the use of single microbial culture to develop a formulation which in turn leads to low capital investment by the industry. Further, large-scale implementation, of this technology requires minimum infrastructure and zero involvement of skilled labour. Strict segregation of non-biodegradable materials is also not mandatory, since they can be separated from the manure at the end of the process. Beyond the environmental issues that are addressed, it opens up avenues for dignified stable employment to people from the marginalized sections of the society like rag pickers in a hygienic set up. This is in direct contrast with the dumping grounds where they forage for useful material in the waste. In agronomic and horticultural practices compost can be used as a very good soil amendment, in the form of natural fertilizer which enhances physical, chemical and biological properties of the soil.

It is pertinent to mention that many nations are signatory to the COP 28 where steps have been taken to achieve carbon neutrality. These technologies owing to their circular nature of utilizing resources will not only aid in reducing carbon emissions but also help in earning carbon credits, thus enhancing their commercial potential. Composting is an oxygen-demanding process which involves the hydrolysis of organic matter into humus. Further, sensor-based automations in aeration and reduction of leachate can decrease the time of processing. This can also help in getting rid of anaerobic pockets within the composting mix improving its acceptability in public. Efforts will be taken up for defining a parameter for assessing compost maturity and reducing leachate production. Future direction of research will involve manufacturing value-added products from compost like humic acid and fulvic acid and a semi-organic fertilizer formulation.

10. Acknowledgements

All the authors thank Head, NA&BTD and Associate Director, BSG for their encouragement and support. Authors acknowledge Dr. Mukesh Kumar towards his tireless effort in editing this compilation. We also thank all the former section heads of plant pathology and microbiology section (earlier pesticide residue and soil science section/environmental biotechnology), former Heads of NA&BTD and former Group Directors. All authors acknowledge the very pioneering contribution of Dr. S. P. Kale, former Associate Director, BSG and former Head, NA&BTD.